A BOOKLET ON

GUIDELINES FOR ANOMALOUS GEOTECHNICAL AREAS IN PLATINUM AND GOLD MINE STOPES

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1. Introduction

This booklet deals with the identification and treatment of hazards associated with anomalous geotechnical conditions in tabular mine stopes, focussing on those that result from local changes in geology. Up to 80% of fall of ground accidents occur where mining conditions can be considered anomalous, often influenced by geological structure.

Non-standard or anomalous conditions can be broadly defined as ***those areas where the level of hazard, or risk of falls of ground, is increased relative to normal conditions in a mining area***.

This guidebook examines the consequences of naturally occurring and mining induced anomalous conditions, it proposes a broad risk categorisation of anomalous conditions and more importantly provides generic methodologies for identification and support of anomalous conditions on mines.

The booklet was completed as part of SIMRAC Project, GAP607, which deals with the considerations for geotechnically anomalous stope areas in gold and platinum mines in South Africa. It is based on the results of literature reviews, an examination of industry-wide practice and opinions, discussions with rock engineering and production personnel from 18 gold and 5 platinum mines, backed up with underground observations made during mine visits. The project has drawn data from stopes examined at various depths on reefs including the Ventersdorp Contact Reef, Carbon Leader, Basal, Vaal, Merensky and UG2 reefs.

The reader is provided with a methodology for determining the occurrence of non-standard or anomalous conditions, broadly categorising the resulting consequences of geologically anomalous mining conditions that may not be normally catered for under basic or standard, stope support designs. The booklet is for use by rock engineering practitioners, planning engineers, safety officials and production line supervisors. Design charts and checklists for determining changing mining conditions may prove particularly useful to line supervisors who observe underground conditions on a daily basis. Further information on the content of the different sections of this guidebook can be found in the GAP 607 final report.

In order to avoid confusion with conditions that are “substandard” or do not comply to mine standards, this booklet adopts the term “anomalous” rather than “non standard”.

1.1. How to use this book

The objective when mining intersects a geotechnically anomalous area is to create an excavation that is adequately safe and stable for the life of the stope. There are two aspects:

- First to minimise the risk of exposure of workers to fall of ground hazards.
- Second to ensure the functionality of the stope.

The path to ensuring a safe, stable underground environment comprises:

1. Anticipation of unusual or anomalous conditions and identification of associated hazards.
2. The selection of an appropriate support design or mining geometry.
3. Taking appropriate mining practice measures underground to ensure that the selected design is correctly and effectively applied.

Conceptually this path to a safe mining environment is illustrated in figure 1. The purpose of this guide is to provide a recommended practice for dealing with anomalous conditions. It is split into three sections covering first examples of the various hazards, secondly identification of anomalous conditions and associated hazards and lastly, examples of practical issues relating to mining practice and support.

Due to the variability in geological conditions encountered throughout the industry, it is impossible to be fully comprehensive and cover all situations in a booklet of this size. Hence the intention is to provide some broad ideas that individual mines can adapt to their own local conditions.

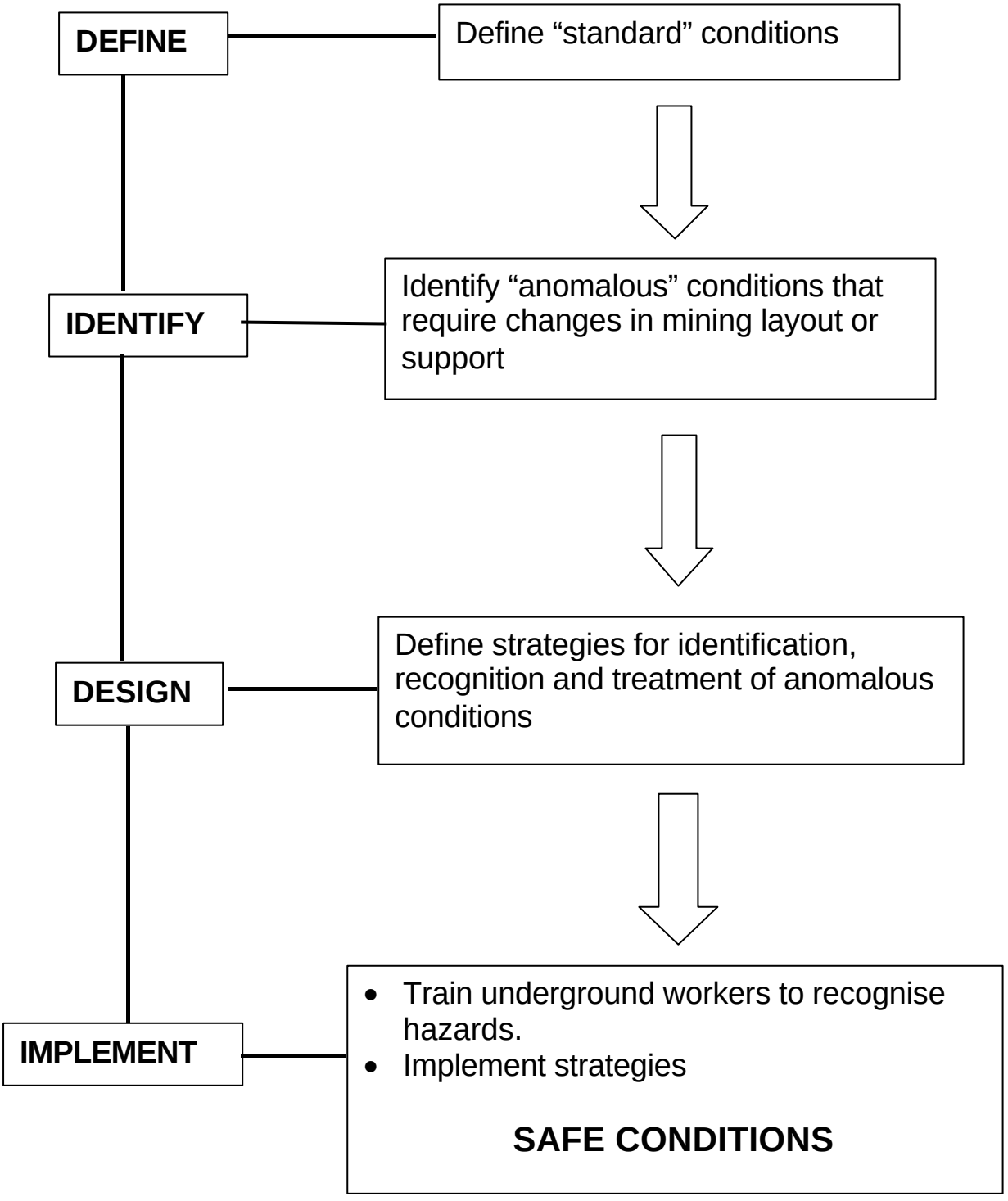


Figure 1 – Simplified path to safe management of anomalous conditions

2 What are anomalous conditions?

It follows from the definition of anomalous conditions on page 1 that the most important aspect relating to their management is a method to identify when ground conditions change, and hence when mining standards should be changed or rock engineering recommendations, or special instructions from line supervisors should be issued. All physical conditions resulting from anomalous rock mass conditions require similar responses from a design or management point of view since ultimately, the support pattern, support type or mining layout may require modification or total change.

2.1 Standard conditions versus anomalous conditions

"Standard" mining conditions are those generally applicable in any selected ground control district on a mine, where a ground control district is defined as an area where geotechnical conditions are sufficiently similar to adopt a particular mining strategy and support layout, normally included in the mine standards. *"Anomalous* conditions" are then situations within these ground control districts where the standard strategies may no longer prove adequate.

Broadly tabulated definitions of standard stopes classified by depth are shown in Table 1. Three categories (stress, closure and geological factors) cover the main criteria that influence mining layout and support design. Situations that can be broadly considered anomalous in each area are listed in the lower section of the table. These conditions normally result from unforeseen changes in the mining environment, either as a consequence of local geology or due to factors induced by poor or inappropriate mining practice.

Note that not all geotechnical factors would be considered anomalous at all depths. For example, dense fracturing resulting from stress concentrations, or high density jointing would be anomalous at shallow depth, but at great depth high stress and stress fractures form part of the basic geotechnical environment. Under these conditions any local changes in joint density become largely unobservable, as they contribute little to an increase in discontinuities, and may not be classed as anomalous in terms of increasing hazards.

An alternative categorisation of anomalous conditions is shown in Table 2. Emphasis here is on the factors that lead to unanticipated hazards in stopes, and the consequences of them. For reader awareness, and completeness, the categories include those due to mining practice and human factors, rather than those of a purely geotechnical nature. These two factors fall outside the scope of this booklet.

The risk associated with the lists of geological hazards will vary from mine to mine depending on the mine's frequency and severity of accidents associated with the hazards.

Table 1: Definition of standard versus anomalous conditions classified by depth below surface

Standard Conditions			
Description	**Stress conditions**	**Closure rate**	**Geological factors**
Shallow stope	• Low Stress. Stress fractures non- existent or very infrequent. • ERR less than 10MJ/m^2 • Seismicity rarely occurs	very low (less than 10mm per day)	General joint and bedding patterns dictate "standard" support design
Stope at intermediate depth	• Moderate stress • Moderate fracturing with a relatively low frequency of occurrence • ERR not • more than 30MJ/m^2 • Seismicity may occur periodically	low to moderate (up to 30- mm per day)	General geological structure (joints, bedding, weak units) influence support design
Stope at Depth	• High stress • Intense stress fracturing with a high frequency of occurrence • ERR more than 30MJ/m^2 • The threat of seismicity is ever present	high (more than 30mm per day)	General geological structure is of less significance than stress fracturing and seismicity in support design
Anomalous Conditions			
	Stress conditions	**Closure rate**	**Geological factors**
Shallow stope	High stress possible in remnant pillars	Backbreak at wide spans	• Domes • Faults • Dykes • Rolls • Potholes • Increased jointing • Narrow bedding • Weak strata • Weathering
Stope at Intermediate depth	High stress will occur in pillars	High when mining remnants	As for shallow stope, except weathering
Stope at Depth	Stress is not anomalous	High closure is not anomalous	• Faults • Dykes • Rolls • Potholes

Table 2 - Definitions of non-standard conditions categorized 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.	• Mining layout (e.g. remnant) • 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 • Weathering or oxidation of strata	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 • Use of an inappropriate mining layout or support strategy. • Failure to adhere to planned strategies or support.	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

2.2 Contribution of anomalous conditions to accidents

A break down of contributing factors to accidents, under the headings of the four anomalous condition categories listed in table 2, is shown in figure 2. The data comes from a review of 89 rock-related accident cases, which cover a varying range of mining depths and conditions. Not all the contributing factors were necessarily anomalous in nature. The numbers however do highlight the relative importance of the contributory factors that result in accidents on the mines. Accidents often have more than one contributing factor, and the numbers in figure 2 represent the percentage of the 89 accident cases where each category formed one of the contributing causes.

Geological factors influenced 55% of cases, and were largely conditions that could be considered anomalous. This is only marginally higher than the influence of human error.

Although stress fractures contributed to accidents in 40% of cases, most of these were at depth where stress fractures could not be considered anomalous.

