Safety in Mines Research Advisory Committee

Final Project Report

Survey and assessment of support for non-standard (anomalous) stope areas in the gold and platinum industry.

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Executive Summary

Non-standard (or anomalous) mining conditions can be described as those areas where the level of hazard, or risk of falls of ground, is increased relative to normal conditions in a mining stope. Normal conditions would be those defined as a Ground Control District in a mine's code of practice, and for which mine standard support layouts are generally drawn up.

A high percentage (70-80%, Gay 1993) of falls of ground accidents occur where non-standard mining conditions exists, typically in the vicinity of geological weaknesses. The definition, percentages of mining lease area, and geotechnical classification of non-standard conditions is often poorly addressed in mine codes of practices. The generic definition of non-standard (anomalous) mining conditions was formulated after canvassing the opinion of Rock Mechanics and Production Personnel from 18 gold and 5 platinum mines. These conditions can be categorized under four broad headings comprising those due to stress and stress damage and possibly increased rock deformation, geological conditions, mining considerations, and human factors. This permits a clearer identification of specific hazards and to highlight the consequences and severity of non-standard conditions in gold and platinum mines. The focus of the report is however, those anomalous conditions arising from unexpected geological reasons.

Systems to identify non-standard or anomalous conditions in gold and platinum mines have been examined to ascertain the most prominent anomalous conditions on mines and the ability of these systems to properly deal with the consequences of anomalous conditions. It was found that the gold and platinum mining industries lack methods to properly identify changing rock mass conditions. It follows that methods to ameliorate hazards associated with anomalous conditions are often reactionary rather than proactive.

The report, after establishing what current practice in the industry is, puts forth methodologies to assist with identifying changing rock mass conditions in the gold and platinum industries. This can be use as the first step to enable management measures to be tailored to the particular geotechnical characteristics of a defined Ground Control District. The report deals broadly with the design of support or layouts to combat anomalous conditions, since the possible range in conditions is very wide and often site-specific. The design of support for anomalous stoping areas should follow the recommendations outlined in the Guideline for the Compilation of a Mandatory Code of Practice to Combat Rock Fall and Rock Burst Accidents in Tabular Metalliferous Mines (Ref: DME 7/4/118 AB1). A number of previous SIMRAC research projects (http://www.simrac.co.za) deal with methodologies for designing support for various geotechnical conditions in hard rock mines. A non-exhaustive list of SIMRAC reports relevant to support design and anomalous conditions include GAP 033, 034, 055, 102, 112, 223, 330, 416, 513, 530, 627, 723 and GAP 032.

In addition to this report, a primary output of this project has been the development of an accompanying guidebook, which summarises methodologies for recognising and categorising the occurrence of non-standard or anomalous conditions, and provides guidelines and recommendations to ameliorate the effects of anomalous conditions. The booklet is aimed for use by rock engineering practitioners, planning engineers, safety practitioners and senior production line supervisors. It is intended to be particularly useful to line supervisors who observe underground conditions on a daily basis, and could serve as a training aid.

Acknowledgements

The co-operation of the following mines and organisations in supplying data for this project is gratefully acknowledged.

The offices of the Department of Minerals and Energy in Johannesburg, Rustenburg, Klerksdorp and Welkom for access to accident documentation.

Library services at CSIR Miningtek in Johannesburg and the Council for Geoscience in Pretoria.

Access to panel rating systems and monthly panel support recommendations at Amandelbult, African Rainbow Minerals, Kloof, Savuka and Mponeng.

Access to routine underground stope audit data at Impala Platinum and Beatrix mines.

Underground visits to various working places and discussions with rock engineering or geology department staff on the following mines:

- Platinum mines: Western Platinum (Karee), Impala Platinum, Amandelbult, Northam, Kroondal Platinum, and Rustenburg Platinum.

- Gold mines: Beatrix, Oryx, St. Helena, Bambanani, Tsepong, Hartebeestfontein, ARM, Tau Lekoa, Kopanang, Elandsrand, Deelkraal, Savuka, Mponeng, TauTona, Driefontein, Kloof, and Placer Dome-Western Areas Joint Venture.

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1 Introduction

1.1 Terms of reference and project scope

This report presents the work carried out by Itasca Africa (Pty) Ltd and subcontractor Spencer Rock Mechanics Consultancy c.c. for SIMRAC project GAP 607, “Survey and assessment of support for non-standard stope areas in the mining industry”. The title has been modified to refer to anomalous conditions because non-standard was frequently assumed to mean a failure to comply to standards, when the project was discussed with mine personnel.

The original call for proposals issued by SIMRAC called for a survey and assessment of support for non-standard stope areas in the mining industry with focus on conditions arising from geological structures, such as faults, brows and undercutting. As made clear at the proposal site meeting, the project also considers the frequency of occurrence of such conditions. A main objective of the project is to provide a document that raises the level of awareness of non-standard conditions amongst mining people, and provides a guideline for the types of support that should be used or designed for these areas. The end-user must be able to identify non-standard conditions and the follow-on from the project is intended to be improved awareness of the increased hazard and need for support in non-standard areas and consequently a reduction in fall of ground accidents arising from poor, or inappropriate, support practices.

The project is therefore about problematic geological conditions and the support measures required to contain them. Obvious contributing factors will include mining practices (correct or otherwise) and human error, or failure to correctly recognise and address problems.

The project considers gold mines in the Witwatersrand basin and platinum mines in the Bushveld Igneous Complex, at all depths from near surface to in excess of 3500 m, on a range of economically important reefs.

The primary outputs of the project, as defined in the accepted proposal, are:

1. Comprehensive field and literature survey that examines the frequency of occurrence of non-standard stope areas and practices used to support them in gold and platinum mines.

2. A practical recommendation for the best practices to use in the support of non-standard stope areas.

This report deals with both outputs. The latter output has been compiled into an accompanying guidebook. Due to the overall range in conditions resulting from local lithological changes associated with the individual reefs coupled with the range in depths, specific recommendations for practice have proven difficult to assemble, hence recommendations are of a more generic nature.

A full definition of what is considered “non-standard” (where “anomalous” is a better description) is presented below, however in terms of the original call for proposal this is essentially a project dealing with geological or rock mass structure, and is closely allied to the definition of geotechnical areas, or Ground control Districts. The main justification for the project was that a high percentage of stoping fall of ground accidents appear to occur where non-standard mining conditions exist, typically where geological weaknesses occur. The presence of weak joints, dykes and fault planes frequently leads to conditions where the risk of falls of ground from the stope hangingwall is increased. In general either additional support is required in such areas, or, if hangingwall falls occur, brows are created and undercutting is required to get stope width back to optimal or normal dimensions. Special precautions are generally required when undercutting or negotiating structures. These problem areas can be made worse by the presence of bedding or weak horizons in the hangingwall. Most mines have some form of special support recommendation for these areas. In general, those areas where joints or faults cause stability problems are considered non-standard and general stope support design is based on supporting a standard condition, i.e. where the hangingwall is planar and not disrupted by significant discontinuities. However, it is generally not clear what proportion of the mined stope area should be considered (or might prove to be) non-standard. If this constitutes a high percentage, then general stope support should be designed for the supposedly non-standard condition if problems are to be adequately countered. A survey has been made using various data sources, as part of this project, to assess the frequency of non-standard conditions. Where there are throws on faults or dykes some form of panel re-establishment, through undercutting, re-raising or trenching is unavoidable. Fall of ground hazards generally increase where there is lack of confinement of fracture and bedding bound blocks. Various excavation and support practices are in use, some more successful, or appropriate, in particular mining environments than others. Most mines have generally developed their own variants on a trial and error basis and an industry survey of these methods has been carried out, and recommendations given for best practices under various geotechnical conditions. The intention of this project is to provide a review of the extent of supposedly non-standard stoping conditions in gold and platinum mines, together with a review of current mining and support practices used in such areas. From these, guidelines for the best practices to apply in such areas have been drawn up. These guidelines are based on analysis of historically successful methods.

In carrying out the project a number of snags were encountered, the most significant being a reluctance amongst mining people to discuss “non-standard” conditions, assuming the project to be an assessment of non-compliance to mine standards, in other words a policing operation. Care has been taken to explain that this is not the case and the reader of this document must be clearly aware that this is not what this project is about. Discussions with mine personnel on 22 gold and platinum mines have shown widely varying views of what should be considered non-standard, or anomalous. Some mines claim that within the scope of their definitions of geotechnical areas there are no non-standard conditions. There has also been some confusion that it is only concerned with designated “special areas”.

A second problem encountered while gathering data for this project is that while most rock engineering practitioners recognise anomalous conditions when they occur, prediction of likely anomalous situations is poor due to limited available rock structure data. This reflects a general inability in the South African mining industry to integrate geology and rock engineering. Geologists are expert underground mappers, but other than significant faulting do not map rock structure. Rock engineers need data on minor joint and fault patterns and locations, but, unless trained as geologists originally, fail to recognise this and in any case do not have the skills to map, collect, or interpret this data. Too frequently during the course of this project we have met with the impression that rock engineering is about safety and support, whereas on a more fundamental level it is really about understanding rock mass behaviour. This is difficult without first obtaining an understanding of rock mass structure within the ground that mining is taking place. Geological knowledge is fundamental to successful rock engineering, and as is discussed in later sections of this report, there are useful geological techniques under development which can provide the rock engineer with tools for hazard prediction.

This leads into a third problem area noted in carrying out this project which is the effect of scale on the incidence, or identification, of anomalous conditions. By this it is meant that on a broad scale geotechnical areas can be identified, major faulting for instance can be picked up by the mine geology department, and rock engineering staff can discuss extra stope support requirements at planning meetings with section managers and mine overseers. On the smaller scale, minor brows and faults are intersected on an apparently ad-hoc basis underground resulting in local hazards which must be identified and made safe by the man on the face. These latter cases are only recorded or brought to the attention of senior line management or rock engineering when control is lost and small problems have developed into major hazards, influencing production and requiring cost and effort to address. In terms of this project, the first, broad scale, category has proven easiest to identify, quantify and categorise. Occurrences of the second, local scale, category has proven considerably more difficult to quantify.

1.2 Broad definition of non-standard conditions

As this project has progressed, the definition of “anomalous” or “non-standard” stoping conditions has by necessity been changed. Initially it was defined as ***those areas where the mine standard support systems have proven inadequate under localised mining conditions*** and either stope conditions have deteriorated (falls of ground, etc.), or additional support has been installed over and above the locally applied mine standard. A better definition would be ***those areas where the level of hazard, or risk of falls of ground, is increased relative to normal conditions in a mining stope or area***. This varies as a function of the minimum mine support standard in use.

As noted above, the project is primarily concerned with anomalous conditions of a geological, or geotechnical, nature.

The main reason for a change in definition is that many mines have a range of standards for varying geotechnical conditions. Key then, in deriving guidelines for inclusion in a final document are the definition of methods for detecting when ground conditions change, and hence when standards should be changed or rock engineering recommendations, or special instructions from production overseers, should be issued. From data gathered from various systems on a number of mines, the ability to detect and address hazards appears very variable. Anomalous areas have essentially been taken to refer to problem areas that were unplanned for, and where some form of corrective action had to be taken.

To assess the definition of anomalous areas or conditions has required a brief evaluation of what individual mines actually design to support and what is actually achieved underground. The objective is to define what constitutes normal support practice, rather than target minimum levels. Some interesting results have been noted. In the case of a deeper mine, using timber pack support, fatal accident reports showed that support unit spacings were consistently 10 to 15% tighter than standard, or more when poor ground conditions were noted. The implication for this mine was that either pack spacing was inadequate, which did not appear the case in most accident records, due to location of damage between packs and face, or was largely irrelevant from the point of prevention of accidents as it contributed little to face area support. More recent changes to this mine’s standards bear out the latter point.

A second case is provided by data from a shallow mine. Here stope gullies are excavated as short headings and a comparison was attempted between measured width at time of development, and distance between support across the gully, back from the face. The mine standard dimensions are 1.2 m and 2 m respectively, however in 223 measurements only 19% were developed at standard width, with the maximum variance being 1.8 times standard. In the case of span between supports across the gully only 13% were standard with maximum deviation reaching a 2.7 factor. However gully stability problems are minimal, indicating that standards in this instance are generally conservative, and that spacings could be opened up at this mine, making mining less onerous and saving on cost (or allowing funds to be directed to other issues) without compromising safety.

These two cases would tend to indicate that many mines do not fully understand the conditions that they are designing stope excavation geometries or support for. This in turn tends to complicate any identification of abnormal conditions or requirements for additional support.

Types of anomalous stoping conditions can be categorised, broadly, into conditions resulting from changes in local geology, stress and deformation and conditions resulting from poor mining controls and human factors. In terms of the original proposal, only geological reasons are focussed on. However significant hazards arise through human issues in particular, which include inadequate training, production pressures and attitudes to safety, which are beyond the original scope of this project.

1.3 Industry opinion of what constitutes an “anomalous” stoping condition

Discussions with mine personnel have proven a useful source of data for this project. Mine standards and codes of practice have been found to be frequently inadequate when determining what mines do in terms of recognising and addressing anomalous stoping conditions.

Because of the difficulty in defining what exactly constitutes a non-standard stoping area it was decided to canvas the opinion of rock engineering and production personnel on a total of 23 mines, 18 gold and five platinum. The following list records their understanding of the term “non-standard” or “anomalous” stoping area.

- Not mined to the required standard. In other words sub-standard conditions.
- Not the expected or normal mining practice. For example a trial of a new product.
- Not the expected mining configuration.
- A remnant or awkward shaped block of ground.
- An area that requires a different mining layout to the standard. For example to mine an old abandoned area.
- A different geotechnical area with a higher risk than average.
- Where specific geological conditions exist.
- Any area where after installation of standard support, there is a fall of ground.
- An area that for whatever reason requires more than the standard support.
- A designated special area.
- An area requiring some form of support rehabilitation.

This list is extremely broad. For this project, based on the original scope, the focus is on those anomalous areas that occur as the result of unexpected geological or geotechnical conditions.

1.4 Project methodology

The basic project methodology has been as follows.

- Define what constitutes a non-standard, or anomalous, condition.

In the process it has become clear that there are a range of non-geological conditions which can be also considered anomalous and which clearly raise the level of risk, or hazard, in a working place. While these have been broadly defined, the project has remained focused on geologically anomalous situations.

- Define a list of distinct geologically anomalous conditions

- Determine the frequency of occurrence of non-standard stoping conditions in gold and platinum mine stopes.

- Determine and evaluate the support strategies currently employed by mines for non-standard stopes, and identify any best practices.

- Provide guidelines towards the best methodology to employ in managing non-standard stoping areas

1.5 Sources of data

A number of sources were used to examine firstly the most significant anomalous conditions that lead to hazards and accidents and secondly the spatial frequency with which these hazards occur. These have included the following:

- Discussions held with rock engineering staff on 23 gold (18) or platinum (5) mines. A questionnaire on “non-standard stoping areas” was used in some cases.
- Copies of mine Codes of Practice and Mine Standards and any other relevant documentation.
- Panel Risk Rating systems, and other methods for identification of hazards have been examined.
- Examination of some 117 fatal accident records in the Carletonville, Klerksdorp and Free State regions.
- Underground visits to areas considered anomalous by mine rock engineering staff on a range of mines.
- Certain underground observations from audits of support and stoping hazards on all AngloGold mines.
- Regular panel audits of compliance to standards carried out by strata control observers on former Genmin mines (Impala Platinum and Beatrix).
- Monthly support recommendations on a mine-wide panel by panel basis from two mines.
- Various panel rating systems used for selection of support at African Rainbow Minerals (ARM) operations in the Klerksdorp area, and at Amandelbult.
- Monthly production data from a number of mines, where centares mined along faults and structures, plus waste centares, are identified from the total centares mined for purposes of the local bonus scheme in use.
- Various published papers, previous SIMRAC reports.
- Routine geological mapping carried out by Itasca Africa staff at a platinum mine over a two-year period.

Although originally considered as a practical option, mapping of joints, faults, rolls, etc. underground as a means of identifying the proportion of mined ground which can be considered anomalous has proven pointless: too much ground has to be covered on too many mines to develop meaningful industry averages. A better approach has proven to be based on panel data gathered by either a mine’s stope observers (e.g. on former Genmin mines) or input used in panel rating and support selection schemes (certain AngloGold mines), or mine production data. Using these methods, data from a large number of panels, or whole mines, can be examined together with reasons and recommendations for changing support systems.

2 Level of hazard posed by anomalous conditions

The significance of supposedly “anomalous” conditions can broadly assessed by examining their contribution to mine accidents. In a sense all mine accidents can be considered anomalous as there was some factor that lead to a rock fall, whether a support or layout design failure, or an error in mining practice. As a means of defining contributing geotechnical factors that could be of an anomalous nature, a total of 117 fatal accident cases from 1996 to 1999 have been examined across the industry from DME records. The objective was to:

- Identify anomalous conditions or factors that lead to accidents.
- Attempt to place some relative measure of importance on these anomalous conditions from a safety perspective.

Three approaches were used. First 89 consecutive recent cases were drawn from the Department of Minerals and Energy archive. These were selected on the basis of consecutive dates, irrespective of reef mined, with the intention of being more indicative of industry-wide trends, but possibly clouded by issues of varying depth and varying geological structure.

Secondly, a group of 28 consecutive incidents from a single reef on a single mine were examined in detail. The objective was to illustrate local behaviour under constant geotechnical conditions (of both reef, hangingwall stratigraphy and mining depth).

Lastly, mine codes of practice were examined and a list of industry-wide recognised hazards was assembled and compared to the criteria identified from the accident record.

2.1 Influence of anomalous conditions on the industry safety record

89 consecutive rock related fatal accident cases were drawn from the Department of Minerals and Energy archive. These comprised 46 from the Gauteng region (consecutive cases from March 1997 to November 1998), 20 in the Klerksdorp region (March 1998 to June 1999) and 23 from the Freestate region (March 1996 to November 1998). Although not the most recent cases, they were considered adequate to cover current trends in mining methods and support types. In the case of the Freestate region data from a slightly longer period was required to generate an adequate database.

The distribution of incidents on the basis of mine, reef and depth are shown in figures 2.1 to 2.3. The data has not been normalised as a function of production, as adequate production data could not be easily accumulated, hence the relative importance of reefs and depths is not certain.

Identification of factors which appeared to significantly influence the occurrence of each incident, and could potentially be considered anomalous, are shown in figures 2.4 and 2.5 as a function of depth below surface and reef mined. The contributing factors are grouped into four categories. Interpretation of accident documents was frequently subjective due to possible erroneous interpretation put on local geological, or stress, situations by the investigating inspector. From the standpoint of geotechnical anomaly interpretation, the 28 VCR cases in the next section are considered more reliable.

The four categories of contributory factors can be summarised as follows.

- Stress – high stress levels lead to high levels of stress fracturing. This would included cases where stress fracturing is more intense than would normally be expected due to, for example, a panel face having been stopped for a period of time, or panels mining adjacent to a long lead or an abutment.

- Geology – includes cases where faults, jointing, bedding, dykes or sills were contributory or provided bounding partings to falls of ground. Cases where brows were noted also fall within this category.

- Mining practice – cases where mining practice were obviously poor, such as excessive support spacings, poor approach to structures, lack of additional support adjacent to prominent geological structures, or non-compliance with standards and codes of practice.

- Human factors – cases where a careless working attitude, lack of experience or training, or a lack of appreciation of local conditions were contributory to accidents were grouped in this category.

In general, the last two categories are not a prime concern of this project but cannot be ignored when considering causes of accidents, as frequently good mining practice, and good work ethics can ensure that geological structures or other geotechnical conditions are safely handled.

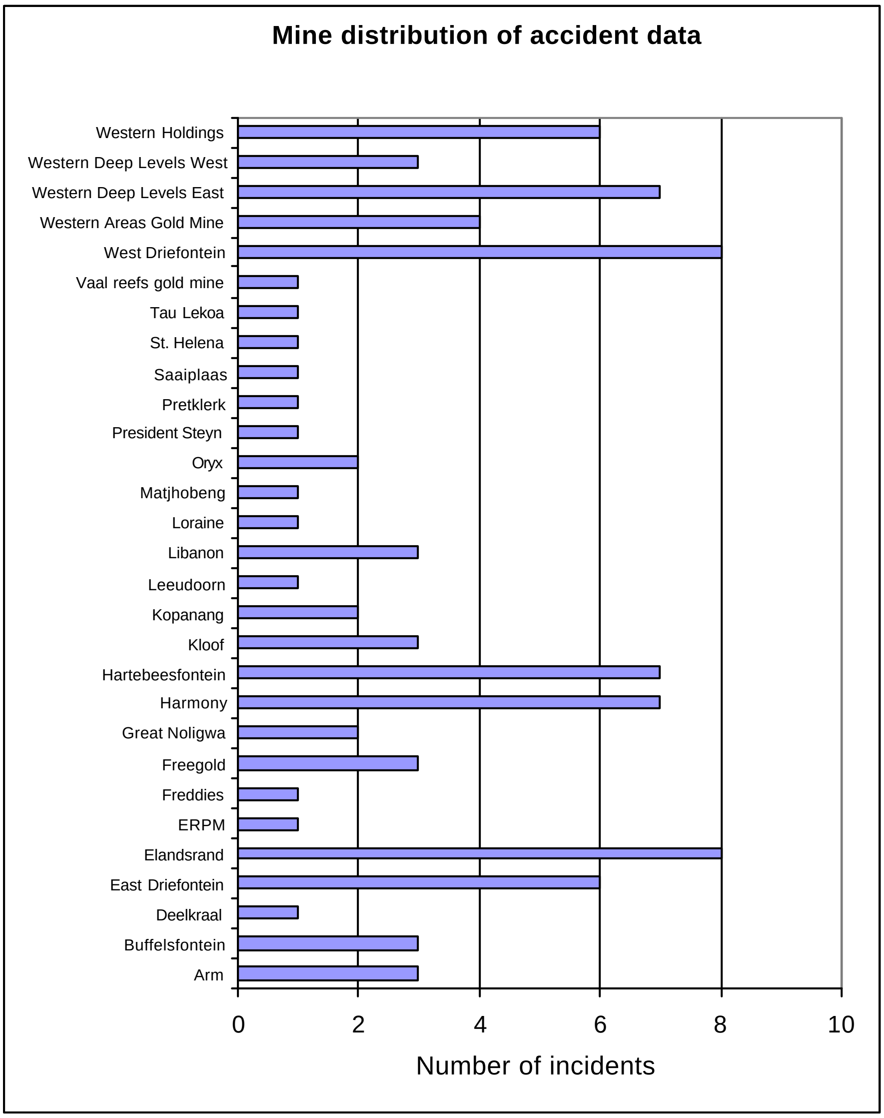


Figure 2.1 - Distribution by mine of the 89 accident cases used in analysis.

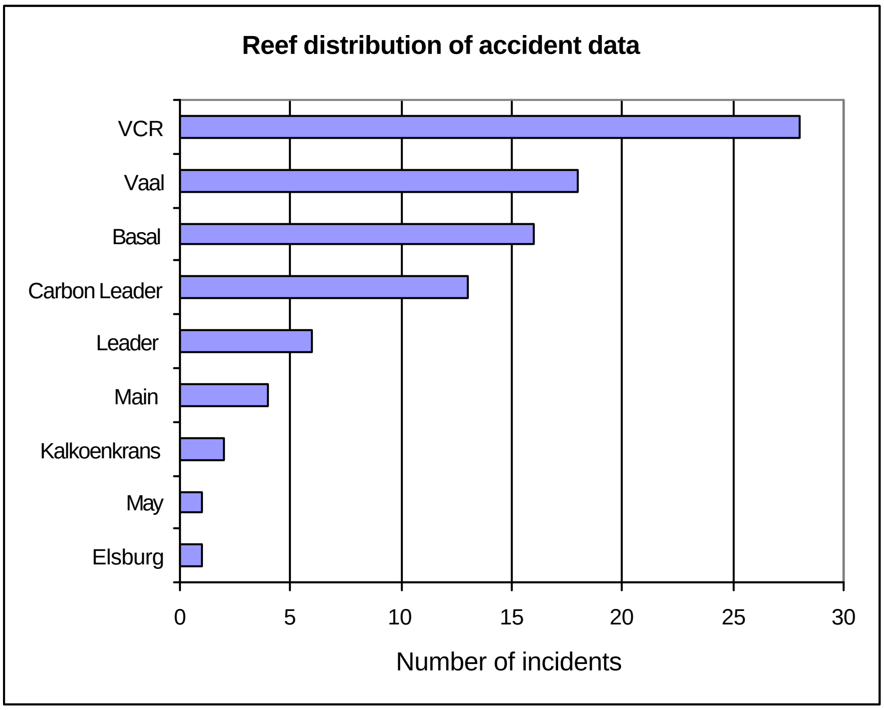


Figure 2.2 - Distribution by reef of the 89 accident cases used in analysis.

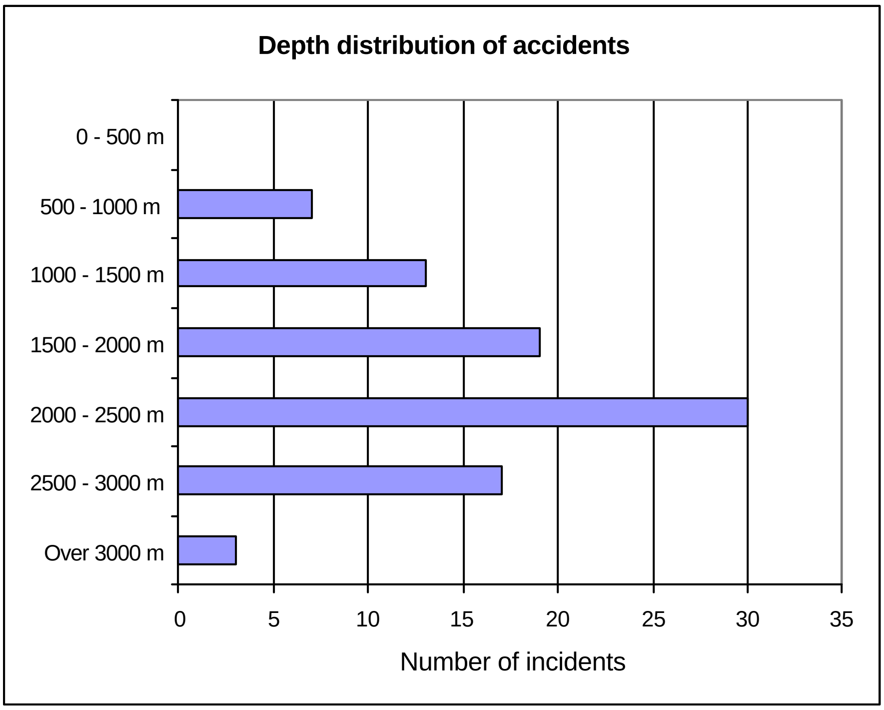


Figure 2.3 - Distribution by depth of the 89 accident cases used in analysis.

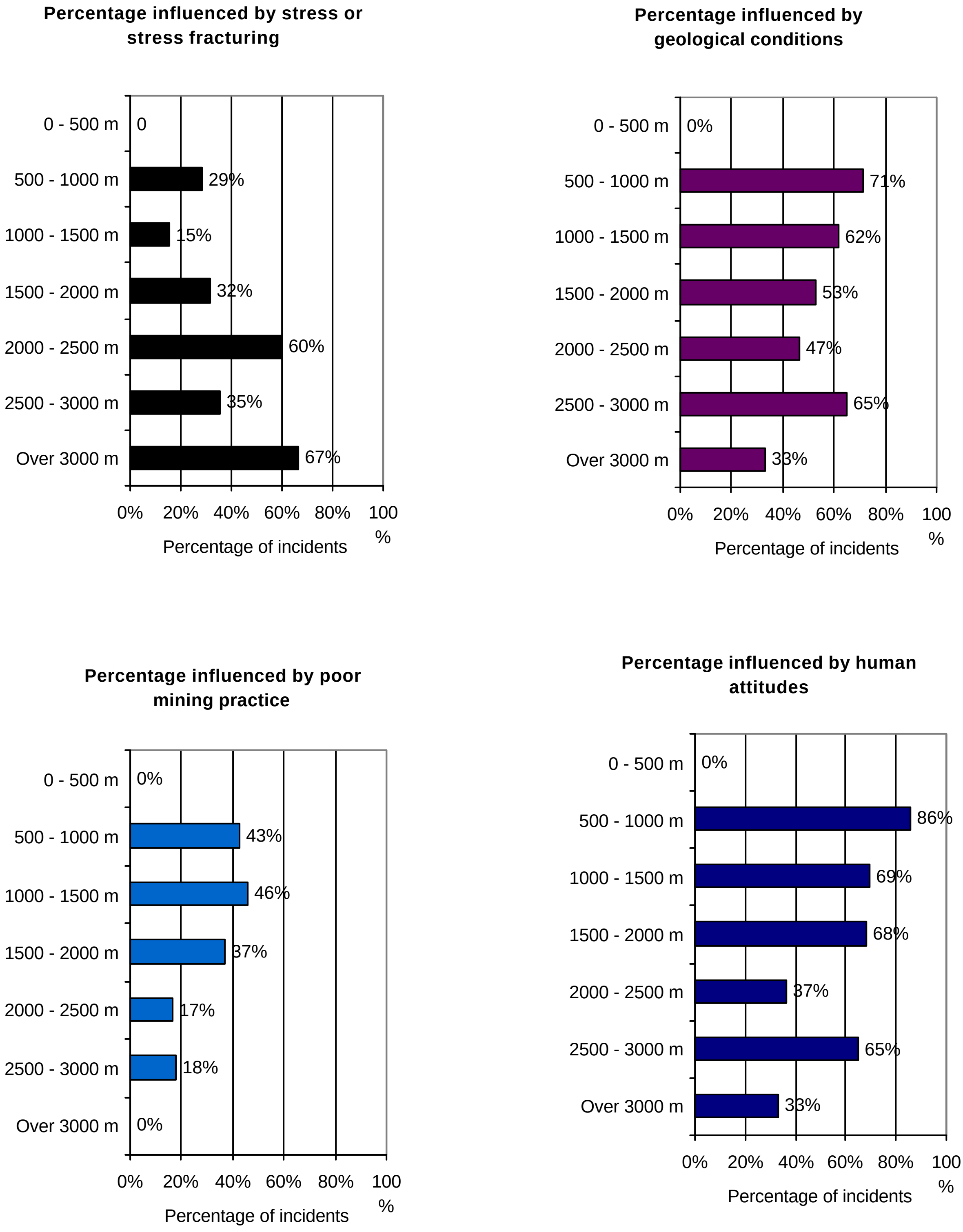


Figure 2.4 - Contributing factors to 89 accident incidents as a function of depth below surface. These figures reflect proportion of cases influenced by each factor in each 500 m depth category. As cases have multiple contributing factors they do not add up to 100%.

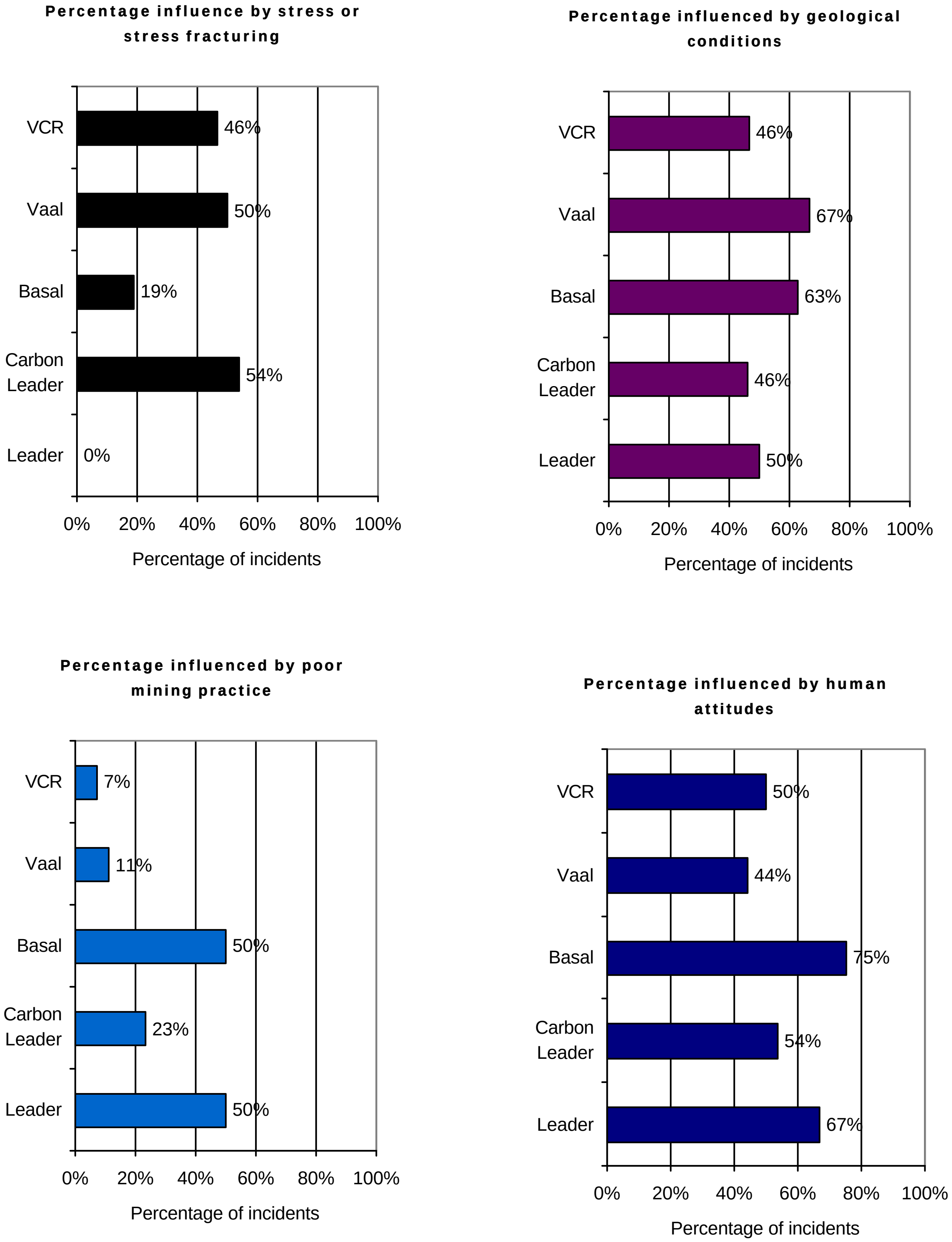


Figure 2.5 - Contributing factors to 89 accident incidents as a function of reef. Note that those reefs shown in figure 3.2. above which had less than five cases are omitted from these graphs (Main, Kalkoenkrans, May and Elsburg reefs). These figures reflect proportion of cases influenced by each factor on each reef. As cases have multiple contributing factors they do not add up to 100%.

Of the total 89 cases, the percentage that showed contributory factors in each category were as follows. Note that numbers do not add up to 100% because certain individual cases may have both geological factors and, say, human factors as contributing anomalous conditions, and the figures represent the percentage of cases in which each factor was contributory.

High Stress or stress fracturing	Geological factors	Mining considerations	Human Factors
40%	55%	26%	53%

The focus of this project is on anomalous rock mass conditions and the geological factors category can be further subdivided into individual contributing geological features. Accident report documents generally provided fairly scant detail of the geological situation at any accident site; in particular data was insufficient to permit an analysis of the proportion of rolls or increases in stope width.

Type of geological feature

Fault	Dyke	Joint	Bedding	Dome
18%	2%	53%	47%	2%

In terms of useful information to be drawn from this data for the purpose of this project, the following would appear key.

2.1.1 Effect of depth

The bulk of cases come from the deeper mines, or those predominantly mining remnants, with most cases coming from the 2000 m to 2500 m depth range.

As might be expected the contribution of stress effects to incidents increases as a function of depth. Stress cannot be considered a generally anomalous condition at depth although increased stress fracture density such as along long leads or ahead of panels that have been temporarily stopped and then restarted would be. At shallower depths, most of the stress related cases involve remnants, or similar situations.

The proportion of incidents influenced by geological conditions appears to decrease as depth increases. This is not unreasonable: in deep stopes stress fracturing is so pervasive and forms the closest spaced discontinuity set that jointing and other geological structure is indistinct. Stress fracturing tends to control fall of ground geometries. At shallow depth most falls are geologically controlled and stress fracturing may be absent.

2.1.2 Effect of reef mined

By a large margin, the most cases are from the VCR, followed by Vaal, Basal and Carbon Leader reefs. Reasons for this could be influenced by tonnage mined on each reef, which could not be determined for the period spanned by the data.

Stress effects are mainly seen on the Carbon Leader, VCR and Vaal Reefs. As these tend to be the reefs mining at greater depths this is not unexpected.

The influence of geological factors is relatively similar across all reefs, with a range from 46% on the deeper reefs where geological structures take second place to stress fracturing, to 63 and 67% on the Basal and Vaal reefs. In general jointing and bedding flow bedding in the case of the VCR), contributing to the formation of brows, or interacting with stress fracturing to create keyblocks, are the main contributing geological factors.

The spread of individual geological factors on the various reefs is shown in Table 2.1. What is not apparent from these statistics is the level of hazard caused by rolls on the VCR. Note that figures represent the percentage of cases in which each factor played a role. For example on the VCR, 92% or cases involved joint-bound falls, 15% involved flow-bedding partings, etc. In most cases there were multiple features involved hence figures do not add up to 100%.

Table 2.1 – Geological factors influencing accidents as a percentage of the total cases on each reef horizon

	Geology cases	**Fault**	**Dyke**	**Joint**	**Bedding**	**Dome**
VCR	13			92%	15%	8%
Vaal	12	33%	8%	50%	42%	
Basal	10	20%		20%	70%	
Carbon Leader	6	17%		33%	67%	
Leader	3	33%		67%	67%	
Main	3			33%	100%	
Kalkoenkrans	1	100%				
May	1			100%		
Elsburg	0					

As noted previously, many cases have multiple factors that influence falls, with no single factor being readily identifiable as the unique cause. Hence the figures in table 2.1 represent percentage of cases where each factor was influential or present, and do not add to 100%.

