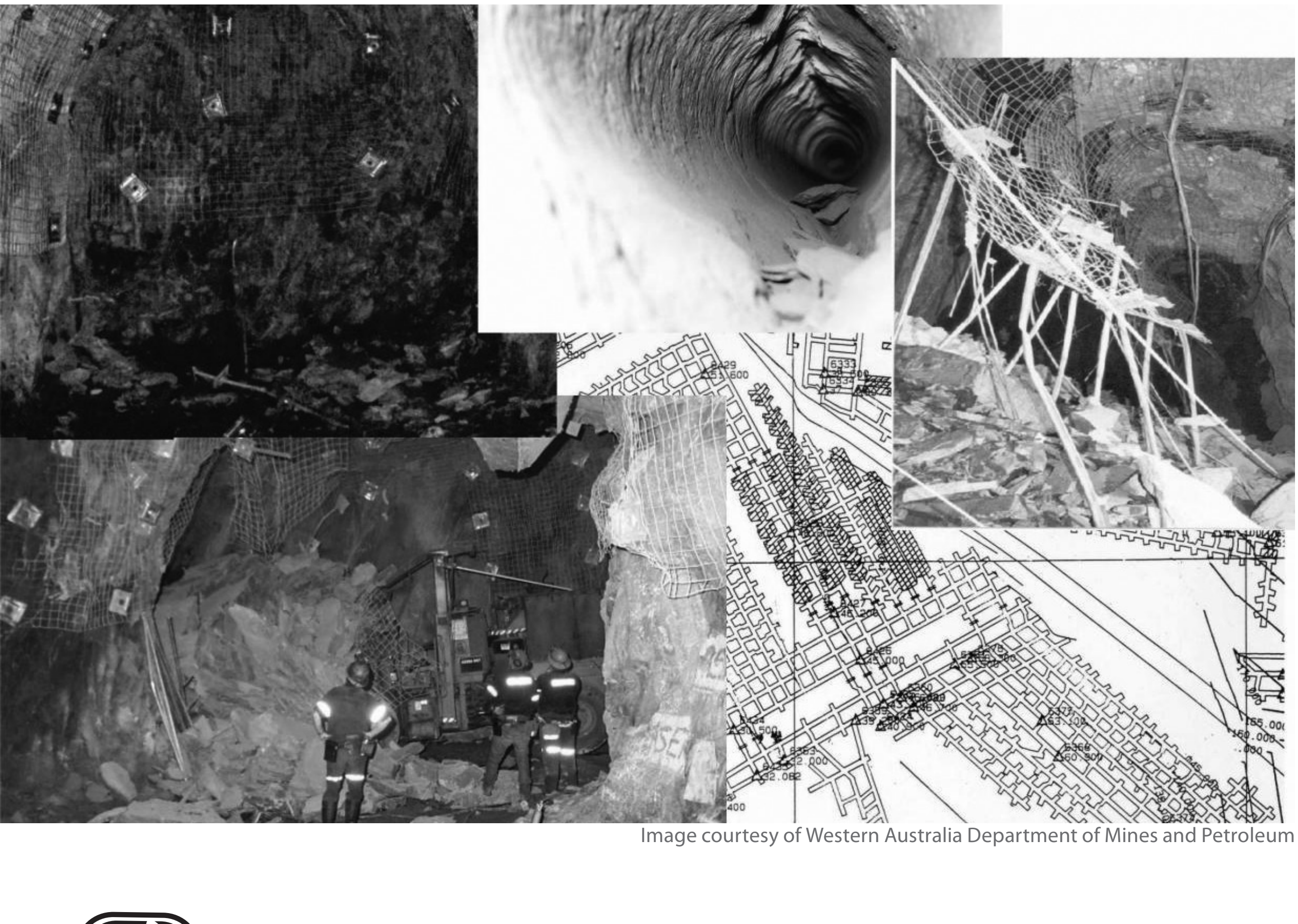
DRAFT

Code of Practice

GROUND CONTROL FOR UNDERGROUND MINES



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FOREWORD

This Code of Practice (this Code) on ground control for underground mines is an approved code of practice under section 274 of the *Work Health and Safety Act* (the WHS Act).

An approved code of practice is a practical guide to achieving the standards of health, safety and welfare required under the WHS Act and the Work Health and Safety Regulations (the WHS Regulations).