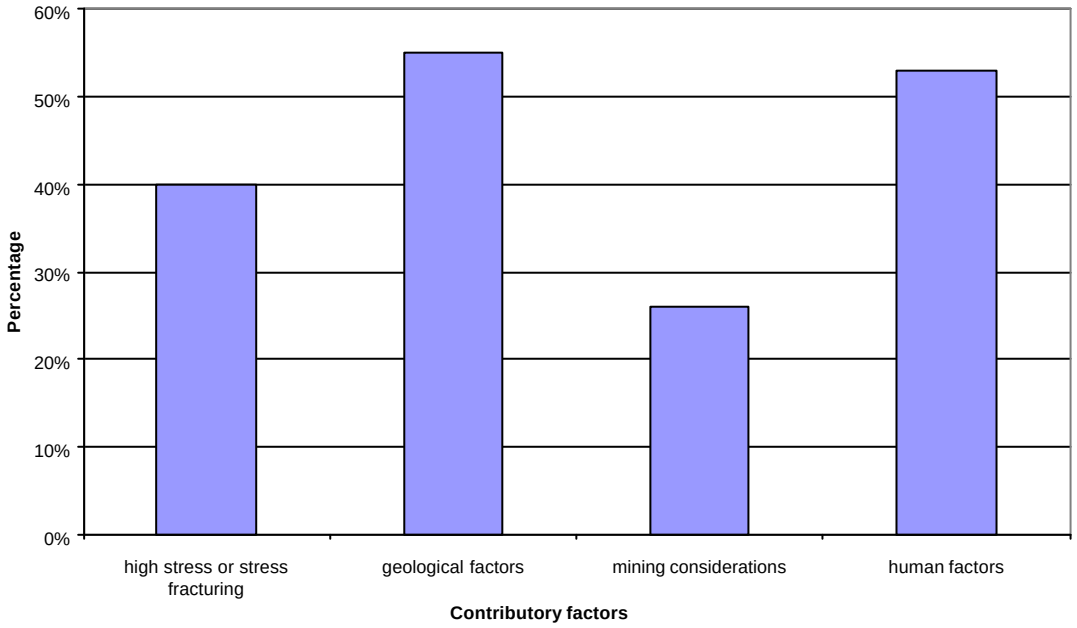


Figure 2- Graph showing the various factors that influence anomalous conditions based on 89 accident cases

2.3 From anomalous hazard to control measures

The key to controlling anomalous conditions is firstly to be able to detect and identify when they occur, and secondly recognising when they result in an increase in hazard. If the hazard can be identified then strategies for its management can be implemented.

Looking only at geotechnical anomalies, these can be subdivided into those that are natural, resulting from geology and rock fabric and structure, and those that are induced as part of the mining process. Figure 3 is a flow chart that starts with anomalous conditions, and identifies the effect that each has on rock mass behaviour. It lists the observable characteristics of each and those issues that may influence layout and support design, and lastly leads into the response required to address the change in hazard resulting from the change in conditions.

The focus in Figure 3 is on naturally occurring anomalous conditions. Changes in mining practices that result in anomalous conditions produce similar rock mass responses to those listed for natural occurring cases. Changes in the face shape, panel length, mining height, rate of advance or blasting practice will result in changes in one or more of the local stress regime and stress fracture pattern or rock mass deformation.

Note again that certain geological hazards would be considered to fall within the normal operating conditions of any mine. Hence standards, codes of practice and operating procedures should be in place to deal with these hazards. Examples of standard geological conditions would be the general joint patterns that influence stope span limits at shallow depth, or the presence of shale layers in the strata overlying some reefs. These conditions are locally not anomalous, provided standard mining practices are carried out correctly. However if there is a failure in mining practice anomalous conditions may arise, requiring support of brows or undercutting of collapsed areas for example.

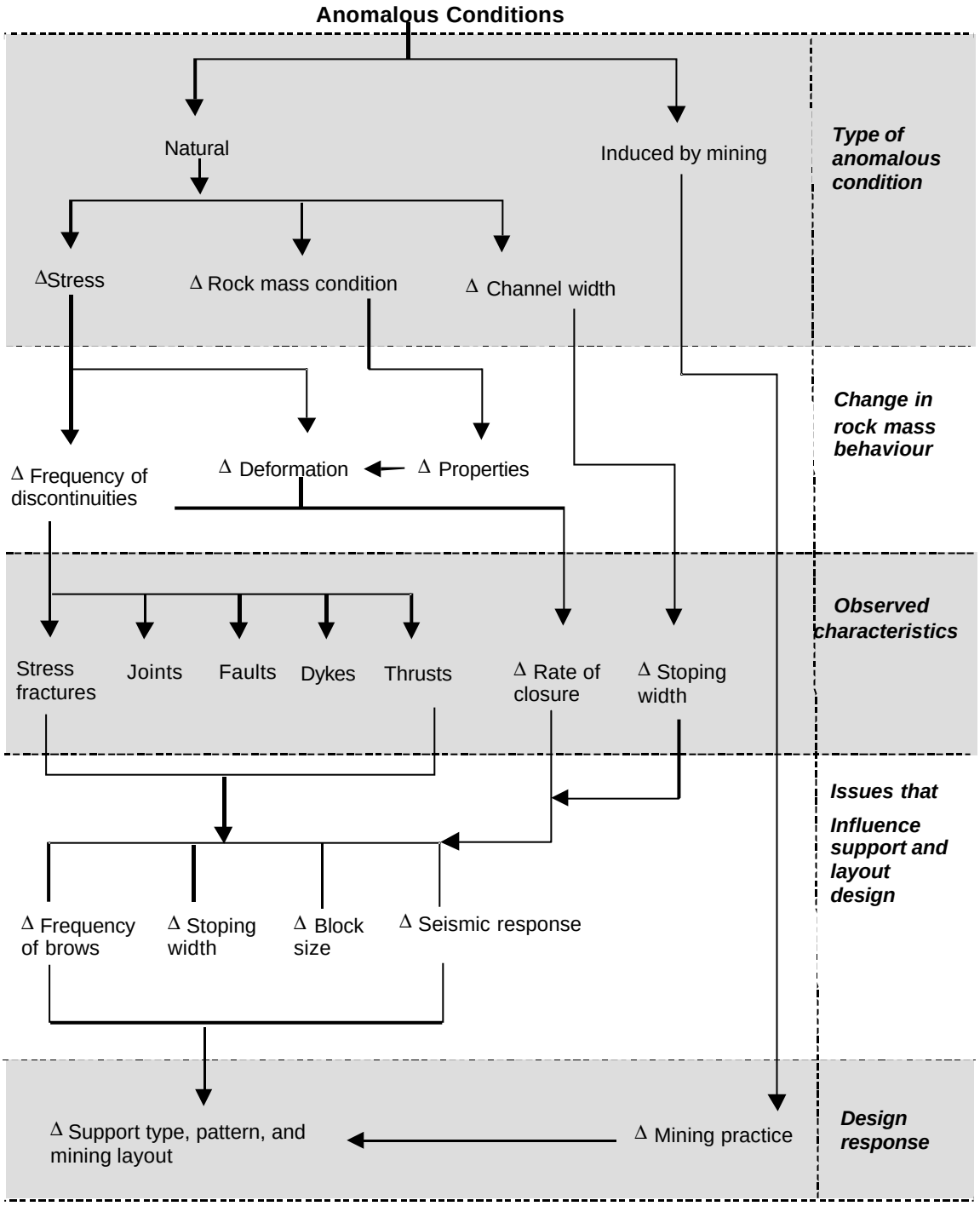


Figure 3 – Flow chart depicting the probable rock mass and design responses to changing conditions

3 Examples of anomalous conditions

Examples of typical types of geotechnically anomalous conditions observed on gold and platinum mines are shown in figures 4 to 15. These cover a range of the expected conditions that can be encountered on a mine and indicate the possible hazards to look out for. The aim of this section is to assist in identification of hazardous conditions.

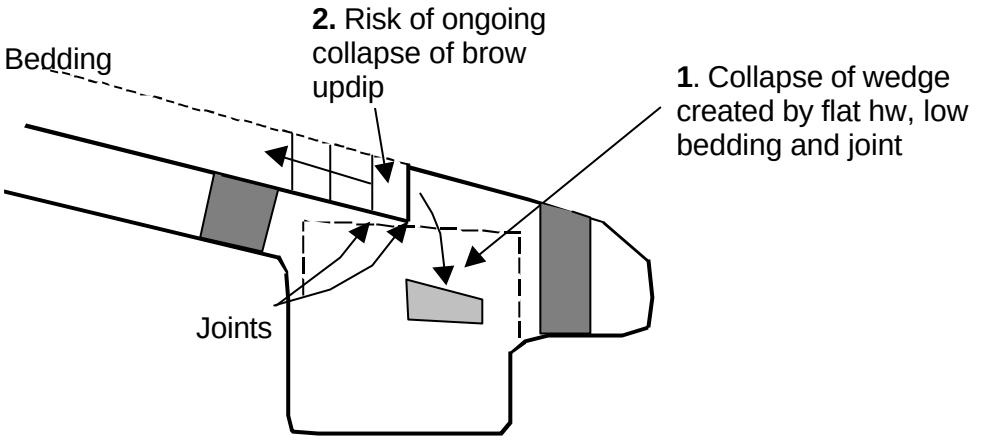
Examples cover the effects of:

- joints,
- domes,
- bedding,
- brows,
- stress fractures,
- faults,
- dykes,
- rolls and potholes,
- weathered ground.

Some of these are not universally a problem in all mines, such as potholes in platinum mines, where problems relate both to rolling of the reef and increased joint frequency. Other anomalous conditions result in different hazards in different mining environments. An example would be a dyke, where at shallow depth the hazard is local to the dyke and is largely one of an increased risk of falls of ground due to jointing. However in a high stress environment dykes are frequently burst prone, where seismic activity has the potential to induce falls remote from the dyke.

The examples shown are not intended to be comprehensive. It is suggested that individual mines should develop similar diagrams to illustrate their own particular conditions. These form useful training aids.

Joints and brows



Problems

1. Flat hangingwall of reef drive cuts across lava flow bedding
2. Brow may collapse updip into stope if brow support is inadequate

Figure 4- Typical joint bound fall of ground along a reef drive in a VCR panel. Once the initial key wedge has detached there is a likelihood that collapse of the brow migrates up dip into the stope panel.

Curved joints and low angle thrust (or dome) structures

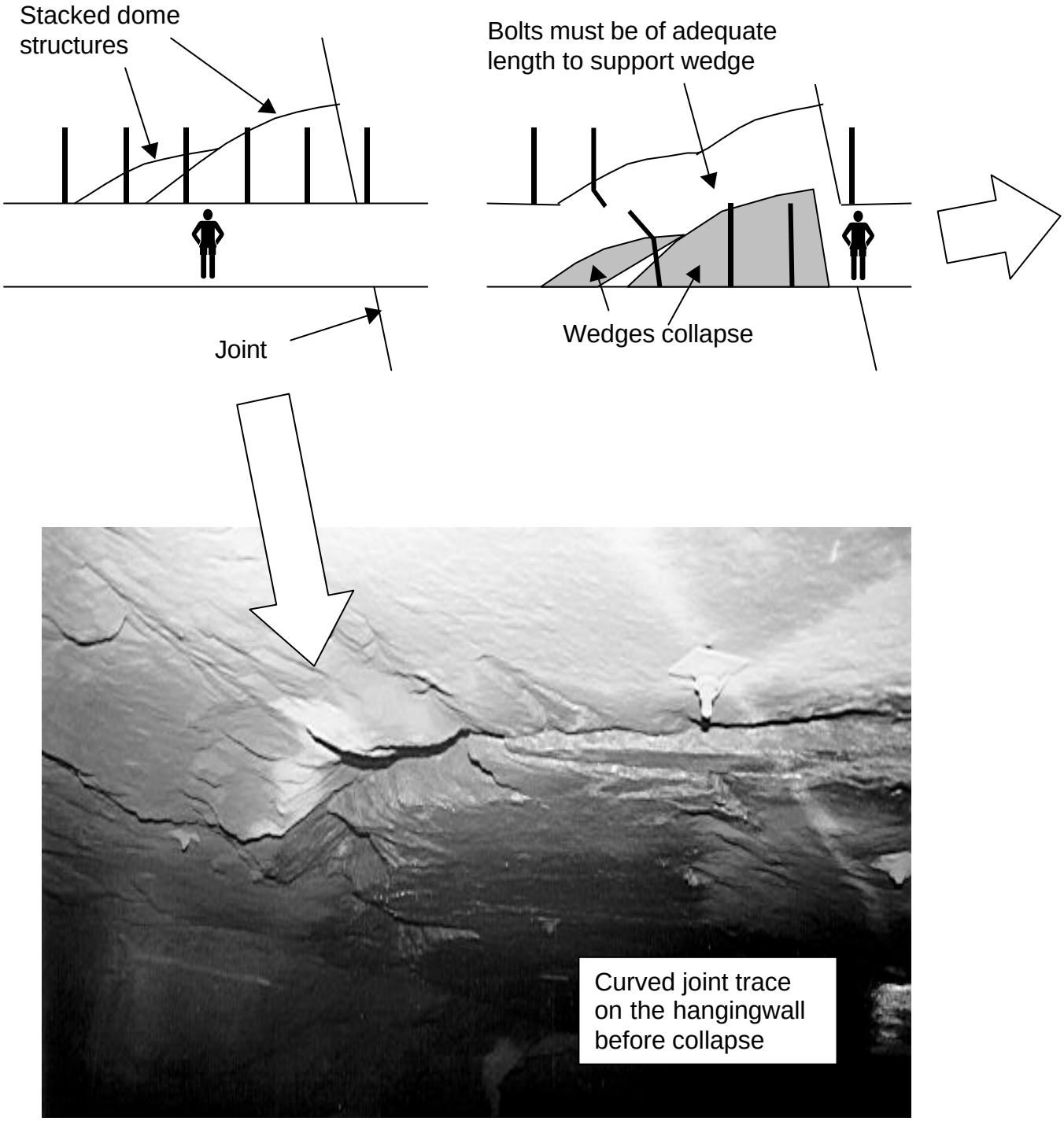


Figure 5A - The effect of curved joints or domes at shallow depth. Joints must be identified before collapse is initiated