2.1.3 Mining and human factors

At depth, due to a constant presence of denser fracturing and tighter support requirements, factors associated with poor mining practice and human attitudes appear less than at shallower depth where complacency with normal good conditions can arise. Consequently those reefs generally mined at shallower depths, in the Free State for example, appear more affected than the deep reefs of the West Rand area.

2.2 Anomalous conditions related to accidents on a single mine

28 consecutive accidents (not all fatal) were examined over a six year period from 1988 to 1993 that occurred consecutively in stoping on the Ventersdorp Contact Reef (VCR) horizon on one mine over a limited depth range between 2010 m and 2258 m below surface. Detailed site knowledge was considered, including details of local geology and other factors contributing to damage. Apart from availability of data, a reason for selecting this area as a case study was that, as can be seen from the fatal accident case data in the previous section, proportionately more accidents occurred on the VCR than on any other reef.

In all cases but one, damage was induced by seismicity, with events ranging in size from minor strainbursts to magnitude 3.4 events. Most were the results of events between magnitudes 1 and 1,5 as recorded by the mine seismic network.

In the mining area from which the cases were taken the VCR is characterised by a reef thickness varying from 30 cm to over 2.5 m, a quartzite footwall and a strong lava hangingwall, with regular, and frequent jointing. Morphologically the reef is tabular with local rolls and dips on average at 21 degrees. It shows both thicker terrace reef and thin slope or roll areas where dip may suddenly change, and can be severe.

From the cases there are a number of clear categories of potentially anomalous conditions, identifiable as contributory to each accident. These include the presence of:

- jointing, faulting and stress fracturing as structures bounding falls,
- rolls which frequently result in off-reef mining, or cause an increase in face height and associated increase in face-burst potential,
- Increased stope width, or channel width, similarly leading to increased face height, or inaccessibility of the hangingwall to bar or put in support, and also leading to reduced support effectiveness (e.g. when using packs or props), and
- Poor mining practice, which includes excessive face to support distances, missing support, or poor approach to major geological structures.

In all cases at least one of these features can be found. No incident can be considered entirely free of potential anomalies, and in some instances up to four conditions can be identified. Of the 29 incidents only 14% of cases could be considered free of any form of geological anomaly.

Of the 29 incidents, the percentage that featured in each category is shown in table 2.2. Note that stress fractures and joints feature in almost sixty and fifty percent respectively of the 29 cases. At the mining depths examined stress fracturing is ubiquitous to the mining process and cannot honestly be considered abnormal. Likewise jointing is also a standard condition of the VCR in this area. In some of the cases it was clear that unusually weak or extensive joint planes were present, or that stress fracturing was highly developed, usually because a panel had recently been restarted after standing for several months or was mining below a long lead, or an old abutment. In these cases the nature of jointing or stress fracturing could be considered unusual, and should have required some form of recognition or additional support.

If “standard” jointing and stress fracture conditions are eliminated from the list, and only key, and clearly (not potentially) anomalous conditions are identified, a clearer ranking of conditions is identified, as shown in the lower line in table 2.2, and graphically in figure 2.2.

Faulting and jointing stand out as key factors influencing stope instability, with poor mining practices also being a significant contributor. In 25% of cases the presence of a fault or dyke influenced the accident occurrence.

Where stress fracturing is genuinely anomalous it is either the result of restarting mining in temporarily halted panels, or results from layouts in which unusual stoping layouts have been created during roll or structure negotiation. Note that for much of the time period covered a gully layout was favoured in which an ASG was developed and down dip sidings lagged, giving rise to frequently unfavourable stress fracture orientations. Thus stress fracturing anomalies should, generally, be more correctly attributed to mining practice.

Table 2.2 - Breakdown of potentially anomalous features associated with accidents on the VCR

Joint	Fault or dyke	Roll	Stress fracturing	Increased s/w	Poor mining practice
Potentially anomalous conditions associated with incidents					
46%	29%	14%	57%	21%	25%
Key single anomalous conditions causative to accidents					
18%	25%	11%	11%	11%	25%

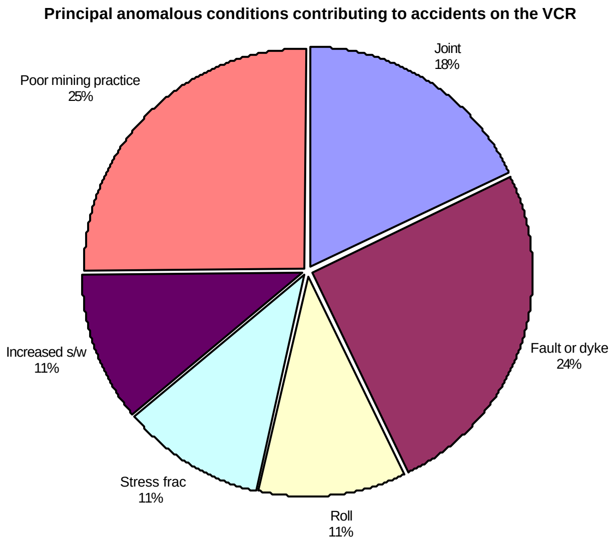


Figure 2.6 - Relative proportion of key factors contributing to anomalous conditions on the VCR, as determined from 28 incidents.

2.3 Proportion of contributory factors identified in codes of practice

Codes of practises of 10 mines have been scrutinised for information regarding the frequency of occurrence of non-standard conditions and support practises pertaining to these. Detail of the specific hazards is given in the next section. A number of mines attempted to quantify contributing factors to fall of ground related accidents in their codes of practices. These factors can be grouped into the five main categories identified above and the following breakdown of contributing factors was found:

Stress related factors: 1 6%
Deformation related factors: 23%
Geological factors: 21%
Mining related factors: 40%
Human factors: 23%

2.4 General mining hazards identified in codes of practice and contributing to accidents

Part of the process of improving safety has to be recognition of the main factors, or hazards, that are causative to accidents, and for which procedures and practices can be introduced to reduce the level of risk. Largely, these then become hazards that can be related to mining practice.

The ability of mines to gauge the hazards resulting from anomalous conditions can be broadly assessed from relevant information contained in rock engineering Codes of Practice and mine standards. If in line with DME guidelines, these should identify non standard stope areas, and identify strategies for their treatment. Support methods contained in standards are examined later in the report.

Ten codes (from both gold and platinum mines) have been examined covering a reasonable spread of mines across the industry from shallow to deep and including a range in reef horizons.

Table 2.3.1 is a list of the range of hazards identified by mines in their codes of practice. The number in the second column indicates the number of accidents (from the accidents examined from DME archives) that could be attributed to that particular hazard. Note that this attribution is somewhat subjective as it is recognised that an accident may have resulted from an accumulation of these hazards. For each of the incidents an attempt was made to isolate one primary hazard per accident. The hazards of a potentially anomalous geological nature are highlighted.

In addition, the hazards listed in table 2.3.2 were not listed in codes of practice but were identified from the accident survey, and underground visits, and can be listed here.

Frequently codes of practice are deliberately vague about anomalies in geological conditions and the overall impression is that frequently occurring structure orientations and distributions of joints and minor faults are generally not well understood.

Table 2.4 – Hazards of an anomalous nature not listed in Codes of Practice

Anomalous conditions from accident survey/underground observations	***No of accidents***
Support removed by scraping operations	2
Scraping and rigging procedures	5
Waterjet operations	1
Transporting equipment	2
Support – during installation process	3
Support – lack of or inadequate (where support falls out, or fails to prevent falls)	15
Support – deterioration	1

Table 2.3 – Hazards of an anomalous nature identified in mine codes of practice

Anomalous conditions from codes of practice	***No of accidents***
Backbreak	
Bad ground not recognised	
Barring - incorrect procedure	9
Barring unsuccessful	3
Beam failure	
Blasting practice and damage resulting from bad blasting	
Blocky conditions of hangingwall	
Brows	
Bumping hangingwall with equipment	1
Closure rate increases	
Depth of mining	
Domes and potential for collapse	
Flat dipping planar joints or sills and potential for associated panel collapses	
Faults and dykes	
Geological features not recognised (8)	8
Geological structures - poor conditions in their vicinity	
Hanging wall slabbing	
Hangingwall stripping	
Hangingwall undercutting	
High intensity fracturing	
Jointing	
Lack of appreciation of hazards – i.e. complacency with conditions (2)	2
Lack of information	
Large spans	
Leads and lags	
Mining rate	
Potholes and blocky conditions associated with them	
Pillars	
Plug failure – shallow mining collapses or caving that can extend to surface	
Poor rock conditions (falls of ground) associated with lamprophyre dykes and faults.	
Poor entry and midshift examinations	3
Poor layouts	
Re-establishment of faces	2
Seismicity	25
Stoping width	
Support – Footwall not clean before installation	
Support - incorrect installation of	1
Support - removal of temporary	4
Support blasted out	
Support punching hanging or footwall	1
Travelling through unsafe back areas	2
Unstable rock wedges	

2.5 Conclusions: anomalous conditions and mine safety

Perhaps one of the most difficult and subjective aspects of examining past accidents is deciding whether situations are truly unusual or anomalous, in so far that the situation is not “normal” and the level of hazard is elevated above “normal” conditions. Gay, 1993, estimated that between 70% and 80% of falls of ground accidents occur where non-standard mining conditions exists, typically in the vicinity of geological weaknesses. It is a far easier matter, as has been done above, to identify factors that are causative in terms of accidents.

Looking only at geological structure, of 89 industry-wide accident cases, 15% occurred in designated special areas and 29% involved seismic activity. 55% were influenced by geological factors, however out of 28 cases from a single mine as many as 86% appear influenced by features considered geologically anomalous, in so far that the support in use failed to adequately prevent damage. The standard support was, however, largely *intended* to cope with a reasonably discontinuous hangingwall due to jointing, bedding and stress fracturing. Problem features were those where a change in hangingwall position occurred and blasting tended to break into the hangingwall, either due to rolls, minor faults, or any other reason.

Faults and dykes accounted for the anomalies in 20% of cases industry wide cases, and appeared causative in 25% of cases on a single mine, although present in 29% of cases. The significance of this will be evaluated in a later section of the report, where frequency of geological structures is assessed in terms of mining area.

The main problematic geological features can be summarised as follows in table 2.4.1. Numbers show proportion of accident incidents where each item occurred. Falls result from interaction of one or more of the features, plus stress fracturing. There are differences as a function of reef and depth, with stress fracturing becoming the dominant and ubiquitous discontinuity at greater depth.

Table 2.5 – Summary of geological structures involved in rock related accident cases

Source	**Faults or dykes**	**Bedding**	**Jointing**	**Rolls**	**Increased stope width**
89 industry cases	20%	47%	53%	No cases	Unable to specify
28 VCR cases	29%	Almost all (flow bedding partings)	46%	14%	21%

From the 89 industry-wide accident data cases examined, the key hazards are broadly listed in Table 2.4.2. These alone account for some seventy-percent (62 of 89) of the stoping rock-related accidents examined and help to narrow the list of significant anomalous conditions.

Table 2.6 - Hazards associated with accidents (n = 62 of 89)

Hazard	**Number of attributed accidents**	**% Of total number of accidents**
Seismicity	25	28
Lack of or inadequate support	15	17
Poor barring procedures	9	10
Unrecognized geological features	8	9
Scraping and rigging procedures	5	6

In this list, the “lack of support” item reflects cases where workers were operating in areas where support installation prior to the accident was questionable, and in some instances was clearly not correctly in place or was damaged. It also includes cases where people were in the face area prior to temporary support installation, and cases where collapse occurred despite support installation, in which case, given the ground conditions, the support had proven inadequate. In these latter cases, rock either fell between supports or support units fell out. In some respects seismic damage could also reflect an inadequacy in support, if it is assumed that adequate support for seismically active conditions can, in fact, be designed. All in effect could represent poor or inadequate mining practice, and could be eliminated by training.

Only a small percentage result from failure to recognise geological structure. In most cases the records indicate that structures were probably observed and some form of plan was in place.

The scraping and rigging cases involve damage to support, leading to loss of support, or cases where snatch block attachments came loose as a result of being anchored in loose ground, making them rock-related incidents.

3 Types of geologically anomalous condition

Although, as shown in the previous section, there are a variety of conditions that can be considered “anomalous” in stopes, the focus of this project is on those that result from geological, or geotechnical, reasons. There are a number of geological conditions which may be considered anomalous, and give rise to mining conditions requiring local changes in layout or support that are outside the scope of normal mine standards.

In the gold mines, bedding planes play a major role in falls of ground, particularly if parting planes with poor cohesion separates strata. Faults and joints define other planes of weakness from which blocks of rock may fall. Studies of the geometry of falls in gold mines show that most vary in area from 2m ^{2} to 5m ^{2} and that the form of the initial fall or ‘keyblock’ is that of an acute triangular prism bounded by planes dipping 25^o to 70 ^{o} (Gay et al 1988). Most geologically anomalous conditions become problematical because these keyblocks are generated.

3.1 Underground observations of geologically anomalous conditions

The following section is based on underground observations made during data collection visits to different mines in the Witwatersrand Basin and Bushveld Complex. Most visits were carried out jointly for this project, GAP 607, and SIMRAC project GAP602, and provide examples of a range of conditions that can be considered geologically anomalous. Most working places examined had dips ranging from 15 to 25 degrees. An exception was the Kimberley reef at Durban Deep where 80 degree dip stopes were examined, and some steep areas on the Basal reef at Bambanani. In these cases, apart from dip, the conditions were not strictly anomalous.

The main purpose of the underground visits was to confirm the nature of contributing geological factors to anomalous conditions identified in the accident data and examine any possible differences between the various reef horizons, or reef-specific conditions. The following subsections examine the characteristic of the most significant reefs identified in the accident records, plus the Merensky and UG2 reefs in the Bushveld Complex, and also examine certain key problems common, or potentially common, to all reefs. The range of areas examined, as a function of reef and depth, are indicated in figure 3.1, focussing on those reef where most accident incidents occur.

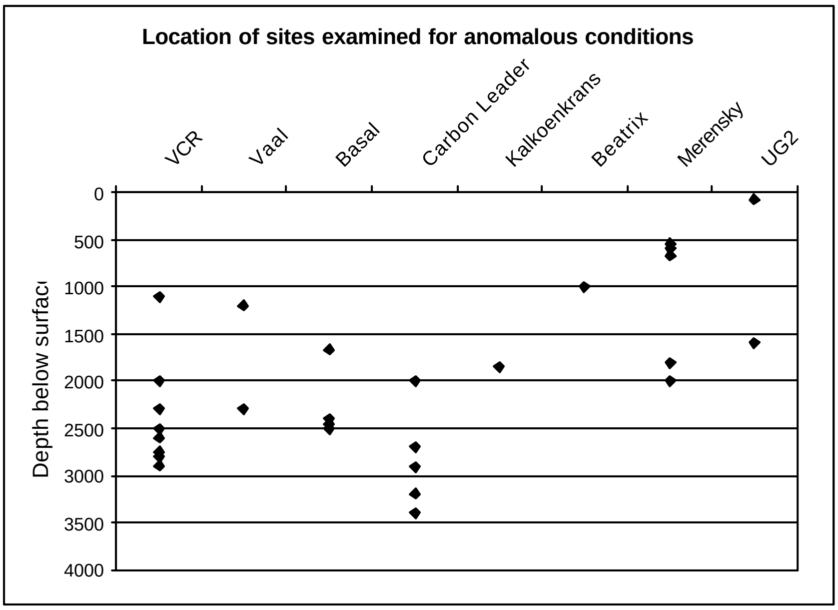


Figure 3.1: Location of areas examined for anomalous conditions.

3.1.1 Ventersdorp Contact reef

Areas inspected on the VCR were primarily in the West Rand at depths between 2000 m and 2900 m, with shallow mining conditions examined in the Klerksdorp area at 1100 m depth. In general the VCR is characterised by a generally strong and jointed lava hangingwall and a quartzite or shale footwall. However in some areas the lava may be weak, or a non-mineralised quartzite band may separate reef from lava. This quartzite band shows considerably denser stress fracturing than a hard lava and care has to be taken to utilise suitable support spacings to prevent falls of ground if the immediate hangingwall in a panel changes from hard lava to quartzite.

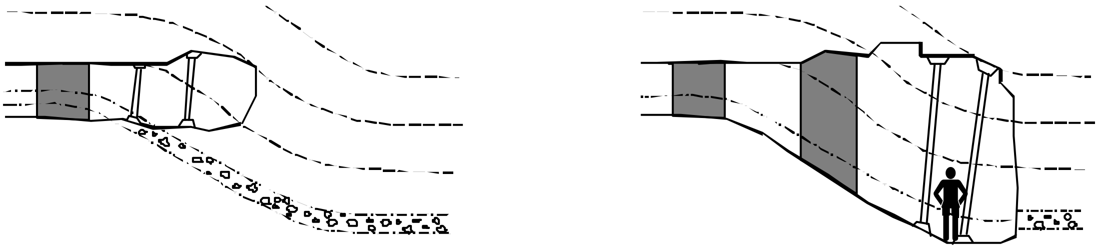
Figure 3.2: Typical joint-bound fall of ground along a reef drive on the VCR.

In general jointing appears to give rise to most falls of ground on the VCR, usually through interaction with stress fractures. An example is shown in figure 3.2. Blocks tend to be larger than those encountered on reefs with a quartzite hangingwall where stress fracturing is more dense. At shallower depth, flat dipping jointing tends to lead to large unstable wedges, requiring limited in stope spans of typically 16 m with stick support, or 10 m with bolting.

The VCR shows a terrace-slope-channel paleotopography, with resultant rolls in the reef. When intersecting a roll, panels tend frequently to run off reef into the lava, and a case was examined where mining persisted on breast even though some 3 m of lava had fallen out above the reef. This is illustrated in figure 3.3. Under these conditions, tall packs are insufficiently stiff to provide adequate hangingwall support and the hangingwall tends to fall out at the face to greater heights, barring becomes increasingly difficult, and due to the height of face, face bursting is more likely to occur. The only solution becomes panel re-establishment, as undercutting is rarely successfully carried out. This type of problem is a regular occurrence on many mines working the VCR.

Considerably better hangingwall conditions are observed where a smooth parting forms the reef to lava contact, generally thought to be where lava was deposited in water (Henning, 1992). Where a welded contact is present (generally in those areas which form higher terraces in the paleotopography) the hangingwall is more blocky and blast damage more prevalent.

In the West Rand area, a joint set tends to run parallel with breast faces when advancing West, making West mining somewhat more hazardous than advance to the East. This is a common problem on both Carbon Leader and VCR is this region.



Problems caused by poor mining controls

1. Stoping advanced flat & fails to follow reef roll
2. Cuts through bedding in hangingwall causing loose blocks
3. Need to trench in footwall to follow reef

Problems caused by poor mining controls

1. Trenching to follow roll results in increased stope width
2. Now have very high stope face that needs undercutting
3. Due to face height support is less effective, leading to FOG and further increase in face height
4. Safest means of recovery is panel re-establishment by re-raising

Figure 3.3: Loss of control in a VCR panel after encountering a roll. Reef is approximately 1 m thick at base of face (on the right), and 3 m of lava have fallen out. Tall packs and mechanical props are ineffective as support. The upper sketches explain the cause of the problems that arise with rolls. The high resulting stope face becomes prone to face-bursting in the hard, strong VCR lava.

3.1.2 Carbon Leader reef

Areas were visited at West Driefontein, Savuka and TauTona, at depths from 2000 m to 3400 m below surface. All were characterised by high stress and hence a high density of stress induced fracturing, and included a shaft pillar extraction, and mining both on breast and up dip, all using backfill as the main in-panel support.

In general panel face conditions were reasonable with a tendency for deterioration along gullies. This is influenced by the presence of jointing which interacts with stress fractures to create loose blocks, and the thickness of the quartzite middling from reef to Green Bar shale, which ranges upwards from 1.5 m. An example of the stope hangingwall conditions arising from the interaction of jointing and stress fracturing at depth is shown in figure 3.4. Collapse problems in gullies arise where cubbies are excavated for winches. Cubby excavation involves removal of packs and opening up wide spans and collapses occur prior to installation of alternative support. Runaway collapse occurs once the Green Bar is exposed.

Figure 3.4 - Blocky hangingwall conditions arising from the interaction of jointing and stress induced fracturing when mining West on the Carbon Leader Reef at approximately 3400 m depth. In this instance in-stope ground control of these conditions is good.

3.1.3 Vaal reef

Areas on the Vaal reef in the Klerksdorp area at depths of 1200 m and 2300 m were inspected. From a geotechnical viewpoint, the Vaal reef is conglomerate band, typically less than 1 m thick, with a largely siliceous quartzite footwall (MB5 unit), overlain by MB4 argillaceous quartzites. The hangingwall is well bedded, with bedding planes spaced from 10 cm to 150 cm, is often cross-bedded, and bedding-bound wedges may occur. The footwall may locally contain a weaker bed into which support may punch.

Locally an altered, weak, hangingwall condition may exist, associated with alteration near certain faults. Jointing, bedding and faulting is known to be weaker in these areas and unstable hangingwall areas occur. In some areas on the Vaal reef, hangingwall bedding is consistently less than 100 cm, and shale or comminuted material is observed to create weak, cohesionless bedding partings.

Where spans are wider on the Vaal reef, such as at gullies, bed separation is prevalent and in higher stress areas (such as in remnants) where denser stress fracturing occurs re-establishment, re-support and possibly abandonment and re-excavation of original centre gullies or raises is a regular occurrence.

3.1.4 Basal reef

Stoping was inspected on the Basal reef at depths of 1650 m and 2300 m. Dip varies between near-horizontal to over 45 degrees. The Basal reef in the Freestate region can vary considerably in terms of sedimentary facies but frequently comprises a lower conglomerate unit grading into an overlying intermittently-mineralised quartzite, the full thickness of which may vary from 20 cm to 3 m. The reef is overlain by the Khaki shale, a highly sheared weak unit, above which is the Waxy Brown quartzite. The reef footwall is generally a competent siliceous quartzite some 50 m thick.

Where mineralised, the quartzite is mined with the conglomerate, and a full cut is taken. Where poorly mineralised and thicker (over typically 0.5 m) and where Khaki shale is thick, the quartzite is undercut and left in the stope hangingwall.

Where undercut, problems may arise with collapse of the quartzite middling up to the weak Khaki shale, which tends to be very weak and mobile. The Khaki shale is not always present (such as over parts of Bambanani), making undercut operations easier, and may range in thickness from 20 cm in the South of Welkom, to several metres thickness to the North. Adequate barring, to ensure stable hangingwall, is a prime issue in these areas.

Where a full cut is taken the Waxy Brown quartzite forms the immediate hangingwall. This is well bedded. In addition, shear partings tend to rise out of the top of the Khaki shale, and may be near-parallel to reef. These may give rise to what are referred to as “ball and pillow” structures which are often observed in the base of the Waxy Brown unit. Partings are often infilled with weak shaley material and form major instabilities, giving rise to brows and unstable wedges of ground. Examples of Basal reef brows are shown in figures 3.5 and 3.6. Falls associated with “ball and pillow” structures can extend to 5 m into the hangingwall.

Figure 3.5. - Typical brow on Basal reef where shear parting rolls sharply upwards into the hangingwall. Rock is loose on the up-dip side of the marked brow (to the left), while the brow on the parting is generally stable.

Figure 3.6 - Brows along a gully on Basal reef where bedding-bound blocks have collapsed. Rockprops are being used to controll further collapse on the up dip side of the gully.

3.1.5 Merensky and UG2 reefs

A large number of stopes on the Merensky reef were inspected on Northam, Amandelbult, Impala Platinum and Western Platinum's Karee mine, ranging in depth from approximately 500 m to 2000 m below surface. Examination of UG2 conditions carried out in over-stoped conditions at Impala and shallow room and pillar workings at Kroondal Platinum.

Most mines operate a typical shallow mining method using crush pillars with sticks, packs, or bolts internally in panels. Geological structures are the main cause of local falls of ground in shallow stopes. They from blocks of rock of various shapes and sizes, and depending on their geometries, the blocks can be either stable or potentially unstable. The lack of a significant fracture zone that would cause horizontal dilation ahead of the stope face means that no horizontal compressive forces are developed in the stope hangingwall and footwall, to clamp the blocks of rock together (Gay et al 1988).

The Merensky reef is typically a pegmatitic pyroxenite, with pyroxenite immediate hangingwall. Depending on whether mining is in normal reef, or in a pothole, the footwall units may vary from anorthosite, to norite, to pyroxenite. Anorthosites may be weak. The UG2 is hosted entirely in pyroxenite, with minor chromitite stringers possibly providing weak partings similar to bedding. Generally the rock mass is fairly massive, without the bedding of the gold mine sedimentary strata, but with joints, potholes (rolls), faults and intrusions. These introduce various anomalous conditions. The following are the main ones noted in general on Bushveld mines.

- Cross cut reef intersections. In these areas excessive width to height ratios were observed on packs. Also the footwall to hangingwall height often exceeds 3 metres making it difficult to deal with poor hangingwall conditions.

- Negotiating rolls from one reef elevation to a lower one around the edges of potholes. This often results in footwall lifting of gullies causing excessive heights and poor width to height ratios of gully packs. When rolling down, mining off reef into the hangingwall is also a problem, as on the VCR.

- Dyke and prominent joint intersections in gullies. In conditions where packs have excessive width to height ratios or their spacing across the gully is excessive, the supporting action is less effective and partings tend to open. Sidings are frequently omitted to reduce the span where major features cross gullies, to control joint instability.

- Where weak jointing or fault planes are particularly extensive additional 2 by 2 m pillars may be placed along gullies or in panels to reduce the span and prevent discontinuity-bound falls.

- Carrying the hangingwall of UG2 raises along a parting plane about 70 centimetres above the top contact of the required stoping hangingwall. A brow is then created where the stope ledge is established adjacent to the centre raise.

- Stoping in excessively fractured ground resulting from stress induced damage. This occurs for example when a panel has to be mined along a stoping abutment created by a long lead or lag.

- Inadequate strike pillar width. In moderate depth Platinum mining strike crush pillars are generally left in-situ along gullies. The pillars can become too narrow mainly in situations when the down dip panel leads and the face length becomes gradually longer as the top corner of the panel tends to creep up dip after each blast. This encroaches into ground that should be left as pillars. To keep the top gully straight and on-line while still maintaining the strike pillars, the gully siding for the up dip panel is frequently omitted. The result is that slabbing occurs directly along the gully wall as the pillars crush, causing a hazard in the gully that cannot be adequately controlled by bolting.

- Cooling domes, often associated with low-angle thrust structures or minor reverse faults, on various scales cause fall of ground hazards in stopes. Practice is to cut additional instope pillars beneath them when edges are picked up. This often prevents major collapses. Locally dense jointing is often associated with domes. An example of a limited collapse was observed where only sticks were used as support (figure 3.11). In other cases rock bolting proved successful where the dome height had been correctly predicted and bolts were of adequate length to pin through the dome (figure 3.14).

The following specifically hazardous areas, considered anomalous by mine personnel, were examined.

An area on Merensky reef at 660 m was experiencing poor ground conditions and open jointing due to the rolling nature of the reef, and hence poor stope width control, plus apparent horizontal tectonic stresses, indicated by damage in the hangingwall of footwall crosscuts.

A flat-dipping dyke was present, creating weak partings and falls of ground over a gully, up to the sticks that formed the gully-edge support. Some falls continued between sticks into the panel face area. Conditions were considered sufficiently poor that theface had been stopped. The gully was advanced and the face was to be re-established by re-raising, leaving a pillar against the current, partially collapsed, poor condition face area.

In general, rock engineering practice is to cut pillars in panels to control joint related falls in anomalous areas of high joint density, or where joints are exceptionally long and planar. The joints generally inevitably lead to falls in the back area, which in turn can induce instability nearer to mining faces. One remedy for such places is to use RSS packs throughout on a 5 m by 5 m pattern, but grout pumping may be unable to keep pace with face advance. Consequently a denser pattern of sticks (1.2 m by 1.8 m spacing) is used, giving an equivalent support resistance. The spacing of rockbolting in gullies may also be reduced to 1 m by 1 m.

In one area at 1500 m depth, a 1.5 m wide vertical dyke had additional stick support installed on each side, but not beneath the jointed dyke itself. As a result some falls had occurred.

At shallow depth weathering may become problematical. Stopes may enter weathered ground where groundwater has caused oxidation along joints, bedding or other partings. The rockmass may be very broken up and blocky or friable, and the rock material can sometimes be crumbled by hand. Partings may be infilled with a muddy gouge. Generally this sort of ground is limited to depths of less than 30 m to 40 m below surface.

Some examples of geologically anomalous conditions observed on Bushveld mines are shown in figures 3.7 to 3.14.

Figure 3.7 - Interaction of joints and a minor fault at shallow depth on the Merensky reef produce typical unstable wedges of ground in the otherwise massive rock mass. Example is at the face of a stope mining along a pre-developed reef drive.

Figure 3.8 - Collapse of 0.5 m to 1 m of hangingwall within a 1.5 m wide dyke in a Merensky reef stope. Additional support is placed along the dyke contacts, but not beneath the dyke.

Figure 3.9 - Prominent jointing causing unstable conditions over a Merensky reef stope gully. An additional support pillar has been left on the up dip side of the gully, on the right of the picture.

Figure 3.10 - Fall of ground associated with flat dipping sill on Merensky reef at 1800 m depth. Bolting failed to prevent falls in gully; RSS packs captured brow and prevented migration of fall into panel.

Figure 3.11 - 2.5 m high brow created by partial collapse of a dome on the Merensky reef. Controlled by stiff elongates cluster

Figure 3.12 - Typical pothole showing rolling of the UG2 reef horizon in a platinum mine. Potholes are generally near circular or oval in plan and vary considerably in size from a few metres to hundreds of metres, with varying degrees of severity of roll. Mining has entered the hangingwall along the roll.

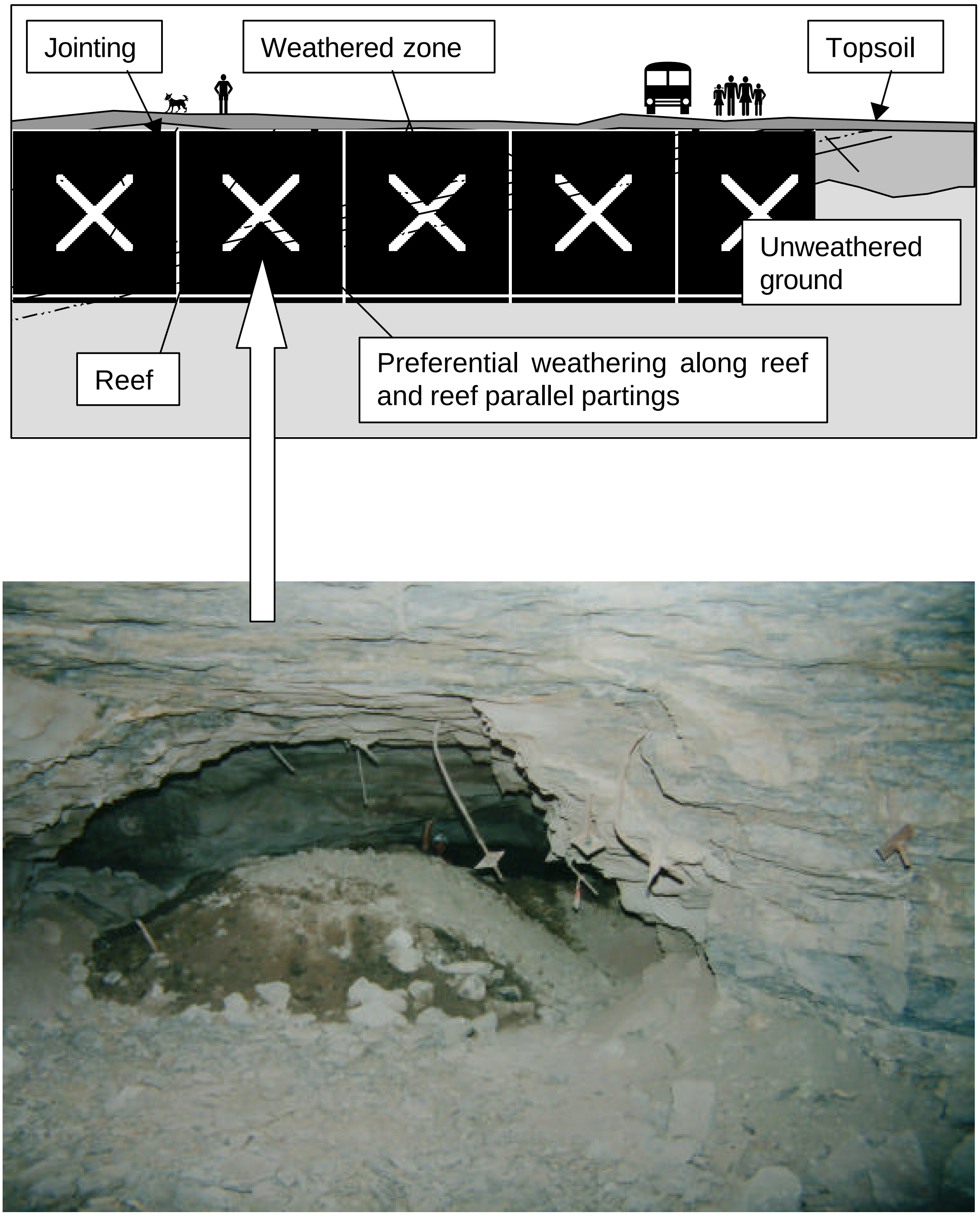


Figure 3.13 – In-stope collapse in a shallow platinum mine in highly weathered pyroxenite ground

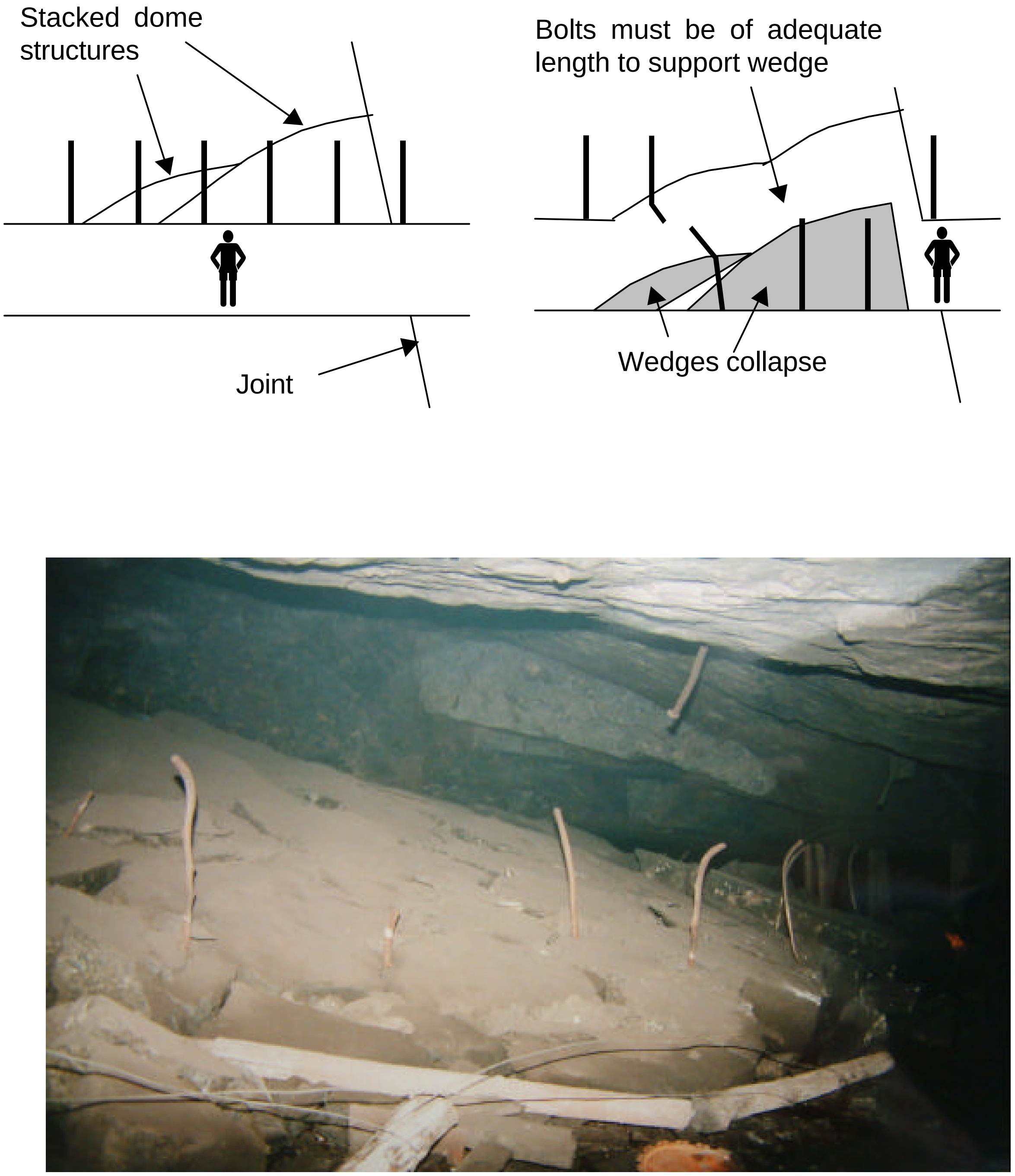


Figure 3.14 - Collapse of a major dome in a platinum mine at shallow depth: installed rebars proved inadequate to support the large wedge of ground. In this example the wedge is approximately 50 m long, 8 m wide and up to 4 m high. The sketch, top, explains the mechanism.