A code of practice applies to anyone who has a duty of care in the circumstances described in the code. In most cases, following an approved code of practice would achieve compliance with the health and safety duties in the WHS Act, in relation to the subject matter of the code. Like regulations, codes of practice deal with particular issues and do not cover all hazards or risks which may arise. The health and safety duties require duty holders to consider all risks associated with work, not only those for which regulations and codes of practice exist.

Codes of practice are admissible in court proceedings under the WHS Act and Regulations. Courts may regard a code of practice as evidence of what is known about a hazard, risk or control and may rely on the code in determining what is reasonably practicable in the circumstances to which the code relates.

Compliance with the WHS Act and Regulations may be achieved by following another method, such as a technical or an industry standard, if it provides an equivalent or higher standard of work health and safety than the code.

An inspector may refer to an approved code of practice when issuing an improvement or prohibition notice.

This Code has been developed by Safe Work Australia in conjunction with the National Mine Safety Framework Steering Group as a model code of practice under the Council of Australian Governments' *Inter-Governmental Agreement for Regulatory and Operational Reform in Occupational Health and Safety* for adoption by the Commonwealth, state and territory governments.

A draft of this Code was released for public consultation on *[to be completed]* and was endorsed by the Select Council on Workplace Relations on [*to be completed*].

SCOPE AND APPLICATION

This Code has been prepared to ensure that the mine operator at an underground mine has given adequate consideration of all geotechnical / ground control aspects relevant to the safe design, operation and abandonment of the mine they are responsible for.

The Code provides practical guidance to a mine operator on how to meet the requirement, (under the WHS Regulations for underground mines) to develop, implement and maintain a documented Principal Hazard Management Plan (PHMP) for ground stability.

This Code seeks to encourage the application of current geotechnical knowledge to the practical solution of ground control issues in underground mining. When situations arise with geotechnical issues that are intractable with the current level of knowledge and/or technology, it may be necessary to undertake research and development work.

This Code covers the identification of hazards and control of risks associated with ground movements and inundation in underground mines. This Code concerns the safety of both workers, visitors and any persons that may inadvertently entering the general mine area and has been issued to assist relevant mining personnel with the development of procedures relating to the application of sound geotechnical engineering practice in underground mines.

Due to the widespread and varying nature of potential geotechnical hazards and control measures in underground mines, this Code has been prepared as what could be considered to be a performance based standard that states the result to be achieved rather than a detailed prescriptive methodology for achieving the result.

It is emphasised that, although this Code is not totally inclusive of all factors concerning the application of geotechnical engineering in an underground mine and that it may not be totally suited to the specific requirements of every mine; any variation from this code will need to be suitably justified / verified.

Who should use this Code?

You should use this Code if you are a person conducting a business or undertaking and have management or control of an underground mine. You should also use this Code if you design, manufacture or supply plant or a structure that can influence ground movement or inundation.

This Code will help you determine an appropriate strategy for maintaining ground movement at an acceptable level, and preventing mine inundation through the process of identifying potential hazards and how to eliminate or minimise the risks associated with ground movement and inundation in an underground mine.

This Code can also be used by health and safety representatives and workers who need to understand the hazards and risks associated with ground movement and inundation in underground mines.

1 INTRODUCTION

1.1 What is ground control?

Ground control is the methodology applied to maintain all the risks associated with various forms of ground movement and inundation in underground mines within an acceptable level. It is applied to all stages of a mine – from feasibility through operation and finally abandonment.

Ground control methodology is largely determined as a function of the interaction of various qualities of the rock mass with various aspects of the mine planning and design methodologies. Depending on the nature of these interactions, rock support and reinforcement will required to achieve effective ground control.

Consequently, effective ground control (EGC) may be considered to be a function of three main components:

- Site Ground characteristics (SGC);
- Mine planning and design (MPD); and
- Ground support and reinforcement (GSR).

$$i.e. \qquad EGC \propto \int (SGC, MPD, GSR)$$

It can be argued that GSR can be included as a part of MPD; however, for the purposes of the code, and due to its relative importance, GSR has been isolated as an integral parameter for EGC.

Factors to be considered when assessing/quantifying SGC are discussed in Chapter 3 of this Code. MPD aspects are discussed in various parts of Chapter 4. GSR issues are discussed in Chapter 5.