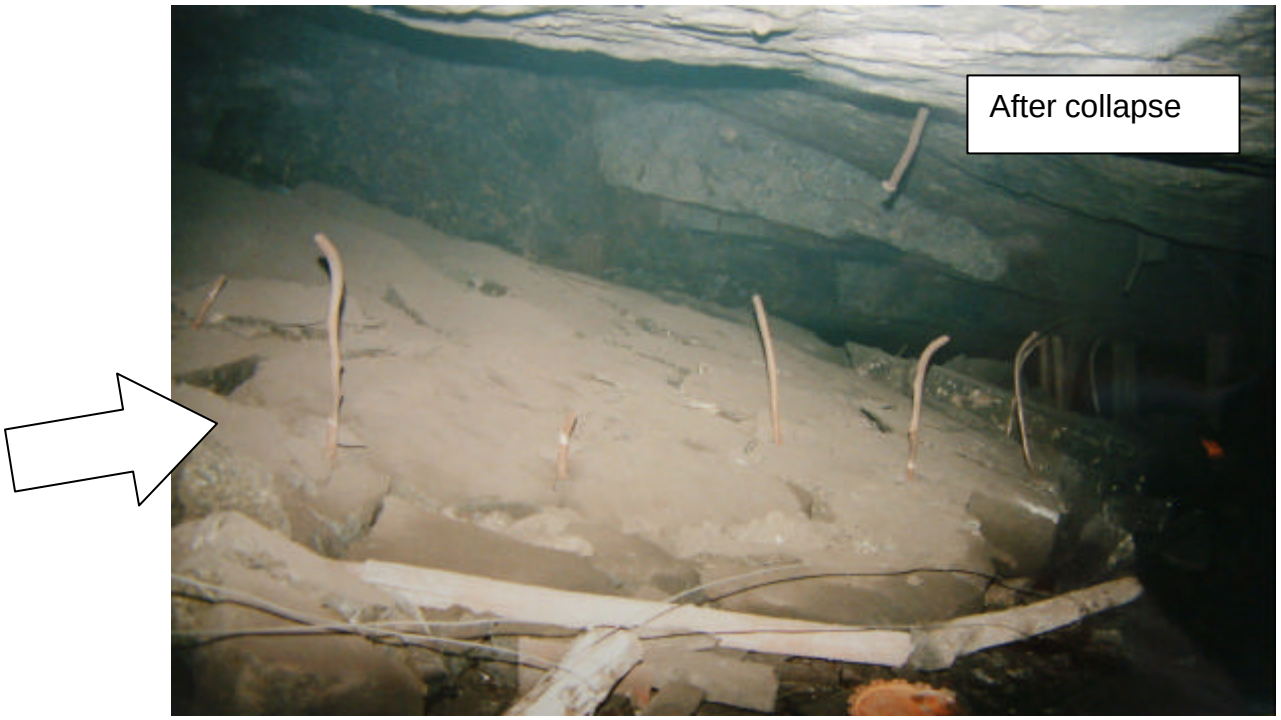


Figure 5B- Collapsed domes at shallow depth: installed rebars proved inadequate to support the large wedge of ground

Intersecting joints

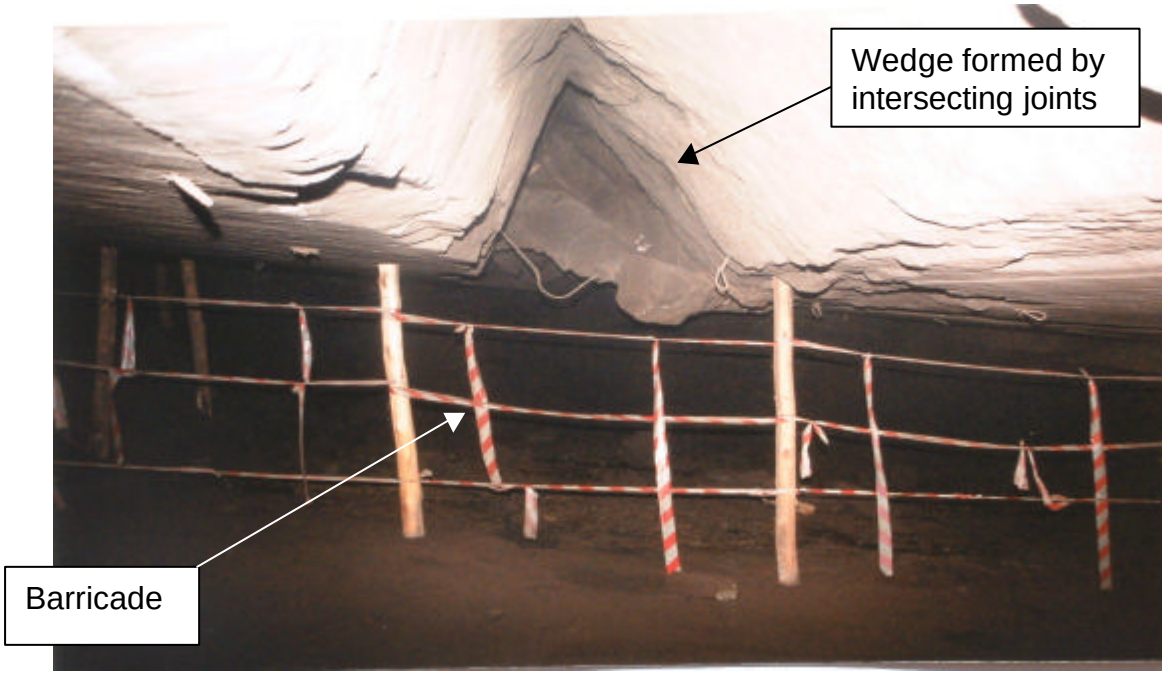
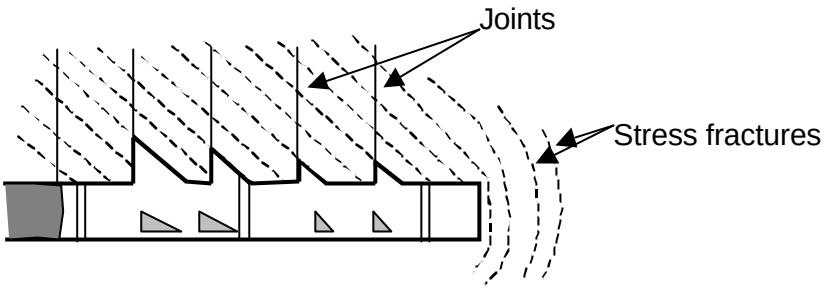


Figure 6 – Collapse of a wedge formed by two intersecting joints. In this example a large wedge has dislodged. As there is potential for further collapse along the extension of the intersection, the area has been barricaded to prevent casual entry into the hazardous area.

Joints and stress fracturing

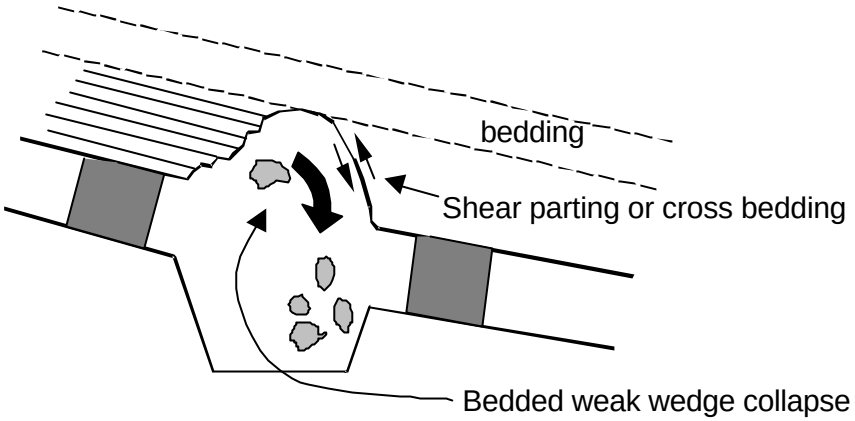


Problem

1. Interaction of stress fractures and joints leads to minor falls between support
2. Interaction would be reduced if the stope face was not parallel to a major joint set
3. Support spacing may need to be reduced to control falls

Figure 7– Blocky hangingwall conditions arising from the interaction of jointing and stress induced fracturing when mining west on the Carbon Leader reef at approximately 3400m depth. Local areas of increased jointing lead to increased and localised fall of ground hazards.

Brows, shear partings and cross bedding



Problems

1. Hangingwall support required over gully
2. Two brows created, up and down dip

Figure 8– 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. Brows are clearly paint-marked.

Undercutting, faults and jointed brows

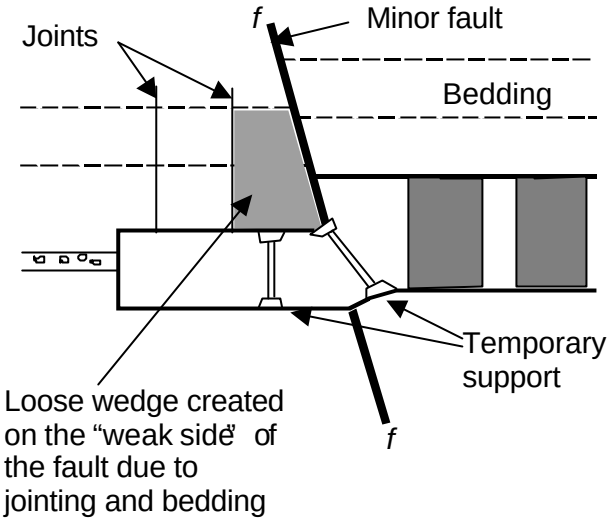
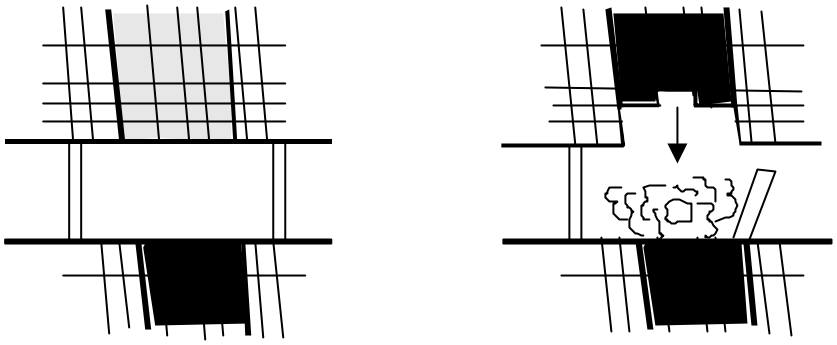


Figure 9 – Hazard resulting from undercutting a brow.