3.2 Other Anomalous Conditions Examined

3.2.1 Pillar Mining areas

A pillar mining area was examined at St. Helena. This was extracting the Basal reef at a depth of 1629 m below surface. Few geological discontinuities were noted but stress fractures reached a density of 5 to 20 fractures per metre, significantly higher than normal for this depth, and requiring a special support system that was operating successfully. Pillar areas, often referred to as remnants, typically show elevated levels of stress.

3.2.2 High stope widths

The methods for handling high stope widths (2.5 m to 7 m) at shallow depth were examined at approximately 1000 m on the Beatrix reef. A pillar and bolting mining method was in use, mined in two cuts. Discontinuities comprised mainly bedding, joints and minor faults and all brows were well marked and supported with additional bolting.

3.2.3 Deliberate creation of brows

On some mines, for example mining the Kalkoenkrans reef at 1850 m depth in the Freestate; a practice of blasting down gully hangingwalls to create space for rock handling was observed. Presumably this is done in preference to footwall ripping as the hangingwall quartzite is generally more competent than the footwall. However, it creates brows along gully edges, and in the case observed a 10 cm thick shale band was present some 50 cm into the hangingwall. Opening of a parting along this band was seen, and the resulting brow was unstable, causing a hazard.

3.2.4 Minor strike faulting and gullies

Strike faulting with several metres throw frequently leads to hazards in strike gullies. In general, to avoid extensive off reef mining, a preference will often tend to be to site the gully close to the fault on the down-thrown side to facilitate cleaning of the panel mining the down thrown reef block. With holings upward through the fault, this gully may often provide top access also to the stope on the up thrown side. Gullies need to be straight for a clear scraper pull, whereas faults tend to wander and are rarely directly on strike. As a result there are frequently long sections of gully where the fault plane runs in the gully. A brow tends to develop on the fault, and, with bedding present, may tend to break back into the adjacent stope panel. Obviously this sort of layout is likely to be of high risk in situations where the fault could be seismically active.

Contributory factors to collapse at faults are soft packs, such as brick composites where bricks are missing due to blast damage, or due to an absence of pack pre-stressing, or the tendency to taller and hence softer packs along gully shoulders due to loss of shoulder integrity. Use of ASG-type gully layouts with headings and lagging sidings promote the development of adverse, low angle, stress fractures. These contribute to collapse at fault intersections. Cases where faults run along gullies were examined on the Vaal Reef at 1200 m depth, and on the VCR at 2000 m depth and Carbon Leader at 3400 m depth. At shallow depth it is feasible to reduce spans in gullies to enhance stability by eliminating sidings or leaving small in-situ pillars. This is not an option at depth, and the end result due to poor control of span is usually an extensive collapse, which has to be re-supported. Methods involving sets anchored in packs, cribbing and cementitious void filling appear the most successful, if expensive.

Problems resulting from faults crossing gullies, where spans between support are greater than in-panel, appear to be a regularly occurring non-standard condition and hazards almost inevitably arise before remedial action is taken. From the fatal accident incidents a number were noted to have occurred in these circumstances.

4 Frequency of occurrence of geotechnically anomalous conditions

One of the main aims of this project is to assess how frequently anomalous conditions occur. In other words are anomalous conditions actually unusual, or do they occur so frequently that they should be considered part of the standard design procedure for stope layouts and support.

Several sources of data have been examined to gauge the frequency of occurrence of anomalous conditions. In addition, techniques have been identified which could be used as a means of predicting how often anomalous conditions may be encountered in a particular mining area. Data sources include:

- In-stope observations obtained from stope audits carried out by some mine rock engineering departments.
- Panel rating systems used on many mines to assist in monthly planning, provide comments and information concerning stope conditions on a mine-wide basis for any point in time.
- Mapping of geological structure at a platinum mine
- Fault population studies from the various gold field areas.

4.1 Stope audit systems

A number of mines of former Genmin (or Gencor) ownership use a stope auditing system to assess firstly, compliance to mine standards, and secondly to audit and quantify geotechnical conditions and hazards. The system is generally based around a number of stope observers whose task is to carry out daily visits to stope panels and measure support spacings, excavation dimensions, and in some cases the location of faults, dykes, joints, brows and carry out rock mass ratings. The intention is to visit all panels on a regular basis, but in many instances problem areas tend to take priority. These systems compile a large volume of stope history data and hence can provide valuable information for this project.

Data was taken from two mines working the Merensky and Beatrix reefs, both operating at almost comparable shallow to intermediate depths and hence in theory providing a comparison between massive, jointed, Bushveld igneous rock behaviour and bedded, sedimentary strata. Unfortunately, detail on geotechnical conditions was limited in the Beatrix data, which was primarily intended purely as a measure of compliance to mine standards. Impala use their system as a basis for checking panel conditions and hence as a monthly guideline for making new support recommendations. The Impala data was consequently more useful than that available from Beatrix.

4.1.1 Merensky reef

Stope audit data was compiled for the Merensky reef at Impala Platinum, where both this reef, and the UG2 reef, has been worked at depths from 30 m to 1100 m, using a typical scattered mining layout where support comprises crush pillars, and internal panel stick or pack support. Geological features include joints, faults, chrome stringers (forming reef-parallel weaknesses), dolerite and lamprophyre dykes, and potholes.

At Impala, stope observers undertake very comprehensive stope audits on a regular and systematic panel by panel basis. Information that is recorded includes the following:

- Q value of rock mass rating.
- Panel length.

- Distances of temporary and permanent support from each other and the face up to a distance of 10 metres back from the face.
- Gully hangingwall support, including angle of rebar installation.
- Distance of the ASG ahead of the face plus its width.
- Span of support across the gully plus the siding depth if present.
- A support percentage is calculated which compares the actual to the required standard.
- The position of any geological features including brows, faults, dykes, rolling reef, shear zones, prominent joints and potholes.

Note that only the Platinum mines have generally made use of true rock mass rating systems. At Impala the NGI Q system (Barton, 1976) is used, while on the Amplats mines the Bieniawski CSIR RMR system is preferred. The categorisation scheme used at Impala is slightly different to the original NGI scheme:

A total of 223 stope audit forms were taken at random from five areas of the mine and analysed in terms of the following:

- The number of panels containing non-standard geology.
- A comparison of actual to the required standard for both temporary and permanent support.

As the data was selected at random it is representative of the general conditions over the mine and does not focus only on problem panels.

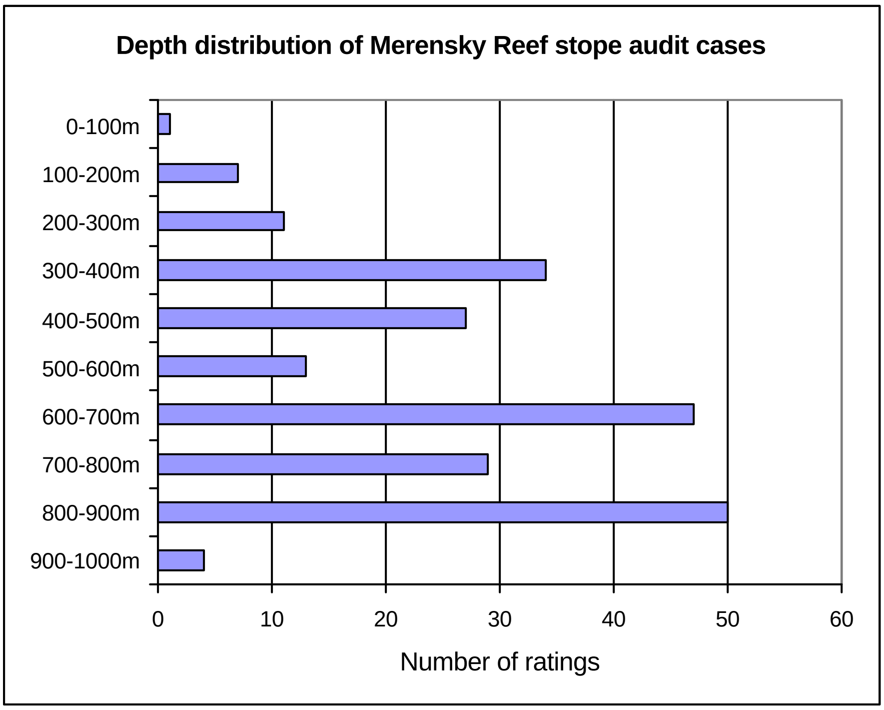


Figure 4.1: Distribution by depth of 223 panel ratings for mining on the Merensky Reef at shallower depth.

The distribution of selected data as a function of depth is shown in figure 4.1. There is a reasonable spread down to 1000 m depth, with the bulk of data coming from the 400 m to 900 m range, where mining methods and mining problems are similar, generally the result of geological structure, large mined spans, and largely uninfluenced by high stress. From the sample of stope audits chosen, on average as many as 80 percent of stoping panels at Impala Platinum contain some form of geological conditions which are non-standard in the sense that geological features over and above the standard jointing are present. This includes faults, dykes, potholes, or dense jointing. Table 4.1 shows a summary of the panels containing non-standard geology in each area.

Table 4.1: Summary of platinum mine panels containing non-standard geology

Area.	**Average depth of panels**	**Number of panels.**	**Geological Conditions.**		**Percentage.**	
			Standard.	**Non Standard.**	**Standard.**	**Non Standard.**
1	317 m	37	17	20	46 %	54 %
2	751 m	46	6	40	13 %	87 %
3	381 m	44	5	39	11 %	89 %
4	733 m	47	5	42	11 %	89 %
5	743 m	49	14	35	29 %	71 %
Total.	**601 m**	**223**	**47**	**176**	**21 %**	**79 %**

79% of panels contained some form of geological structure, resulting in potentially non-standard, or anomalous conditions. The following geological structures contributed to the geologically non-standard conditions. Proportions are expressed as percentages of the total 223 panels, and hence, very approximately, of area mined.

Type of geological feature

Fault	**Lamprophyre dyke**	**Dolerite dyke or sill**	**Pegmatite vein**	**Pothole**	**Dome**
21%	14%	9%	16%	5%	1%

Note that these add up to 66% (out of 79%). In the remaining cases non-standard geological conditions could be attributed to low rock mass rating, probably due to joint density (13%).

The stope audits identified all brows in panels. A rough estimate of the level of hazard in any panel can be made on the basis of the number of brows, plus the complexity of contributing geological structures in panels.

The following is a summary of the proportion of panel audits containing brows (grouped as all cases from one or more, and severe cases with more than three) and structure (single fault/dyke/vein, or in excess of three features).

Geological complexity

One or more brows	**More than 3 brows**	**Any structure**	**Complex structure**
48%	24%	47%	16%

While numerically there appears to be similarity between proportion of cases contain one or more brows and the proportion containing any structure (48% versus 47%), and likewise between more than three brows and complex structure (24% versus 16%), the source panel audit data shows that brows do not necessarily occur in the panels with structure. In only 17% of panels do the presence of brows and structure coincide, and this falls to 6% when more than three brows and structure are considered. This implies that natural jointing is most probably the major contributor to brow formation. This is incorporated in the Q rating system, although density of jointing was not specifically identified or discussed on audit record sheets. The proportion of the 223 audited panels at various Q ratings are as follows.

Q rating

Very poor **Q < 1**	**Poor** **Q 1 - 5**	**Good** **Q 6 - 10**	**Very good** **Q > 10**
7%	39%	15%	35%

Essentially most panels appear to be rated either as poor, or very good, with few other cases. The Q rating system focuses on discontinuities and is primarily based on fracture density, number of joint sets, and fracture conditions. Table 4.2 lists the numbers of panels with brows and structure in each Q rating category. This shows, for example that 26% of complex geological structure is associated with panels with a high Q rating, but is otherwise not overly informative as it fails to account for the low number of panels audited with very poor or good Q ratings.

In the second percentage section of the table the data is turned round to reflect the proportion of panels with brows, etc., which fall under each Q rating category: for example, 87% of panels with a very poor Q rating contained one or more brows. These percentages clearly show that proportionally more brows occur in panels with low Q ratings. Further, proportionally more panels with low Q rating are associated with complex geological structure, although there is no clear inter-relationship when only single structures are considered.

Table 4.3 examines the relationship between types of geological structure and Q rating, and has a similar structure to table 4.2. In general the 223 panel sample contained too few potholes and domes for an accurate estimate to be made of the level of hazard created by these structures. From the second percentage section of the table it is clear that faults and lamprophyre and dolerite dykes are more closely associated with lower Q ratings. This is not unexpected. Interestingly, pegmatite veins and potholes do not seem to be closely related to low Q ratings, suggesting that, contrary to observations elsewhere, the ground conditions are not necessarily more broken in potholes.

Table 4.2 - Q rating data related to panel structural complexity

Q rating	Total Panels	Brow (one or more)	Severe brows (more than 3)	Geological structure (one or more)	Complex geology (3 or more struct)
very poor	15	13	10	10	4
Poor	81	52	28	37	16
Good	46	8	5	27	6
very good	81	33	11	30	9
Totals	223	106	54	104	35
very poor		12%	19%	10%	11%
Poor		49%	52%	36%	46%
Good		8%	9%	26%	17%
very good		31%	20%	29%	26%
		100%	100%	100%	100%
Percentage of panels in each Q category with brows, structure, etc.(i.e. 13 out of 15 panels with very poor Q rating, or 87%, contained one or more brows)					
very poor	15	87%	67%	67%	27%
poor	81	64%	35%	46%	20%
good	46	17%	11%	59%	13%
very good	81	41%	14%	37%	11%

Table 4.3 - Q rating data related to types of geological structure in panels

Q rating	Total Panels	Pothole	Pegmatite vein	Lamprophyre dyke	Fault	Dome	Dolerite dyke/sill
very poor	15	0	1	3	7	1	2
Poor	81	4	2	20	19	0	10
Good	46	6	18	3	11	1	3
very good	81	1	15	6	9	0	5
Totals	223	11	36	32	46	2	20
very poor		0%	3%	9%	15%	50%	10%
Poor		36%	6%	63%	41%	0%	50%
Good		55%	50%	9%	24%	50%	15%
very good		9%	42%	19%	20%	0%	25%
		100%	100%	100%	100%	100%	100%
Percentage of panels in each Q category with faults, dykes, etc. (i.e. 1 out of 15 panels with very poor Q rating, or 7%, contained a pegmatite vein)							
very poor	15	0%	7%	20%	47%	7%	13%
Poor	81	5%	2%	25%	23%	0%	12%
Good	46	13%	39%	7%	24%	2%	7%
very good	81	1%	19%	7%	11%	0%	6%

In terms of support installation, the stope observer data also provides considerable insight into mining practice. An evaluation of the proportion of installed support to a basic “standard pattern” has been made in an attempt to quantify firstly the actual support installed underground, and secondly the level of increase in actual support when adverse geological conditions are encountered.

A base standard for permanent support was adopted for this exercise, using sticks on a 2 m by 2 m pattern, 8 m from the face as permanent support, and a base level of temporary support consisting of units on a 2 m dip spacing, no further than 2 m from the face. This is a typical basic level of support for several platinum mines. A summary of the proportion of the 223 audit cases that meet this standard level is presented in table 4.4.

Table 4.4 - Levels of support in panels in relation to the “base standard” 2 m pattern used for evaluation

Area	**Number of panels**	**Temporary Support**		**Permanent Support**		**Temp and Perm Support**	
		100 % to standard	**< 100 % to standard**	**100 % to standard**	**< 100 % to standard**	**100 % to standard**	**< 100 % to standard**
1	36	1 - (3%)	35	1 - (3%)	35	1 - (3%)	35
2	46	13 - (28%)	33	9 - (20%)	37	5 - (11%)	41
3	44	14 - (32%)	30	8 - (18%)	36	6 - (14%)	38
4	47	9 - (19%)	38	18 - (38%)	29	7 - (15%)	40
5	49	18 - (37%)	31	34 - (69%)	15	13 - (27%)	36
Total	**222**	**55 - (25%)**	**167**	**70 - (32%)**	**152**	**32 - (14%)**	**190**

The method used to calculate whether audit cases were acceptably within standard, in terms of volume of support within the mining area, involved the following procedure:

1. Dividing the panel length by two and adding one. This gives the standard number of sticks that should be installed.
2. The actual number of sticks installed along the panel is counted on the stope audit form.
3. By dividing the actual number by the standard number, an actual support percentage is calculated.

This approach provides a quick and easy way of producing a single number that represents an overall compliance of the installed support to the standard pattern. The selected base standard of a 2 m spacing was chosen because it is typical of many basic standards in use on mines in the Bushveld Complex. However, it has been shown in table 4.1 that 79 percent of panels contain some kind of geological anomaly that might require additional support (as referred to in the mines Codes of Practice), hence the audit data should show some form of increase over the base selected standard.

From the sample, on average temporary and permanent support is fully to the selected standard in 25 and 32 percent of the panels respectively. In 14 percent of the panels both temporary and permanent support simultaneously complied with the selected standard. It should be noted that many of the panels were within 90 percent compliance to the standard. However for this exercise only those panels that were 100 percent or more qualified as being to standard.

By viewing these results together with the audit forms it became apparent that the simple method used to calculate the support percentage (normalising the data to a bases standard) was not taking the additional support required into account. Therefore it is possible that panels may have 100 percent actual support based on the calculation but this may fall short of what is actually required in terms of increased density specified by a Code of Practice for the particular geological feature present.

As shown in tables 4.2 and 4.3, the Q rating provides a reasonable relation with the level of geological complexity and problematic structure. Figures 4.2 and 4.3 relate Q rating to first the percentage of support that is to standard, and second the reported face to support distance.

In figure 4.2 there is no obvious relationship or trend between changing Q and the proportion of installed support. Note that the percentage compliance to standard is shown in this graph, hence percentages less than 100% reflect support that on average is more widely spaced than the standard 2 m spacing, while over 100% reflects an overall average tighter spacing.

In figure 4.3 temporary support appears to be within the required standard at all Q ratings, however there are more wide face to permanent support distances when Q rating is high compared to when Q rating is low. This would tend to indicate recognition of the need to get support installed early when Q is low and ground conditions are poorer. Conversely it suggests mining practice becomes more lax when Q is high and conditions are better.

Neither figure 4.2 or 4.3 clearly indicates significantly reduced support spacings when ground conditions are poor, at least in terms of Q rating.

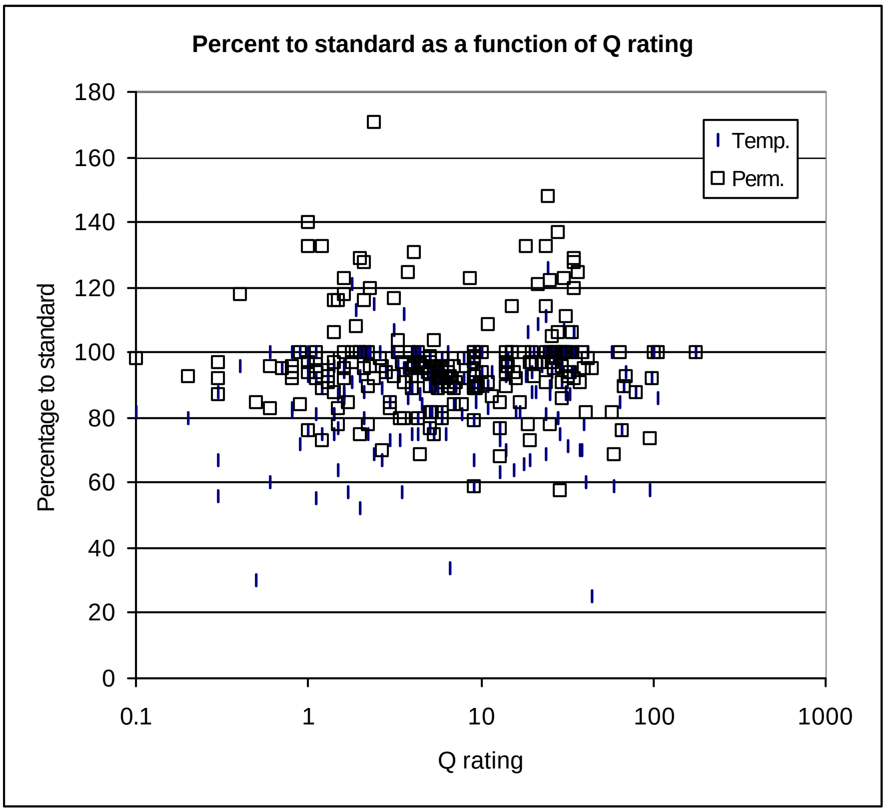


Figure 4.2 - Relationship between panel Q rating and percentage installed support

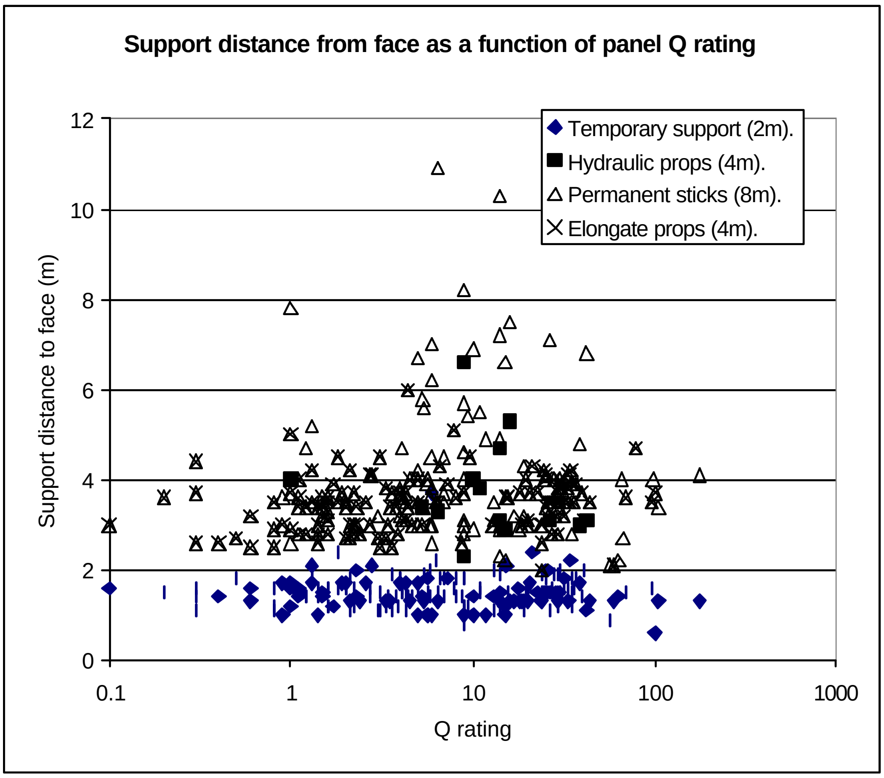


Figure 4.3 - Relationship between panel Q rating and distance from face of installed temporary and permanent support units

4.1.2 Beatrix reef

The Beatrix reef is only mined in the Southern-most part of the Freestate gold field, at shallower depth, between 750 m and 900 m depth, and at dips between zero and 16 degrees, with frequent faulting. The Beatrix reef is similar to many other Witwatersrand reefs in that reef width is generally less than 2 m (but may reach 10 m) and the hangingwall is competent, but well bedded quartzite. The immediate footwall tends to be weak and may yield under support units. As result of wide reefs and incompetent footwall, some areas are mined using a room and pillar system where the inter-panel support comprises rock tendons. Stope observer data was available from an area that works a total of approximately 80 panels at any one time.

The stope observer sheets provide a record of measurements of support unit spacings relative to the face and to each other and are used by the mine rock engineering department to determine adherence to standards. They focus on problem areas, rather than being random audits. In addition there are numerous short memoranda on rock engineering department visits to stopes. Some of these reports are routine, casual visits to the stopes, but most were on the request of production personnel and prompted by strata control related problems and hence focus on problem areas, which in many instances can be considered to be non-standard panels.

Data from a total of 30 cases has been examined. The contributing factors to panel problems were assigned according to the contents and context of each report read. Hence, this investigation was very subjective. In terms of overall generalised categories of contributing factors the cases subdivided as follows:

	Stress	**Geology**	**Mining**
Frequency	3	23	10
Percentage of 30 cases	10%	77%	33%

If the geological influences category is subdivided further the following relative importance placed on various geological hazards by the rock engineering and production staff is apparent:

	Dykes	**Bedding/cross-bedding/shale partings**	**Jointing**	**Faulting**	**Brow**
Frequency	5	5	1	14	1
Percentage of 30 cases	17%	17%	3%	47%	3%

From these figures faulting appears the most frequent hazard. However, in terms of this project, requiring a quantification of anomalous conditions, these figures must be treated with some caution, as they do not reflect the proportion of features causing accidents. The mine's Code of Practice provides a list of fall of ground incidents of which 29 are stoping related. From the descriptions, none are obviously mining or stress related but in 28 cases geological influences are noted. The breakdown is as follows.

	Dykes	**Bedding/cross-bedding/shale partings**	**Jointing**	**Faulting**	**Brow**
Frequency	0	14	2	3	9
Percentage of 29 cases	0%	48%	7%	10%	31%

This data raises the question of whether the use of accident data is a good way of quantifying anomalous condition categories. Clearly from the mine's own underground visits there are frequent faults, joints, dykes and brows that create mining problems, but mining attention and practice appears to ensure that accidents do not frequently occur. Possibly the hazards are just relatively easy to recognise and counter. Observations made for this project tended to confirm good mining practice as all brows at Beatrix resulting from geological structures were well marked and supported (figure 4.4). The problematical (or accident causing) geological features are primarily bedding, and cross bedding in particular which is difficult to identify before the hangingwall breaks and a wedge of ground drops out.

Overall however, this Beatrix reef data, was not of adequate volume to give a clear proportion of total mining area that could be considered anomalous, or problematical.

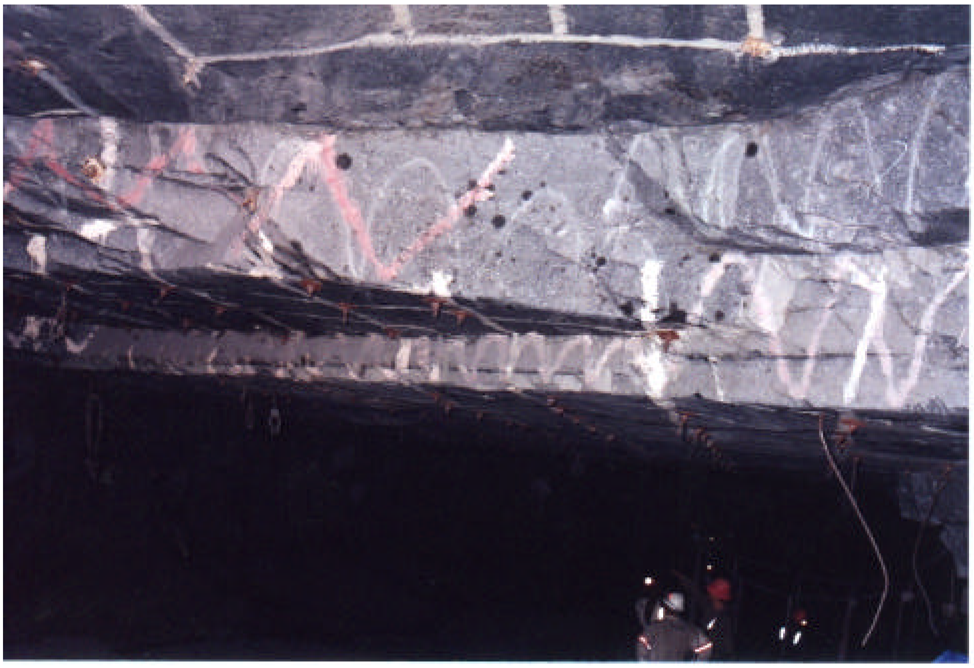


Figure 4.4 - Well identified (paint-marked) brows formed by distinct bedding plane partings, with additional pattern bolting support installed, on the Beatrix reef at approximately 850 m depth. Total height of the multiple brows is approximately one metre

4.2 Stope support rating and recommendation schemes

While few mines use a stope observer-based audit system as comprehensive as the one at Impala, many mines derive a list of rock engineering stope support recommendations on a panel by panel basis. These are compiled or revised month by month and are used for stope planning at Section Managers monthly pre-planning meetings. In many instances some form of risk rating system has been devised based on geotechnical criteria to improve the objectivity of support standard selection and requirements for special visits and support recommendations.

In the main, these rating systems are armchair assessments, made on the basis of computer modelling of stresses and energy release rates, information on structure from geology departments and production officials, and observations made during any visits by rock engineering staff during previous months. They are generally made without detailed underground data on jointing, bedding and rock condition for each working place. Despite this they provide reasonable insight into likely problem areas and anomalous conditions on a mine, giving a mine-wide snap shot at a single, monthly, point in time.

Data from three systems was examined, each system being notably unique in approach. Vaal, VCR and Merensky reefs were covered. Note that the aim in examining data from these systems as part of this project is not to compare, criticise or evaluate rating system effectiveness, but to provide a measure of quantification of where extra levels of support are required, how many panels are influenced by geological structure, and in turn the proportion of areas mined which are influenced by obvious anomalous conditions. These systems fail to pick up the abnormal conditions resulting from minor falls, brows, etc. but do provide a record of places where more severe hazards are anticipated or have developed.

4.2.1 Vaal reef panel ratings

Data was obtained from a panel rating system employed by African Rainbow Minerals (ARM) for operations in the Klerksdorp area, mining the Vaal reef during 1997 and 1998. Scattered breast mining is the dominant method and backfill was at that time extensively used. The predominant mining depths range from approximately 1500m to 2500m below surface. While not current, the data is considered reasonably typical of Klersdorp mining operations. Of the panel rating systems in use in the industry at that time, this one contained reasonable detail, and a short description of the system used and the information extracted follows.

The panel rating system operates in three stages: a Panel Index, a Panel Rating and lastly Action Levels (Dunn and Laas, 1999).

The Panel Index rates potentially hazardous factors considered controllable or man-made, relating to mining layout, sequence, geometry relative to major structures, and stope access. The Panel Rating takes this index and adds factors considered uncontrollable such as geological structure complexity, mined out span, rockburst hazard and face stress levels. The Panel Rating is assigned values ranging from 1 to 5, which have associated required actions relating to support requirements.

A rating of 1 relates to panels mining (mainly ledging) under low induced stress and low seismic risk, while those with a 4 or 5 rating have high seismic risk. Different factors in the Panel Rating are assigned weightings or importance factors and the weighting for seismic risk tends to make it over-ride all other factors. For this project, an examination of the five factors that make up the rating has been made, with focus in particular on the geological factors. Data was taken from roughly 50 panels for the months of November and December 1997 and January and March 1998, giving a total of 205 ratings, or data points. The distribution of these as a function of depth below surface is shown in figure 4.5. Depths of working places are estimated on the basis of level, for example a panel on 75 level is 7500 feet below surface, or 2286 m.

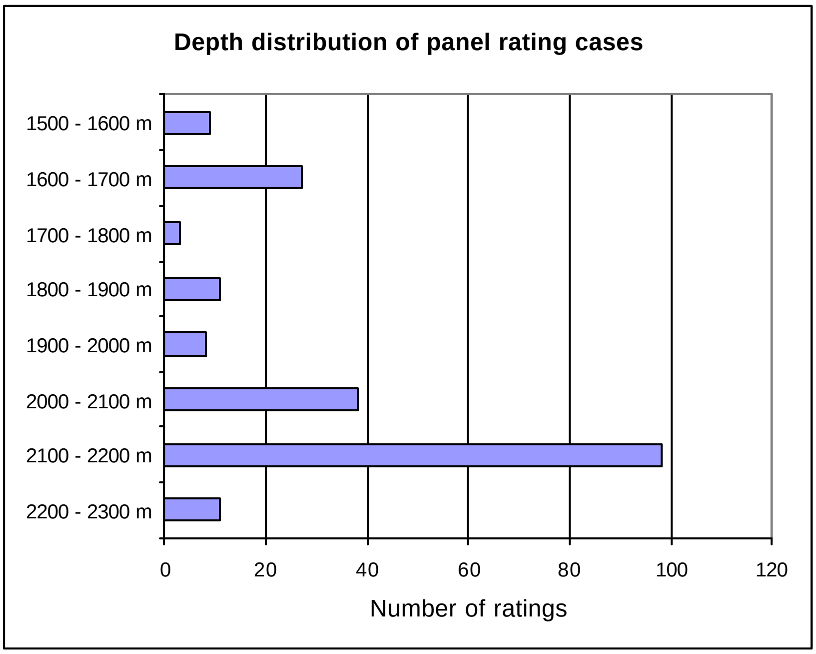


Figure 4.5 - Distribution by depth of 205 panel ratings for mining on the Vaal Reef.

Details of the meaning of rating values used to evaluate each workplace are shown in figure 4.6. Panels are rated in terms of geological complexity, mining span, rockburst hazard, face stress and panel index. Panel Index values are derived from mining practice related factors, while the rest conveniently provide a direct measure of geological or stress anomalies, with high values being generally indicative of unusual or non-standard conditions. For a full description of the rating scheme, the 1999 paper by Dunn and Laas should be consulted.

For this analysis of 205 data points, the following was considered:

- If a factor scored a rating of 5, that factor was automatically considered to contribute to non-standard conditions.

- The factors in the panel index were considered to be mining related factors in general. However, if a high rating (4 or 5) were assigned to high stress concentration (in the panel index part) and a high risk rating was also assigned to face stress, and/or seismicity (in the risk assessment part), non-standard conditions in the panel would be partly attributed to stress. Similarly, if approach and distance to geological structures scored high in the panel index part and geology in the risk assessment part also scored high, the non-standard conditions would be partly attributed to geological factors. The following example is offered:

A panel has a final risk rating of 5
In the initial Panel Index assessment the scores are:

- Mining sequence: 5
- High stress concentration: 4
- Sidings/Headings: 2
- Approach and distance to geological structures: 4

In the Risk Assessment based on figure 4.6 the scores are:

- Geology: 4
- Closure: 4
- Seismic Risk: 3
- Face Stress: 4

In this example non-standard conditions would be attributed to mining, stress and geology. On each panel rating sheet, the number of panels in any particular raise line are recorded and the ratio of non-standard panels to total panels mined were determined by dividing the sum of the panels with risk rating 5 by the number of panels mined.

A summary of the proportion of each of the 205 data cases that scored each rating is provided in table 4.5.

Looking at the data as a function of depth, Figure 4.7 shows the proportion of cases in each 100 m depth range category that fall in the various geological structure rating categories. Figure 4.8 examines the data in terms of stress categories. Essentially the conclusion from these plots is that over the range examined, depth plays no significant role.

Over the data available, table 4.5 shows most cases were mining small spans of less than 60 m, close to seismically active structures (88% high or very high risk), but mainly showing low to medium risk of stress problems.

77% of cases showed some form of geological structure, with 44% cases considered complex or very complex structurally. As a result, 42% of places were rated as being difficult mining with a rockburst risk. Very broadly this could be taken as the level of anomalous conditions. Only 1% was classed as “normal” stoping, which reflects the general final pillar or remnant mining conditions being carried out in the mining area, where most remaining ground lies along or between structures.

In terms of the broad categories of types criteria that contribute to anomalous conditions, the Vaal Reef data can be divided as follows:

	Stress	**Geology**	**Mining**	**Human factors**
Percentage of panels	40%	68%	47%	Not determineable

Hazard risk rating parameters

Parameters		**Rating**
1	*Geological complexity*	
	Very complex (.3 minor structures at intersection of major structures	5
	Complex (wedges, low angle structures, sills, cross-bedding, major intersection)	4
	Moderately complex (3 minor structures)	3
	Minor variations (1 small fault or dyke)	2
	Simple (no structures)	1
2	*Mining span*	
	Small span (<30m)	3
	Medium span (30 – 60m)	2
	Large span (> 60 m)	1
3	*Rockburst hazard*	
	Very high (remnant < 60m from a seismically active structure)	5
	High (mining < 60m from a seismically active structure)	4
	Medium (mining 60-90m from a seismically active structure)	3
	Low (mining near a non-seismic structure or > 90m from a seismically active structure	2
	Very low (mining in open ground)	1
4	*Face stress regime*	
	Very high (< 20m to bolting and mining a remnant)	5
	High (< 30m to holing)	4
	Medium (< 40m to holing or 2000 – 2500m below surface)	3
	Low (open ground or 1500-2000m below surface)	2
	Very low (open ground or < 1500m below surface)	1
5	*Panel index*	
	Very poor (> 1.53)	5
	Poor (1.25 – 1.52)	4
	Average (0.97 – 1.24)	3
	Good (0.69 – 0.96)	2
	Very good (0.4 – 0.68)	1

Figure 4.6 - Table showing meanings of rating values assigned to Panel Rating criteria in the ARM panel risk rating system (after Dunn and Laas, 1999).