Ground refers to rock in all the possible forms that it may take from a fresh, high strength material to an extremely weathered, very low strength, essentially soil like material. This term also includes all (back) fill materials, both cemented/stabilised in any way, or uncemented.

Ground movements relevant to this code include events such as falls of ground (static and dynamic), subsidence/sagging, swelling, bulking, buckling, heave, elastic strain, inundation, and movement caused by explosions. Inundation hazards can be very complex in nature; involving a large number of influencing factors and variable combinations of water and ground and/or waste materials.

In dealing with the complex range of issues in geotechnical engineering, it is useful to consider two types of ground control:

1. “Workplace” scale ground control, and
2. “Mine-wide” scale ground control.

Workplace ground control involves those factors that the workforce can have significant control during their day to day mining activities; with input from mine design and geotechnical staff. Ultimately, however, these matters are the responsibility of the mine operator.

Mine-wide ground control involves those factors that affect the stability of the whole mine, or large sections of the mine, and may typically include one or more stopes, pillars, abutments and development openings. These matters are usually beyond the capacity of the individual miner or general workforce to deal with and are under the control of mine designers and geotechnical staff. Again, the responsibility of managing these matters falls to the mine operator.

The terms workplace ground control and mine-wide ground control, as described above, will be used in the remainder of the code. There are no clear cut boundaries between these ground control divisions as the two obviously grade into each other. Consequently some of the statements that are made later for one particular area of ground control may apply equally to the other, depending on the mining method, the depth of mining and/or the scale of mining operations.

1.2 Why is it necessary to pay attention to ground control?

Controlling the potential for hazardous ground movements and inundation of an underground mine to within acceptable limits is essential. Both hazards can result in serious harm or death of workers or persons that may inadvertently enter a mining area. The hazards are not always obvious. For example, the outcome of the hazard of a loose rock falling from a sidewall and striking someone can be fatal by either direct physical contact, or damaging the plant in which the worker is working. The presence of certain geological structure (natural planes of weakness in the rock) that override the effectiveness of any ground control measure, is not always obvious from within the mine.

The potential risks of working at a location within a mine that is exposed to inadequate ground control include:

- loss of consciousness, injury or death due to the immediate effects of contact with moving objects
- loss of consciousness, injury or death due to the immediate effects of physical entrapment
- asphyxiation resulting from damage to ventilation systems leading to an area that has been isolated

The potential risks imposed on localities near to a mine that has inadequate ground control include:

- subsidence and seismic damage
- surface water or groundwater depletion or contamination,
- surface mine structures (e.g. rock waste dumps) spilling onto that location etc.

1.3 Who has duties in relation to ground control?

All persons who conduct a business or undertaking have a duty of care under the WHS Act to ensure, so far as is reasonably practicable, that workers and other persons are not put at risk from work carried out as part of the business or undertaking.

A mine operator must not allow a worker to enter the mine unless the person has complied with the requirements under the WHS Regulations as they apply to the mine, and unless it can be demonstrated that the risk for hazardous ground movement or inundation is negligible. This duty involves identifying all hazards, assessing the risks and putting in place specific risk control measures.

Designers, manufacturers or suppliers of plant or structures have a duty to ensure that the product being supplied to the mine is suitable for the purpose it is intended and quality guaranteed.

Workers have a duty to take reasonable care for their own health and safety and that they do not adversely affect the health and safety of other persons. Workers must comply with any reasonable instruction and cooperate with any reasonable policy or procedure relating to health and safety at the workplace. If personal protective equipment is provided by the person conducting the business or undertaking, the worker must use it in accordance with the information, instruction and training provided on its use.

Emergency service workers under the direction of an emergency service organisation are not necessarily required to comply with the WHS Regulations for ground control in underground mines during the course of rescuing a person from an underground mine, or providing first aid to a person in an underground mine. However, the principal employer of that mining operation must provide clear instruction and necessary training within the scope of any activities that need to be undertaken.

After all hazards, risks, and control measures have been identified, it is the responsibility of the mine operator to develop a formal Principal Hazard Management Plan (PHMP) which clearly specifies the actions to be taken to ensure safe working conditions with respect to ground movement and inundation in all areas of the mine, from the construction stage through to mine closure. The PHMP is to be used as a “working document” that is updated / modified as and where necessary as the mine expands and the level and types of risks to the safety of workers (and adjacent landholders) change. The PHMP forms part of the Work Health and Safety Management System (WHSMS) required by the regulations.