Blocks forming brow are too loose to safely support. Rock mass is too jointed and must be undercut in a direction normal to jointing.

Dykes and joints

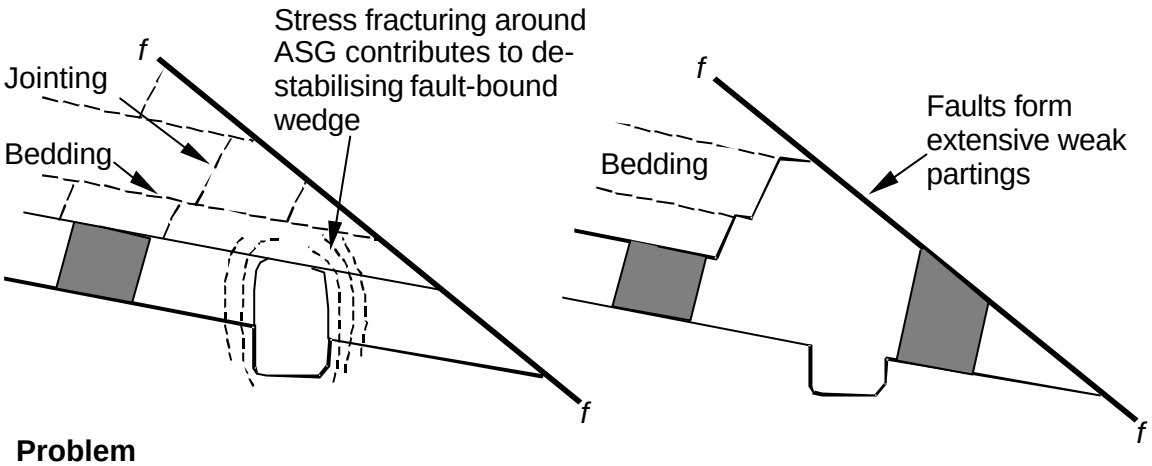


Problems

1. Most dykes are more jointed than the surrounding rockmass with joints parallel and normal to dyke contacts
2. Dyke contacts may be weak and altered (eg. Serpentinised)
3. In the example, no additional support is installed within the dyke, only on the contacts
4. Core of dyke collapses knocking over adjacent support

Figure 10 – Collapse of 0.5m to 1m of hangingwall within a 1.5m wide dyke in a Merensky reef stope. Additional support was placed along the dyke contacts, but not beneath the dyke

Faults

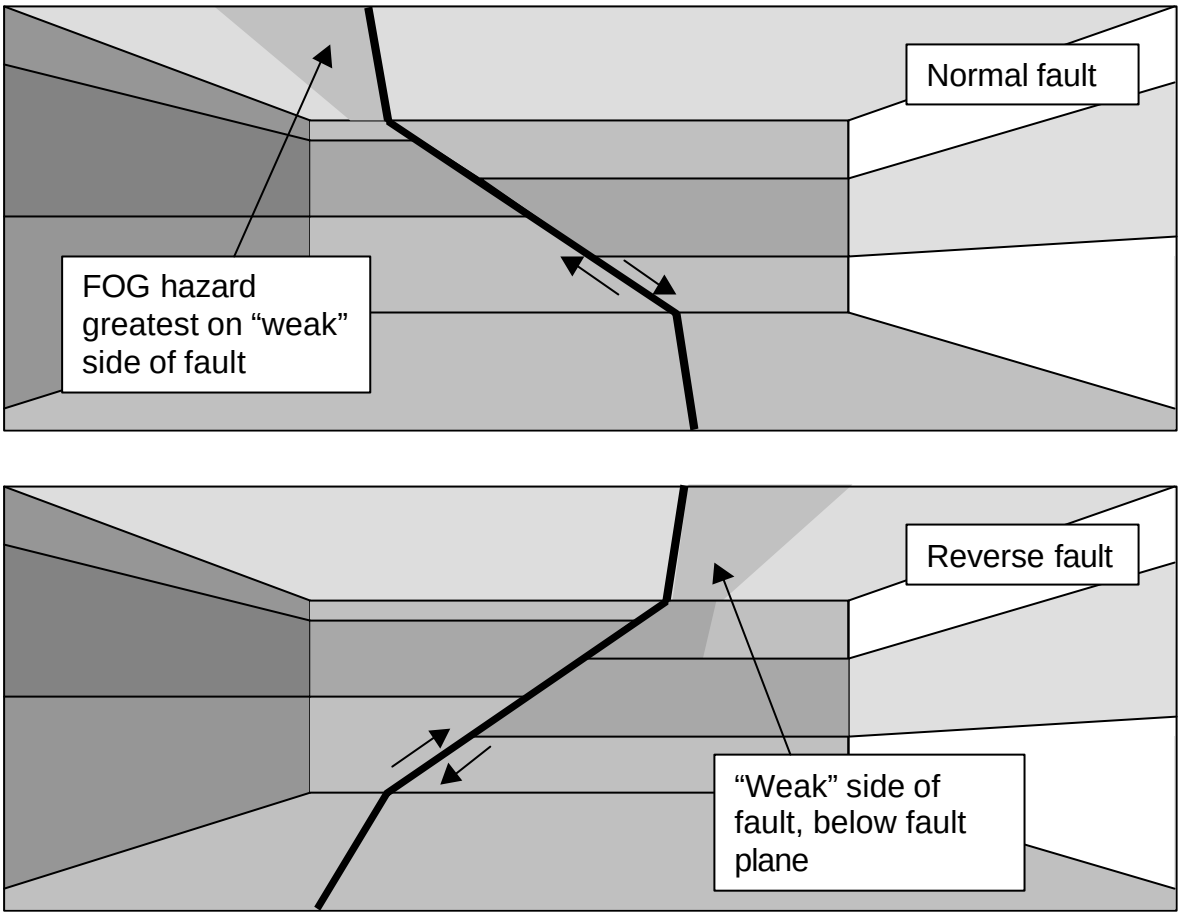


Problem

1. Wedge of ground collapsed on weak side of fault
2. Difficult to support very large wedges of ground in deep mines where pillars are burst prone and not safe to leave as support

Figure 11 – Collapse of a large wedge beneath a fault plane at depth on the VCR

Normal and Reverse faults



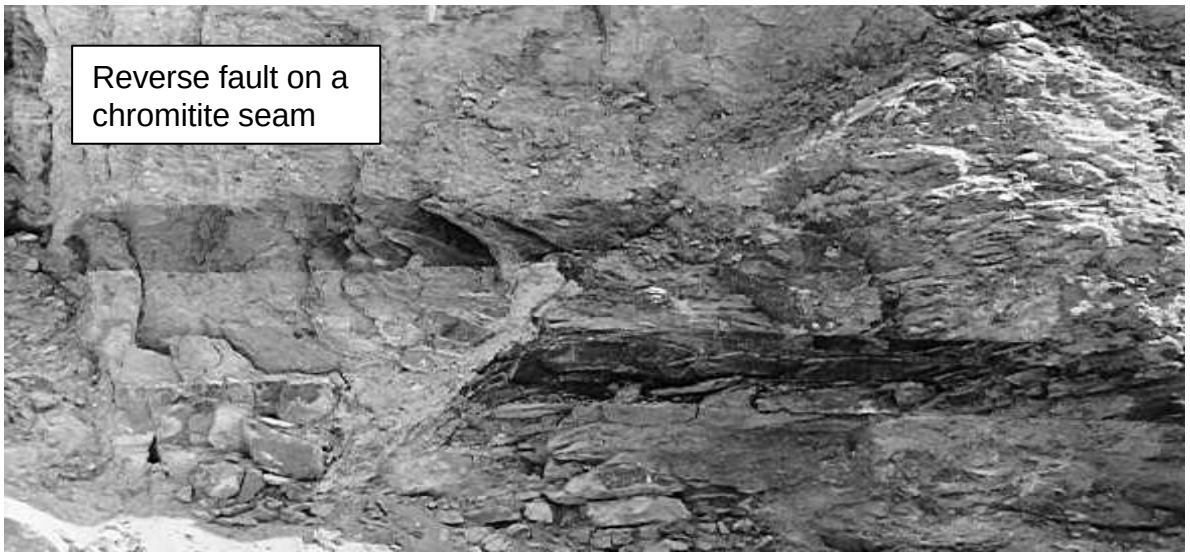
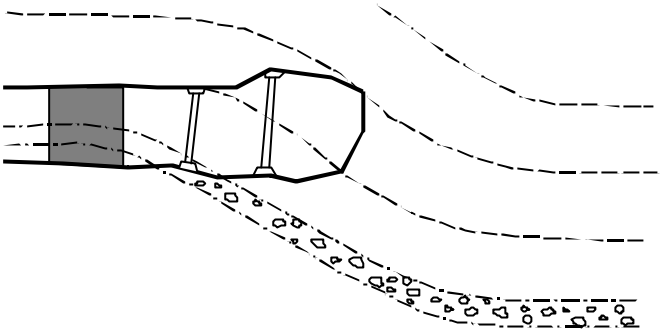


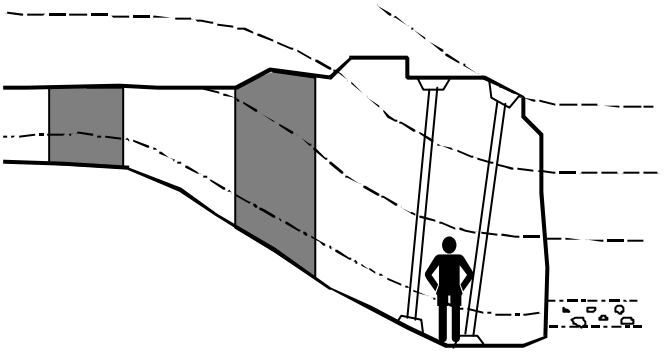
Figure 12- Typical normal and reverse faults, with “weak” side indicated

Rolls and potholes



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

In the immediate vicinity of potholes and rolls, the pattern and intensity of jointing may increase. Low angle jointing and wedges are often associated with potholes. This may lead to overall poor hangingwall conditions that may be exacerbated by poor blasting.

Figure 13- Loss of control in a VCR panel after encountering a roll. Reef is approximately 1m thick at base of face, 3m of lava has fallen out. VCR rolls largely result from the river channel and terrace environment in which deposition took place and hence follow varied paths.

Figure 14- 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.

Weathered ground

At shallow depth, primarily in platinum mines, 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, and the rock material can sometimes be crumbled in the hand. Generally this ground is restricted to depths less than 30 to 40 metres below surface.