Table 4.5 - Summary tables from Vaal Reef panel rating data (205 cases)

Geological categories	Number of panels	Percentage of panels	
5	19	9%	Very complex (>3 minor structures at intersection of major structures)
4	71	35%	Complex (wedges, low angle structures, sills, cross bedding, major intersections)
3	29	14%	Moderately complex (3 minor structures)
2	39	19%	Minor variations (1 small fault or dyke)
1	47	23%	Simple (no structures)

Closure/span categories	Number of panels	Percentage of panels	
5	113	55%	Small span (<30m)
4	2	1%	
3	64	31%	Medium span (20-60m)
2	1	0%	
1	25	12%	Large span (>60m)

Seismic categories	Number of panels	Percentage of panels	
5	42	20%	Very high (remnant <60m from a seismically active structure)
4	139	68%	High (mining <60m from a seismically active structure)
3	20	10%	Medium (mining 60-90m from a seismically active structure)
2	4	2%	Low (mining near a non-seismic structure or > 90m from an active structure)
1	0	0%	Very low (mining in open ground)

Face stress categories	Number of panels	Percentage of panels	
5	28	14%	Very high (<20m to holing and mining a remnant)
4	28	14%	High (<30m to holing)
3	66	32%	Medium (<40m to holing or 2000-2500m below surface)
2	77	38%	Low (open ground or 1500-2000m below surface)
1	6	3%	Very low (open ground or <1500m below surface)

Panel Index	Number of panels	Percentage of panels	
5	2	1%	Very poor (>1.53)
4	55	27%	Poor (1.25-1.52)
3	68	33%	Average (0.97-1.24)
2	58	28%	Good (0.69-0.96)
1	22	11%	Very good (0.41-0.68)

Risk rating	Number of panels	Percentage of panels	
5	87	42%	Difficult stoping with rockburst risk
4	96	47%	Stoping with rockburst risk - 21 kJ/m^2 energy absorb.
3	19	9%	Stoping with geological complexity
2	3	1%	Stoping - SR 28 kN/m^2
1	1	0%	Ledging - SR 28 kN/m^2

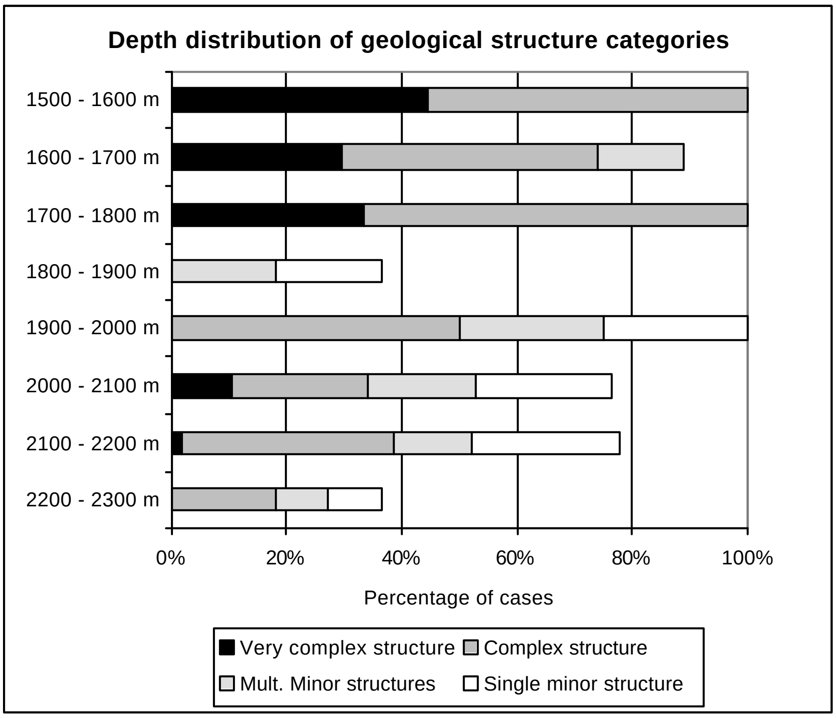


Figure 4.7 - Proportion of panels mining with geological structures at various depths. The data appear to fall into two populations: at shallower depths mining is being carried out around structures which were previously left unmined in preference to easier ground, while at depth more mining is carried out in geologically undisturbed ground (data add to 100% if cases with no structure are included).

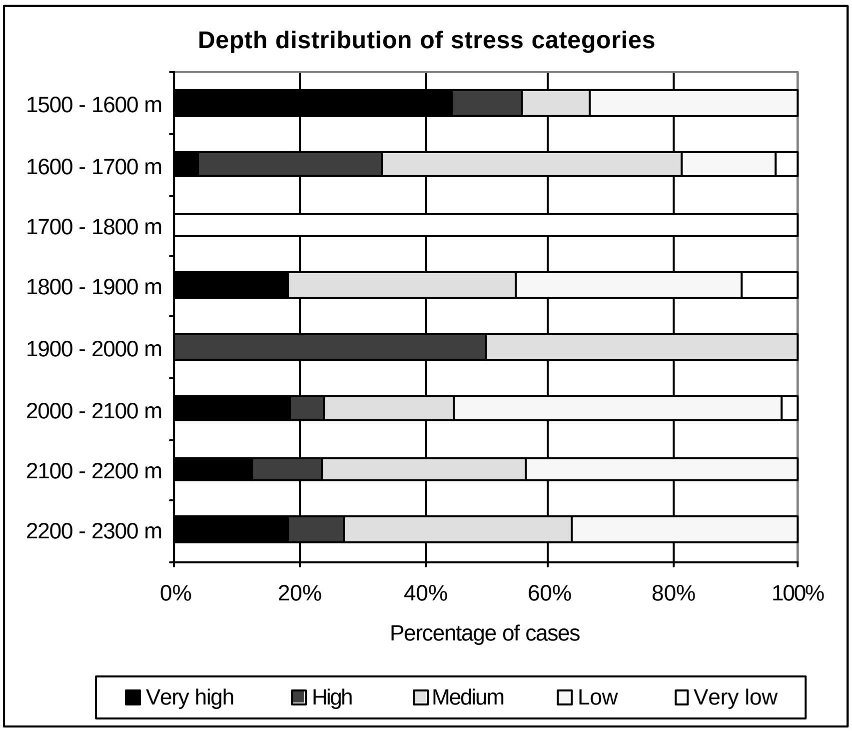


Figure 4.8 - Proportion of panels mining under varying stress levels as a function of depth. High stress conditions at shallow depth are indicative of frequent remnant conditions.

4.2.2 Ventersdorp Contact Reef

Panel risk rating data was acquired for the VCR at Kloof for August, 1999. The VCR horizon is worked at depths that vary between 2500m and 3500m. Some areas have a soft tuffaceous Westonaria Formation Lava hanging wall and present strata control problems, but in general it was considered that seismicity was the main cause of rock falls at that time. Most stope panels formed part of breast-advancing mini longwalls, although up and down dip mining also featured prominently.

For the stope panel risk rating database at Kloof, eight weighted parameters are taken into account resulting in a single risk rating that can take a value of 0,1,2 or 3. These are interpreted as low, medium, high and very high risk. As was the case with the Vaal Reef ratings, for the purposes of this research the final risk rating was used to identify abnormal stoping conditions. In this case panels with risk rating 3 were considered non-standard.

The eight rating parameters used by Kloof are as follows: -

- ERR
- Stoping Width
- Seismic Rating
- Leads and Lags
- Mining type
- Type of structure
- Throw of structure
- RD factor (This parameter is assigned a value at the discretion of the rock engineer in recognition of some condition that may cause additional hazard in the panel)

These parameters were considered in terms of the defined contributing factors in this report in the following way:

- ERR and Seismic ratings were considered to be stress related factors
- Stoping width, leads and lags and mining type were considered to be mining related factors
- Type of structure and throw of structure were considered to be geological factors.
- The RD factor was not taken into account, as these were not reported on the sheets provided by the mine for the purpose of this investigation.

The "field notes" used for this project lists quantitative data of the parameters rather than a rating for each. So the ERR values computed are listed and the type of structure is generally listed as "Dyke" or "Fault". However of the available cases noted as rated geological hazardous, 44% of geological cases listed dykes, 4% listed faults and in 52% of cases the cause was unspecified – suspect rock mechanics discretionary factors relating to poor ground.

Table 4.6 shows how the parameters used by Kloof mine were linked to the four contributing factor categories as defined earlier in the report.

Data was used from 45 out of 102 panels rated across the mine, in the month of August 1999. These 45 (44%) all had a risk rating of 3. Effectively this 44% could be classed as anomalous, within which the breakdown of causes is as follows.

	Stress	**Deformation**	**Geology**	**Mining**
Number of cases out of 45 panels	28	24	25	23
Percentage of 45 panels	62%	53%	56%	51%
Percentage of 103 panels	27%	24%	25%	23%

On the basis of this, 25% of places are anomalous due to geological reasons. The break-down of contributing geological structures was not apparent from the data, but is assumed to comprise faults and dykes.

Table 4.6 - Attribution of Kloof Mine rating parameters to non-standard categories

Parameter and criterion	Attributed to				Remarks
	Stress	Deformation	Geology	Mining	
ERR greater than 10MJ/m^2	yes	yes			ERR is a product and it is not possible to determine which has greater influence
Stope Width > 1.8m				yes	Even though geology might be the root cause for variable stoping width, it is considered that it can be controlled and is therefore a mining related parameter
Seismic rating > 1	yes				The seismic rating is based on historical data taking into account the frequency of events of magnitude ranges and the potential damage that might be associated with such magnitudes
Leads and Lags > 20m				yes	20 m is recognised as a critical distance on the mine
Downdip or updip mining				yes	Used in some areas
Structure type			yes		Includes faults, dykes, etc.

4.2.3 Merensky reef panel ratings

Panel rating data for Merensky reef operations was obtained for January and May 1999 from the North-western section of the Bushveld Complex at Amandelbult section of Anglo Platinum's operations. Panel risk and support guideline assessments are conducted using the following eight parameters.

- Rock mass rating (CSIR RMR).
- Support (type and spacing).
- Geology.
- Hangingwall pyroxenite thickness.
- Panel span.
- Face sequence (leads and lags).
- Pillar size.
- Presence of water.

The risk rating process involves taking the relevant information from the mine plans. As a routine matter during underground visits rock mass ratings, geology and the presence of water are logged and transferred onto mine plans. Geological structure is recorded and complex geology, comprising multiple intersection structures, potholes or domes are flagged as being a potential hazard requiring additional support.

Data was obtained for two individual months, January and May 1999, and analysed in terms of their rock mass rating and the presence of non-standard or complex geology. The results are contained in the table 4.7. There is consistency between the data for the two months, even though separated by five months in time.

This sample suggests that just over one third of the panels (34%) contain unusual geological features in excess of the standard jointing. The data shows a clear relationship between the percentage of class 4 (weak) ground and the frequency of non-standard geology. The panel rating system only identifies geology as standard or complex, hence identification of contributing geological structures is not possible.

Table 4.7 - Summary of Merensky Reef panel ratings

Month	**Number of panels**	**Rock Mass Rating.**		**Geology.**	
		Class 3 (good)	**Class 4 (weak)**	**Standard.**	**Non Standard.**
January	183	122 (67%)	61 (33%)	121 (66%)	62 (34%)
May	165	106 (64%)	59 (36%)	109 (66%)	56 (34%)

4.3 Distribution of geological structures

The frequency with which anomalous stoping conditions occur is directly related to geological structure. This obviously varies considerably across the industry: for example the faulting in the Klerksdorp area includes a significantly larger number of large throw faults than are observed in the Carletonville area. The original intention of the project was to map the frequency of occurrence of structure in a number of different environments. Essentially, on the limited scale originally intended (say one or two panels or gullies per mine) it is not representative enough of mine conditions to provide useful data. Hence an approach has been adopted here to examine the sorts of techniques that could be adopted to attempt to predict geological variability. An example which examines of the mapped frequency of occurrence of structures on a platinum mine is provided, with considerations for identification of the conditions that can be considered anomalous. On a broader scale, several mine based geology departments have started examining the statistical predictability of fault populations, the intention being primarily to examine likely levels of waste dilution and lost ground in mining areas. However a spin-off is a potential for identifying those areas where mining will prove more complex or difficult.

4.3.1 Mapped structures on a platinum mine

Detailed mine-wide geological data has been acquired from a shallow platinum mine working the UG2 reef horizon, using a room and pillar layout. The most problematic hazard is the unexpected encountering of shallow dipping dome type structures, that by intersection other structures, can result in the formation of very large unstable wedges of ground, such as those illustrated in figure 3.14, above. Accurate mapping was carried out Itasca staff, over a two-year period. Mapping focussed on locating joints, potholes, pegmatite veins, and particularly dome-type thrust structures which gave rise to large wedge-shaped falls of ground. An example of the level of detail of mapping is shown in figure 4.9, and was carried out over the entire mine workings, extending approximately 1500 m on strike and up to 800 m down dip.

Structures fall into two broad categories. Those with high frequency, which include joints and pegmatoid veins, and those with low frequency, which include domes or thrusts, faults, dykes and potholes. An account of the occurrence and condition of these structures as observed at both Central and East Declines follows. In many respects the high frequency structures represent those that are largely ubiquitous across the mining area, and for which standard support practices apply. The low frequency structures are those that may give rise to more localised and unusual or unexpected hazards.

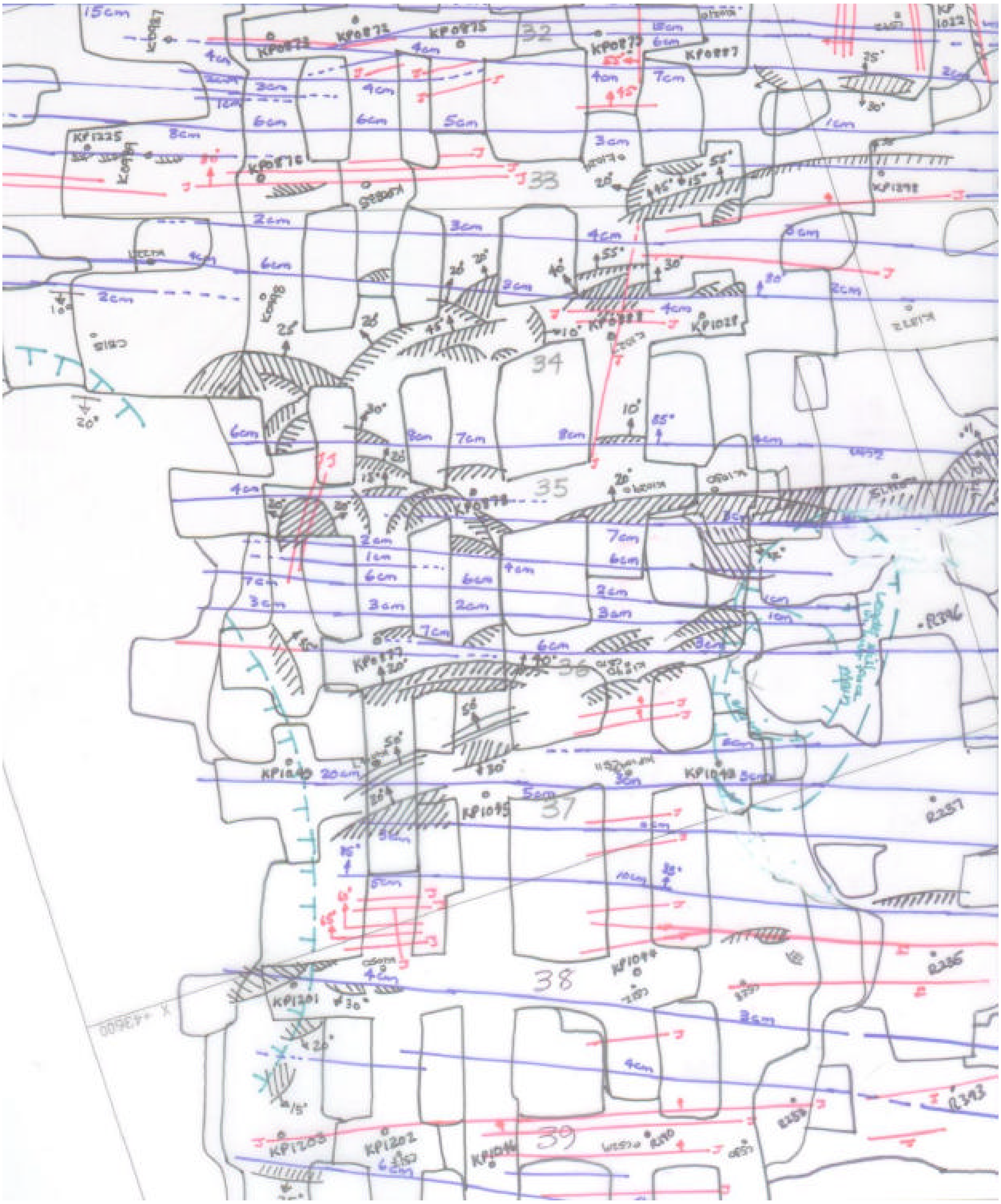


Figure 4.9 - Example showing typical level of detail in mapping carried out in room and pillar platinum workings. Joints are shown as red lines, pegmatite veins as blue lines, and significant dome collapses are cross-hatched. These latter features form stacked bands across the mining area. Potholes are present on the left and right of the area shown

Structure frequencies have been examined, by dividing the mining area in 100 by 100 m square (10 000m^2) regions based on mine coordinates, and counting structures within each area. This gives a general indication of the variation in geological characteristics, and highlights those areas that could be considered geologically anomalous. It could also be used as a basis for developing a new form of hazard rating scheme, although most mines do not compile this level of mapped geological structure.

The following descriptions summarise the characteristics of each of the main geological structures.

4.3.1.1 Description of structures

Pegmatite veins

These veins predominantly strike from NNW to SSE, almost strike parallel to the reef. They are near vertical and get dislocated on reef parallel partings and chromitite seams. Examples are shown in figure 4.10. Infilling comprises predominantly coarse crystalline quartz and biotite mica, and width varies from millimetres up to 20 cm, with weak partings on the contacts. Veins can be continuous for over 700 m along strike. Locally veins can show en echelon step behaviour where they can abruptly terminate and step across sideways by typically a metre. Spacing is around 10 to 20 m between veins in the reef down-dip direction, giving one to two veins typically per mining panel between pillars. Veins are largely only problematical where they intersect other structures and provide a particularly weak parting.

Figure 4.10 – Example showing pegmatite veining in a pillar. These are planar features, although often dislocated across the various chromitite seams

Joints

There are three main sets of joints present. The first is steep dipping, and trends parallel to the pegmatite veins, and also parallel to a major strike parallel dyke. The second set trends down dip, approximately NNE-SSW, and is parallel to a second major dyke. Although the frequency of these two joint sets is greatest around the dykes, these joints occur to a greater or lesser degree across the mining area. The third set trends North-South, slightly diagonal to reef dip direction, and may dip from 50 degrees to vertical. In other areas other varied joint patterns occur, such as in shear bands, at pothole edges, in dyke chill zones or fault splays.

Locally, the edges of domes may appear as curved joints. And joints may tend to bend around potholes.

The following structural associations where observed with high joint counts:

- High frequency jointing usually straddles dykes.
- Pothole edges may have tension gashes up to 10m before intersecting the pothole, but frequently joints merely follow normal patterns, just becoming more frequent in occurrence. Joints and slips are generally more apparent because of blast damage in the hangingwall as the reef starts to roll.
- Curved joint traces may be indicative of very large or clustered potholes.
- Curved joint traces are usually extensive and may cover 2 to 3 panels whereas linear joint traces rarely extend beyond a single panel.
- Curved joints tend to be more prominent on dip than on strike.

Shear bands are sporadically located in the mining area and are usually orientated either along reef dip or strike. These bands are rarely more than 3m wide and are usually intensely jointed. Joints tend to lie diagonally to the direction of the shear. Minor intrusives are often found peppered along the length of the shear band. Low grade metamorphism (chloritisation) often occurs within the shear band.

Domes/low angle thrusts/reverse faults

Domes or low angle thrust structures are found across the mining area but often form bands or groups, Individual domes appear curved in plan and are often stacked one upon another, as indicated by the black cross-hatched areas in figure 4.8, and illustrated in figure 3.14. In some instances a reverse fault follows a band of domes, with shear movement occurring on the dome edges. Throws are small, less than 2 m. Falls of ground occur along almost all domes, where joints or pegmatite veins are intersected. Falls can be very large if the dome runs along a room between pillars and is not identified early enough to modify layout or support.

The following exacerbates the collapse of domes:

- Intersection with pegmatite veins.
- Intersection with joints that lie parallel to the dome edge
- Stacked domes – multiple layered domes

Potholes

Potholes, like any other low frequency structure that is not extensive in terms of area, have severe consequences for mining. Potholes result in a roll in the reef, with the reef dropping an uncertainly elevation in the centre of the pothole, and frequently being unmineable. Unless access can be gained to the centre of a pothole, most are left as pillars and mining negotiates around them. Hazards result from locally increased jointing around pothole boundaries, and changes in orientation of reef parallel partings, which often get exposed due to blasting into the hangingwall as the reef rolls.

Prediction of potholes (and domes, dykes and faults) can be done through mapping and understanding the changes in vein and joint patterns in the areas. Joint condition, persistence and dip and dip direction are very good indicators of major structure intersections. Changes from the normal patterns of jointing almost always result in the intersection of either a large pothole or a dome group or indicate the proximity to one of the large regional dykes.

4.3.1.2 Frequency of occurrence of structures

The frequency of veins, joints and domes (number per 10 000m^2) are shown in plan view in figure 4.11, and as a histograms in figure 4.12.

Note that the histograms report figures in terms of the average structure count expected over a typical 20 x 20 m area within the 100 m blocks. This reduced size area is more representative of the centre to centre distance between pillars in the room and pillar layout in use on the mine, and hence gives a count of the typical number of discontinuities expected with open spans in rooms.

The colour density plots in figure 4.11 indicate that there is considerable spatial variation in structures. The mining area covered is not quite large enough to indicate real trends in structure or discontinuity frequency. But, conceptually, the colour density plots could be used to predict structure in unmined areas by using a weighted average of all blocks surrounding the unmined block. This could be continually updated as new information is derived, and used to roughly forecast or predict more hazardous areas for the purpose of monthly planning, aiding in selection of proper and adequate support and mining plans to be put in place to reduce falls of ground.

The frequency distributions in figure 4.12 show structure counts averaged for 20 x 20 m areas with each 100 m counting block. In each graph the values are listed in order of magnitude, largest to smallest. Each graphs shows a large number of counting blocks with relatively low structural counts, with a small number at the left-hand side of each graph where counts are significantly higher. These high-count blocks effectively could be classed as the geologically anomalous areas.

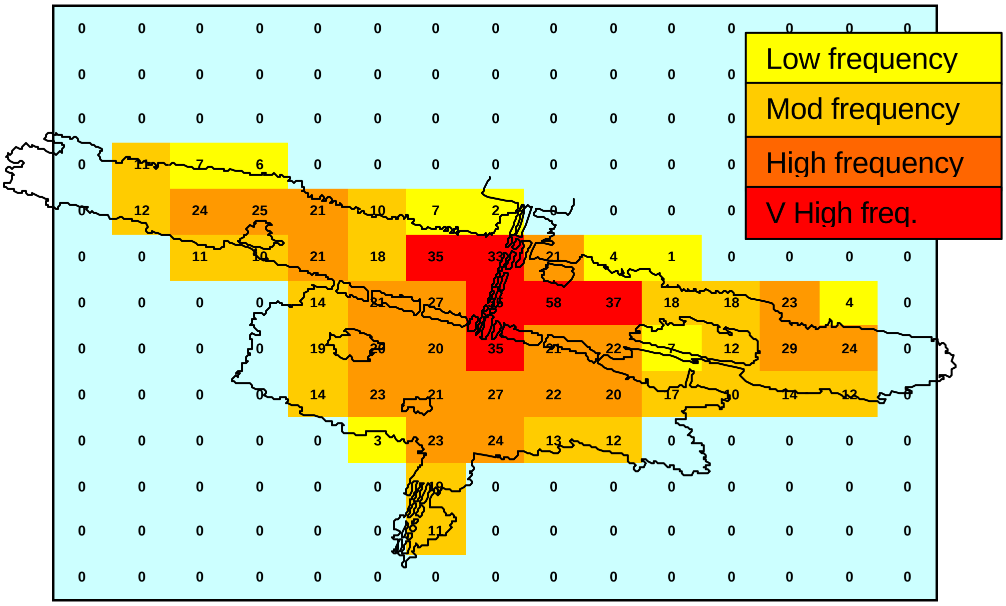
Looking at pegmatite veins, most areas of the mine show a count of less than 1.5 per 20 x 20 m mining panel area. Panels with up to 4 veins are rare but have been observed. 15% of the area mined have vein counts in excess of 1.5, and can be considered anomalous. Since the vein frequency increases in 15% of the area, the result would be a change in potential fall out block sizes in these areas.

For joints, most joint counts are below two. With 18% appearing anomalous with a joint count greater than 2. The greatest number of joints mapped in any given panel was seven. Like the pegmatite veins, the joint count is indicative of increased risk of falls of ground.

Dome frequencies are considerably lower, within typical conditions (88%) being less than 1.2 per 20 x 20 m area. The highest number of domes mapped per pillar tribute area was 3.

In general, for all three types of structure, there is approximately 15% of the mining area that could be considered to contain anomalous levels of structure. Probably the most important factor from a mining standpoint, and that makes an area truly anomalous, are cases where more than one structure shows increased frequency at the same place. Figure 4.11 shows that different types of structure exhibit different distribution patterns. Some structures, such as potholes, do show definite inter-relationships with other structures, which allows for the prediction of one structure based on the occurrence of the other.

If the three maps in figure 4.11 are overlain, it is found that approximately 32% of the total mining area is affected by geological structure of one form or another that is potentially anomalous, with no more than 18% of the total mining area affected by any one type of structure. Within the anomalous areas, joints form 56% of the anomalies, domes forming 38% and 47% results from pegmatite veining. Potholes remain largely unmined. Dykes form a very small percentage.



Pegmatite veins

0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0			
0	0	0	0	0	0	0	0	0	0	0	0			
0	11	7	6	0	0	0	0	0	0	0	0			
0	12	24	25	21	10	7	2	0	0	0	0			
0	0	11	10	21	18	35	33	21	4	1	0	0	0	0
0	0	0	0	14	21	27	55	58	37	18	18	23	4	0
0	0	0	0	19	20	20	35	21	22	7	12	29	24	0
0	0	0	0	14	23	21	27	22	20	17	10	14	12	0
0	0	0	0	0	3	23	24	13	12	0	0	0	0	0
0	0	0	0	0	0	19	0	0	0	0	0	0	0	0
0	0	0	0	0	0	11	0	0	0	0	0	0	0	0
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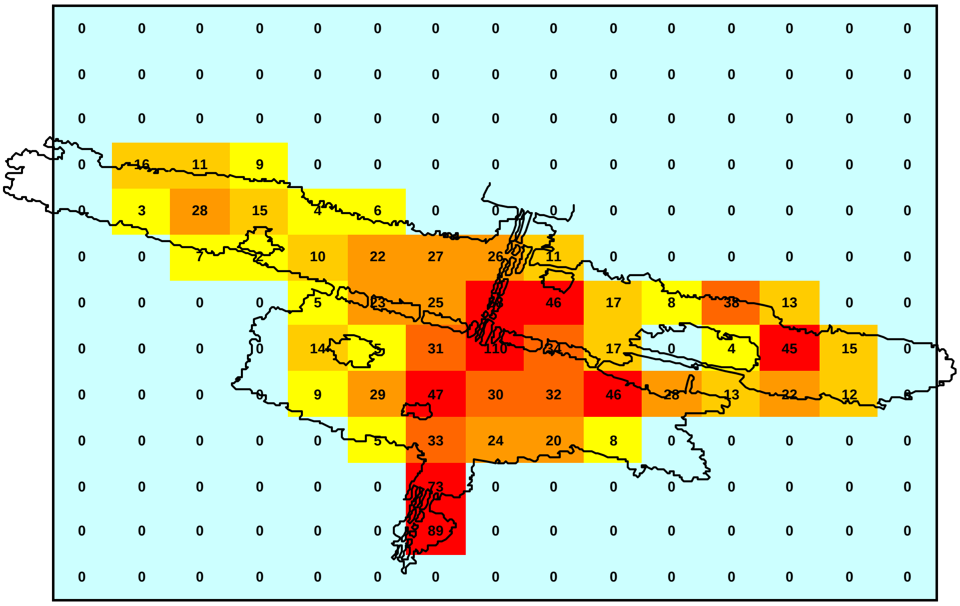

Joints

0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	16	11	9	0	0	0	0	0	0	0	0	0	0	0
0	3	28	15	4	6	0	0	0	0	0	0	0	0	0
0	0	7	2	10	22	27	26	11	0	0	0	0	0	0
0	0	0	0	5	23	25	58	46	17	8	38	13	0	0
0	0	0	0	14	5	31	110	34	17	0	4	45	15	0
0	0	0	0	9	29	47	30	32	46	28	13	22	12	6
0	0	0	0	0	5	33	24	20	8	0	0	0	0	0
0	0	0	0	0	0	73	0	0	0	0	0	0	0	0
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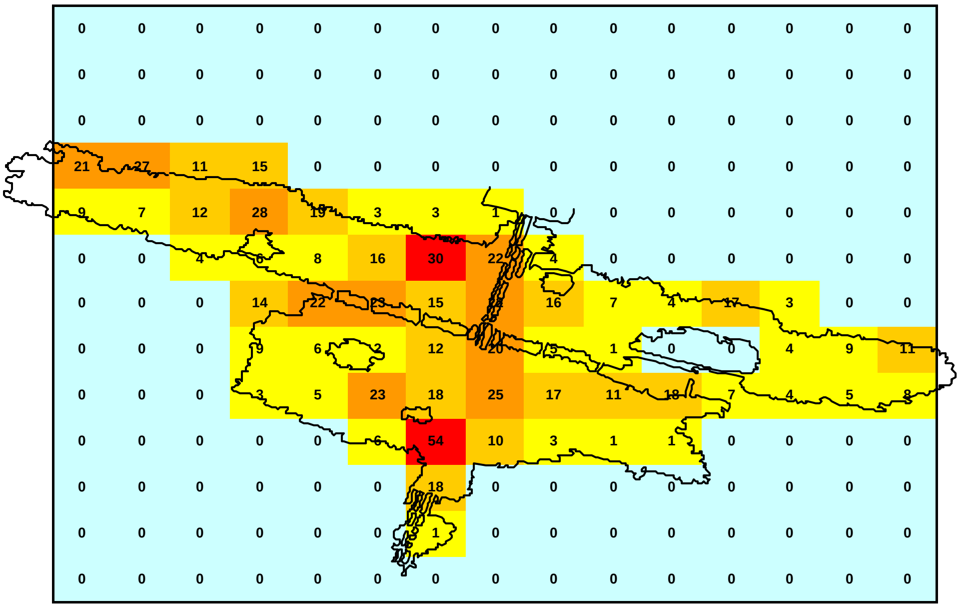
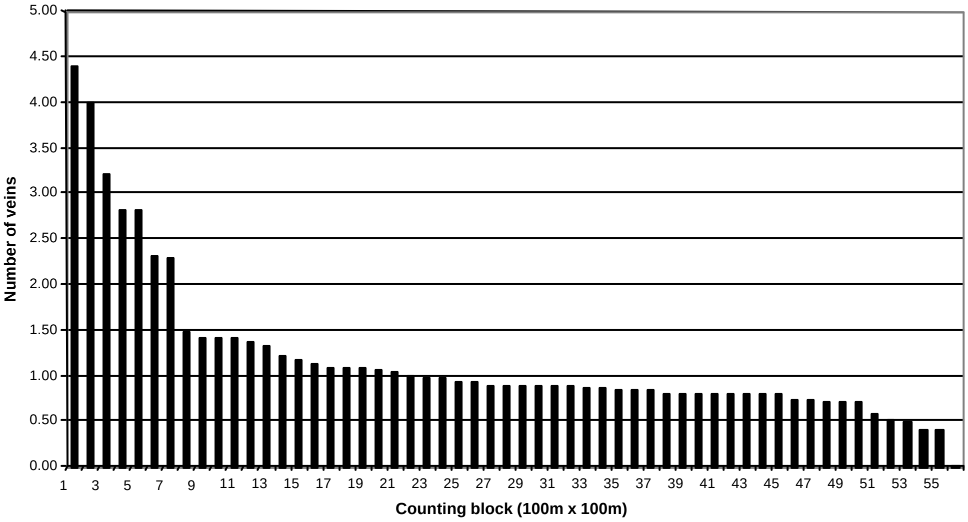


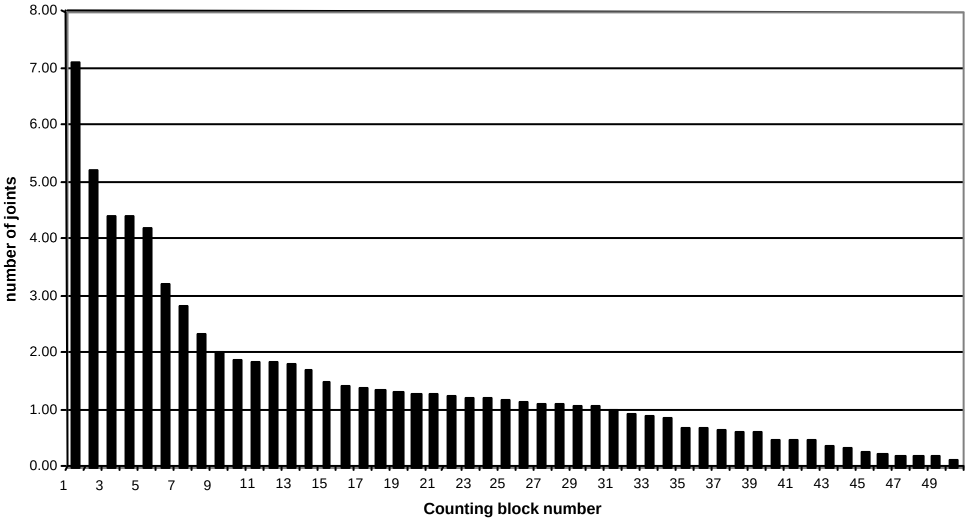
Domes and low angle shears

0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
21	27	11	15	0	0	0	0	0	0	0	0	0	0	0
9	7	12	28	19	3	3	1	0	0	0	0	0	0	0
0	0	4	6	8	16	30	22	4	0	0	0	0	0	0
0	0	0	14	22	23	15	[illegible]	16	7	4	17	3	0	0
0	0	0	9	6	2	12	20	5	1	0	0	4	9	11
0	0	0	3	5	23	18	25	17	11	18	7	4	5	8
0	0	0	0	0	6	54	10	3	1	1	0	0	0	0
0	0	0	0	0	0	18	0	0	0	0	0	0	0	0
0	0	0	0	0	0	1	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Figure 4.11 – Plans showing the frequency of occurrence of veins, joints and domes across a mining area. Numbers of structures per 100 x 100 m area are indicated



Pegmatite veins



Joints

Domes and low angle shears

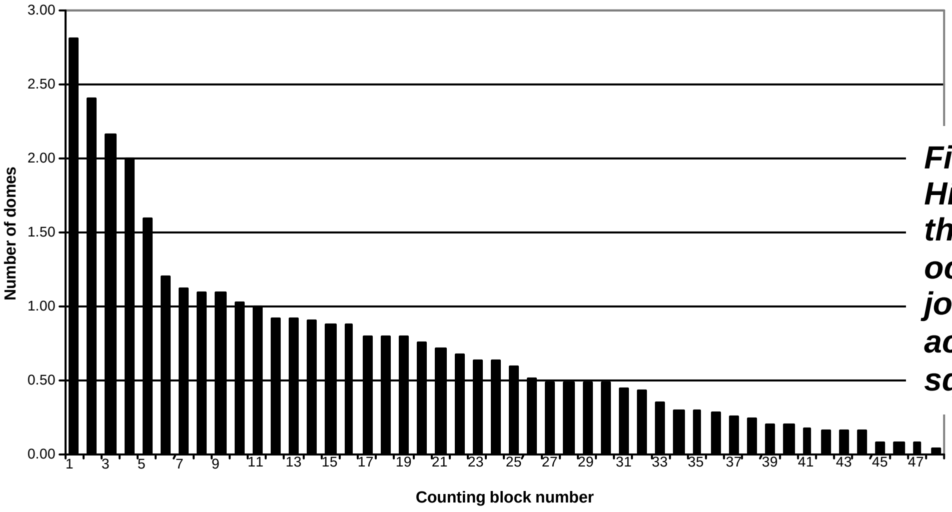


Figure 4.12 – Histograms showing the frequency of occurrence of veins, joints and domes across over 20 m square average areas

4.3.2 Statistical relationships for structure distribution

Mine geologists in various mining groups are increasingly using Fault Population Analysis as part of the mining reserve analysis process (Birch, 1996, 1999). Their objective is primarily to rate mining blocks in terms of likely waste dilution in relation to grade, and to also to broadly assess likely mining difficulty, which in theory would lead into scaled costings for the area for mine planning estimates. It is a method that can be used to quantify fault densities in two dimensions, i.e. in plan or in the plane of the reef. Information gathered from a fault population analysis can be used to statistically determine numbers of faults and fault throws in a particular geotechnical area, mining block or mine.

The technique, also known as "fractal analysis", has been previously extensively and successfully applied in the oil industry to assist with prediction of connectivity, flow paths and rates of flow from oil reservoirs (Walsh and Watterson, 1992). Other work in this field in hard rock mining is being conducted by the Rock Deformation Research Group at Leeds University in the United Kingdom.

Fault systems in predominantly extensional structural environments are scale invariant or fractal in nature, similar to many other systems, the most obvious other example in the mining industry being the size frequency of seismic events. Essentially, the relative number of large and small faults is the same at all scales and a power law controls the fault size distribution.

If N is the number of faults with throw greater than or equal to L, then $N = aL^{-D}$, where a is a sample size constant and D is the fractal dimension constant, or the slope of the line when the data are represented graphically by a logarithmic plot of cumulative frequency against throw. An example for a Freestate gold mine mine is illustrated in figure 4.13. Note that this is based on the distribution of faults mapped along a line, or a series of lines across the mining area, such as a raiseline, or reef drive. Fault frequencies are scaled to represent a count per kilometre along each mapping line.

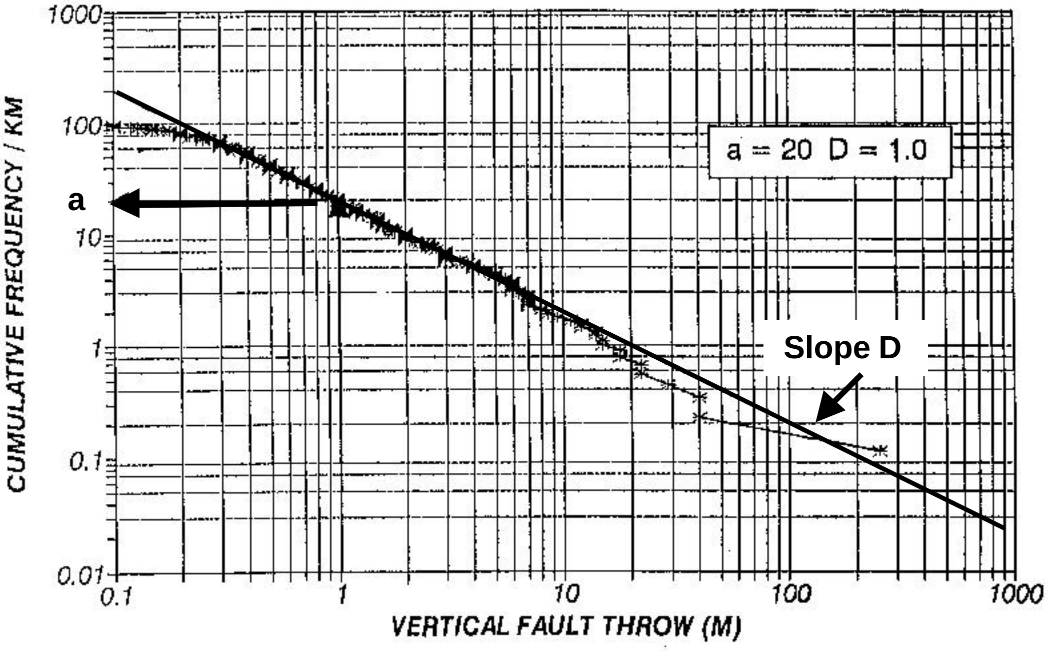


Figure 4.13 - Log cumulative fault frequency per km against log vertical fault displacement (after Birch, 1999). Data was mapped in 40 parallel raiselines in the Freestate goldfield.

Figure 4.13 shows the following features:

- The flattening of the graph at the top left corner indicates the limit of resolution to which the area has been mapped – approximately 25cm.
- The central portion of the graph approximates a straight line with a negative slope D, which determines the relative number of small faults for every large fault.
- a represents the cumulative number of faults per km with throws greater than or equal to a specific throw (in the case of Figure 4.13, this is 1m).
- D represents the relative number of small faults for every large fault, where the ratio increases as D increases.

The values of a and D generally reflect the intensity of faulting, and degree to which the ground is broken up. As a comparison to figure 4.13, figure 4.14 shows a similar frequency distribution graph derived from data from the Vaal Reef in the Klerksdorp area. This was based on the larger faults that could be easily extracted from a regional plan, and hence is reasonably complete only for faults with throws larger than 40 m. The small fault data used in the Freestate was largely unavailable, and is probably over-estimated from the extrapolation of the line in figure 4.14, giving an overly high value for a. Figure 4.15 shows data compiled from a 1:10000 mine plan of a mine in the Carletonville area. While the data sources are different, the best fit lines in figures 4.13 to 4.15 are probably reasonably representative of Freestate, Klerksdorp and Carletonville averages, and significantly different a and D values are apparent.

Table 4.8 – Fault population characteristics in the Freestate, Klerksdorp and Carletonville areas

Area	**a – number of faults larger than 1 m throw per kilometre**	**D – relative number of small faults for every large fault**
Freestate	20	1.0
Klerksdorp	140	0.7
Carletonville	11	0.75

If it is assumed that each fault larger than 1 m in size will affect a strip of ground approximately 3 m wide (up to 1.5 m either side of the fault), then the a values can be used to broadly predict the area of ground where increased hazards exist. This is probably a minimum in terms of area of increased support or increased fall of ground risk, and is effectively the proportion of ground that is influenced by anomalous conditions due to faulting within the area being mined out. This then gives values of 42% for Klerskdorp, 6% for the Freestate and 3.3% for the Carletonville area. These are obviously very approximate numbers but do give a feel for the relative level of hazard posed by minor faulting in the three gold field areas, with the Klerksdorp area being significantly more hazardous. Note that in the Bushveld complex the level of faulting is significantly less, and it was concluded that other geological features, such as domes, were of more significance.

Birch (and Brown, 1995) found that values of a and D could vary considerably between raiselines in the Freestate area, and that by creating a plot of a against D a chart indicating potential mining complications could be derived. This is shown in figure 4.16. Each raiseline from the Freestate data set is plotted as an individual point on the graph. Raise lines or geotechnical areas plotting in the bottom left corner of figure 4.16 (low a and D values) have less intense faulting than points plotting near the top right corner (high a and D values). As shown in figure 4.16, Brown subdivided this graph into a number of ‘mining difficulty’ zones, ranging from easy to extreme. These are based on local observations at the Freestate mine at which the data was collected, and cannot be considered universally applicable. Based on mining history Brown correlated the parameters listed in table 4.9 with these categories.

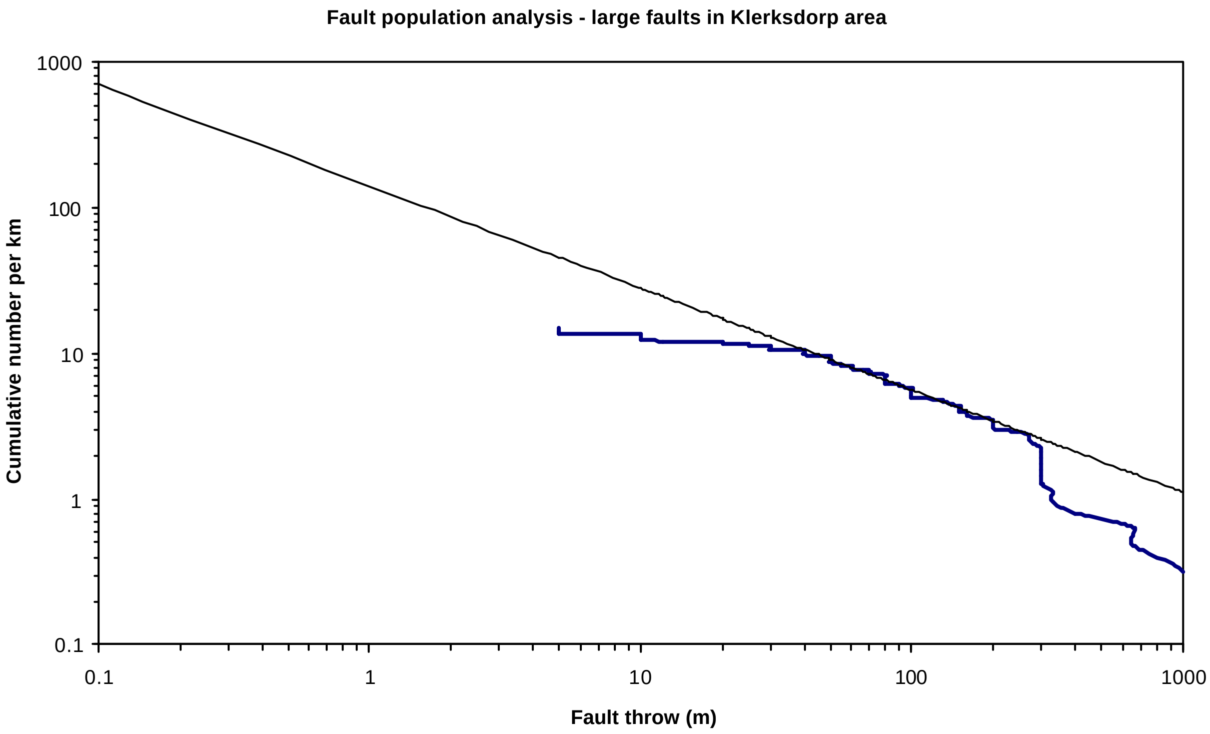


Figure 4.14: Fault population data for larger faults on the Vaal Reef in the Klerksdorp goldfield. Data was drawn from a regional plan and is complete for faults with throws larger than 40 m.

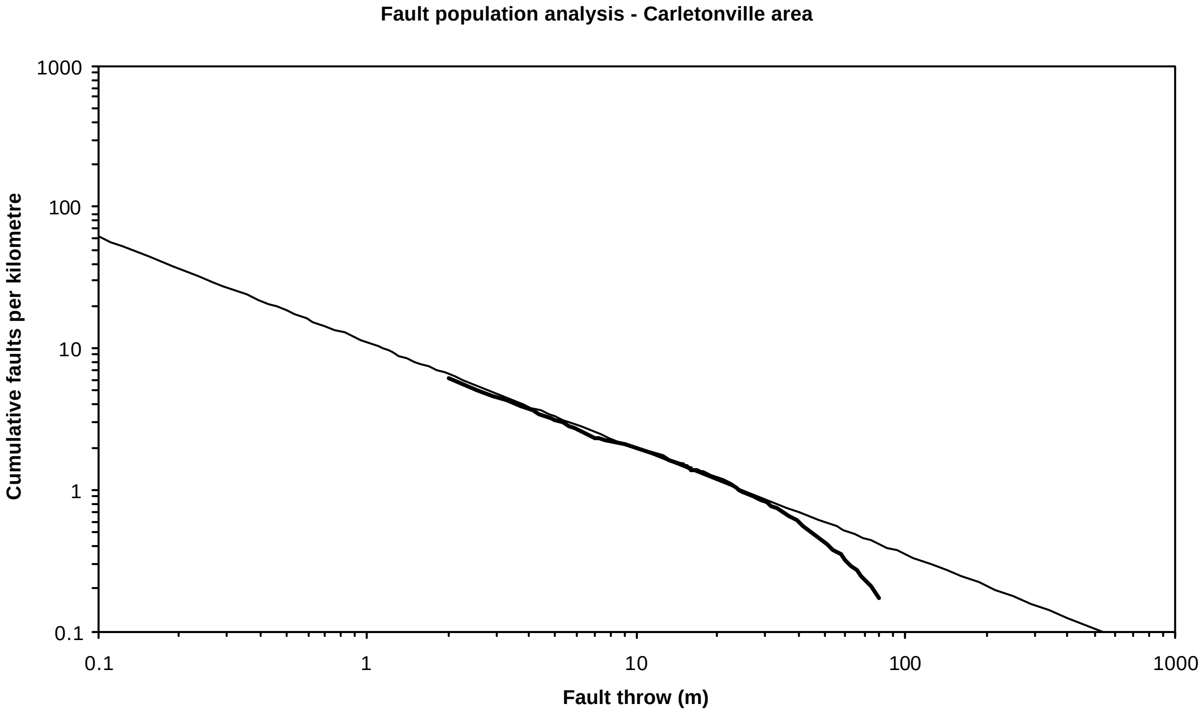
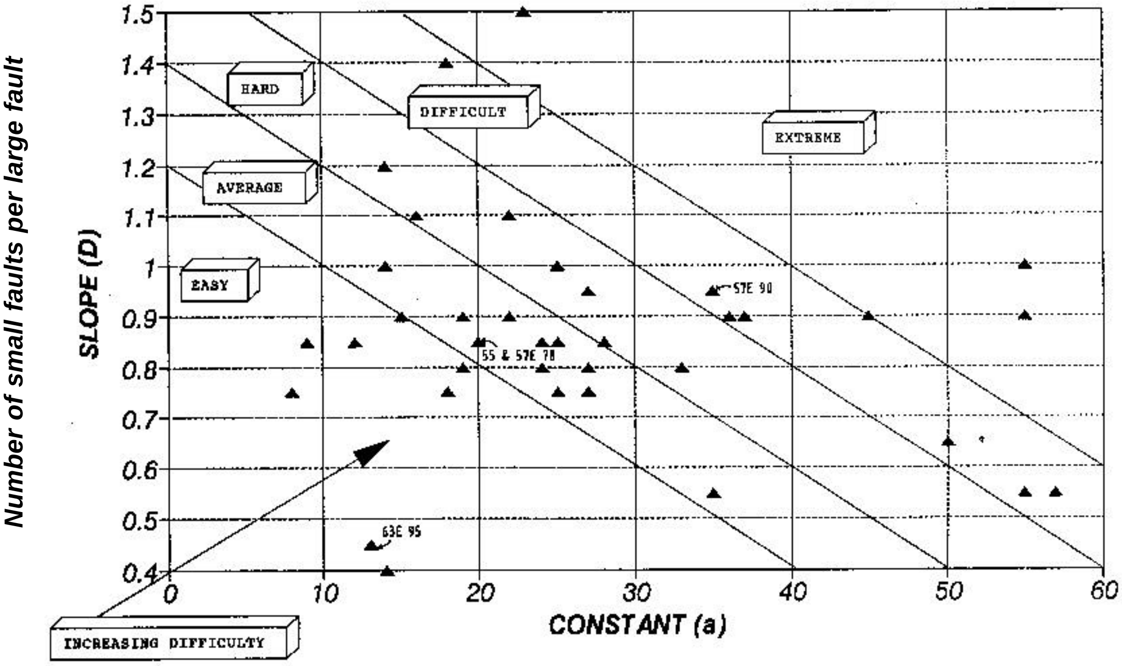


Figure 4.15: Fault population data for faults on one of the mines in the Carletonville area. Data is drawn from lines spanning 11.5 km on plans showing faults down to 2 m throw. Maximum throw 80 m.



Faults with throw larger than 1 m per km

Figure 4.16 - Scatter diagram classifying mining difficulty based on intensity of faulting using fault population parameters a and D (after Birch, 1999 and Brown, 1995)

Table 4.9 – Relationship between mining difficulty parameters and mining production rates for Freestate data compiled by Brown, 1995.

Mining difficulty category	**Typical raise advance rate (m/month)**	**Typical stope advance rate (m/month)**	**Ground lost in fault loss areas and through abandonment**
Easy	> 30 m	8.0 m	3%
Average	23-30 m	7.5 m	9%
Hard	16-23 m	6.5 m	11%
Difficult/extreme	< 16 m	5.5 m	> 13%

Table 4.9 could be extended to cover ground conditions, accident rates, etc., but data was not readily available for this project. The ease with which mining operations are conducted is a a non-quantitative parameter and subdivisions could be based on the geotechnical engineers intuition and experience, using historical production rates in the areas and falls of ground and rock burst statistics. Using the above methodology, it would be possible to detect anomalous fault and dyke populations and hence review design relating to the stability of these structures and associated areas.

4.4 Conclusions concerning the frequency of anomalous conditions

The proportions of mining areas influenced by anomalous conditions have been examined from various sources of data. These include accident records (section 2 of this report), plus underground observation data, monthly panel risk ratings, underground mine-wide mapping, and regional fault population analysis. All give very varied results for the proportion anomalous conditions. In part this is due to variability in mining practice and variability in geology, but is also influenced by whether a mine is in its early stages of mining, advancing into open ground, or is in the final stages, removing pillars or remnant blocks. The latter case can inevitably be expected to have a higher than industry average of unusual mining situations.

If only problem areas are considered, table 4.10 provides a comparison of data from the various sources. This includes accident data reviews, codes of practice, and mine rock engineering audits and panel ratings.

Table 4.10: Comparison of factors that contribute to potentially anomalous conditions in recognised problem or accident areas (numbers represent percentage of cases, and cases can be influenced by multiple factors, so numbers do not add to 100%)

Data source	High Stress or stress fracturing	Geological factors	Mining considerations	Human Factors
89 industry-wide fatal accident cases from DME records.	40%	55%	26%	53%
28 accident cases from the VCR	57%	86%	25%	-
Accidents in 10 mine codes of practice	6%	21%	40%	23%
30 audit cases on the Beatrix reef	10%	77%	33%	Not determined
45 panel ratings on the VCR	62%	56%	51%	Not determined

Essentially the numbers in table 4.10, indicate the factors which influence the occurrence of accidents, or are contributory to designating areas as hazardous, but to not provide information on how frequently hazards, or anomalous areas, may be expected. An interesting aspect is the difference in proportions between the accident causes determined by 10 mines in their codes of practice, and those extracted from the DME accident records.

Table 4.11 summarises the data available from mine workings concerning the frequency of occurrence of features contributory to anomalous conditions. Of the platinum mine cases, possibly the stope observer reports are not as representative of mine wide conditions as originally thought, and roughly 30 to 40% of platinum mine areas are influenced by geological structure.

On the gold mines, the data in table 4.11 indicates that data is strongly influenced by the state of mining on the mine, where the Vaal Reef data can from a mine that was predominantly in the final pillar extraction phase. All the data confirms that there can be enormous variability in conditions from one mine to another.

Table 4.11: Comparison of factors that contribute to potentially anomalous conditions in across all mine workings or mining areas (numbers represent percentage of cases, and cases can be influenced by multiple factors, so numbers do not add to 100%)

Data source	**High Stress or stress fracturing**	**Geological factors**	**Mining considerations**	**Human Factors**
Platinum Mines				
Merensky Reef stope observer reports (223 cases, Impala)	-	79% (66% major features)	-	-
Merensky Reef panel risk ratings (348 cases, Amandelbult)	-	34%	-	-
UG2 underground mapping (KPM)	-	32%	-	-
Gold Mines				
Vaal Reef panel risk ratings (205 cases)	40%	68%	47%	-
VCR panel risk ratings (103 cases)	27%	25%	23%	-
Fault population studies	-	3% to 42%	-	-

Note that the multiple factors influenced conditions in each area reviewed, hence the percentages in tables do not add to make 100%, but reflect percentages of total areas influenced by each factor. There are no reporting or rating system on any of the mines that take cognisance of human factors in determining risk. Factors such as staff turnover, experience, levels of training and competency in hazard identification are not directly recorded in any of the rating systems reviewed.

Within the cases classed as geologically anomalous, or hazardous, table 4.12 summarises the break down of features that contribute to the anomalous conditions, from the various sources examined previously in the report. Note that in most of the panel rating systems, geology was rated along the lines of complex or simple, hence the type of contributing structure is indeterminate.

Again, table 4.12 shows that there is considerable variability in contributing structures. Accident data tend to indicate that the most influential factors are bedding and jointing, presumably because they are frequently unrecognised. Faults and dykes are major contributors on the gold mines, with potholes and veins on the platinum mines. The VCR accident data cases showed that changes in stope width were also important, leading to increased face-burst potential.

Table 4.12: Percentage of types of geological structures that contribute to anomalous conditions (in many instances more than one structure influences conditions, so numbers do not add to 100%)

Data source	**Fault**	**Dyke**	**Joint**	**Bedding**	**Dome**	**Peg-matite vein**	**Pot Hole or roll**	**Brow**
Platinum Mines								
Merensky Reef stope observer reports (Impala)	21%	23%	13%	-	1%	16%	5%	-
UG2 underground mapping (KPMl)	small	small	56%	-	38%	47%		-
Gold Mines								
89 fatal accident cases from DME records.	18%	2%	53%	47%	2%	-	-	-
28 accidents on VCR	29%		46%	-	-	-	14%	-
30 audit cases on the Beatrix reef	47%	17%	3%	17%	-	-	-	3%
VCR panel risk ratings	4%	44%	Over 50% due to unspecified features					

5 Mining and support practices applied by the industry in geotechnically anomalous areas

This section of the report examines mining strategies in use in the gold and platinum mining industries to address the hazards resulting from anomalous conditions due to geological structure. Largely it means recognising partings that may give rise to major falls, adjusting mining strategy to safely negotiate areas that could potentially collapse, and installing appropriate support. As the range of permutations of structure is enormous, particularly in the case of faulting, this section of the report is not intended to be completely comprehensive, but provides some insight into methods available.

5.1 Treatment of hazards in codes of practice

As noted previously, ten mine codes of practice were examined as part of this project and were used to assemble the list of hazards in section 2. Most codes of practice contain some limited detail on the mine's methods for identifying and treating hazardous conditions which fall outside the normal stoping conditions. Four examples follow, briefly summarising either code of practice information, or from discussions with mine staff. These are all Bushveld examples, based on year 2000 codes of practice, and the objective is to indicate the similarities and differences between mines operating in one environment rather than cover the full gold and platinum mining industry spectrum.

Lonrho.
From verbal communication it is understood that the strategy to cope with a non standard situation is as follows.

- Training of personnel in hazard identification.
- Recognition of situation by the responsible miner.
- Implement a procedure depending on the type of non standard condition, be it a fault, dyke, pothole or rolling reef.

Impala.

Two types of special area have been identified, namely :

- Precautionary. This is defined as an area where certain factors, the seven listed below, increase the risk of rock falls.
    - High stress.
    - Water bearing faults.
    - Presence of major geological disturbances.
    - Size of the block and/or geometry of ground to be mined.
    - The proximity of mining to other mining or mined out areas.
    - Where ground conditions require the installation of additional support or where the normal support density has to be increased.
    - Shaft pillar extraction.
- Restricted. This is defined as an area of restricted mining as specified by the Department of Minerals and Energy Affairs. It includes shallow near surface mining underneath surface structures that require protection.

Amplats - Amandelbult section.

The stope face area (which extends a distance of 5 metres back from the face) has been identified as the most hazardous area with respect to falls of ground in all geotechnical areas. A key finding from the risk assessment was the identification of the strong and weak side of faults and brows.

Six criteria, as listed below, are used to identify special areas.

- A rock mass rating of Class 4 ground.
- Unfavourable jointing as indicated by a JBLOCK analysis.
- A remnant area with higher than normal closure resulting in failure of support units.
- A remnant area with a high stress level resulting in excessive stress induced damage.
- Friable and / or wet hangingwall.
- Excessive panel spans that result in an unacceptable support demand.

Northam.

The Code of Practice identifies a total of fourteen hazards, a number of which refer to geological anomalies as listed below.

- Mining Merensky reef in the water zone areas.
- Brows created by faults, joints or falls of ground.
- Stoping near to potholes - blocky ground.
- Falls of ground in footwall development where they intersect water fissures and faults associated with known water zones.

Special areas are defined as any situation, which in the opinion of the Manager is not covered by the identified rockfall hazards.

Most of the other codes of practice examined contained similar comments, and it serves little purpose to list the contents of all of them as codes of practice are developing documents, frequently changed. Further information is provided in Appendix II. One of the main objectives in developing the use of codes of practice is to encourage mines to recognise their own site-specific hazards and develop appropriate strategies to deal with them. From the examples above, most mines incorporate treatment of anomalous conditions into the process for recognising, declaring and managing special areas. Important aspects that are being encouraged with the advent of new code of practice guidelines from the Department of Minerals and Energy are first hazard recognition, followed by commitment to train staff in practical hazard identification underground, coupled with procedures for their treatment. More details and guidelines are provided in section 6. The rest of this section examines mining practices used for a range of geologically unusual situations.

5.2 Hazards due to geological discontinuities, and basic principles for mining practice

5.2.1 Some historical perspective

Since the early days of mining on the Witwatersrand, the hazards associated with geological structure have been appreciated and there have been numerous published examples of methods to employ to reduce fall of ground hazards.

A reasonable example of past thinking concerning the hazards associated with geological structure comes from Spalding (1949). Note that while some terminology has subsequently changed and mechanisms are better understood, the basic principles remain. The sketches in figure 5.1 illustrate mechanisms and hazards understood at that time to be associated with mining towards minor structures. In the top sketch in figure 5.1 a stope face approaches a structure. When the face mines up to the structure (as in B) there is nothing to constrain the triangular portion (shown shaded) of hangingwall which forms an acute angle with the weakness, from expanding into the stope, leading to an increased rate of stope closure (as in C). At some point before the structure is exposed (between the two positions A and B), it was recognised that the rock may fail and sudden closure occur. This may occur just before the face reaches the weakness by crushing of the reef material (L) between the face and weakness, or by the occurrence of a short shear crack (S), as shown in D.

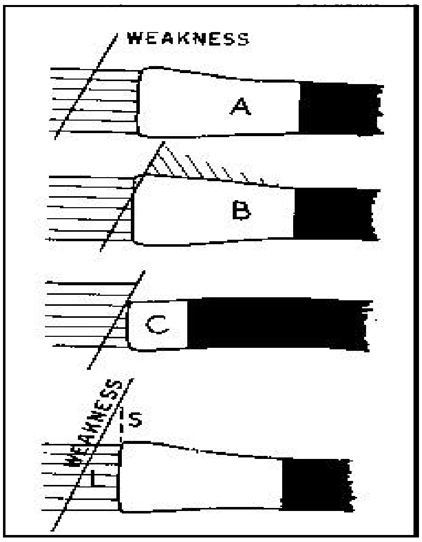
In the centre sketch in figure 5.1, the case is illustrated where stope closure occurs by bending of the hangingwall beam and may cause failure by shear along a geological weakness. Spalding postulated that rupture occurs from A to B and all the wall rock between AB and the fracture dome is freed to expand inwards with an action so violent that it may cause the rock near the stope to disrupt, and the areas labelled “fracture dome” and “expansion dome” to move outwards. Spalding noted that, if a stope face approaches a weakness and the two are roughly parallel to each other, at some point a “danger position” will be reached. There will be a long narrow bar of ground between the face and the weakness stressed to the limit; and the whole energy of the compressed rock in one of the walls will be held by it. Further advance of the face will overload the barrier, crush it, and release stope hanging and footwalls allowing sudden closure. Hence the recommendation that stope faces should not be allowed to approach a weakness while parallel or at narrow angles to it, but at as wide an angle possible, so that the position of critical stress is reached at only one point at a time.

Essentially, this thinking is still generally acceptable, although mechanisms of generation of events on minor structures locally around stope faces are currently better understood. Spalding established one of the basic principles for mining strategy when dealing with geological structure: to approach it at an angle, exposing it incrementally. This not only reduces any risk of bursting but also allows support to be safely installed.

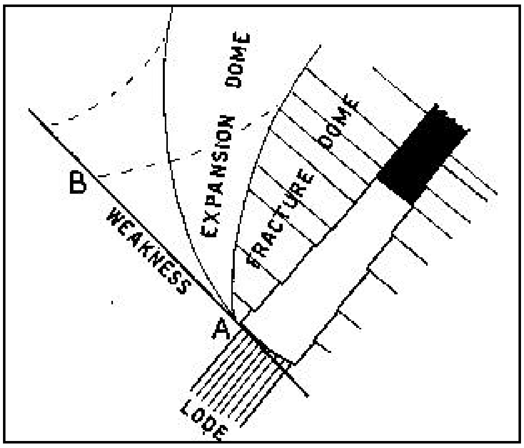
Another point long recognised is the fall of ground hazard associated with the “weak side” of a structure. The “weak side” is the wedge of ground beneath a dipping structure which, if poorly supported, can drop out under gravity.

Dykes are associated with other unique hazards. Dykes are often stiffer than the surrounding host rock and may become highly stressed and burst prone, particularly if a dyke is narrow. Spalding suggested that because of the risk of damage to off reef levels, winzes, or raises which may pass through the dyke it is better to carry stopes right through the dyke instead of leaving it unstoped. If the dyke is wide the intensity of stress may not be as high as in the narrow one. Spalding suggested that all dykes less than 12 ft (4 m) wide should be stoped out and all those over 40 ft (12 m) wide left in. However in many of today’s mining environments this is spurious as a general recommendation.

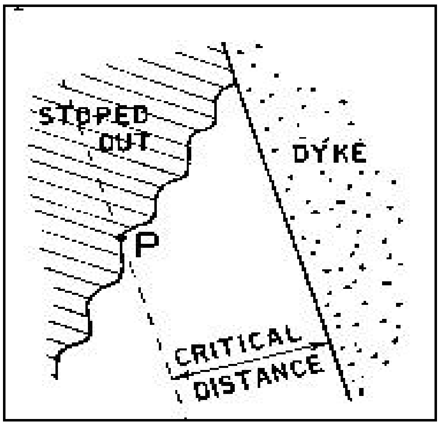
Spalding also proposed that in the case of wide dykes it would be better to start stoping on one side first, working away from the dyke. When these stopes are well under way then stoping on the other side should start, working from the dyke outwards. Similar practices were advocated for faults where there was a loss of ground.



Approach angle to geological weaknesses



Development of a shear burst



Critical distance from 'mining' to geological structure

Figure 5.1 – Example of past understanding of hazards associated with mining up to minor structures (after Spalding, 1949)

5.2.2 Basic guidelines

Discussions with mine personnel, and reference to some standard rock engineering text books (e.g. Jager and Ryder, 1999), have indicated a number of basic principles for support and mining practice. All recognise that faults and dykes constitute geological weaknesses in which the potential for falls of ground or rockbursting is enhanced, and special support precautions in excavations situated in or near them are often required. The principles governing stope support near geological structures are relatively simple:

- Additional support is required adjacent to and within geological discontinuities and dislocations, in particular weak zones should be recognised and adequately supported.

- Both sides of such structures should be supported, but particular attention should be given to supporting the weaker side of hangingwall discontinuities. In general, the possibility of the formation of unstable keyblocks should be recognised and countered.

- Particularly high standards of areal coverage of permanent support should be used in high-risk areas such as travellingways and gullies, and of temporary support in the working face area wherever geological structures are encountered.

- Loose ground should be barred down if it creates a hazard and cannot be adequately supported.

- Geological structures should be identified on stope sheets and mine plans to ensure that adequate attention is paid to them during planning and operational meetings (Jager and Ryder, 1999)

Depending on the operating depth, orebody being mined and mining methods employed, mines adopt varying methods to support anomalous stoping areas. Almost all methods involve an increase in the density of support units in areas prone to increased hazards and risks. The appendices contain a summary of support strategies and standards employed in a number of gold and platinum mines.

Very few codes of practice quantitatively motivate the change in support types and densities in anomalous areas. The design methodologies employed to determine support and layout requirements for anomalous conditions can be viewed as similar to those for normal operating conditions. The different methods of support and layouts formulated for anomalous areas is thus largely a function of changed design input parameters when compared to those used for normal operating conditions, such as size and thickness of block to be supported, increased risk of seismic activity, etc.

If input parameters such as stress regime, rate of closure, block sizes and ejection thickness can be quantified for anomalous areas then it should be possible to design support for these areas using the methodologies stipulated in existing SIMRAC projects.

Some of the SIMRAC projects relevant to the design of support and layouts for all types of conditions are listed in table 5.1. An example would be CSIR Miningtek's SDA which evolved from GAP 032. This list is non-exhaustive hence the SIMRAC website http://www.simrac.co.za should be consulted for the full lists of projects dealing with the support and design of underground excavations. The findings of some of these projects have been condensed into methodologies contained in the Guideline for the Compilation of a Mandatory Code of Practice to Combat Rock fall and Rock burst Accidents in Tabular Metalliferous Mines (Ref: DME 7/4/118 AB1).

Table 5.1 – List of other SIMRAC projects dealing with the design of layouts and support systems that could be applied to anomalous conditions

SIMRAC project code	Title
GAP033	Develop improved strategies for mining highly stressed areas
GAP034	Deep mine layout design criteria to reduce seismicity
GAP055	Assessment of causes and factors of accidents in gold and platinum mines
GAP102	Enhanced behaviour of VCR: improved static support design
GAP112	Computer assisted assessment of rockburst and falls of ground risk
GAP223	Reduction of seismicity through improved design of layouts
GAP330	Stope face support based on site specific geotechnical conditions
GAP416	Methodology for the determination of geotechnical areas
GAP513	Accounting for the variability in rock engineering design
GAP530	Rockburst site response: criteria for support design
GAP627	The zone of support influence and stable span between support units
GAP723	Enhancements to the Support Design Analysis (SDAII) software
GAP032	Efficient stoop and gully support systems design

5.3 Support practices for geological structures

Physically observed anomalous conditions are often specific to a mine, stope or reef. Since each mine may adopt different strategies for mining layout and support, it is impossible to cover all specific cases in this guide. Most mines have access to competent rock engineers who can provide site-specific recommendations. Some general points and examples are provided here. Depending on the operating depth, reef being mined and mining methods employed, mines adopt varying techniques to support anomalous stoping areas. Almost all methods involve an increase in the density of support units in areas prone to increased hazards and risks.

The basic principles governing stope support near geological anomalies are as follows:

1. Additional support is required adjacent to and within geological structures ,
2. Both sides of such structures should be supported,
3. Particular attention should be given to supporting the hangingwall on the vulnerable “weak” side of the discontinuity,
4. The possibility of the formation of unstable key blocks should be recognised and countered,
5. Possible weak zones adjacent to or within the structure should be recognised and adequately supported,
6. Particularly high standards of permanent support should be used in high risk areas such as travelling-ways and gullies,
7. Particular attention should be given to temporary support of geological structures in the working face area.
8. If areas are unsafe, they should be barricaded off to prevent entry until they can be made safe. In extreme cases areas would be abandoned and stope faces re-established.

Geological structures that result in frequently encountered anomalous conditions include dykes, faults, brows, rolls and potholes. These anomalies represent zones of weakness in the rockmass, where the potential for falls of ground is increased.

The following sub-sections examine a range of specific cases, including principles for barring and methods for faults, dykes, brows and undercutting. The points originate from mine standards, discussions with mine personnel, various rock engineering training documents, and published literature.

5.3.1 Making safe and barring

A key issue when dealing with anomalous areas underground is making safe. Most anomalous conditions result in an increase in risk of falls of ground. It is essential that all features, such as brows and faults, are clearly paint-marked, and all loose rock is barred down. There are a number of points considered key for safe barring:

1. Pinch bar must be the correct length and sharp on both ends,
2. Pinch bar should have a gasket on to protect hands from rocks sliding down the bar,
3. All persons in the vicinity should be warned and asked to remain clear before barring,
4. Always have a second escape route from the area to be barred,
5. Stand firmly when barring – there should be no rubble under-foot that might cause slipping or falling,
6. Always stand on the up-dip side of the area to be barred,
7. Bar in small sections, for example for 2m, then stop turn around and look back for other slips, or partings that may not have been previously obvious.

Caution must be taken to identify the direction and angle of the main partings that create loose blocks. Key blocks must be identified and must be taken into consideration when barring. The removal of a key block can trigger a fall that is larger than expected! If a hazardous piece of ground cannot be barred, call for assistance. If this fails, call the immediate supervisor for advice. The hazard could be removed by blasting or controlled by leaving pillars or installing additional support.

5.3.2 Basic practice for additional support along minor faults, dykes, and brows

Falls of ground are liable to occur along structures unless adequately supported. The generally accepted practice is to install additional support, over and above the standard support pattern. Figure 5.2 shows a typical example from mine standards, while figure 5.3 includes diagrams showing generally accepted good practice. More information from mine standards is provided in the appendix. General procedure would be:

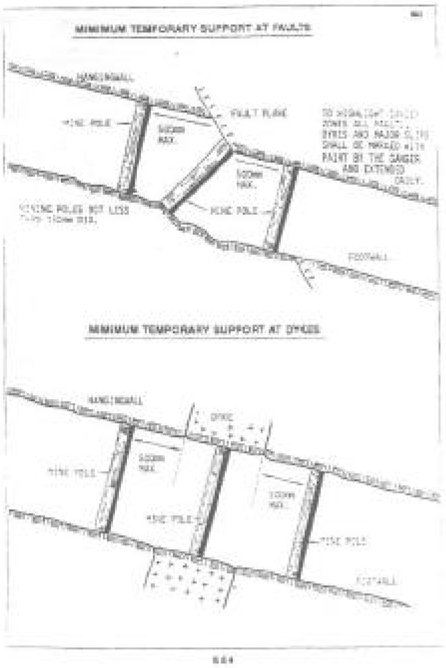
- The structure to be supported must be clearly identified and paint marked (an example is shown in figure 4.4).

- On either side of a fault, or either side of both contacts of a dyke, or beneath a brow, a row of additional support is installed. This is typically 0.5 m from the parting, with units spaced 1 m apart. Units would be in line with the support system generally in use in the stope, and could include props, packs, or tendons.

- Additional support is required within dykes where the width is greater than 0.5m, or where there is obvious risk of collapse of blocks within the dyke.

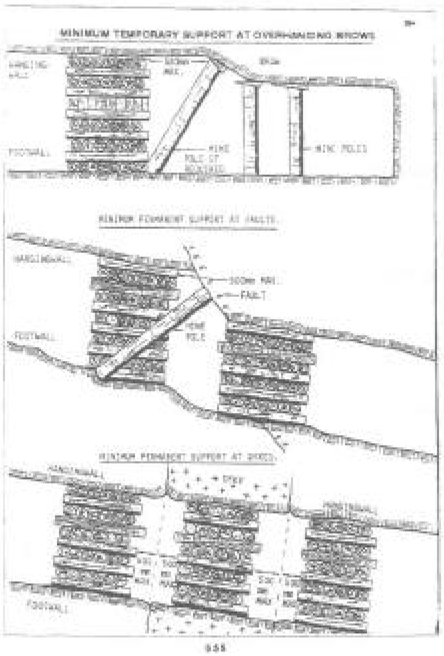
- Additional support requirements apply to both temporary and permanent support.

In areas where faults or structures create large wedges of ground, several rows of additional support may be required. In these cases the dead weight of the wedge should be calculated by the mine's rock engineer and an appropriate capacity support system devised. In shallow mines, where rockbursting is not generally considered a hazard, it is acceptable to leave pillars in stopes along major geological weaknesses. A depth, additional stope support is used.