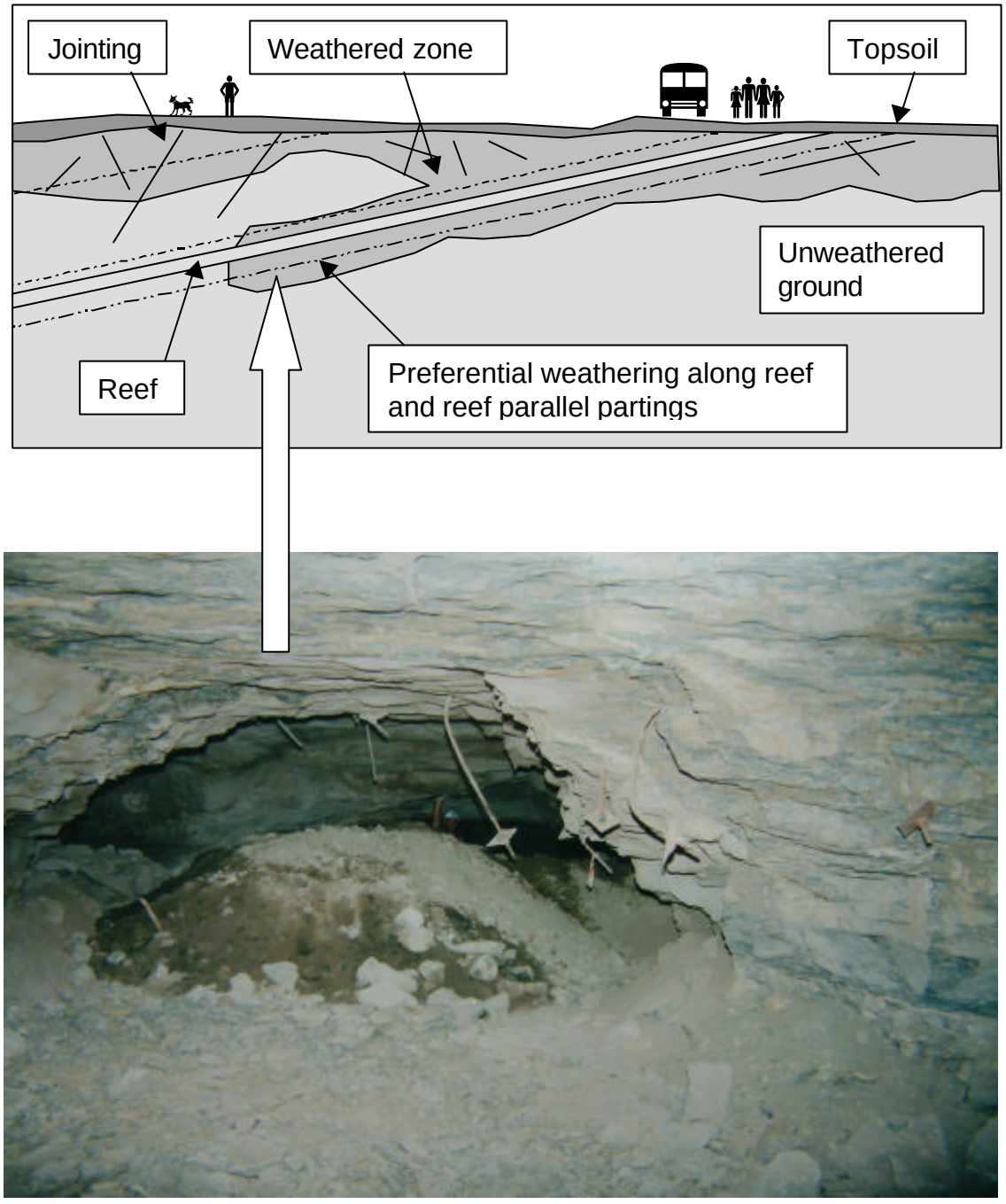


Figure 15- In-stope collapse in highly weathered pyroxenite ground at shallow depth.

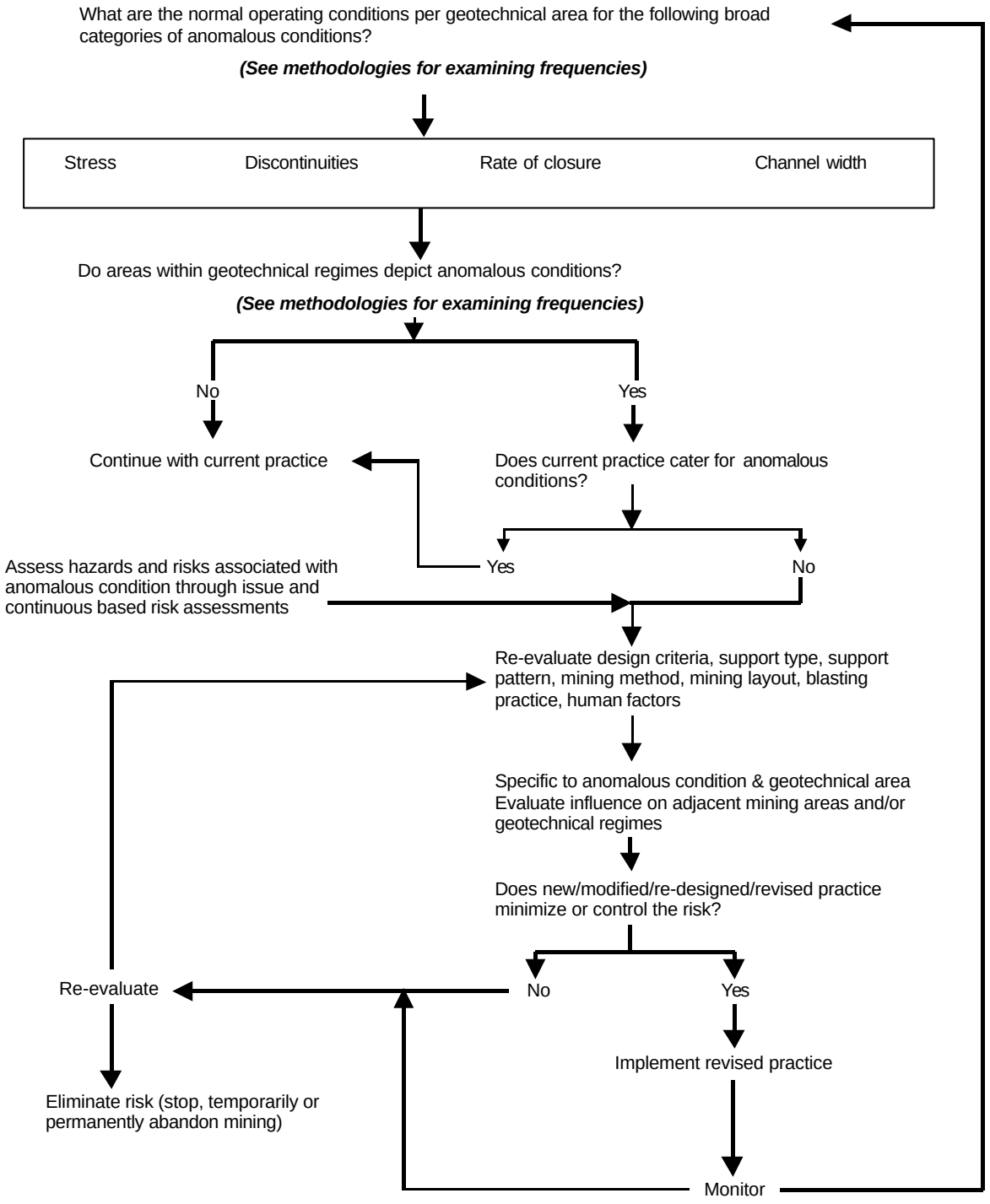


Figure 16 – Process flow chart indicating possible steps to be taken to ensure that risks associated with anomalous conditions are minimized

4 Identification and management of geotechnically anomalous conditions

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 16. 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.

4.1 Mine personnel responsibilities

The management of hazards relating to anomalous conditions requires input or decisions from a range of key mine personnel. These 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 3 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 should be in place to educate people in the identification of anomalous conditions.

Table 3 – 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 the stope • Notify specialists regarding change in standard or design	• Shiftboss • Miner • Team Leader • Geologist Rock engineer and manager input if notified.

4.2 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 4.

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 4: 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?

4.2.1 Are stress fractures or closure rates anomalous?

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. However as a simple way of gauging normal or standard conditions, and the results that a deviation in stress conditions may have, figure 17 can be used. Note that this is intended to be a rough guideline and should not be used as a rigorous design method or a replacement for local mine observations.

In figure 17, field stress is assumed to increase linearly with depth, with lines for various multiplication factors added to account for remnant conditions. Geotechnical condition categories can be defined in terms of the ratio of field stress to rock strength. In using this graph, first standard conditions would be identified for a mining area, then the effects of anomalous conditions can be compared. 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.

Estimation of Geotechnical Conditions

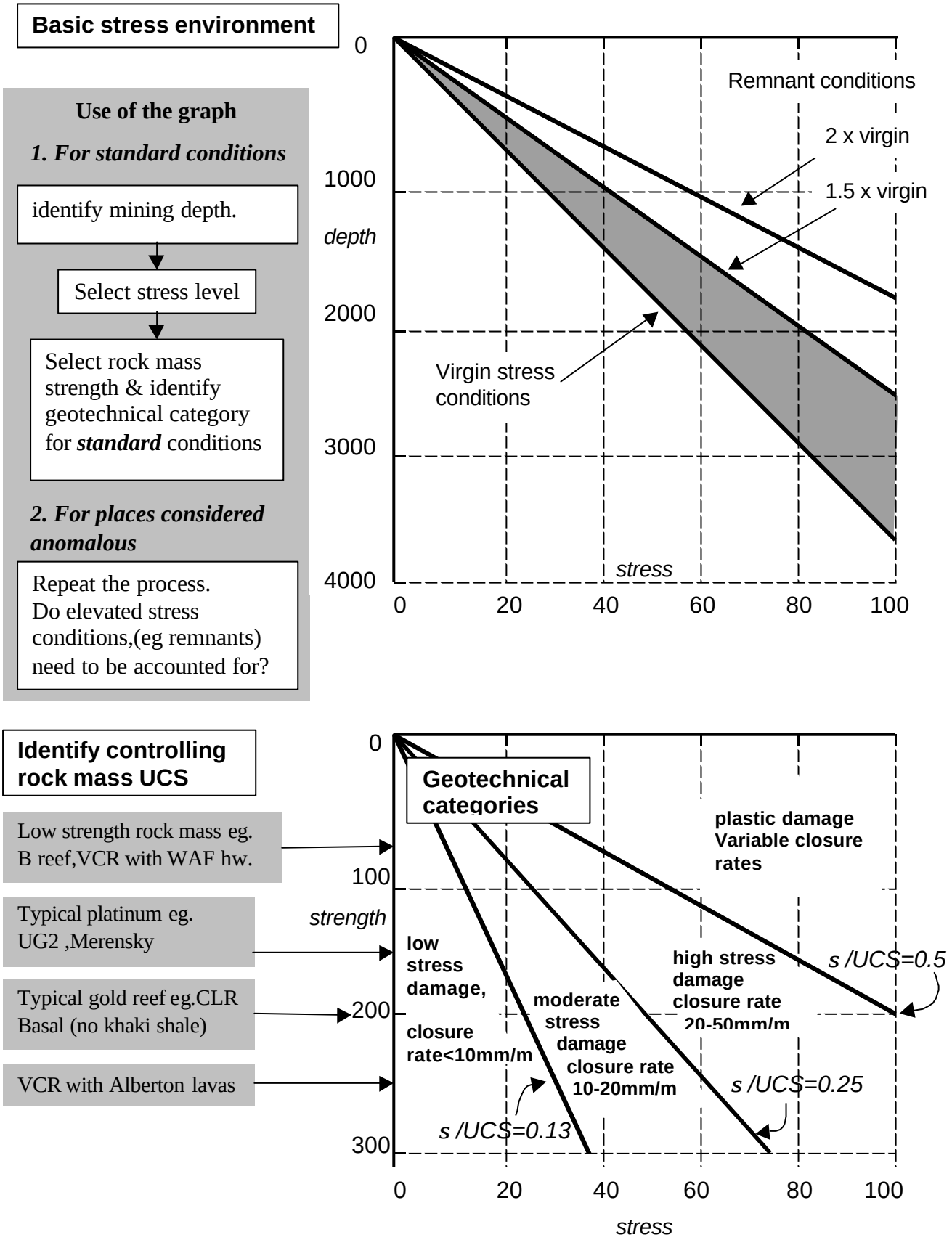


Figure 17: Identification of stress and closure conditions

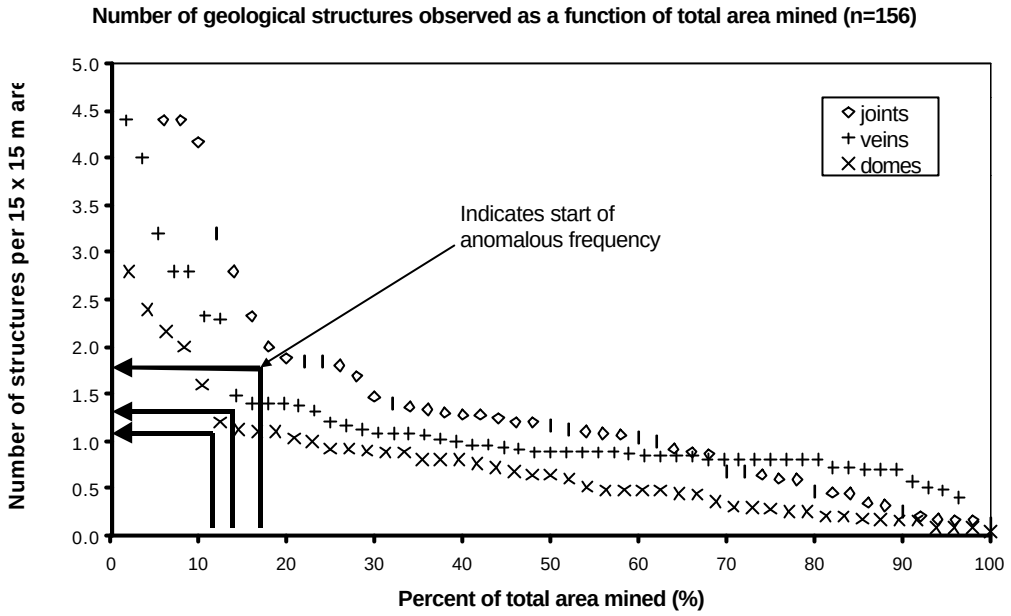


Figure 18 - Joint, vein and dome frequencies determined as a percentage of area mined (data from a platinum mine)

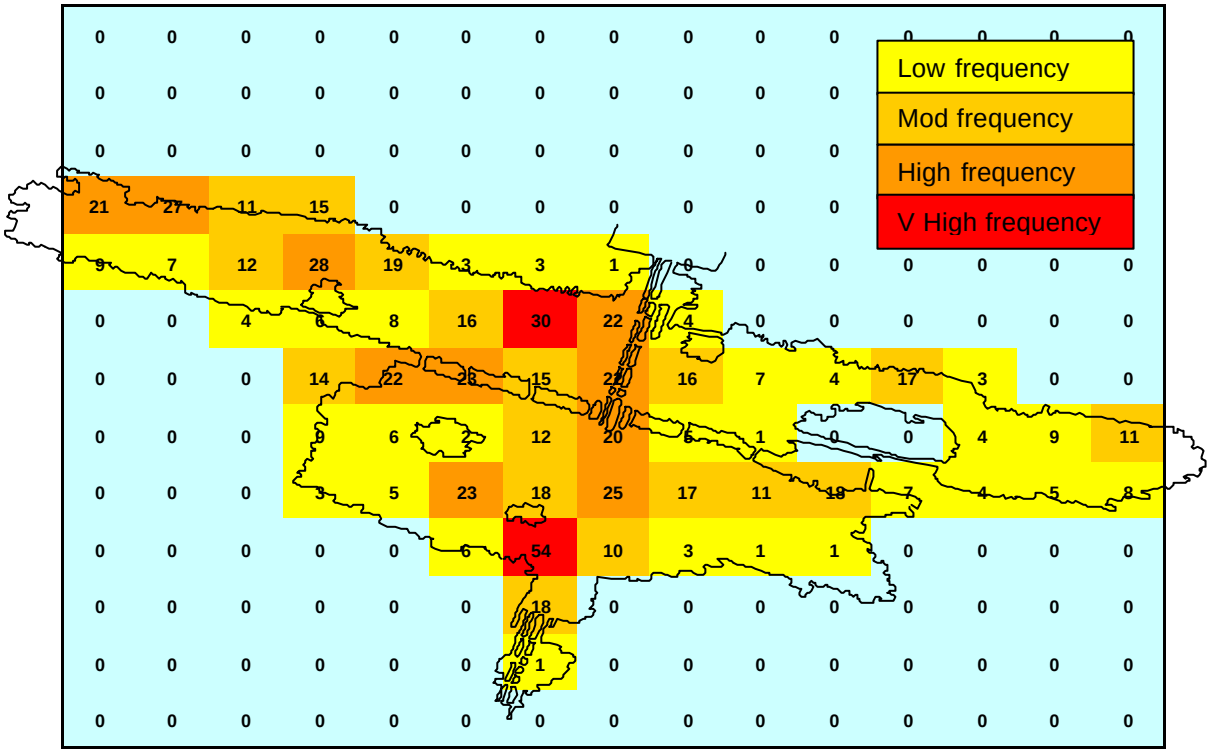


Figure 19 – Example showing the frequency of occurrence of low angle shear, or dome, structures across a mining area. Numbers of structures per 100 x 100 m area are indicated (data from a platinum mine)

4.2.2 What is the risk of mining into geological structures?

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.

An example showing the frequency of occurrence of discontinuities at a platinum mine working the UG2 horizon is shown in figure 18. In this instance hazards result from the intersection of low angle thrust structures (commonly referred to as domes) with pegmatite veins and steep joints. Looking at the joint population, roughly 80% of this mining area has fewer than 2 significant joints per pillar tributary area (approximately 15 x 15 m), while in 18% of the mining area this rises to over 4 joints. Approximately 18% of the area can be considered geologically anomalous from the point of view of jointing. In these areas increases in support density might be needed.

Similar studies can be carried out on any mine. Essentially it requires the compilation of a mine map showing the relevant structures or discontinuities, over which a grid can be laid. Structures are counted within the grid to provide a frequency distribution. An example map, where the count is made over 100m by 100m square areas, is shown in figure 19. In this example the distribution of low angle shear structures, is shown. These tend to group in bands, and more hazardous areas can be identified. Similar maps can be compiled for other structures.

4.2.3 Examining fault populations in a mining area

A slightly modified method can be used to examine faults. Because of throw, faults require changes to mining layouts and support requirements, hence it is useful to anticipate how often faults may be expected in a mining area.

Fault population analysis is a method that 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. A plot of cumulative frequency against throw (figure 20) illustrates a fault distribution. The relative number of large and small faults is controlled by $N=aL^{-D}$. N is the number of faults with size greater than or equal to L, the fault throw, while a is the number of faults with throw larger than 1 m, and D is the slope of the best-fit line to the data in figure 20.

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 20 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*** can therefore be related to possible mining complexity, or level of hazard. A tentative relation is shown in figure 21. 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.

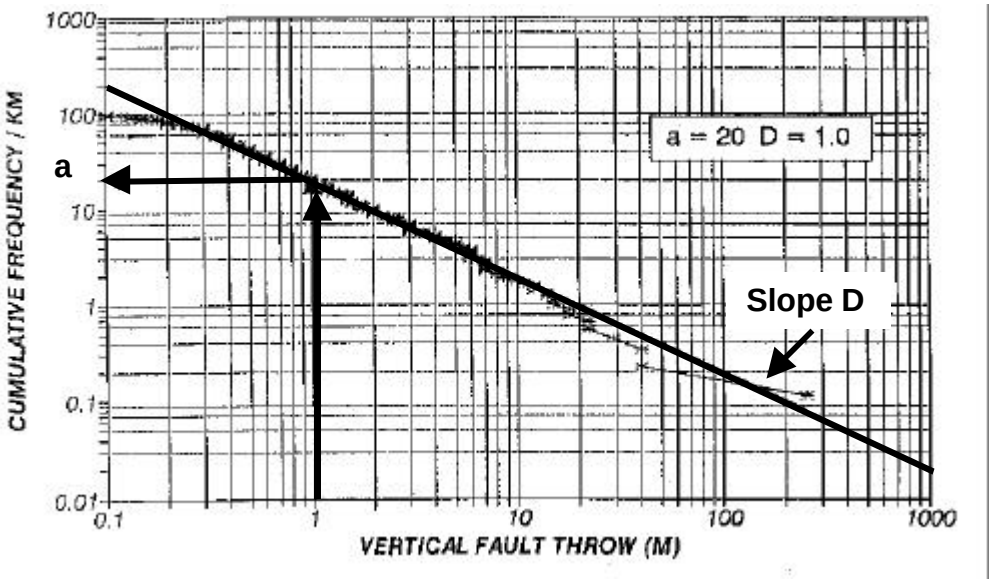


Figure 20 - Log cumulative fault frequency per km against log vertical fault displacement. Data from a Basal Reef raiseline (after M T G Birch)

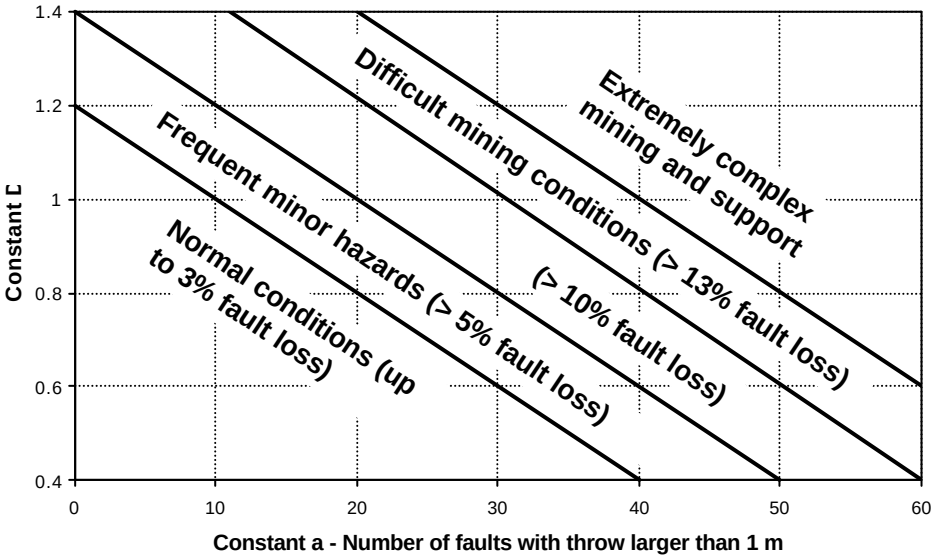


Figure 21 - Scatter diagram classifying mining difficulty based on fault population parameters a and D (adapted from M T G Birch).

4.3 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 5. 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 5: 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?

5 Mining and support practices in anomalous areas

5.1 General Practices

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.