MINIMUM TEMPORARY SUPPORT AT FAULTS

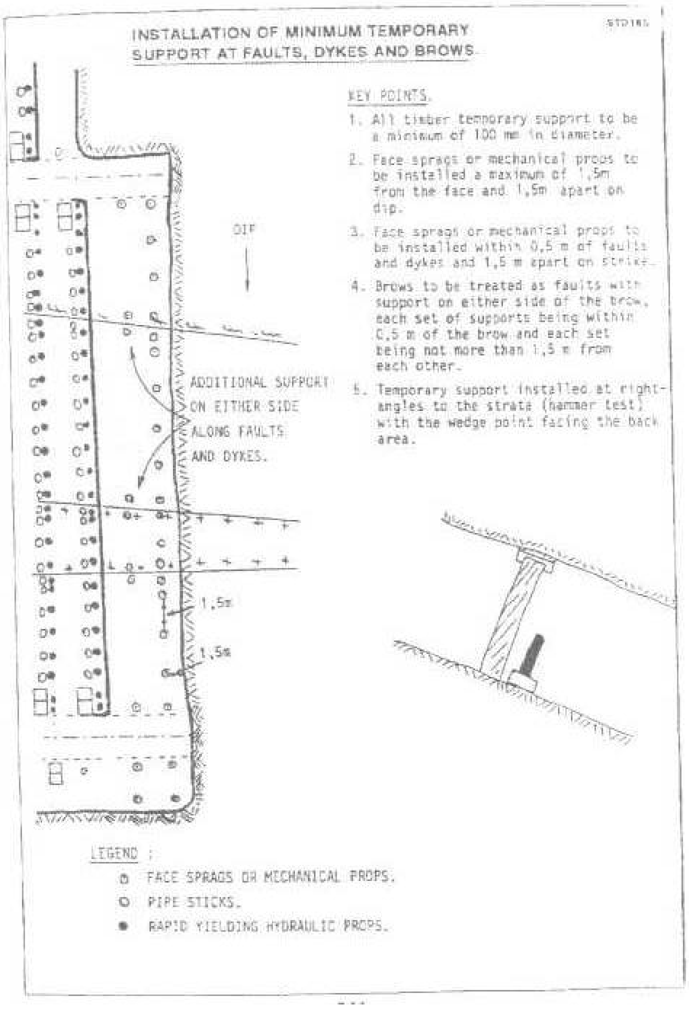
MINIMUM TEMPORARY SUPPORT AT DYKES



MINIMUM TEMPORARY SUPPORT AT OVERHANGING BROWS

MINIMUM PERMANENT SUPPORT AT FAULTS.

MINIMUM PERMANENT SUPPORT AT DYKES.



INSTALLATION OF MINIMUM TEMPORARY SUPPORT AT FAULTS, DYKES AND BROWS

KEY POINTS.

1. All timber temporary support to be a minimum of 100 mm in diameter.
2. Face sprags or mechanical props to be installed a maximum of 1,5m from the face and 1,5m apart on dip.
3. Face sprags or mechanical props to be installed within 0,5 m of faults and dykes and 1,5 m apart on strike.
4. Brows to be treated as faults with support on either side of the brow, each set of supports being within 0,5 m of the brow and each set being not more than 1,5 m from each other.
5. Temporary support installed at right-angles to the strata (hammer test) with the wedge point facing the back area.

LEGEND :

- ◘ FACE SPRAGS OR MECHANICAL PROPS.
- ○ PIPE STICKS.
- ● RAPID YIELDING HYDRAULIC PROPS.

Figure 5.2 - Examples of typical support for geological structures from mine standards

Permanent support is shown, top, with an example of temporary support, left.

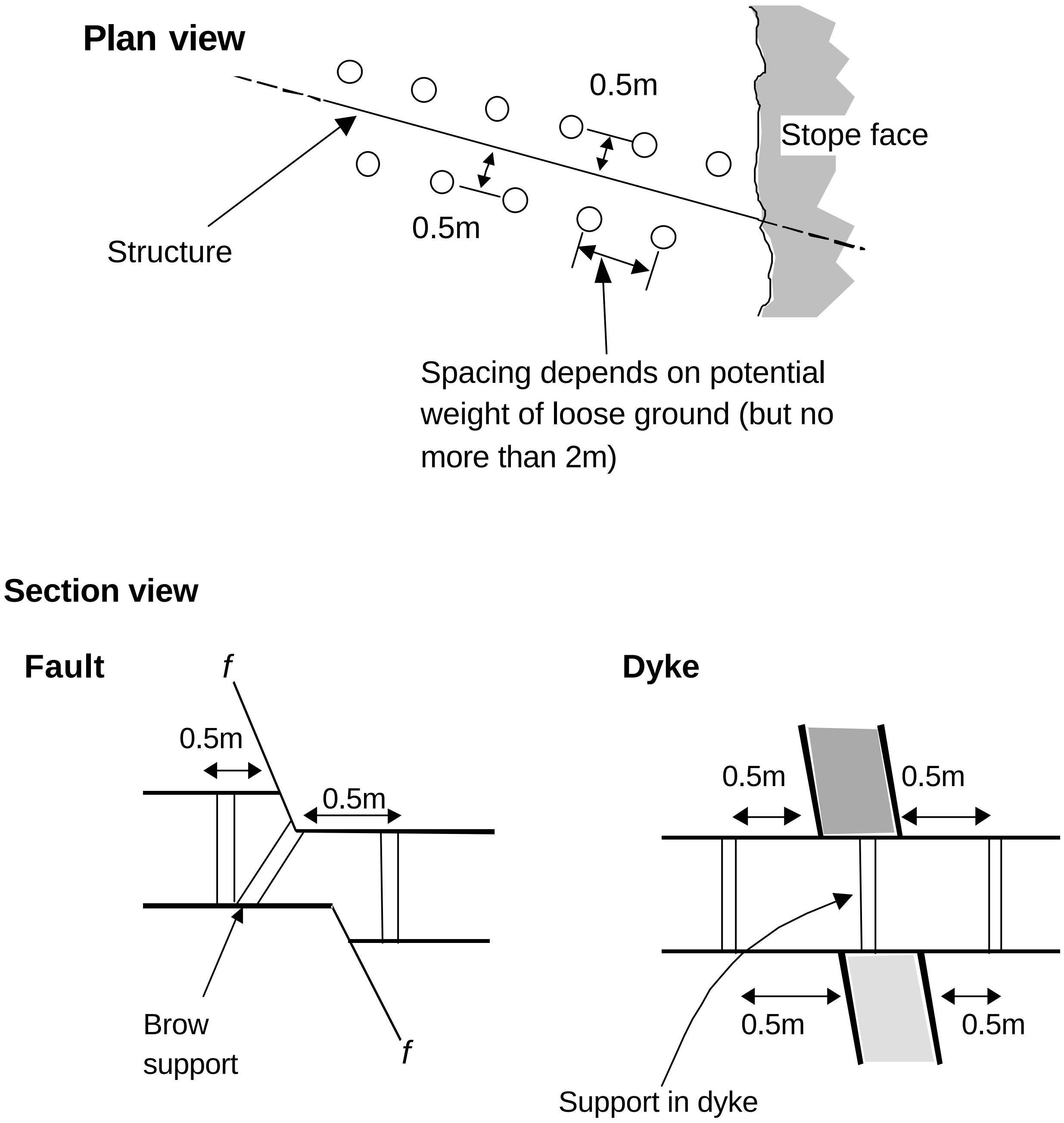


Figure 5.3 – Generally accepted pattern and practice for additional support along minor faults, dykes and brows (based on a range of mine standards).

5.3.3 Use of pillars to control falls of ground along structures

Pillars are used along structures at all depths. In deep mines they usually perform a function to assist in regional support, and control of seismic activity along the structure. At shallow depth, pillars are usually placed along structures to prevent major collapse.

In shallow mines, additional reef pillars are often left in situ along a fault or dyke. These reduce spans and provide support below large wedges of ground. Examples are shown in figure 5.4. Pillars can be used safely at shallow depth where they can be designed based on the weight of ground they are expected to support. At increased depth, where stress fracturing and seismic activity are a normal feature of mining care must be taken with leaving pillars as they may become burst-prone.

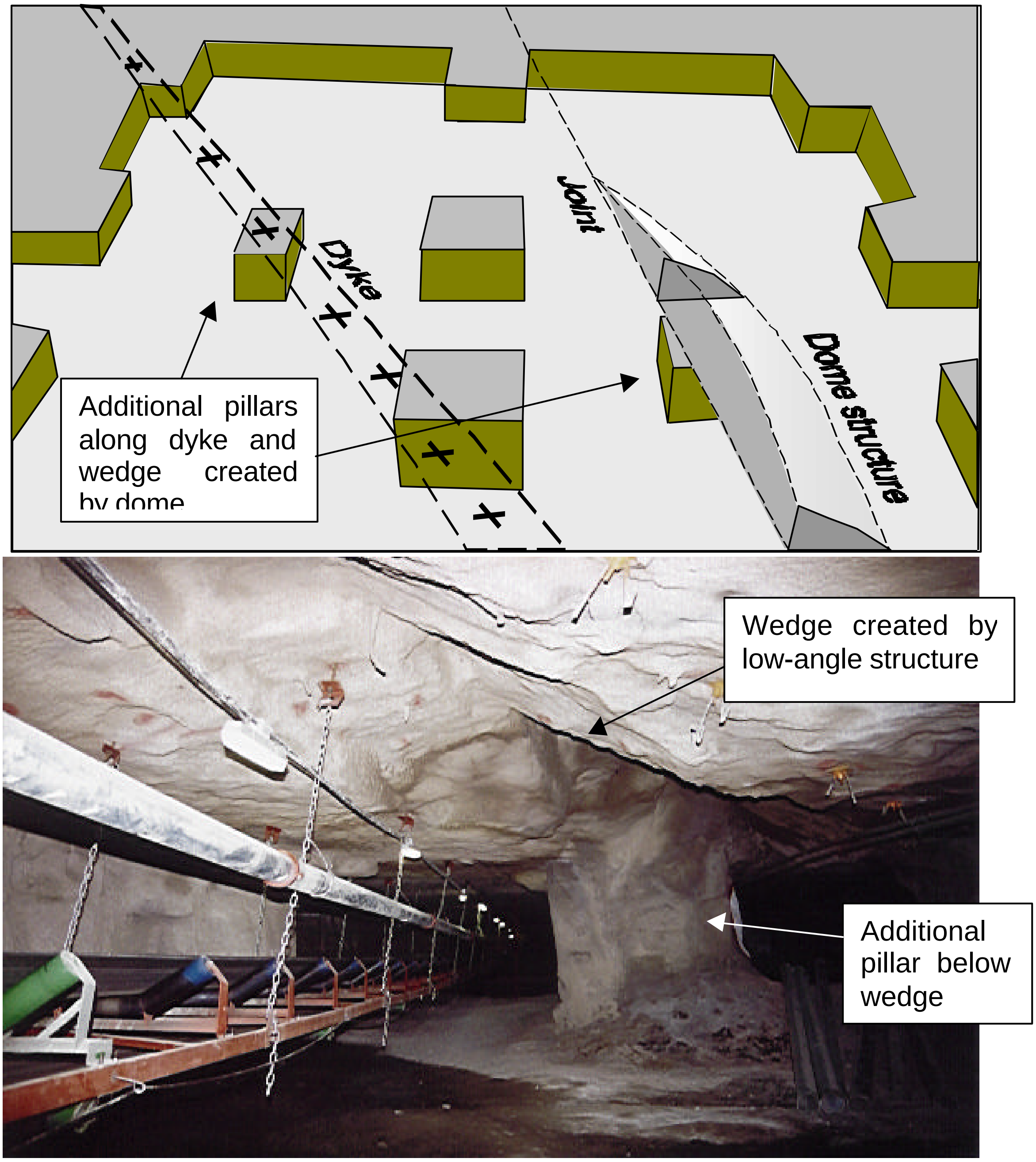


Figure 5.4 – Additional pillars along structures in a shallow platinum mine using a room and pillar layout.

5.3.4 Negotiation of minor faults and dykes

Faults are often problematical as they result in a change of elevation of the reef, and as a result a certain amount of off-reef mining often occurs, including cutting into bedding, creating brows, or exposing weak off reef strata. Various procedures exist for negotiating faults. The choice of method is largely dictated by the throw on the fault, the attitude, or inclination of the fault, whether it is normal or reverse, and if some form of overstoping is required to avoid a stressed pillar situation.

Obviously, in many scattered mining or sequential grid layouts it is possible to mine from raiselines up to either side of a fault or dyke and avoid having to negotiate it. However in some situations, particularly if structures are close to raises, or if longwall mining is being practised, some form of negotiation is required.

When throws are small, less than several metres, stope panels can generally safely roll up or down through the fault. Dunn and Laas (1999) suggest a limit of 3 m, beyond which re-raising is required. When rolling up or down, care has to be taken with support on the weak side of the fault, and, if rolling down, with damage to the hangingwall which could result in an increase in stope width. Care has to be taken to prevent exposing weaker strata in the hangingwall, for example the Green Bar shale above the Carbon Leader Reef.

Examples of some of the hazards of negotiating minor faults are shown in Figure 5.5. Examples of methods of negotiating small throw structures from some industry guidelines are shown in figures 5.6, 5.7 and 5.8. The choice of method depends on the direction and throw on the fault or dyke, the width of a dyke, and the position of the reef on the other side of the structure. The stress and seismic risk environments are also a major consideration. Note that some of the examples shown are relatively old, and the pack and prop types shown have been superseded by preferable types. A basic rule around structures is not to suddenly change support types, for example from props to packs, as the change in support system stiffness may be detrimental especially in deep, highly stressed conditions.

Figure 5.6 shows examples of rolling through small throw structures. Generally this is considered more acceptable when mining through dykes than faults as mining is off-reef within the dyke in any case. When rolling down, many consider five degrees to be an acceptable maximum angle, as problems with gully cleaning and water accumulation increase as the declination is increased. When rolling up, maximum angles are based on local practicalities.

In figure 5.7 a range of options for negotiating small throw faults are shown. These include rolling down after passing through the fault, trenching down along the fault plane, and vertical trenching or slotting away from the fault plane. Selection of method would depend on local conditions, however caution is generally considered necessary when trenching or slotting in high stress areas as the slot walls effectively represent a high face which may be more prone to face bursting than a normal narrow stope face. Bursting may result in closure of the trench or slot, trapping workers within it. In highly seismic areas it is also possibly unwise to trench or slot along the fault plane. The merits of different methods can only be judged based on local mine conditions. In higher stress conditions, if trenching is considered an option, it is best to carry a waste cut through a fault and trench or slot in de-stressed ground. Examples are shown in figure 5.8. Boxholing is an option to slotting when negotiating an up throw.

Where throws are larger and slotting or trenching is not viable, re-raising would be done on the other side of the structure. If development has to pass beneath the structure and the creation of a pillar is to be avoided, a waste cut is needed. Examples for up and down thrown structures are shown in figure 5.9.

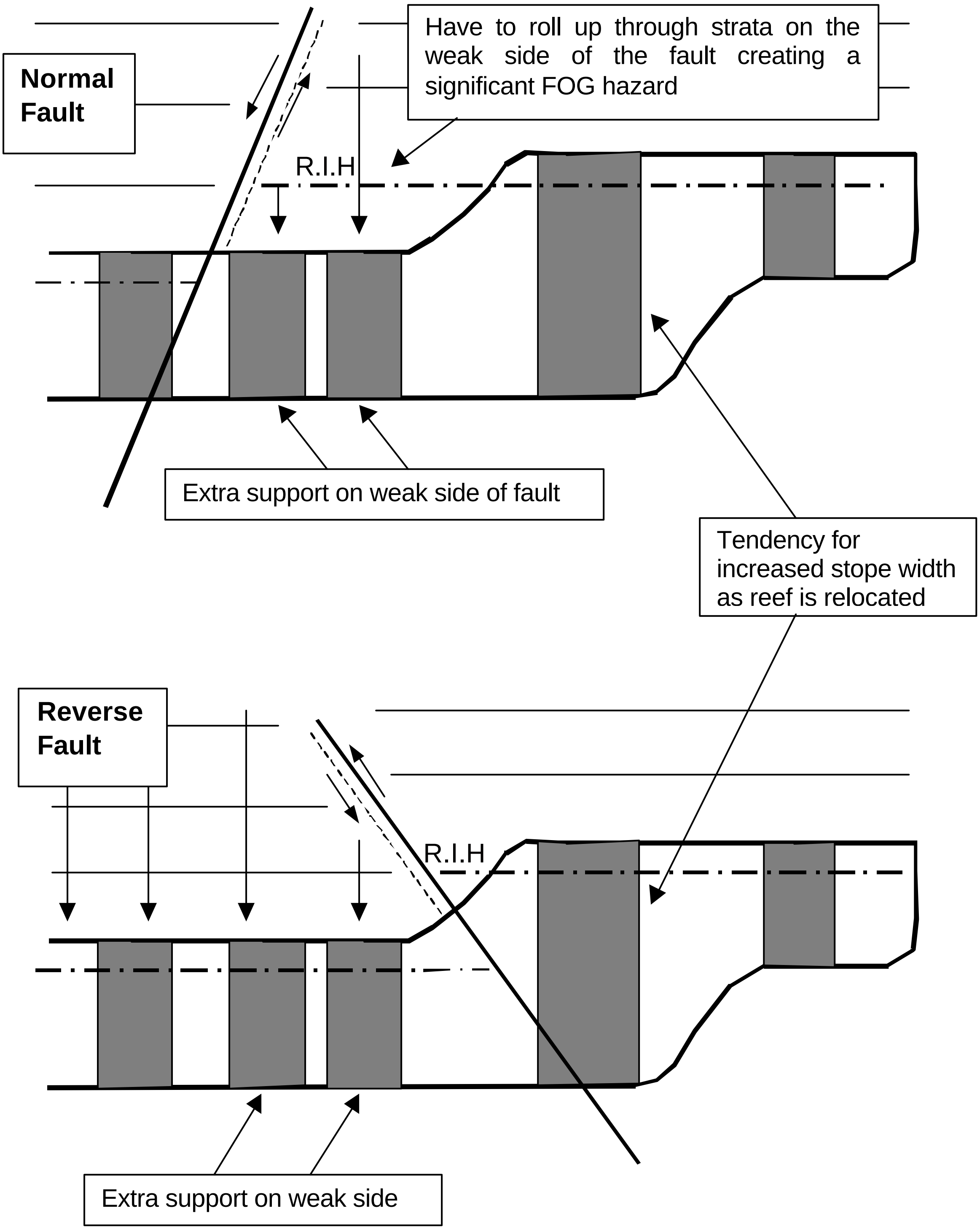


Figure 5.5 - Example showing hazards and support practices for negotiation of a “normal” upthrow fault and a “reverse” downthrow fault (after Emere, 1977)

Dykes – down throw – roll down

Dykes – up throw – roll up

Faults – down throw – roll down

Faults – down throw – roll up

Figure 5.6 - Examples showing rolling up or down to negotiate small throw faults and dykes (after Western Deep Levels, 1987)

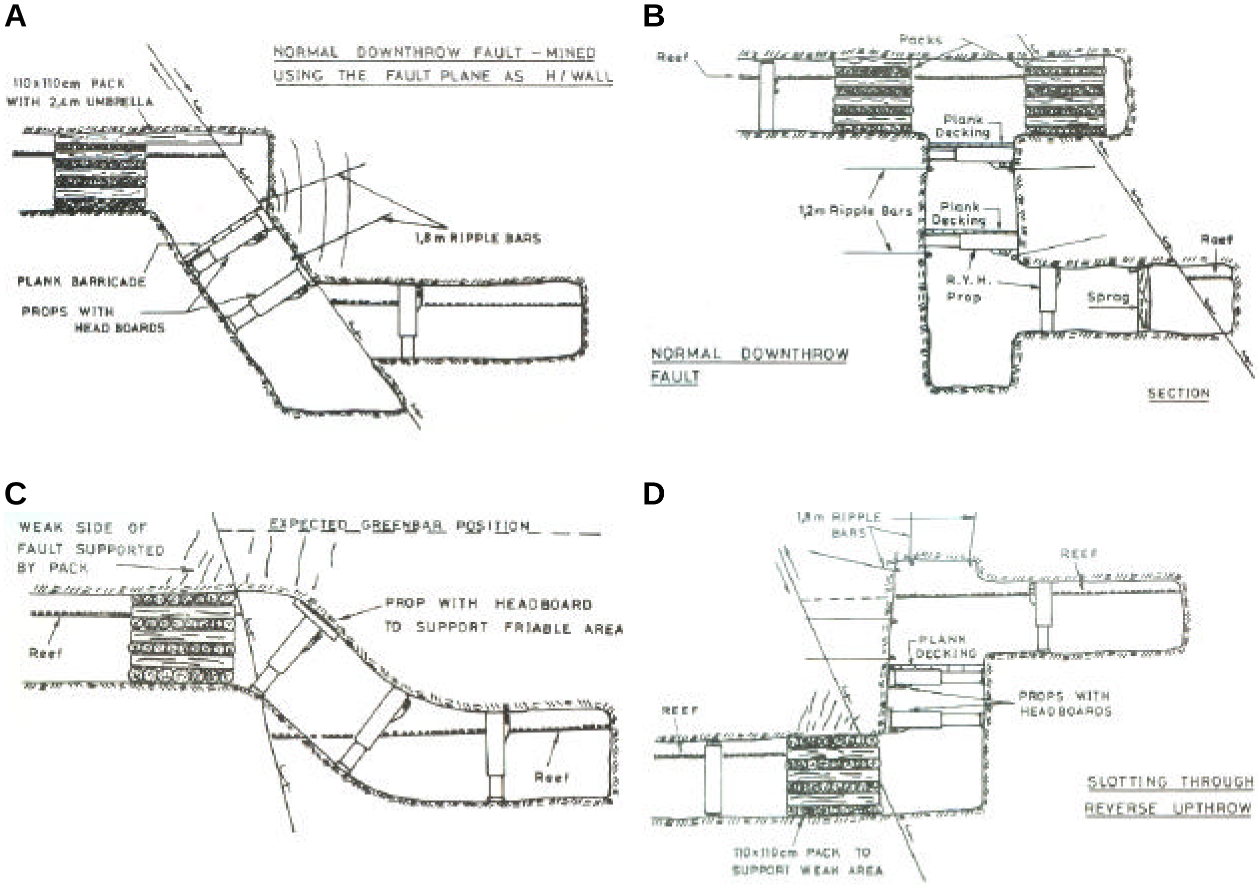


Figure 5.7 - Examples showing recommended practices for negotiation of small throw faults (after Western Deep Levels, 1987)

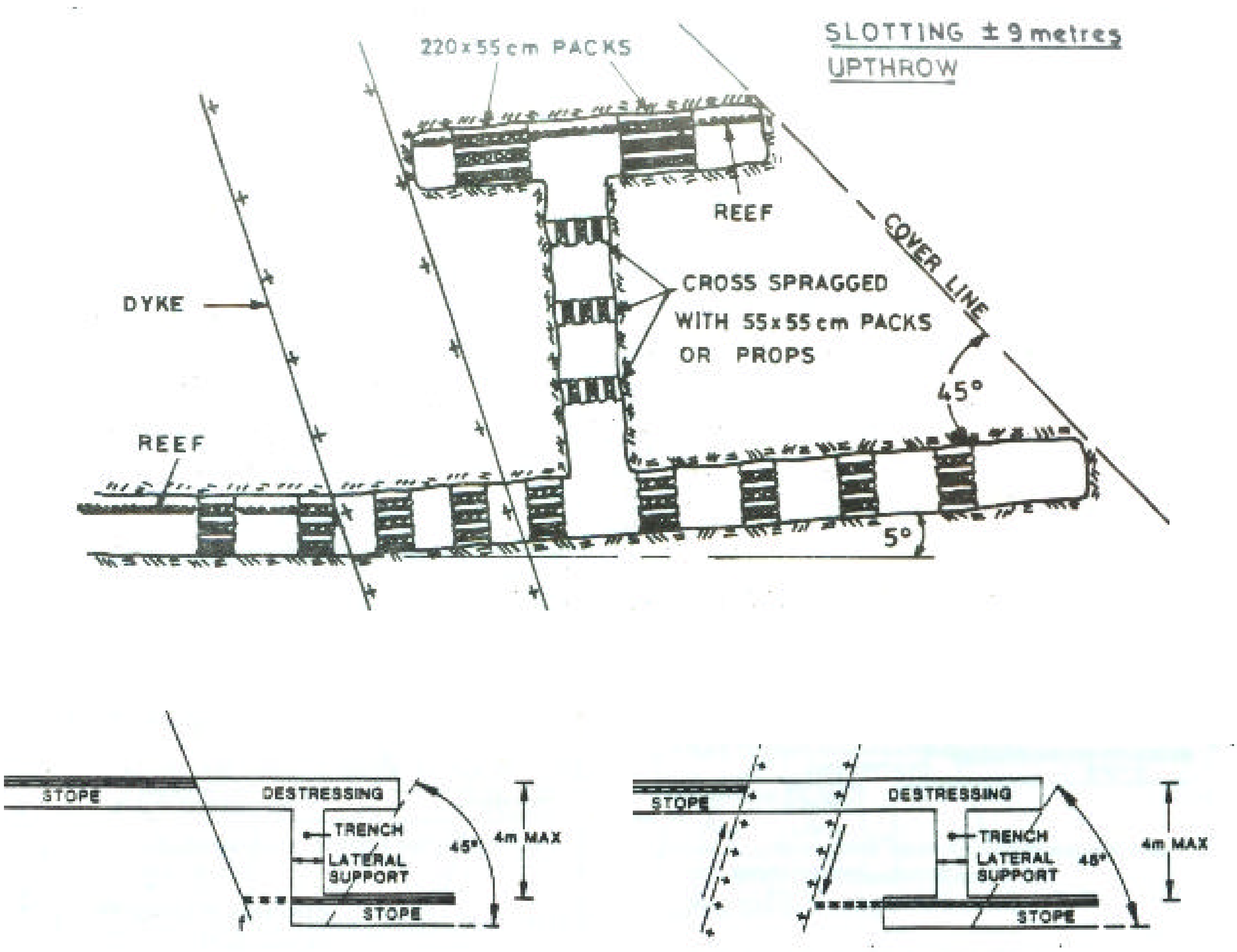


Figure 5.8 - Examples showing recommended practices for negotiation of small throw faults by slotting or trenching in de-stressed ground (after Western Deep Levels, 1987)

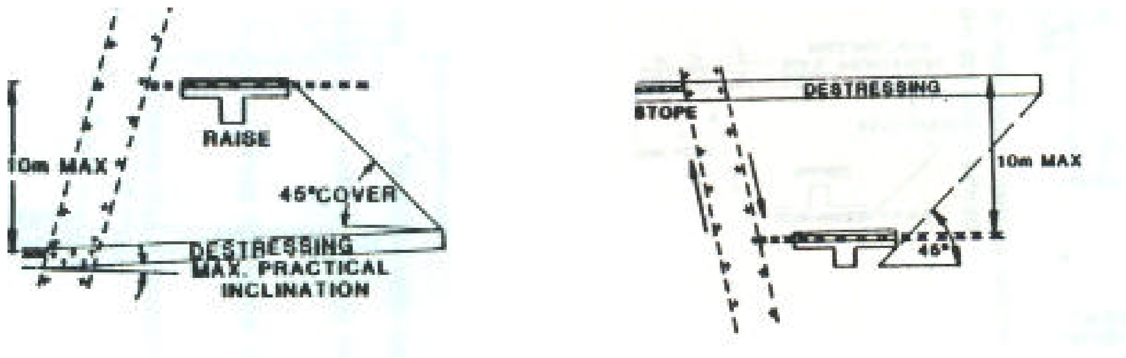


Figure 5.9 - Examples showing recommended practices for re-raising to negotiate moderate throw up or down throw faults, with de-stressing slots cut to prevent the formation of pillars that may damage footwall development (after Western Deep Levels, 1987)

5.3.5 Undercutting brows and weak strata

Brows originate for a number of reasons, including hangingwall falls, collapses in the stope face area, minor faults, rolls and potholes. Some mines, notably those in the Freestate on the Basal Reef, have regularly applied undercutting procedures. There, there is a narrow quartzite beam above reef with the weak Khaki shale above, which flows when exposed. Undercutting is regularly applied to re-establish the quartzite beam. When undercutting, mining needs to advance below the brow, without the brow collapsing, to establish normal stope widths. The main objective of any undercutting technique is to re-establish the continuity of the immediate hangingwall beam in a stop panel by creating horizontal restraint such that slabs of rocks between the fracture planes are prevented from falling out by the frictional forces on the interfaces. In major undercutting exercises it is important that the brow is blocked against adjacent support, as shown in figure 5.10. Obviously this is not always possible where a stope face has collapsed and has to be re-established, but should be feasible where undercutting brows created, for instance, by a minor fault. An alternative to brow confinement using props is bolting, or using cable anchors, as shown in figure 5.11.

Caution must be taken when undercutting a brow. Key issues where advancing beneath brows, or weak structures are:

- Reduce unsupported spans of excavations passing through the brow.
- Ensure that the edge of the brow has been properly barred and is solid.
- Additional support should be installed both under the brow and to confine the brow face.
- Any parts that appear loose, or hazardous, that cannot be easily barred, and would remain potentially unstable even with support installed should be blasted down to remove the hazard.

There are a number of methods for undercutting. The choice of method would depend on local conditions, and the local mining geometry. Some options are:

1. Advancing a short face at an angle along the brow of structure - Advance a heading under the brow or structure at the top of the panel and establish a short diagonal down dip face and advance down dip down the brow in short increments, supporting the brow with packs. This method should only be used where the leaving of pillars is hazardous, and the stope on the high side of the brow is clean and safe, as cleaning of the short face is done in this area. Great care must be taken to adequately support the brow and ensure it does not become hazardous. This method can only be done slowly.

2. Open raising or re-raising - Advance a heading through the brow or weak structure, leave a narrow pillar (crush pillar) along the brow and use a wide heading to re-establish the stope panel face (often referred to as ”open raising”). The width of pillar would be a function of mining depth and the width of the zone of stress fracturing ahead of the stopped face. The method does not require the face stopped along the brow to be accessible or safe (figure 5.12).

3. Pillar and bay methods – The method requires the stope face that is to be undercut to be open and safe along its length. The brow face must be well supported. A number of short headings are advanced beneath the brow at intervals along the face. Once well under the brow these are connected both up and down dip to create a new face. A series of pillars are left to support the brow. This is a good method for relatively low stress environments but where stress is higher the pillars may prove hazardous. While the method creates a large number of attack points, it is labour intensive as cleaning is largely by hand (figure 5.12).

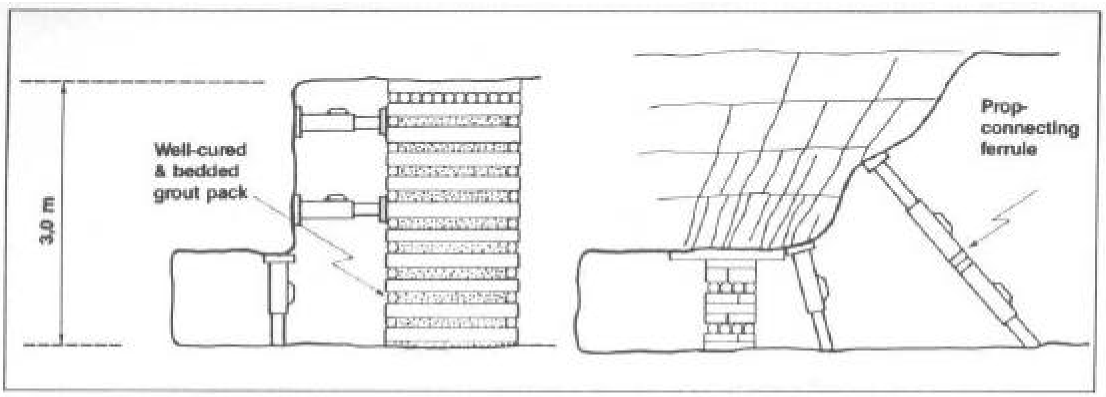
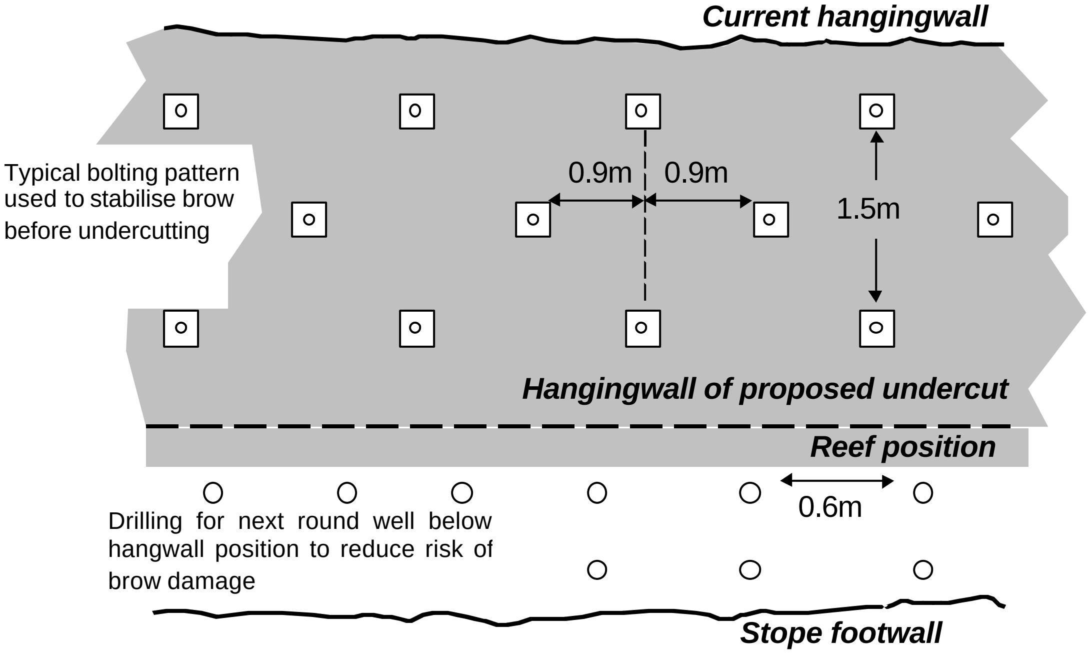


Figure 5.10 - Examples showing recommended practices for undercutting brows using props to confine and support the brow (after COMRO, 1988)

Section along undercut face



Section through undercut

Roof bolts, typically 2.4m long to reinforce brow (provided brow is accessible).

Alternatively packs can be built close to, and blocked tight against, the brow.

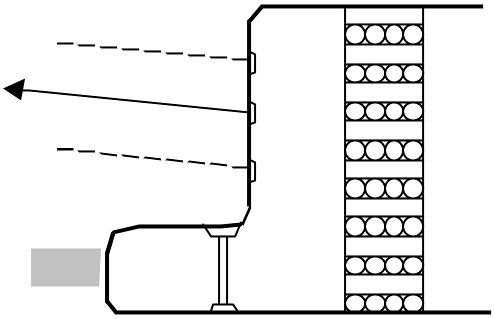


Figure 5.11 – Undercutting employing roof bolts. (Note that pre-tensioned rope anchors & rapid yielding hydraulic props may also be used) (after Emere, 1977)

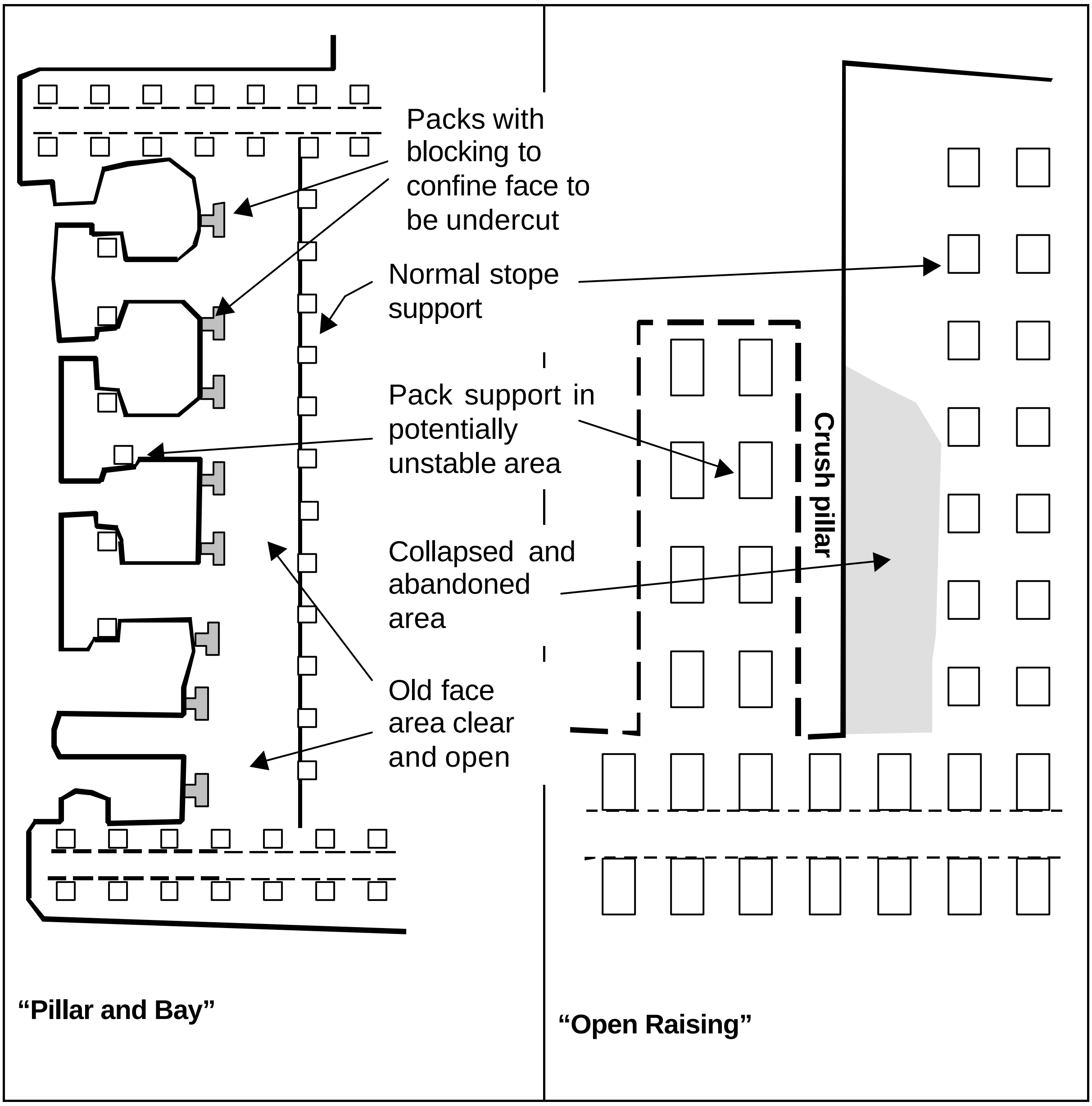


Figure 5.12 – Two possible methods of undercutting brows in stope faces using either a pillar and bay method, or by open raising – re-raising (after Emere, 1977)

6 Methodologies for anticipation and management of anomalous conditions

This section examines a range of methodologies that could be employed to assist in anticipating those areas where anomalous conditions are most likely to occur. These kinds of approach could be useful from a mine planning standpoint, when it would be useful to identify higher risk areas, where mining rates might be slower or support and layout costs higher due to increased hazards.