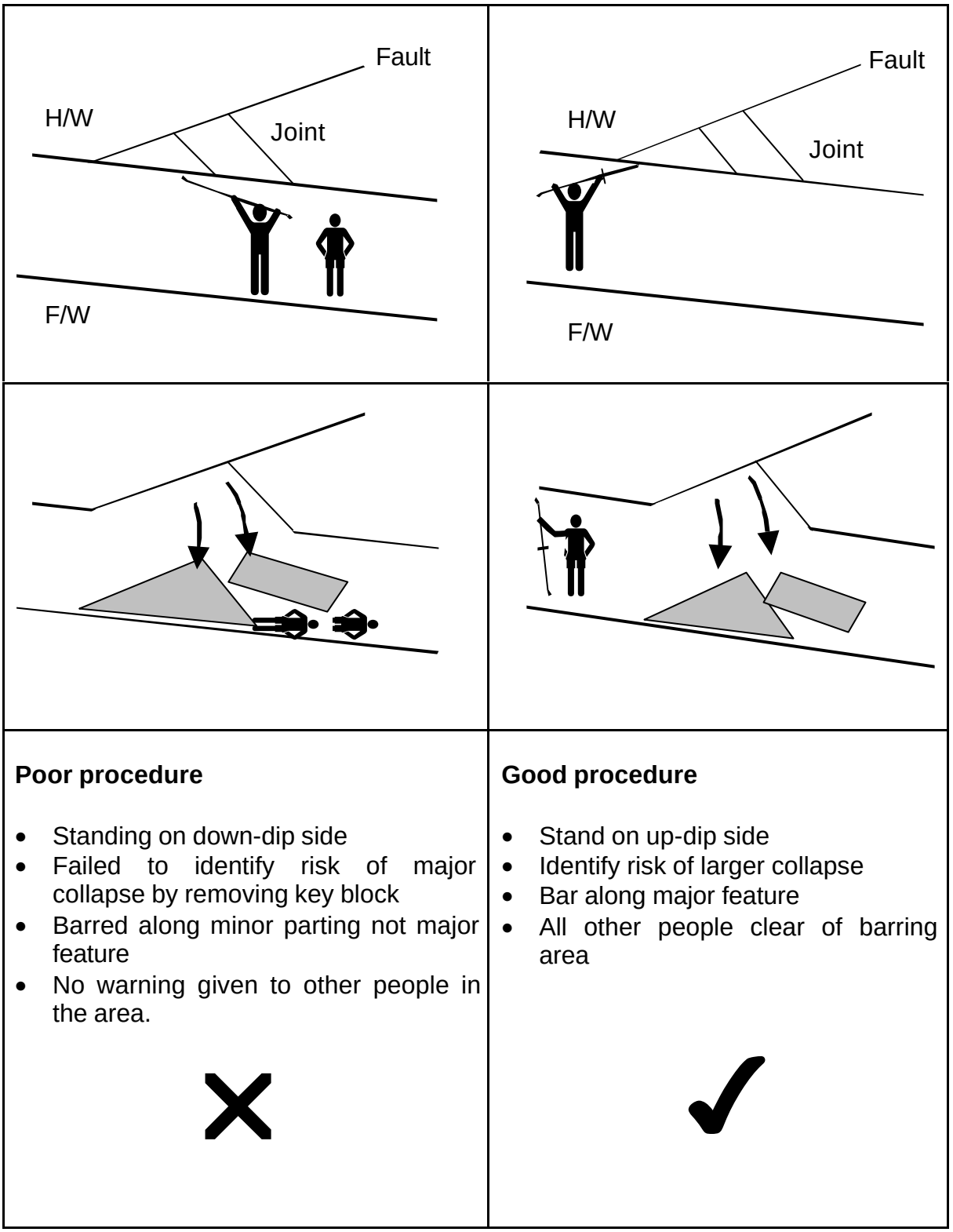
If input parameters such as stress regime, rate of closure, the size of block requiring support, and seismic event ejection thickness can be quantified for anomalous areas it is possible to design support for these areas using the methodologies derived from previous SIMRAC projects. An example would be CSIR Miningtek's SDA which evolved from GAP 032. All strategies for anomalous stoping areas should comply with 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).

5.2 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. Important issues when barring are illustrated in figure 22. There are seven key points to safe barring:

1. Pinch bar must be the correct length and sharp on both ends,
2. Pinch bar must have a gasket on to protect hands,
3. Must warn all people in the vicinity before barring,
4. Always have a second escape route from the area to be barred,
5. Stand firmly – there should be no rubble under your feet that might cause slipping or falling,
6. Always stand on the up-dip side of the area to be barred,
7. Bar for 2m, stop turn around and look back for other slips.

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.



Poor procedure

- Standing on down-dip side
- Failed to identify risk of major collapse by removing key block
- Barred along minor parting not major feature
- No warning given to other people in the area.

Good procedure

- Stand on up-dip side
- Identify risk of larger collapse
- Bar along major feature
- All other people clear of barring area

Figure 22 – Barring practice. All faults, dykes slips and brows must be identified and marked with paint by the miner and extended daily

*Note: If the area being mined is considered to be extremely hazardous the area should be **barricaded** off to prevent access.*

5.3 Support practices for geological structures

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 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.

The final sections provide a few examples of what is generally considered good practice for support in areas that have encountered geological anomalies.

5.3.1 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 23). General procedure would be:

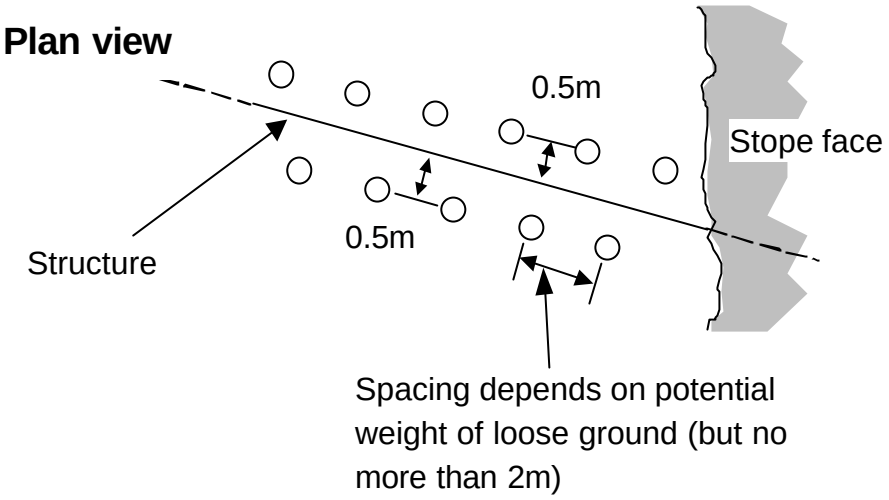
- The structure to be supported must be clearly identified and paint marked.

- 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.

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.



Section view

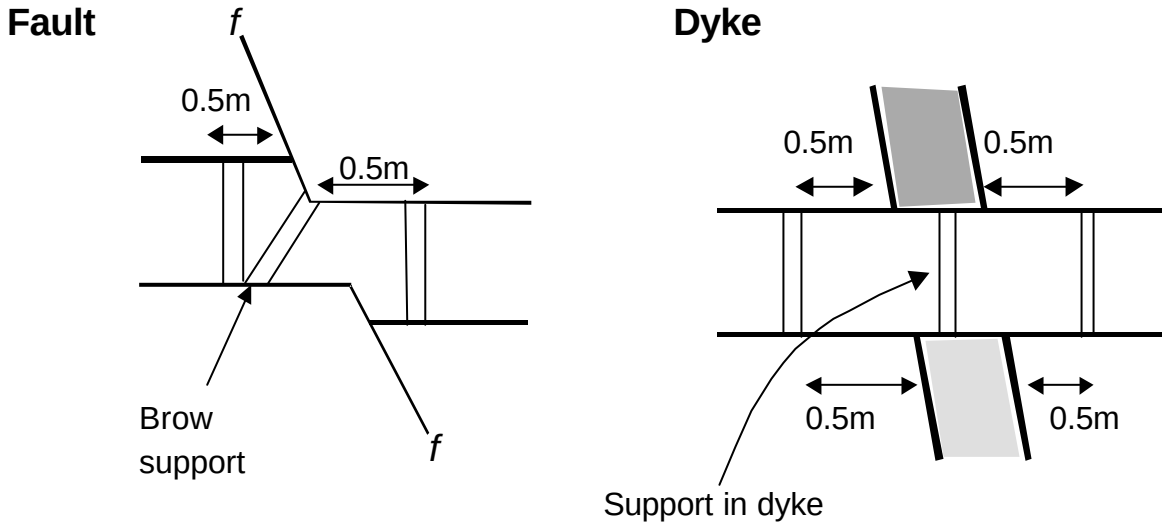
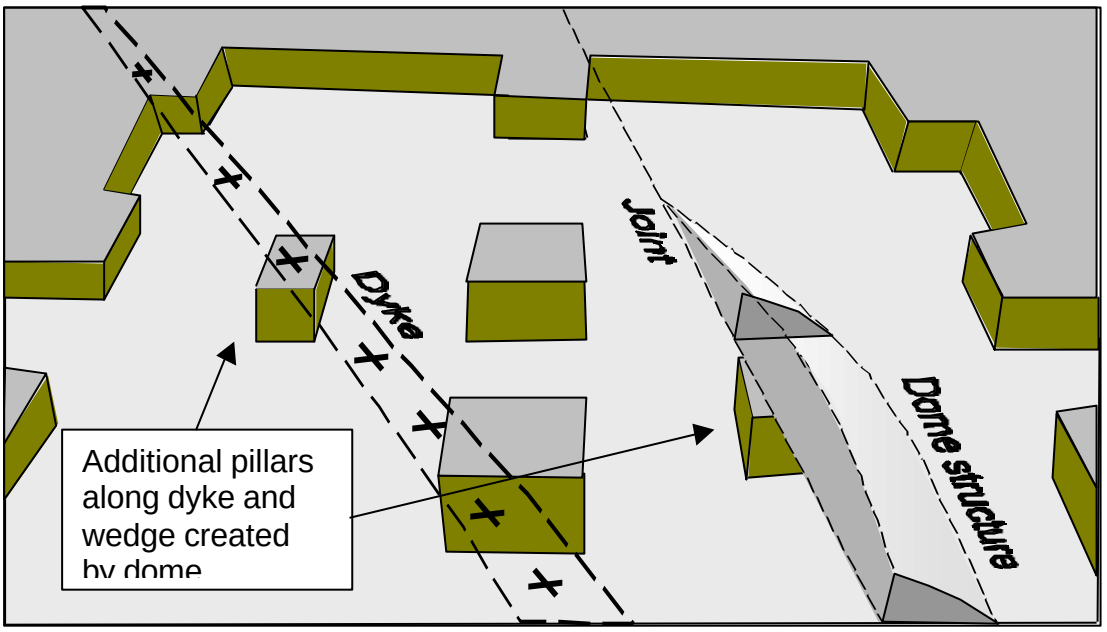


Figure 23 – Generally accepted patterns for additional support along minor faults, dykes and brows

5.3.2 Use of pillars to control falls of ground along structures

Where severe instability is possible, such as the collapse of large blocks along a fault or dyke, reef can be left in-situ to form additional pillars. These reduce spans and provide support below large wedges of ground. Pillars can be used safely at shallow depth (figure 24) 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.



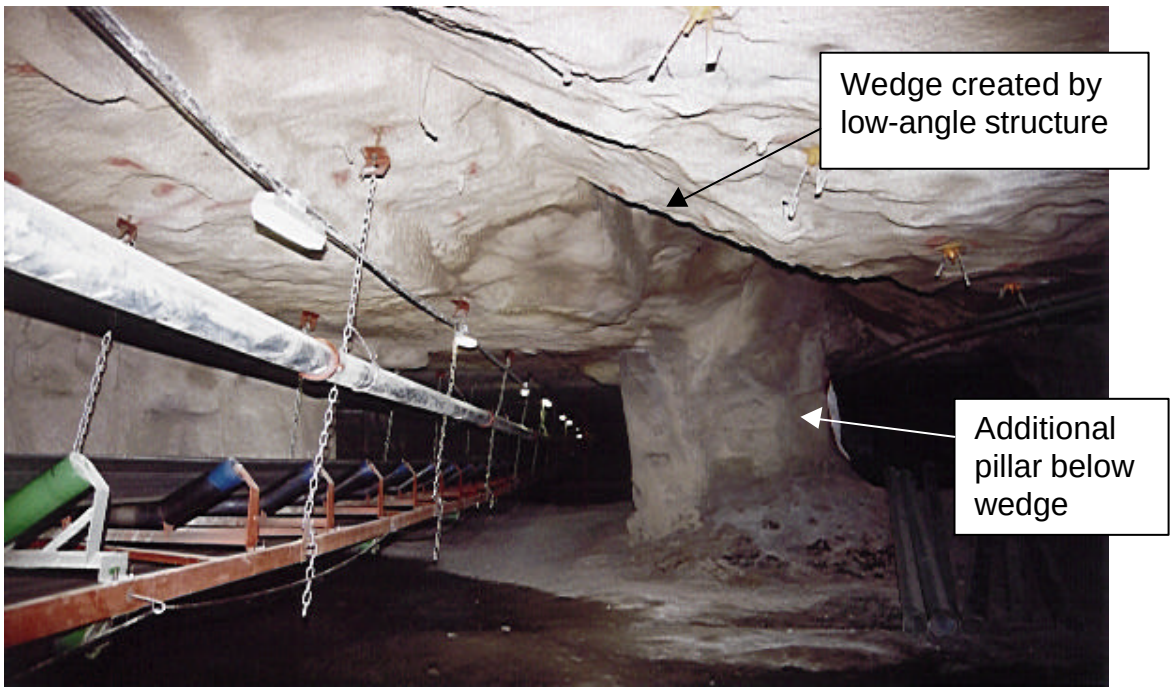


Figure 24 – Additional pillars along structures in a shallow platinum mine using a room and pillar layout.