6.1 Standard versus anomalous conditions

Because of the wide range in mining depths and geological conditions across the South African gold and platinum mining industries, what is considered unusual or anomalous on one mine, may not be anomalous on another mine. For instance it might be that an old mine works almost exclusively on remnants. For that mine remnant mining could be considered as the standard, however on the scale of the industry as a whole, remnants would be deemed as non-standard. It is therefore important to define “standard” conditions. These standard conditions should effectively become the main Ground Control Districts defined on a mine, and reported in the mine’s code of practice.

Within the scope of this project, the terms “standard” and “non-standard” or anomalous have been generally used in the context of an industry wide scale.

As defined earlier in the project, five categories of factors that may contribute to the standard or non-standard status of a stope have been identified. This is based on information obtained from the codes of practice for the control of rock related accidents, information from inquiries into rock fall related accidents by the DME, discussions with various rock engineers and personal experience.

Table 6.1 contains an arbitrary classification of the meaning of high, moderate and low stress as used in table 6.2, which defines standard stopes. Table 6.2 enumerates the identified factors as may be expected for the various stress regimes. Based on interviews with mining personnel, both in production and in rock engineering, as well as information gleaned from various codes of practice (including that in Appendix I), table 6.2 was compiled to define standard stopes. If it can be accepted to list reasonable definitions of standard conditions, then adding the contribution that the human factor might have, non-standard conditions may be identified using table 6.3 as a criterion list. This notes the major factors contributing to non-standard conditions. After presenting this table to several practising rock engineers sufficient agreement was reached for it to be accepted as the base according to which non-standard conditions could be defined.

Table 6.1 - Classification of stress intensity

Classification	**Principal stress/Uniaxial compressive strength.**	**Pillar factor of safety**
Low Stress	Less than or equal to 0.3	Greater than or equal to 1.5 (Stable Pillars)
Moderate Stress	Greater than 0.3 but less than or equal to 0.6	Greater than or equal to 1 but less than 1.5 (Yield Pillars)
High Stress	Greater than 0.6	Less than 1(Crush Pillars)

Note in tables 6.2 and 6.3 that at 2000 m, stress fracturing is ubiquitous, and hence is a basic condition of mining and is no longer anomalous, whereas at shallower depth stress fracturing only tends to occur in remnant or similar areas and hence is anomalous. Similarly, areas of increased jointing are masked by stress fracturing at greater depth, and again are less anomalous and rarely individually identified. The two platinum cases highlight the differences between an assessment of panel risk based purely on a surface study, where only significant structure is marked on plans, versus the increased degree of detail picked up when detailed underground panel audits are conducted. As might be expected, panels where accidents occur invariably include some degree of anomaly that was causative to the accident.

From the information obtained from various sources, (including mines codes of practice, accident reviews, interviews with various practitioners and personal experience) it is possible to categorise broadly what is perceived to be standard conditions in the mining industry and from that to define criteria for determining non-standard stoping areas. These are tabulated in tables 6.2 and 6.3.

Table 6.2 - Definitions of standard stopes

Description	**Depth below surface**	**Stress conditions**	**Geological factors**	**Mining considerations .**
Shallow stope	Less than 1000m	Low Stress. Stress fractures non-existent or very infrequent. Err less than 10MJ/m^2 Seismicity rarely occurs	Similar in frequency and appearance to that in the rest of the geo-technical region	Mined continuously according to the mining method employed by the mine, where the developed and approved standard procedures and designs are enforced.
Stope at intermediate depth	Between 1000m and 2150m below surface	Moderate stress Moderate fracturing with a relatively low frequency of occurrence Err not more than 30MJ/m^2 Seismicity may occur periodically	Similar in frequency and appearance to that in the rest of the geo-technical region	Mined continuously according to the mining method employed by the mine, where the developed and approved standard procedures and designs are enforced.
Stope at Depth	Greater than 2150m	High stress Intense stress fracturing with a high frequency of occurrence Err more than 30MJ/m^2 The threat of seismicity is ever present	Similar in frequency and appearance to that in the rest of the geo-technical region	Mined continuously according to the mining method employed by the mine, where the developed and approved standard procedures and designs are enforced.

Table 6.3 - Definitions of non-standard conditions categorised by stress, geological, mining practice and human factors

	Description of condition	**Possible causes**	**May result in**
Non-standard stress conditions	• Significant changes occur in stress regime.	• Changes in tectonic stress (e.g. due to the presence of geological structures or change in k-ratio) • Changes in rock properties • Over or under stoping	Any or all of the following: • Increase in frequency of occurrence of fracturing • Change in direction of fracturing • Change in inclination of fracturing • Change in appearance of fractures • Seismicity and rock-bursts
Non-standard geological factors	• Changes in the frequency of occurrence and/or type of structure	• Faulting • Dykes or sills • Bedding/stratification • Ball and pillow structures • Exposure of shale in hangingwall • Dense jointing • Potholes • Domes	Changes in any or all of the following characteristics: • Channel width • Frequency of occurrence • Direction of features • Inclination of features • Appearance of features • Rock type • Reef dip, strike or elevation • Occurrence of striation marks on shear surfaces
Non-standard mining practice	• Changes in the mining method, direction or mining sequences.	• Changes in geological features or manipulation of mining sequences	Changes in any or all of the following characteristics: • Mining layout • Face shapes • Panel lengths • Pillar positions • Mining height • Support type • Support density • Rate of advance • Blasting practice • Cleaning operations
Human factors	• Changes in staff experience or attitude • Supervisional changes • Lack of appreciation or awareness	• Staff transfers • New or unfamiliar to working place. • Inter staff relationships • Inadequate training or information transfer or alertness	• Poor understanding of local conditions • Poor understanding of requirements for task • Inappropriate or incorrect procedures • Incorrect equipment • Incorrect use of equipment

6.2 When should anomalous conditions be anticipated?

It follows from the definition of non-standard conditions in table 6.3 that methods are required to detect when ground conditions change, and hence when standards should be changed or rock engineering recommendations, or special instructions from line supervisors should be issued. Anomalous conditions normally result from unforeseen changes in the mining environment either as a consequence of natural anomalous rock mass conditions or those induced by incorrect or changed mining practice.

Viable methods for determining the proportion of mine ground that can be considered non-standard vary from mine to mine. In some cases detailed recommendations for every working panel are made monthly by the rock engineering department, in which reasons for any additional support requirement is stated (see panel rating systems in section 4.2). In other cases the mine has stope observers who make regular random panel visits, measuring compliance to standards and recording stope conditions. On some mines, geological plans provide reasonable detail concerning the proportion of areas affected by anomalous conditions. These all provide sources of data to allow a quantification of the frequency that support outside basic standards is applied, or required.

In most cases it appears that limited underground mapping of joints, brows and falls of hanging cannot be realistically extrapolated to be considered representative of large regions. From the data gathered in section 4 it is apparent that there is no industry-wide consistency in the frequency of occurrence of anomalous conditions, although local areas may prove reasonably predictable.

One of the most important aspects in dealing with non-standard or anomalous conditions is to employ quick, easy to use methods for assessing the change from normal to anomalous operating conditions. Obviously in many geological circumstances this relies on observation of hazards underground, but in the longer term, from a planning perspective, methods can be used to assist in identifying changing conditions. From this perspective, the most pronounced influence on ground control and support requirements occurs through a change in frequency of discontinuities (stress fractures, joints, veins, domes, faults and dykes) and the rate of closure.

Since the change in frequency of discontinuities and the rate of closure are easy to measure or observe, simple methodologies for assessing changing rock mass conditions can be developed for these anomalies.

6.2.1 Anomalous conditions due to unusual levels of stress and closure

6.2.1.1 A simple empirical method

Ideally numerical models can be used to examine face stress levels and Energy Release Rates, which can be related to in-stope conditions. However as a simple way of gauging normal or standard conditions, and the results that a deviation in stress conditions may have, figure 6.1 can be used. This was developed out of observations of stope gully conditions for SIMRAC project GAP 602, and it should be noted that this is intended to be a very rough guideline and should not be used as a rigorous design method or a replacement for local mine observations. Simple estimated of closure rates have been made and added in figure 6.1.

In the upper graph in figure 6.1, field stress is assumed to increase linearly with depth, with lines for various multiplication factors added to account for remnant conditions. Geotechnical condition categories, in the lower graph, can be defined in terms of the ratio of field stress to rock strength. In using this graph to examine anomalous conditions, the first step would be to identify standard conditions for a mining area, then the effects of anomalous conditions can be compared. For example, in a mine operating at 1000 m depth, largely in open ground the level of stress under virgin conditions would be approximately 30 MPa. Following down from the top graph to the lower graph, if the mine is operating in the Bushveld complex with an average rock strength of 150 MPa, the standard (or normal) stoping condition would be within the “moderate stress damage” geotechnical category. However if extracting a remnant in this area, a 1.5 times field stress multiplication factor might be appropriate. This gives a field stress of approximately 45 MPa, which results in a shift into the “high stress damage” category in the lower graph. This would constitute anomalous levels of stress fracturing and potentially closure also.

Ideally mines should develop their own relationships for face stress, span, stope closure, mining depth and fracture frequency based on local observation. Mine support standards would be designed to cater for a “normal” local fracture density and closure rate.

Various other methods have been briefly examined to use to identify unusual levels of stress and closure.

6.2.1.2 Determining anomalous stress fields from underground observations

As an alternative to figure 6.1, an alternative chart was experimented with, based upon roughly calculated face stress levels and observed fracture frequencies. It is not exceptionally rigorous, and is flawed, but is included here for completeness, as it was examined as part of the project.

If it is generally assumed that the frequency of stress fractures increases proportionally with an increase in stress (which is not entirely correct), a relationship can be established between mining span, operating depth and stress fractures measured per metre. An anomalous increase in stress ought to be reflected in an anomalous increase in stress fractures observed underground. A design chart can then be formulated that allows underground observers to identify when stress conditions are changing from the normal operating range to anomalous or non-standard conditions. Figure 6.2 shows an example of the possible increase in fracture frequency with an increase in operating depth and as a function of mining span (where stope face stress levels would also increase as a function of span). This chart was created by first estimating face stress by calculating the root mean square vertical stress at the face given by:

$$\sigma_{rms} = q\sqrt{2\pi l / h}$$

In this formula σ_{rms} is the root mean square vertical stress at the face, q is the vertical component of the in-situ stress field (which is depth related), l is the mining half span and h is the stoping width. Stress levels were directly related to stress fracture frequency based on the assumption that it would be a linear increase, and at depth (say 2000 m) the fractures around a typical stope face have an average spacing of 60 mm (Jager and Ryder, 1999).

Ideally a chart of this type would be scaled to local mine observations. Then, if an observer maps fractures in a stope, the observed fracture counts can be plotted on Figure 6.2 and it becomes possible to determine whether the state of stress in a panel should be considered standard or anomalous for a given mining half span.

Charts similar to Figure 6.2 can be produced for individual panels, raise lines/drives or entire mines and regions. The face stresses or panel/mining region spans can readily be obtained from mine working plans and the fracture count for the face position obtained from routine underground observations. If the operating depth is similar for the entire mine then mining span can be plotted against fracture counts to assess deviations from the normal operating fracture frequency range.

Estimation of Geotechnical Conditions

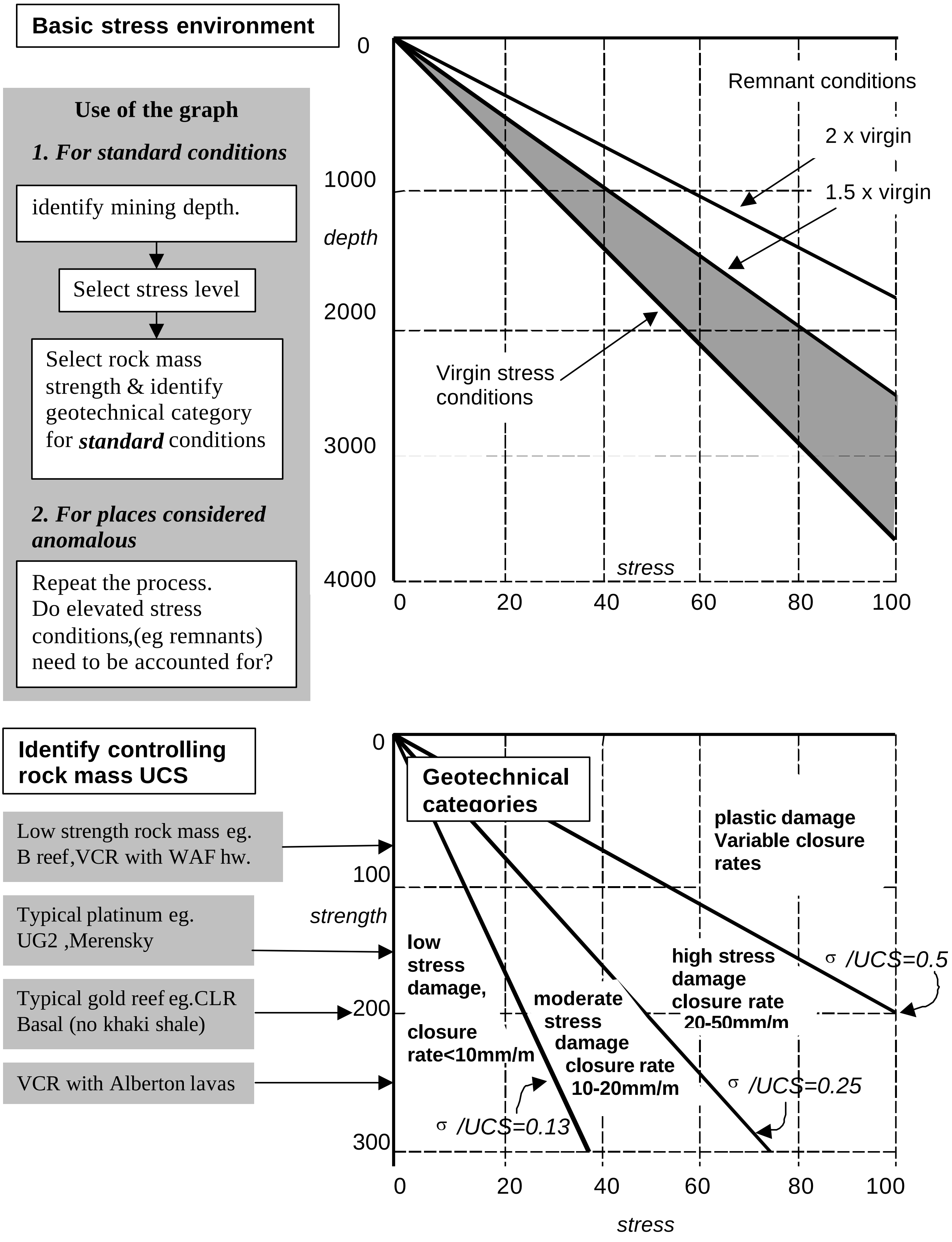


Figure 6.1 – Simple empirical identification of stress and closure conditions

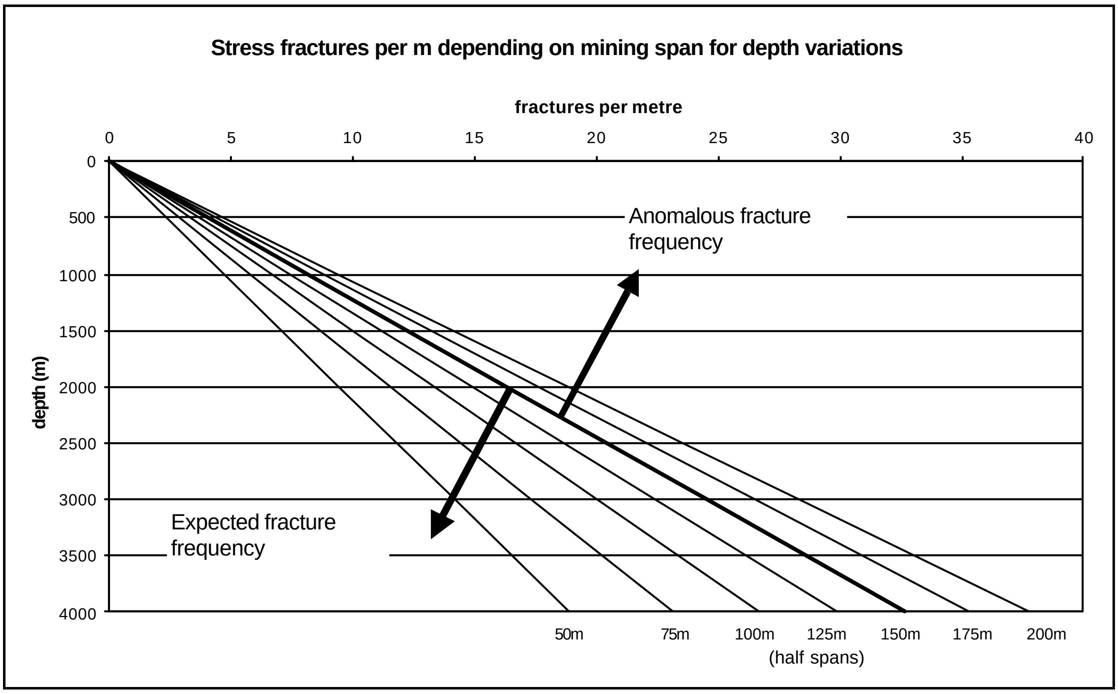


Figure 6.2 - Stress fracture frequency depicting the change from normal operating stress conditions to anomalous conditions for variations in mining spans (the arrows indicate anomalous and expected fracture frequencies for a span of 300m)

6.2.1.3 Determining anomalous closure rates from underground observations

A similar process was used to attempt to develop a simple criterion to assess whether closure rates could be considered anomalous. Again it is included here for completeness but is not considered exceptionally rigorous.

Expected elastic rates of closure for a mine or region or geotechnical area can easily be obtained from analytical formulae or numerical models for variations in both operating depth and mining spans. To obtain a more realistic rate of closure, a factor of say 1.6 can be applied to the elastic closure rate to account for the inelastic component of closure. Using the elastic convergence formula, a relationship between operating depth, mining span and closure rate can be obtained:

$$S_z = \frac{2(1-\nu)q}{G}\sqrt{l^2 - x^2}$$

In this formula S_z is the elastic closure rate, l is the stope half span, x is the position of the point at which closure is calculated (relative to the centre of the half span), G is the modulus of rigidity and ν is the poisson's ratio. The resulting chart relating operating depth, mining span and elastic closure rate is shown in Figure 6.3. The closure rates used for stope support design at 32 mines are also plotted on the chart in Figure 6.3, and indicate that there is enormous variability, and that while this chart may provide a reasonable avaerage, mine-specific charts are probably required. The chart allows the user to determine whether the rate of closure for a particular section or geotechnical area deviates from average, or normal. The change in rate of closure from normal conditions should prompt the user to check if, first, the implemented design is adequate, and second, if design modification or changes to support should be implemented.

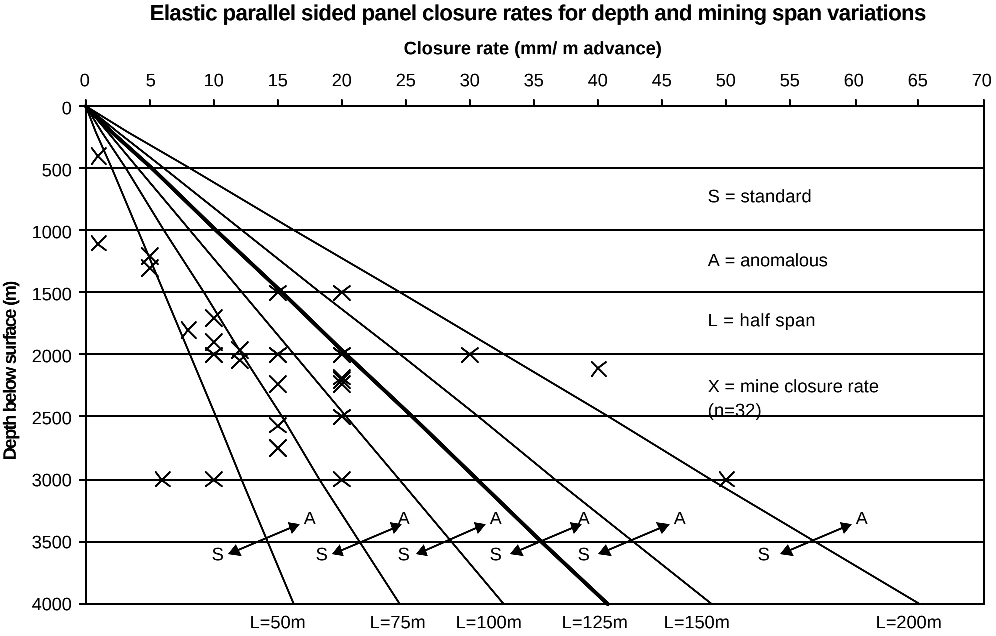


Figure 6.3: Defining anomalous closure rates based on elastic closure variations for a range of mining spans

6.2.1.4 Determining anomalous high frequency geological structures

Techniques used in section 4 to look at the frequency of occurrence of geological structures can be adapted to examine probabilities of encountering geologically anomalous conditions in mining areas.

Geological structures can be grouped into high and low frequency structures. High frequency geological features include joints, veins and domes. Low frequency structures would be faults, dykes and potholes, for example.

To determine whether the support pattern, type and layout employed in a particular mine or geotechnical area are still appropriate in terms of the high frequency geological features that are present, any changes to the spacing, condition, persistence, dip and dip direction of these features needs to be known. Simple methods can be employed to determine what the normal operating range of the parameters governing the stability of blocks bound by these features are and conversely which areas of the mine or geotechnical area are anomalous.

- A first pass discontinuity count analysis can be conducted per area (defined by rock engineer or geologist) which will broadly indicate whether anomalous high frequency structures persist or are likely to persist on the mine. The method simply requires the analyzer to divide the mining area into equally sized blocks on preferably a geological plan and count the number of discontinuities in each block. A graph of block number (or mining area name or raise line) versus the number of discontinuities will indicate normal and anomalous operating conditions.

- Anomalous frequencies should prompt responsible mining personnel to inform relevant mining experts to conduct a second phase analysis of the anomalous mining areas

- A second phase analysis could include determination of the mean spacing, condition and dip and dip direction of the anomalous areas.

- The second phase analysis will form the input to design of new/modified support, layouts or mining methods that will ameliorate hazards associated with anomalous high frequency structures. Alternatively the existing design could be adequate to ameliorate hazards associated with the anomalous conditions.

- An example of a broad-based analysis of anomalous high frequency structures is shown in Figure 6.4 for a platinum mine (this is a compilation of data used in section 4).

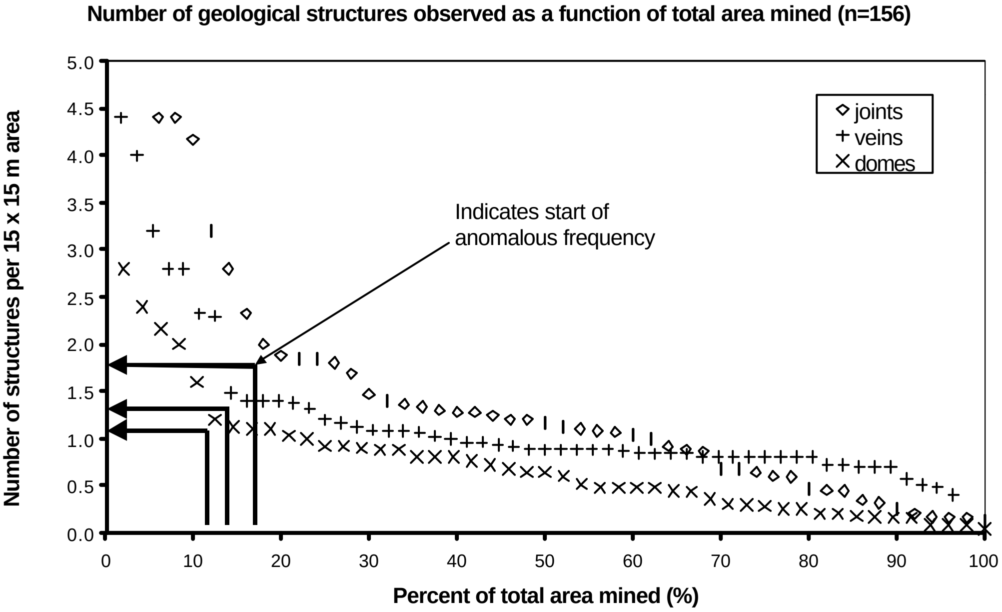


Figure 6.4 - Joint, vein and dome frequencies determined as a percentage of area mined (data from a platinum mine)

In figure 6.4, between 12% and 18% of the mining area have unusually high (anomalous) joint, vein or dome frequencies. This might prompt mining personnel to assess the applicability of current design methodologies to the anomalous areas. This method to determine anomalous high frequency structures relies on detailed geotechnical mapping of mines, above normal mapping levels. Geotechnical mapping can be tailored to suit the scale at which these structures are intersected on a mine.

For low frequency structures, the fault population analysis methodology used by Birch and others (see section 4.3), is a useful approach for identifying areas where the level of geological hazard is likely to be higher than normal. It can be used to quantify fault densities in the plane of the reef, predicting numbers of faults, fault throws and potentially the degree of mining difficulty for a particular area of a mine. Faults of varying throw are counted, for example along raiselines or reef drives and a plot of cumulative frequency of faults against throw (figure 6.5) is compiled. Important parameters from the graph, which characterise the fault population are ***a***, the number of faults with throw larger than 1 m, and ***D***, the slope of the best-fit line to the data, which represents the relative number of large and small faults.

In a gold or platinum mining environment, where raiselines are developed, data would typically be gathered from raise mapping. To enable comparison between raiselines, fault frequencies would be reported “per 100m” or “per kilometre”. Population frequency distribution graphs such as figure 6.5 can be developed for each raiseline or geotechnical area. A high ***a*** value indicates a large number of small faults, while a high ***D*** value would add a large number of large faults. ***D*** and ***a*** values can therefore be related to possible mining complexity, or level of hazard. An adaptation of the Birch and Brown diagram shown previously in figure 4.16, is shown in figure 6.6. This is largely illustrative and mines should identify local relationships based on experience, historical production rates in the areas and fall of ground and rock burst statistics. Using this method, areas with anomalous fault populations can be identified and appropriate measures to reduce hazards can be planned well in advance.

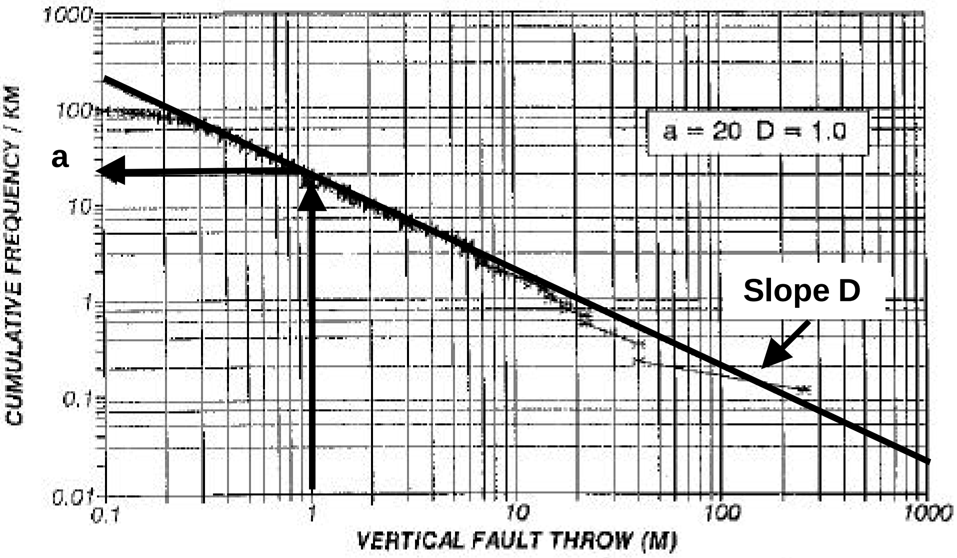


Figure 6.5 - Log cumulative fault frequency per km against log vertical fault displacement. Data from a Basal Reef raiseline (after M T G Birch)

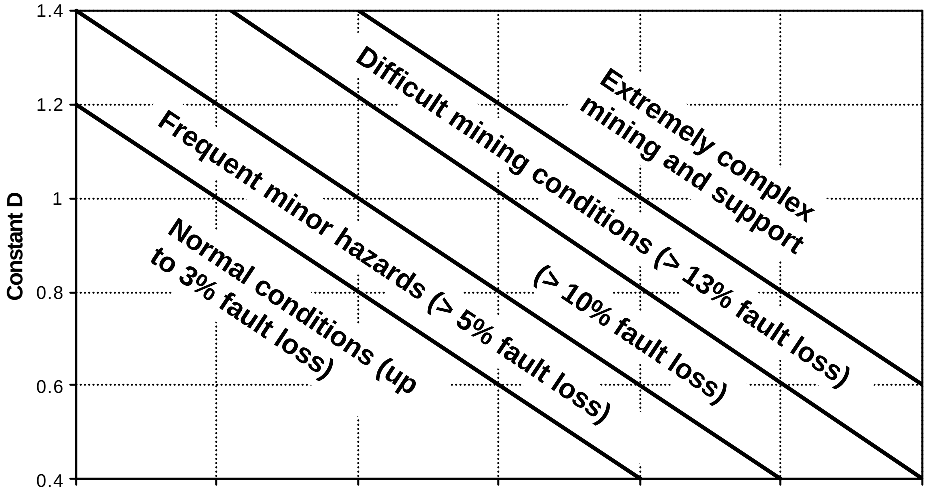


Figure 6.6 - Scatter diagram classifying mining difficulty based on fault population parameters a and D (adapted from M T G Birch).

6.3 Management of anomalous conditions

The following section has been compiled based on discussion with various rock engineering practitioners and other mine staff across the industry. It provides a general guideline for the identification of the issues relating to being prepared for, and countering, the unexpected occurrence of anomalous conditions in stopes. All strategies put in place should be documented in the mine's code of practice, and all strategies should be in-line with the DME code of practice guidelines. Strategies to manage the hazards associated with geotechnically anomalous conditions require first the identification of these situations, followed by decisions concerning necessary changes to mining layout and support. As part of this process it is necessary to decide whether the hazard is local in nature, or occurs frequently enough to warrant general changes to mine standards and definition as a specific Ground Control District within the mining area. A broad methodology for identification of normal and anomalous operating conditions, with a process for deciding on requirements for changes to support and mining practices, is shown in Figure 6.7. It outlines the steps to be taken to ensure that anomalous conditions are firstly identified, secondly controlled through a risk-based analysis and finally incorporated into the mine's Code of Practice.

Observed anomalous conditions are often mine, stope or orebody specific. Since mines adopt different strategies to exploit the orebody and support excavated areas, no specific support or layout recommendations are made here, but a generalised summary of main management principles is given. These include identification of the areas of responsibility of mine staff, the planning process, and the development of adequate observational (or hazard recognition and appreciation) techniques amongst the underground workforce.

6.3.1 Mine personnel responsibilities

The management of hazards relating to anomalous conditions requires input or decisions from a range of key mine personnel involved in the mining process, and is not merely a rock engineering issue. All persons in a stope share responsibility for observing hazardous conditions and, to a greater or lesser degree, decisions concerning taking corrective measures.

Observations, decisions and other input are required not only on a day to day basis in the operation of a stope, but also as part of the monthly planning and long-range planning process. Table 6.4 lists ground control and support design issues as a function of mine operations, together with roles that should be performed by various personnel on the mine. In order for these processes to operate effectively, training programs need to be in place to educate people in the identification of anomalous conditions. As in the case of development of mine's codes of practice, ownership of strategies to deal with anomalous conditions must lie with the mining personnel, with rock engineering specialists providing an advisory role.

Table 6.4 – Key roles to aid in mine planning and operations

Time Scale	**Ground Condition issues**	**Support Design issues or options**	**Responsibility**
Long term (years)	Compile codes of practice and identify Ground Control Districts (average conditions)	Compile mine standards	• Rock Engineer • Approved by managers and production supervisors
Medium term (monthly planning)	Identify changes in ground control districts	Change from one standard to next	• Rock Engineer • Mine overseer • Section manager
Short term (daily response to changes in stope)	Identification of hazards in the stopes	• Adjust support spacing • Install extra temporary support • Withdraw from stope • Notify specialists regarding change in standard or design	• Shiftboss • Miner • Team Leader • Geologist Rock engineer and manager input if notified.

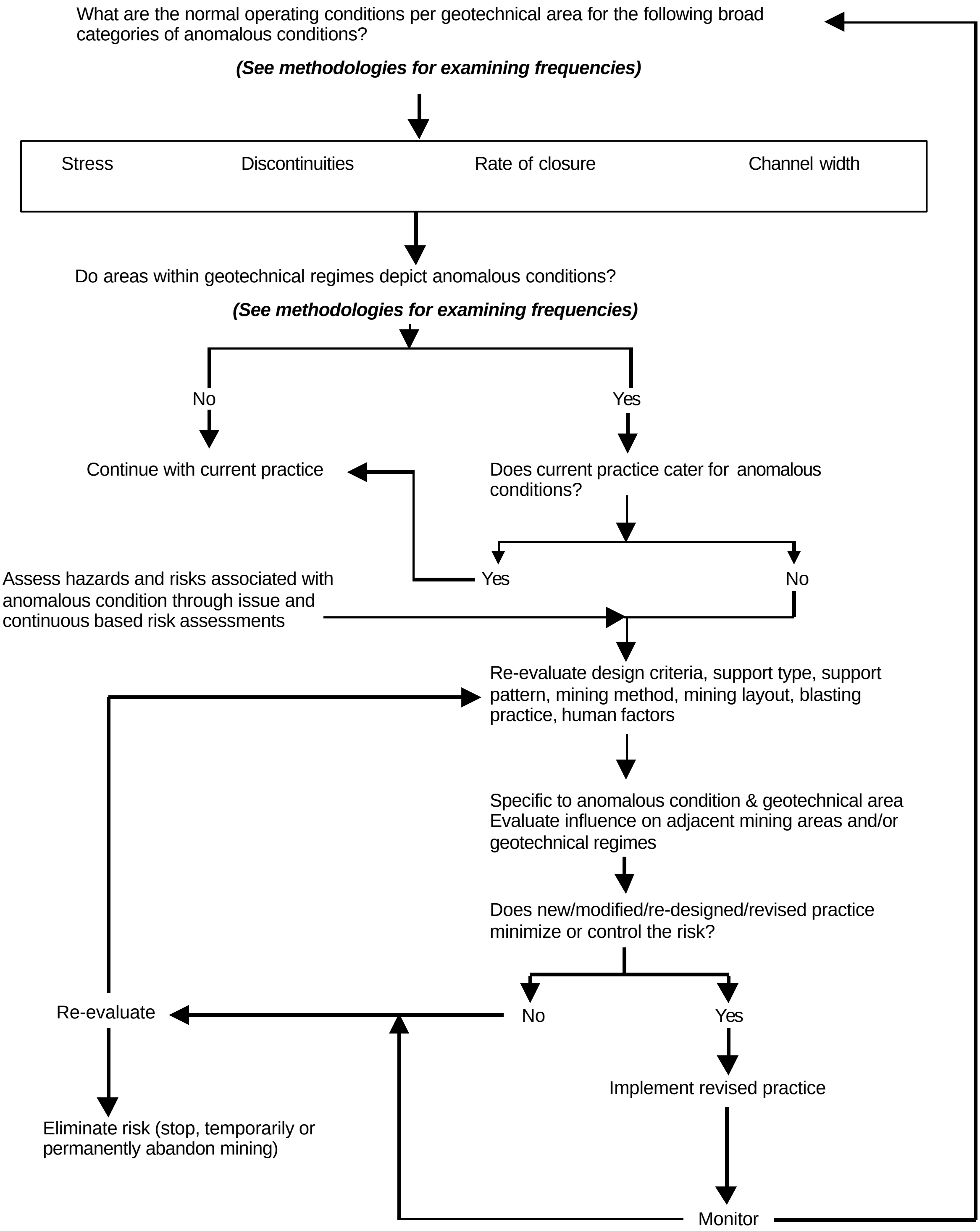


Figure 6.7 - Flow chart depicting the probable rock mass and design responses to changing conditions

6.3.2 Identifying anomalous conditions for mine planning

In terms of monthly or longer-term mine planning, one of the most important aspects in dealing with anomalous conditions is employing quick, easy to use methods for assessing and anticipating the risk of change from normal to anomalous operating conditions and the associated hazards. The most significant influence on requirements for ground control and support occurs through a change in frequency of discontinuities (stress fractures, joints, veins, domes, faults and dykes) coupled with rate of closure, or changes in the local stress regime.

A checklist for monthly planning purposes is highlighted in Table 6.5.

Since the change in stress, the frequency of discontinuities and the rate of closure are easy to assess with numerical models, or measure or observe underground, simple methods for assessing changing rock mass conditions can be developed for these categories of anomalies. Likewise the frequency of occurrence of geological structures is statistically predictable. Using simple methods as part of the planning process estimates can be made of the potential for encountering anomalous conditions, and to help identify when support or mining layouts outside the scope of mine standards might be required. The following sections outline some simple methods.

Table 6.5 - Checklist for anomalous conditions during monthly planning

Checklist for anomalous conditions in each panel during planning
1. Have stress conditions in the panel changed since the last month? 2. Are closure rates expected to increase? 3. Have ground control problems been experienced underground? 4. Are geological hazards anticipated?
If any answer is **YES** *then* *:*
• What are the causes of changes • Does support need to change? • Does the mining layout need to change?

From the point of view of mine planning, prediction of the likelihood of anomalous conditions would make use of the types of methods examined in section 6.2. Stress fracture frequencies and closure rates are approximately proportional to local field stress levels, coupled with mined spans. For a given ground control district on a mine a “standard” set of operating conditions is normally defined in the Code of Practice, which includes an assessment of stress and stress damage/fracturing, and definition of normal closure rates.

For any stope panel, factors that would influence anomalous (or elevated) stress conditions include:

- Locally identified changes in the in-situ stress k ratio.
- Larger than normal mining spans.
- Mining in isolated pillars or remnant mining conditions.
- Final closure stages when mining between adjacent raiselines.

The occurrence of stress fracturing or stress damage is a function of the ratio of rock mass and material strengths to the level of field stress. Factors that could lead to anomalous closure rates include:

- Elevated stress levels.
- Larger than normal mining spans (leading to back break).
- Changes in rock structure or strength (increased inelastic deformation).
- Seismic activity.

The most important consideration is to be able to identify those situations that may lead to an increase in stress damage or closure rates in any particular mining environment. And then to recognise whether the changes are severe enough to require an increase in support density, or a change to a more yielding type of support. In a shallower mining case where risk of back-break can result in increased closure, a stiffer, stronger, and less yielding support may be required.

Ideally numerical models can be used to examine face stress levels and Energy Release Rates, which can be related to in-stope conditions.

Geological features including joints, veins, dykes and faults vary considerably in frequency in the rock mass over the area covered by any one mine. Where frequency is higher than normal, there is an increased hazard from falls of ground. This may require a change to support pattern, type and layout. Any changes to the spatial frequency of spacing, condition, persistence, dip and dip direction of these structures should be identified. For forward planning, the frequency of occurrence of geological structures is statistically predictable in any volume of the rockmass, in so far that it is possible to say what proportion of ground will be influenced by structure. The fault population analysis methodology examined in section 6.2.1.4 provides a useful technique for quantification of areas most affected by geological anomalies.

6.3.3 Daily identification of anomalous conditions in stopes

Outside the planning process, minor structures (faults, dykes, brows and joints) are encountered daily in all stope panels in mines. Many give rise to local hazards, falls of ground, and require changes to support pattern or mining direction. To anticipate the hazards it is important that anomalous conditions are detected as early as possible, requiring daily review of stope conditions by the responsible production supervisors. To assist in identifying those factors that could lead to ground control or support problems a simple checklist is presented in Table 6.6. Depending on the experience of the supervisor, many issues can be solved in the stope by the production crew, however in all instances where major changes in mining layout or support are required, rock engineering advice should be sought.

Table 6.6 -: Checklist for daily usage in stopes

Daily underground checklist ***for changes in conditions in the stope since the last blast***
1. Are there changes in stress in the panel? • Are stress fractures more intense? • Are stress fractures flat or steep dipping?
2. Are there changes in closure rate? • Do you see more fresh cracks in timber packs and props close to the face? • Are hydraulic props and mechanical props tending to freeze?
3. Are there geologically anomalous conditions? • Are you approaching a new fault/dyke or pothole? • Have there been any new falls of ground that you need to undercut? • Are there any new brows?
4. Are there changes in ground conditions? • Has there been a fall of ground in the panel? • Have seismic events occur in, or close to, the panel?
If **YES** *to any of above then following questions need to be answered*: • Do I need to change support type or spacing? • Should I change mining layout? • Do I need to consult the rock engineer?

7 Conclusions

This concluding section should be read in conjunction with the conclusions sections at the ends of certain chapters of this report, notable chapters 3 and 4. Chapters 5 and 6 are largely summaries and conclusions in their entirety.

This project has examined the occurrence of non-standard, or anomalous, conditions in gold and platinum mine workings, focussing primarily on those of a geological nature. Project aims have been to examine the types of anomalous condition, attempt to quantify the frequency of occurrence, and to identify a range of appropriate support techniques.

The main sources of data have included the accident records of the DME, a range of mine codes of practice and standards, mine plans, discussions with mine personnel, and underground inspections of a range of conditions at various mines across the industry.

Geological features that result in anomalous stoping conditions include joints, veins, potholes, weak strata, rolls, dykes and faults. These vary considerably in frequency of occurrence across the mining regions, and in many instances within the area covered by any one mine. Where frequency is higher than normal, there is often an increased hazard from falls of ground. This may require a change to support pattern, type and layout.

One of the main points identified early on in the undertaking of this project was that because of the variability in situations resulting from geological structure, it has been very difficult to identify generally optimal support practices, or derive figures which accurately and generally represent the proportion of stope areas that can be considered anomalous. This is in part because what is considered anomalous varies from mine to mine. An example of this would be instability resulting from jointing. At shallow depth joints create obvious wedges of ground in the hangingwall which require support. Areas of high joint density, or of particularly prominent jointing are of increased hazard and can be considered anomalous in relation to overall shallow mine conditions. However at depth, joints are often invisible in stopes due to the high density of stress-induced fracturing. Under these conditions variations in joint frequencies are often largely irrelevant.

7.1 Conditions considered anomalous

From a review of accident records, coupled with discussions with mine personnel, there are a number of main factors that result in support systems being required over and above base mine standard levels that can be considered anomalous, or non-standard. These factors can be grouped under the headings:

- Stress conditions – leading to unusual levels of stress damage or stope closure
- Geological conditions
- Mining practice – where hazards have arisen due to poor mining practice, or through the layout or support system in use.
- Human factors – resulting from careless attitudes, lack of experience or training, lack of appreciation of conditions or changes in staff.

Factors that contributed to fatal accidents can also all be grouped under these headings. From 89 cases across the industry the proportion to times that each factor contributed to the occurrence of an accident were found to be as follows:

Stress	**Geology**	**Mining Practice**	**Human factors**
40%	55%	26%	53%

Accepting that many cases were from deeper mines where falls are inevitably stress fracture bound, the greatest contributing factor was geological structure, the hazards of which were often unrecognised. Human factors, although noted, are outside the scope of this project.

Of the geological influences, ubiquitous geological features such as joints and bedding, influenced 53% and 47% of cases respectively, with infrequent structures such as faults, dykes and domes influencing approximately 20% of cases. In 28 incidents from a single mine faults and dykes were causative in 25% of cases.

From the fatal accidents cases examined, it was often very difficult to conclusively say whether the conditions were truly anomalous, in other words resulting in situations that were not designed to be supported by the support system in use, or where mining practice had been obviously changed in recognition of some anomalous condition.

7.2 Frequency of occurrence of geological conditions

To identify the proportion of mining areas that can be considered non-standard or anomalous various sources of data were used. These included stope audit systems (where observers audit stope panels), monthly panel rating schemes used to assess stope support for monthly planning purposes, mapped geological structures over an area of approximately 1 000 000 m^2 in a platinum mine, and various plans showing geological structure from a number of mines. The data provided a reasonable comparison of three platinum mines and three gold mines, although sources were different in most cases.

The evaluations showed that there is not necessarily any similarity of geological structure and anomalous conditions between any two mines, although it is likely that broadly structural conditions are similar in any one region, say across the Klerksdorp gold filed for example.

Ground influenced by faults and dykes for example ranged from almost nil up to in excess of 40%. This accounts for a strip of ground either side of the structure, or panels influenced by faults at any one time, but does not account for geological losses.

Of the methods used only the underground mapping and reviews based on mine plans could be considered truly representative of the area of the mine affected by structure. Panel rating systems only examined workings influenced at the point in time that the ratings were made, and hence were very much influenced by the age of the mine. In younger mines, panels tend to be working in new, open areas, often avoiding the more structurally complex areas. In old mines, pillar mining is often the most frequent condition, focussing on last blocks that were previously abandoned along structures, or in past problem areas. Neither case gives a good average of overall mine hazards.

In terms of comparing the likely levels of hazards from, for example, faults in different sections of a mine, it was found that fault population studies can be used to statistically predict the frequency of occurrence of faults of all sizes. This can then be used to forecast those areas where mining may prove more complex or hazardous.

7.3 Mining and support practices in geologically anomalous areas

Mining and support practices in geologically anomalous areas at first glance appeared very varied, and of such a wide range that no general conclusions could be drawn. However on closer inspection they largely group into a number of cases. Solutions lie in recognition of hazards, safe barring to remove loose rock, and adequate support to contain ground that could potentially collapse or unravel. The main cases include:

- Change in overall panel support due to increases in stress fracturing, jointing, or other frequently occurring discontinuities.

- Capture of potentially loose ground along infrequent minor structures such as brows, faults and dykes. This is normally encompassed in mine standards, and comprises typical a row of support units on either side of the structure, 0.5 m from it and spaced on a 2 m staggered pattern along it.

- Re-establishment of collapsed stope faces. This would include methods of undercutting collapsed hangingwall areas to reduce stope width to normal or re-raising ahead of a collapsed face, leaving a minor pillar to seal off the collapse. A sub-section here would include negotiating rolls or potholes where undercutting is frequently required due to hangingwall blast damage.

- Negotiation of faults. Appropriate methods are very site (and stress regime) specific, influenced by the throw and attitude of the fault. Methods include rolling through the fault, trenching, slotting or boxholing to find reef on the other side, or re-raising when the throw on the fault is larger.

All methods involve the introduction of sufficient support to confine or retain potentially loose ground. For example when undercutting and forming brows, hangingwall beam continuity is restored by using props or tendons in the brow face to retain it.

There are no hard rules for selection of support or consistent support resistance criteria required. Each situation is largely unique, however to hold the blocks created by geological structures more frequently requires support that is stiff rather than yielding. Stiff packs, props (timber, steel and hydraulic) and tendons are generally favoured units.

7.4 Other considerations for anomalous areas

Probably the single most important point identified while gathering data for this project, was the need to get underground worker to recognise the hazards associated with anomalous conditions and to act effectively to reduce the risk associated with them. In the main this accounted for the high percentage of human factors associated with accident cases.

Effective techniques are available (and in use) for rock engineering departments to pick up hazards on a month to month basis. These included stope observer audits, and panel rating systems. Currently under-utilised techniques (in rock engineering) include fault population studies, which can be used to rate the geological complexity of areas within a mine.

An important aspect of managing anomalous conditions is to ensure that mine codes of practice comprehensively list hazards and identify strategies and procedures to deal with them. This document remains the base upon which all subsequent strategies, training in hazard identification, support practices and monitoring procedures are built.

As part of the best-practice conclusions derived for the project, a number of checklists have been drawn up to assist in rating workings from a monthly planning perspective, and for use when evaluating working places underground on a day to day basis.

The primary output of this project has been the development of an accompanying guidebook that will assist in managing non-standard (anomalous) conditions in the gold and platinum mining industries. In light of the need for an adequate identification methodology for anomalous conditions, the guidebook primarily focuses on this aspect for the major groups of anomalous conditions identified. Identification charts once formulated using the derived methodologies as a guideline are relatively simple to use. The advantages of ‘deviation from normal’ charts is that they allow for use and interpretation by supervisors who’s job it is to daily inspect ground conditions underground.

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APPENDIX 1

SUPPORT PRACTICES FOR NON STANDARD AREAS

Most mines have a base support standard for use in stopes and introduce tighter patterns, or alternative standards, as appropriate on the basis of local conditions. Decisions are generally taken at pre-planning meetings, with consultation between rock engineering staff, mine overseers and possibly shiftbosses or section managers. Special instructions are issued as required by the mine overseer, usually providing a reason for increased support.

Mine support design methodologies, as described in most Codes of Practice, are generally based around the support pressure required to carry a height of hangingwall determined on the basis of the mine's fall of ground history. In shallower mines some form of keyblock analysis is frequently done to assess required support spacing. Anomalous stoping conditions occur where support requires a deviation from the basic design method and appear to arise almost exclusively due to local changes in geological structure. The consequences, or hazards, of local changes in geology are a function of either the ability to plan for changes in support or mining sequence in advance (e.g. when approaching a known fault) or the ability of mining personnel to recognise unexpected features.

In general, a 3 m throw on a fault is considered the limit for comfortable and practical negotiation without re-raising (Dunn and Laas, 1999).

The following is a summary of information dealing with support practices gathered from mine standards, codes of practice and discussions with mine personnel during 2000.

Support strategies from codes of practice, mine standards and discussion with mine staff:

A. West Rand and Far West Rand area

A1. VCR at Depth (Kloof)

Geotechnical classification

- Hard hangingwall - Westonaria and Alberton Lavas
- Soft hangingwall tuffaceous lavas

Support design criteria

Reef	*Hangingwall Type*	*Fall out height (m)*	*Required energy absorption capacity (kJ/m^2)*	*Required support resistance (kN/m^2)*
VCR	Westonaria and Alberton lava	1.05	18.84	28.6
	Tuffaceous lava	1.05	18.73	28.4

Design for dynamic motion where peak particle velocity =3.0m/s
Stable span=3.1m
Temporary support:

- Rapid yielding hydraulic props
- Mechanical Props

Permanent Support
Support
Pre-stressed timber elongates
Disc Props

Areas with tuffaceous lava hanging wall are treated as **special areas**.
The maximum distance between a person and support is 2m.

At Geological discontinuities:

- Additional support is required.
- Both sides of structure/discontinuity must be supported
- Particular care must be given to the weak or lower side of discontinuities.
- The formation of unstable key blocks must be recognized.

Special Areas.

- **Definition**
  - Require precautionary measures that exceed or deviate from the normal mine standard.
- **Factors that are considered for the declaration of special areas**:
  - Proximity of other workings
  - Face shapes
  - Adverse geological conditions.
- **Procedures for identifying special areas**
- These procedures do **not** make mention of identifying geological features such as faults, dykes, prevailing joints, increased channel width etc.
- Geologists are **not** involved in identifying special areas.

A2. VCR, Carbon Leader and Main Reef at depth (Driefontein)

Geotechnical classification

- The mine has 5 geotechnical areas-

Support design criteria

Reef	*Hangingwall Type*	*Fall out height*	*Required energy absorption capacity (kJ/m^2)*	*Required support resistance (kN/ m^2)*
VCR	Lava	1.2	21	32
Main reef	Quartzite with green bar shale above	1.6	28	42
Carbon Leader	Well bedded Composite quartzite	1.0	18	27

Design for dynamic motion where peak particle velocity =3.0m/s
Stable span=2.0m

Temporary support:

    - Face sprags
    - Remote release mechanical props
    - Rapid yielding hydraulic props

Permanent support

- Timber or composite packs
- Cemented backfill
- Pre stressed elongates

At Geological discontinuities:

- See special areas

Special Areas.

- **Definition**
  - Any situation where it is thought that an increased possibility of rock falls and rock bursts exist.
- **Factors that are considered for the declaration of special areas**:
- Remnant extraction
    - Mine away from geological features
    - Approach minor features obliquely
    - Do not split remnant
    - Panels not to approach each other
    - Avoid large leads and lags
    - Increase support density
    - Reduce support to face distance to an absolute minimum
    - Use head boards for areal coverage
    - Pre-stress permanent support units
    - Increase support stiffness
    - Use rapid yielding hydraulic props
    - Use backfill
- The negotiation of geological structures
    - Additional support is required.
    - Both sides of structure/discontinuity must be supported
    - Particular care must be given to the weak or lower side of discontinuities.
    - Recognize the formation of unstable keyblocks
    - Indicate geological structures on stope sheets and mine plans
- Rehabilitation of rock fall or rock burst affected panels.
    - Install additional support while fracture zone ahead of the face is negotiated.
    - Keep support to face distances to an absolute minimum
    - Reduce the rate of face advance
    - Develop wide ends when re-raising
- **Procedures for identifying special areas**
- Special areas are defined by the special areas committee, consisting of the chief surveyor, the chief rock mechanics engineer and the chief geologist.

A3. Western Deep Levels

Geotechnical classification

- Carbon Leader Reef
  - Geologically undisturbed ground (CLR1)
  - Geologically disturbed ground (CLR2)

- VCR
    - Geologically undisturbed ground (VCR1)
    - Geologically disturbed ground (VCR2)
    - Different footwall types (VCR3)
    - Slope reef (VCR4)

Support design criteria

Reef	*Hangingwall Type*	*Fall out height (m)*	*Required energy absorption capacity (kJ/m^2)*	*Required support resistance (kN/ m^2)*
CLR	Quartzite with green bar shale above		38	28
VCR	Lava		32	38

Design for dynamic motion
- Not Specified

Temporary support:
- Rapid yielding hydraulic props, elongate support.

Permanent Support
- Backfill

At Geological discontinuities:
- Pre-stressed elongates on either side of the discontinuity and also in the fault loss normal to the fault plane.

Special Areas.
- **Definition**
    - Any situation where it is thought that an increase in rock falls or rockbursts exist
- **Factors that are considered for the declaration of special areas**:
- Major geological features
- Seismic history
- Stress levels
- Regional support
- Face shape
- **Procedures for identifying special areas**
- The rock mechanics officer recommends sites and the section manager endorses it.

A4. Carbon Leader Reef at depth (Savuka)

Permanent support

Pack Support

Packs, 1.8m skin to skin on dip and 1.6m skin to skin on strike.
Packs installed on a checker board pattern
Maximum distance to face of last line of support 3.8m

Elongate and Backfill support

Elongates 1.5m on dip and 1.6m on strike for non-backfill and 1.0m by 1.6m for backfill areas.

Maximum distance between last line of elongates and face 3.0m
Maximum distance between backfill and face 4.5m

Re- raising support
2.2m x .75m packs with long axis on strike both sides of new raise with centre line 4.5m from collapsed area. Heading supported by rapid yielding hydraulic props 1m apart on strike.

Fault and dyke contact and brows
Elongate support or packs 0.5m on both sides of feature (strike spacing not specified)
Cross sprags to be installed normal to fault plane, overhanging face or brow.

Special Areas
High stress areas: Pack dip spacing reduced from 4m to 3m
Shallow and destressed areas: Pillars, 6m on strike and 3m on dip with 1.4m holings in between on strike maximum 22m centres apart on dip. Inter-panel support is elongate on 2m spacing dip and strike and pack breaker lines every 20m on strike.

B. Klersdorp gold field

B1. Vaal Reef, largely pillar mining, intermediate depth (Hartebeesfontein)

Geotechnical classification
- Competent quartzite with significant geological disturbance
- Competent quartzite with minimal geological disturbance
- Competent quartzite with weak footwall conditions
- Incompetent hangingwall quartzite known as the pseudo breccia zone
- Incompetent quartzite associated with abnormal closure rates
- Steep dipping quartzite.

Design for dynamic motion where peak particle velocity =3.0m/s
Temporary support:
- Rapid yielding hydraulic props
- Mechanical props
- Mine poles

Permanent Support

Stope width up to 1.8m	85cmx85cm Hercules packs
1.8m to 2.5m	120cmx85cm Hercules packs
2.5m to 3.0m	120cmx85cm Hercules packs

Ledging support
Double packs 1.5m from centre gully centre line
Mine poles and reinforcing tendons

Special Areas definition.
Cautionary
Production staff are made aware of possible deteriorating conditions
Obligatory
Special precautionary measures must be taken.
Precautionary measures decided upon by the mine overseer, rock engineer and section manager.

Geological discontinuities:

Re- raising

Pillar, 1.5 times stoping width left in situ between collapsed area and new raise.
Fault and dyke contact and Brows
Mark faults dykes and major slips with paint
Install support 0.5m on either side of contact and 1.5m from each other on the strike of the feature
Brows to be treated as faults

Cave Mining

Props, 1.5m from face and 2.0m apart on dip.
Induce caving when drill steel sticks, face scales, footwall lifts, hangingwall fractures dip towards the face or sticks break in second row.

B2. Vaal Reef, deep mining (Kopanang)

Geotechnical classification

Vaal reef, intermediate to deep mining

Permanent support

Up to 1.1m 55cmx55cm composite pre-stressed packs, Hercules packs or solid matpacks
1.1m to 1.5m 75cmx75cm composite pre-stressed packs, Hercules packs or solid matpacks
Higher than 1.5m 110cmx110cm composite pre-stressed packs, Hercules packs or solid matpacks

Ledging support

Face sprags 1m from the face and 1.5m on dip
1.1m*1.1m packs staggered relative to packs on opposite ledge when faces are 3.4m from centre line

Re-raising

Crush pillar left in situ. Width=1.5xstoping height
Hydraulic props 1.5m apart on dip and strike in 8m wide raise
1.1m packs not further 4.4m from wide raise heading

Fault and dyke contact support

Install face sprags or mechanical props 0.5m on either side of contact and 1.5m from each other on the strike of the feature
Brows to be treated in the same way as faults
Support to be installed at right angles to strata
Cross sprags to be installed at right angles to plane of feature.
In the case of dykes, support also installed between the two dyke contacts

Overhanging Faces

Cross sprags installed normal to overhang with foot of sprag wedged against the footwall, another upright sprag or a pack.

Special Areas

Support prescribed by panel rating and stope width
Higher panel ratings demand denser support patterns when elongates or packs are used.
Higher panel ratings require permanent support to be closer to the face.
Panel ratings 4 and 5 require rapid yielding hydraulic props to be integrated into the support system

C. Freestate gold field

C1. Kalkoenkrans reef – intermediate depth (Oryx)

Geotechnical classification
The mine is one geotechnical area

Support design criteria

Reef	Hangingwall Type	Fall out height	Required energy absorption capacity (kJ/m^2)	Required support resistance (kN/m^2)
Kalkoenkrans	Quartzite and shales		Not Specified	20

The CSIR support design program (SDA) is used for support design

Design for dynamic motion:
Design is for rock falls as rock bursts are not considered a potential hazard.

Temporary support:
20/40 ton rapid yielding hydraulic props

Permanent stope support
Stope width < 150cm: 75cmx75cm Packs
Stope width < 200cm: 75cmx150cm Packs
Stope width > 200cm: 150cmx150cm Packs

Ledging support
Packs, 1.0m skin to skin on dip
Mechanical props 2.0m apart on dip

At Geological discontinuities:
The code of practice does not provide explicitly for support and procedures pertaining to geological features.

Support at Fault and dyke contact and brows
Elongate support, mechanical props or packs 0.5m on both sides of feature 1.5m on strike
Cross sprags to be installed normal to fault plane, overhanging face or brow.

Special Areas.
- **Definition**
- Any block of ground so classified by mine management in consultation of the Special Areas Officer.
- **Factors that are considered for the declaration of special areas**:
- Size of the block of ground to be mined (in terms of proximity of other mined out areas)
- Condition of the hanging wall
- Stress
- Age of the working place.
- **Procedures for identifying special areas**
- Procedures are not outlined

Special Area support
Stopped panels
Line of packs 2.0m from face 3.0m on dip
Line of mine poles 1.0m from face 1.5m on dip

C2. Basal and Leader reefs – intermediate depth (St. Helena)

Geotechnical classification

- Rock-burst prone areas
- Non-rockburst prone areas.

Support design criteria

Reef	*Hangingwall Type*	*Fall out height*	*Required energy absorption capacity (kJ/m^2)*	*Required support resistance (kN/ m^2)*
Basal Reef	Quartzite	0.9	Not Specified	30 for non-rockburst conditions, 76 for rock burst conditions
Leader reef	Quartzite	0.9		

Design for dynamic motion:
Not specified
Temporary support:

- Mine Poles, Mechanical props

Permanent support

- Elongates, packs

Stope width < 110cm: 55cmx55cm Packs
Stope width < 150cm: 75cmx75cm Packs
Stope width > 110cm: 110cmx110cm Packs

Ledging support
Face sprags 1m from the face and 2.0m on dip
Packs, 3.0m on dip on ledge when faces are 3.5m from centre line

Geological discontinuities:

- Additional support must be installed on both sides of a brow/fault.

Sprags 1m apart on strike of feature and 0.5m on either side of feature
Sprags on one side of fault staggered with respect to those on other side of fault.
Cross sprags to be installed normal to fault plane, overhanging face or brow.

Undercutting of hangingwall

- A line of permanent support must be installed along the stope face prior to and immediately after the undercutting has been completed.

Stopped panels

A panel in which mining may resume is to be supported by a line of permanent support along the face upon mining operations cease.

Rock burst prone panels

- Support density to be increased.

Ledges

- Raises to be supported before ledging commences.

Special Areas.

- **Definition**
  - Any area where there is an increased risk of rock bursts or rock falls due to and during the course of routine mining
- **Factors that are considered for the declaration of special areas**:
- Anticipated on reef stress magnitude
- Rock mass properties
- Hangingwall type and it's capabilities
- Seismic history/trends
- Size of area
- Location and proximity to geological structures
- Multi-reef influences
- Face shape and orientation
- Mining direction
- **Procedures for identifying special areas**
- Rock engineering practitioner and Mine manager decide on the declaration of special areas.

Special Area support

High stress areas: Pack dip spacing reduced from 4m to 3m

Shallow and destressed areas: Pillars, 6m on strike and 3m on dip with 1.4m holings in between on strike maximum 22m centres apart on dip. Interpanel support is elongate on 2m spacing dip and strike and pack breaker lines every 20m on strike.

C3. Beatrix reef at shallow to intermediate depth (Beatrix)

Geotechnical classification

- Geotechnical area 'A'
  - Weak quartzite footwall
- Geotechnical area 'B'
  - Weak quartzite footwall containing smectite
- Geotechnical area 'C'
  - Weak quartzite footwall containing laminated shales

Support design criteria

Reef	*Hangingwall Type*	*Fall out height (m)*	*Required energy absorption capacity (kJ/m^2)*	*Required support resistance (kN/m^2)*
Beatrix Reef	VS4a Quartzite	0.70		50

Design for dynamic motion

- Rockbursts do not occur.

Temporary support:

- Mechanical Props
- Mine poles

Permanent Support

- Systematic pillars and elongates
- Special recommendations
- Pack support

Stope width < 120cm: 55cmx55cm Packs

Stope width < 160cm: 75cmx75cm Packs
Stope width > 220cm: 110cmx110cm Packs

Ledging support
Stope width<2.2m: 1 line of packs on ledge, 3.0m on dip. A second line of packs 3m on strike from first line. Thereafter profiled elongates until face had advanced about 10m after which another line of packs are installed
Stope width>2.2m: 1 line of 1.5mx1.5m composite packs on ledge, 3.5m on dip. Thereafter rock props 1.5m apart on strike and maximum of 1m from face, 3.5m on dip.

At Geological discontinuities:

- Install additional support on both sides of structure or brow.

Packs, elongates or tendons 0.3m from fault contact, 3.0m apart along strike of fault for packs and elongates and 1.2m for tendons
Brows treated as faults.

Special Areas.

- **Definition**
  - Any block of ground where bad hangingwall conditions are likely to exist or develop.
- **Factors that are considered for the declaration of special areas**:
- Size of block to be mined
- Physical conditions of the hangingwall
- Stress
- Age of support in excavations (Re-establishing old working faces)
- **Procedures for identifying special areas**
  - The Rock Engineering officer advises management of areas where bad hangingwall conditions may develop or exist and of abnormal conditions.. The declaration is done at management's discretion.
- **Examples of practice**

Very high stope widths(>2.8m):6m square pillars 15m skin to skin on dip and strike and 1.8m end anchor rock studs on 1m by 1m grid

D. Bushveld complex platinum mines

D1. Impala Platinum

Geotechnical classification

- Merensky Reef 30m to 1000m (1a)
- UG2 Seam 30 to 1000m (1b)
- Merensky Reef 1000m to 1500m (2a)
- UG2 Seam 1000m 1500m (2b)

Support design criteria

Reef	*Hangingwall Type*	*Fall out height (m)*	*Required energy absorption capacity (kJ/m^2)*	*Required support resistance (kN/ m^2)*
Merensky Reef	Pyroxenite	1.1		33
UG2 Reef	Pyroxenite	1.1		33

Design for parameters
Design criterion for peak particle velocity: 3.0m/s
Energy absorption capacity: 20kJ/m^2
Required support resistance: 30kN/m^2

Temporary support:
- Mechanical and hydraulic props

Permanent Support
- Timber props

Mine standards are referred to which illustrate the required support.

COP. 10.34.3.3. *Support for stripping or stoping through faults, dykes and shear zones.* This involves leaving additional timber support in the form of mine poles 0.5 metres on either side of prominent joints or slip. In the case of dykes and faults the timber support takes the form of packs. Additional timber support in the form of packs and mine poles are also installed to support major and minor brows respectively.

COP. 10.34.4. *This involves leaving additional pillars (without sidings) where faults, shear zones or dykes intersect gullies.* The same strategy is followed when stoping parallel to or at right angles to the above mentioned features.

COP. 10.34.3.1. *Where dykes, faults or shear zones are intersected in centre gullies, additional 5 metre wide pillars are left on either side of the centre gully.* The length of the pillar must extend at least 3 metres beyond the edge of the geological feature. A 2 metre wide ledge is cut if ground conditions are good enough.

COP. 10.34.3.2. *When faults, dykes or shear zones are intersected in development ends*, the normal rebar support density should be doubled up.

Identified hazards:

Condition	**Support strategy**
Plug Failure	Leave barrier pillars
Beam Failure	Leave in panel pillars
Dome Failure	Install additional support, leave small pillars
Blocky conditions associated with potholes	Leave intact or make stoping crew aware and install additional support
Dykes and faults	Leave intact or install additional packs on both sides
Unstable rock wedges	Bar down and install systematic support
Flat dipping joints/sills	Plot on plans, leave pillars
Blast damage	Training
Brows	Additional support
Weak contact between FW 6/7	Avoid by changing mining direction or blast down and support
Loose rock on face following blasting	Face barring
Blocky or friable ground conditions	Provide extra areal coverage by installing head boards
Slabbing from pillar sides	Grout in re-bars
Flat fractures adjacent to pillars	Blast sidings
Support blasted out	Re-entry examinations and make safe, use blast resistant support.

Special Areas.

- **Definition**
  - The application of limited mining and support recommendations within specific mining areas as designated by the Department of minerals and energy.
  - Where the presence of certain factors increase the risk of rock falls
- **Factors that are considered for the declaration of special areas**:
- Stress
- Water bearing structures
- Major geological disturbances
- Size and/or geometry of block to be mined
- The proximity of other mining or mined out areas
- The nature of the ground
- Shaft pillar extraction
- **Procedures for identifying special areas**
- A special area committee comprising of the Operations manager Operations surveyor, Mine overseer, Rock engineering officer and Health and safety committee representative do risk assessments at meetings and determine special areas and instructions pertaining thereto.

D2. Merensky reef (Amandelbult)

Geotechnical classification

- Western section
  - Back breaks
- Central section
  - Back breaks and fall of ground
- Eastern Section
  - Fall of ground

Support design criteria

Reef	*Hangingwall Type*	*Fall out height (m)*	*Required energy absorption capacity (kJ/m²)*	*Required support resistance (kN/ m²)*
Merensky	Pyroxenite	1.5		60
UG2	Pyroxenite	1.5		60

Design for dynamic motion

- Not seismically active

Temporary support:

- Mechanical props

Permanent Support

- Pillars and prestressed elongates
- Rock bolting

At Geological discontinuities:

Special Areas.

- **Definition**
  - Whenever it appears or is anticipated that an increased risk of rock related incidents, rockbursts or rock falls could arise.
- **Factors that are considered for the declaration of special areas**:
- Rock mass class

- Jointing
- The size of block to be mined
- The conditions and wetness of the hanging wall
    - Panel span
- **Procedures for identifying special areas**

The special areas committee comprising the production manager, certificated rock engineer, a representative from the safety department, a representative from the survey department and a representative from the geology department, identifies and reviews special areas. The special area is then declared by and at the discretion of mine management.

APPENDIX II

TREATMENT OF GEOLOGICAL STRUCTURES IN MINE CODES OF PRACTICE

The following table summarises mine treatment of geological features, as documented in codes of practice.

Mine	Geological features	Code of Practice
West Rand longwalling	Rolling fault or dyke	• Only considered where width of dyke is not excessive and throw facilitates max inclination of –5^{o} • no limit to inclination when rolling upwards
	Trenching through down throw fault or dyke	• Applicable to max trench depth of 4m • Support laterally across dyke or fault • Destress fault or dyke • Specify min dist bet trench & fault or dyke
	Slotting through upthrow fault and/or dyke (max slot height of 10m)	• Dyke width considered when choosing bet rolling & slotting methods • Slot width not to exceed 1.5m • Specify min dist bet slot& fault/dyke • Support laterally across slot • When slotting at faults, always place slot on strong side of fault
	Leaving fault or dyke intact	Decide whether clamping is required *If NO* • Mine to fault or dyke • Direct F/B haulage to avoid high abutment stresses • Re-establish at safe distance on other side • Strip back onto fault or dyke *If YES* • Decide on type, size and orientation of clamping pillars required. • Direct F/B haulage to avoid high abutment stresses • Re-establish at safe distance from fault/dyke • Mine away from fault or dyke
Western Deep Levels	**Re-Raising** Downthrow fault / dyke	Method 1 • Strip against fault/ dyke • Re-raise on overstoped side in waste • Stope thr dyke onto reef Method 2 • Mine thro dyke/ fault • Re-raise in overstoped ground on reef.
	Upthrow fault / dyke (> 10m)	• Mine at max practical inclination to establish shortest stopping distance within 45^{o} stress zone • Establish re-raise position & raise on reef.
	Trenching Downthrow fault / dyke in dip direction (< 5m)	• Strip to dyke / fault • Swing gullies north • Position trench • Stope thro dyke-pillar cutting method and/or destressing

Mine	**Geological features**	**Code of Practice**
	On dip	• Top gully rolls down thr disturbance to reef position. • Establish trench to btm of face • Knowing position of reef cut false gully to intersect reef. • Trench using rapid yielding hydraulic props, which are replaced with waste stowing as they are released
	Upthrow fault/dyke (max 10m)	• Mine thro dyke at max practical inclination • Slot remainder to reef position • Re-establish gullies from boxhole position if necessary
	Rolling	• Only considered where width of dyke facilitates max inclination of -5^{o}
ARM	Faults, dykes and brows	• Face sprags or mechanical props to be installed within 0.5m of faults & dykes and 1.5m apart on strike • Brows to be treated as faults with support on either side of the brow, each set of supports being within 0.5m of the brow and each set being not more than 1.5m from each other • Temporary support installed at right angles to the strata with wedge point facing the back area.
Kloof	Geological discontinuities	• Additional support is required • Both sides of structure/ discontinuity must be supported • Particular care must be given to weak or lower side of discontinuities • Formation of unstable key blocks must be recognised • Temporary support includes rapid yielding hydraulic props and mechanical props • Permanent support includes pre-stressed timber elongates and disc props
West Driefontein	Geological discontinuities	• Additional support is required • Both sides of structure/ discontinuity must be supported • Particular care must be given to weak or lower side of discontinuities • Formation of unstable key blocks must be recognised • Temporary support includes face sprags, rapid yielding hydraulic props and remote release mechanical props • Permanent support includes pre-stressed elongates timber or composite packs and cemented backfill
St Helena	Geological discontinuities	• Additional support must be installed on both sides of a brow / fault • *Temporay support* includes mine poles and mechanical props • Sprags 1m apart on strike of feature and 0.5m on either side of feature • Sprags on one side of fault staggered with respect to those on other side of fault • Cross sprags to be installed normal to fault plane, overhanging face or brow • Permanent support includes elongates and packs

Mine	Geological features	Code of Practice
Beatrix	Geological discontinuities	• Install additional support on both sides of structure or brow • Packs, elongates or tendons 0.3m from fault contact, 3.0m apart along strike of fault for packs and elongates and 1.2m for tendons • Brows treated as faults • Permanent support includes systematic pillars and elongates
Hartebeesfontein	Geological discontinuities	• Pre-stressed elongates on either side of the discontinuity and also in the fault loss normal to the fault plane • Install support 0.5m on either side of contact and 1.5m from each other on the strike of the feature • Brows to be treated as faults
Impala Platinum	Geological discontinuities	• For domes- install additional support, leave small pillars • For blocky conditions associated with potholes- leave intact or make stoping crew aware and install additional support • Dykes and faults- leave intact or install additional packs on both sides • Unstable wedge blocks- bar down and install systematic support • Flat dipping joints or sills- plot on plans and leave pillars
	Support for stripping or stoping through faults, dykes and shear zones	• Leave additional timber support in the form of mine poles 0.5m on either side of prominent joint. • In case of dykes and faults the timber support takes the form of packs. • Additional timber support in the form of packs and mine poles are also installed to support major and minor brows respectively.
	Faults, dykes or shear zones intersect gullies	• Leave additional pillars without sidings. • The same strategy is followed when stoping parallel to or at right angles to the above mentioned features
	Faults, dykes or shear zones intersect in center gullies	• Additional 5m wide pillars are left on either side of the center gully. • The length of pillar must extend at least 3m beyondf edge of geological feature. A 2m wide ledge is cut if ground conditions are good enough
	Faults, dykes or shear zones intersected in development ends	• Normal rebar density should be doubled up