5.3.3 Negotiation of minor faults

Stope panels can generally safely roll up or down through faults with minor throws of less than several metres. 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. Examples are shown in Figure 25.

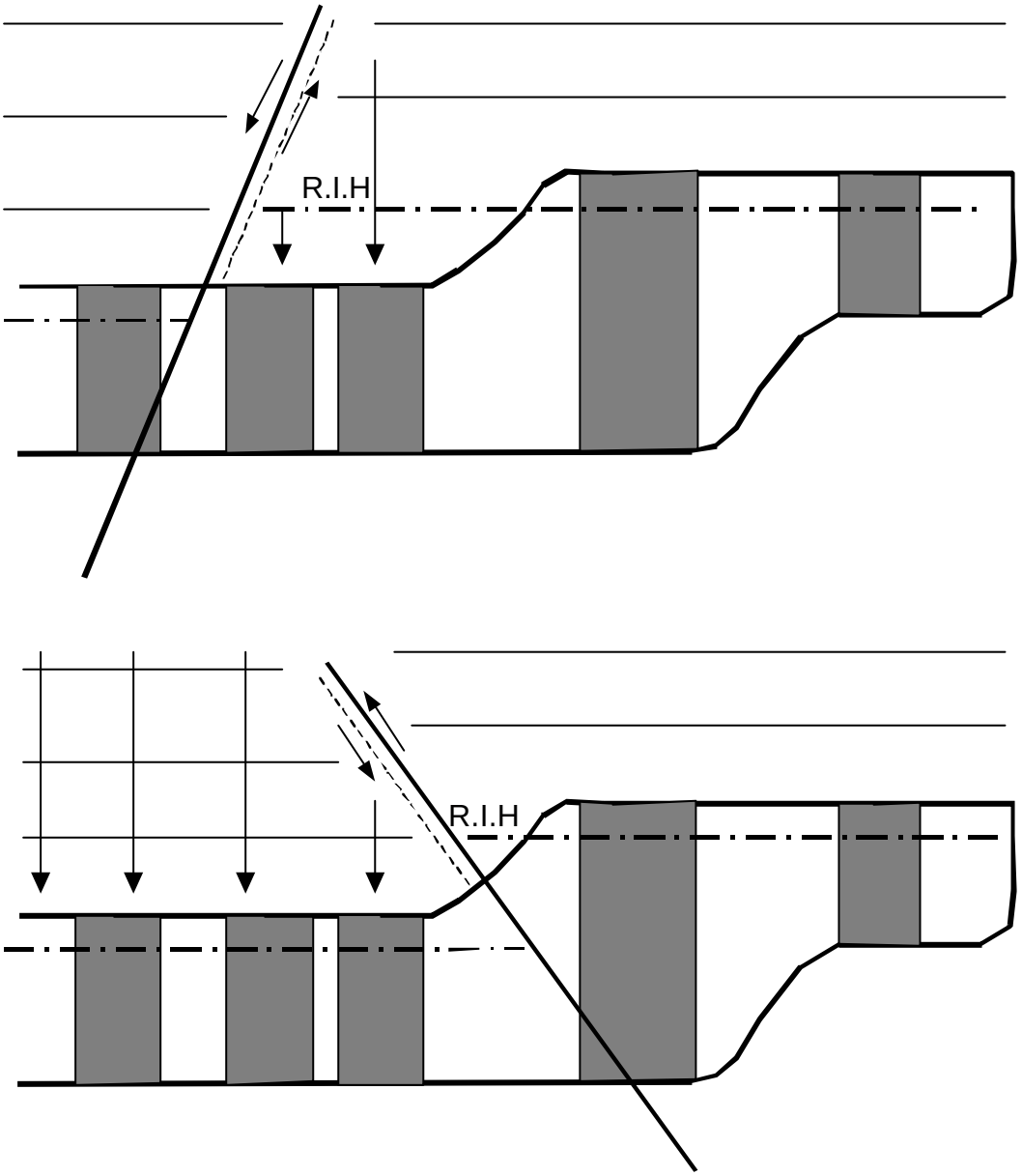


Figure 25 - Example showing support practices for negotiation of a "normal" upthrow fault and a "reverse" downthrow fault

5.3.4 Undercutting brows and weak structures

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 (figures 26 and 27). In major undercutting exercises it is important that the brow is blocked against adjacent support. Obviously this is not always possible where a stope face has collapsed and has to be re-established, but should be feasible where undercutting brow created, for instance, by a minor fault.

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:

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.

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.

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.

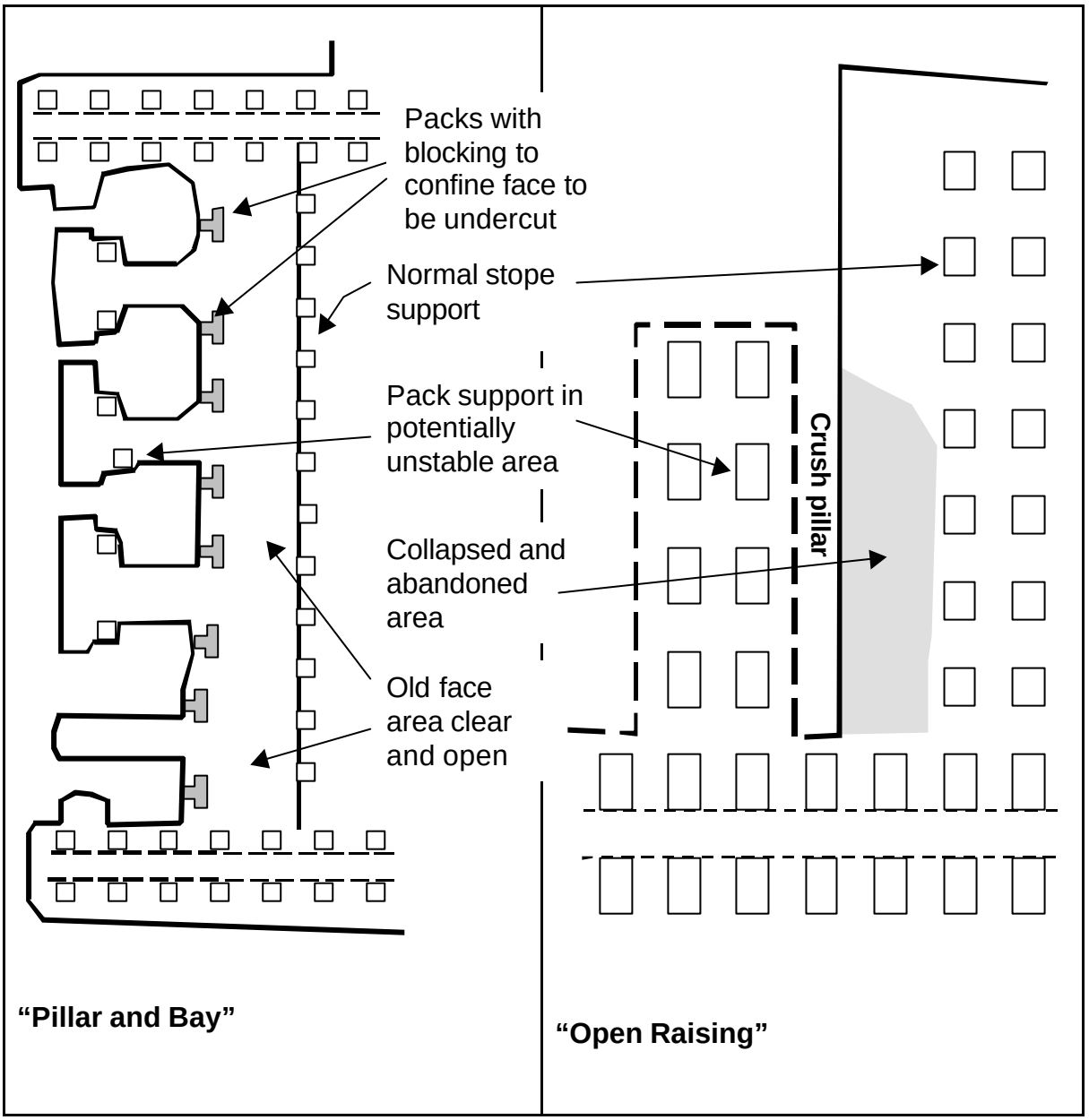


Figure 26 – Two possible methods of undercutting Stope faces

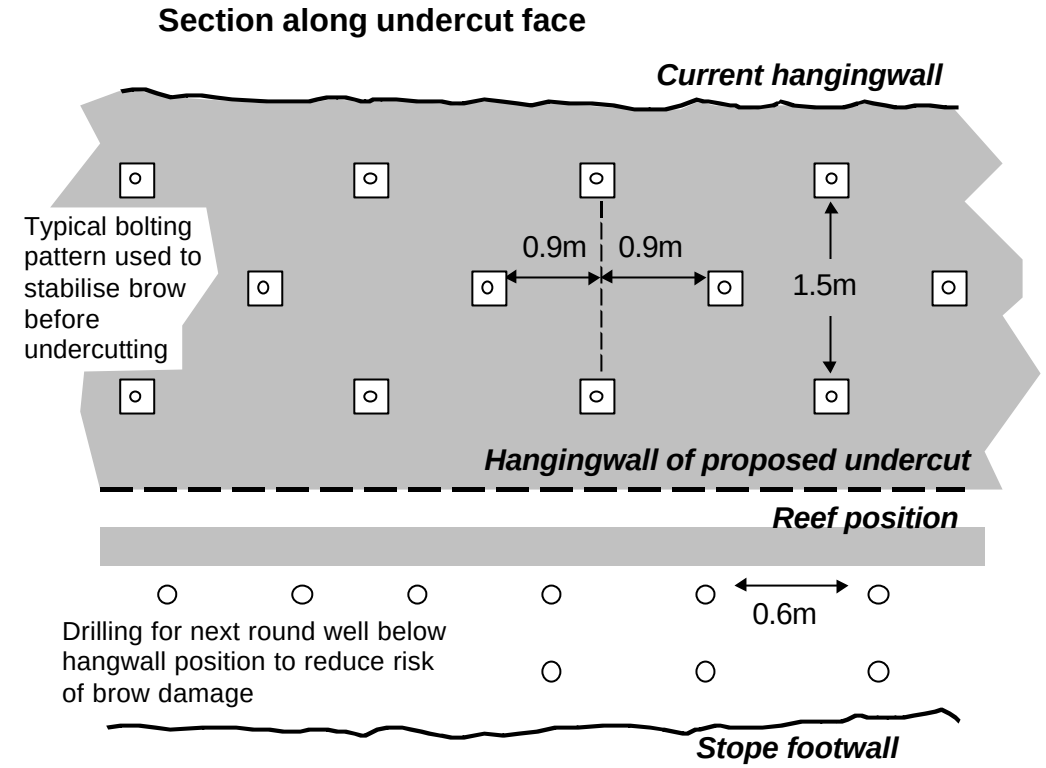


Figure 27 – Undercutting employing roof bolts. (Note that pre-tensioned rope anchors & rapid yielding hydraulic props may also be used)