Managing risks

Prior to mining, it is necessary to develop a hazard register for all issues relevant to ground control in all areas of the proposed mine. This register will form the basis of all decisions made with respect to mining methods/approach to ultimately ensure that a mine can remain viable (safe and cost effective) for the required mine life. For example, where risk mitigation for ground control hazards requires changes to the mine operations that are expensive and/or less productive, (for example, when longwall mining encounters faulted areas or when caving mining methods encroach on other tenements or public infrastructure) then the viability of the mine must be interrogated closely.

This process is known as *risk management* and involves the four steps set out in this Code:

- identify hazards,
- assess the risks,
- eliminate or minimise the risks by implementing effective control measures, and
- monitor and review the performance of control measures.

Further guidance on the risk management process generally is available in the *Code of Practice: How to Manage Work Health and Safety Risks.* Points of interest with respect to ground control risk management are available in reference material such as Potvin and Nedin, 2003.

A useful tool to assist this process is to divide the mine into areas or regions and categorise them according to relative risk (following documented geotechnical risk assessment). It is obvious that this hazard identification and risk assessment process should continue during operation for the life of mine.

With respect to mining personnel, the geotechnical risk assessment shall take into consideration the following risk factors: EGC and exposure risk (ER). The term EGC, mentioned above, is discussed in more detail in Chapter 2, ER is a function of the cumulative length of time personnel are exposed to a particular area/hazard.

For example, mine localities with high frequency or long duration of visitation by personnel (for example, crib rooms, workshops etc.) should have higher standards of ground control. Areas of “no access” are unlikely to require surface rock support. However, the requirement for remedial work shall be assessed if and when such areas are reopened.

In order to comply with this requirement, it follows that all ground control management systems need to be formalised into a working document that is continuously re-evaluated and modified as necessary. This working document is referred to as a ground control management plan (GCMP). Further discussion of the GCMP is provided in Chapter 6 of this Code. As stated previously, the GCMP forms an integral part of the mine’s overall PHMP.

2 EFFECTIVE GROUND CONTROL IN UNDERGROUND MINES

It is to be recognised that underground mining experience and professional judgement are important aspects of geotechnical engineering that are not easily quantified, but which do have the potential to contribute significantly to the formulation of a variety of equally acceptable and potentially viable solutions to a particular situation. A mine operator at each underground mining operation must recognise, identify and address the geotechnical issues that are unique to a particular mine, in an appropriate manner, using current geotechnical knowledge, methodology, plant and software. It will be appreciated that every mine does not necessarily have to apply all the techniques discussed in this Code. Conversely, this Code may not cover all the issues that need to be addressed. However, sound management requires that the techniques applied to a given set of conditions should be carefully selected and justified.

As described in Chapter 3, effective ground control (EGC) is the methodology applied to maintain all the risks associated with various forms of ground movement and inundation in underground mines within an acceptable level.

In order for control ground movements to remain at acceptable levels of risk, it is necessary for the practitioner / mine operator to have a sound knowledge of both the mechanisms that allow ground movement and inundation, and all the factors that can influence or control ground movement and inundation. These influencing factors can be referred to as risk modifiers.

By default, this code requires that all high drives/headings (>3.5m high) have surface rock support applied to control ground movements. This default requirement can be lifted in cases where the mine operator has assessed in detail and determined that the hazard of localised rock fall can be managed by regular monitoring and check scaling, and the details of this assessment and management strategies formally included within the PHMP. It is considered unlikely that the mine operator will be able to obtain enough detailed data prior to commencement of mining in metalliferous mines to allow exemption from this requirement in the very early stages of mining.

[This default requirement is based on the industry understanding that in headings higher than 3.5m it becomes increasingly difficult to check and scale safely without the use of specialised equipment to access the high backs and side walls. In addition, cap lamp illumination is inadequate for identifying hazards in high headings. In high headings where surface rock support is installed the need for regular checking is reduced and the integrity of the excavation is greatly increased.] (MOSHAB, 1999)

It follows that the GSR applied to the surface of a mine void needs to be effective and well suited to each application. (GSR design considerations are given in Chapter 6.)

The underground mining environment across Australia varies widely. Simple issues such as ore body geometry, mining systems and size of mining operations can have a significant impact on ground control; let alone the highly variable nature of the geological/geotechnical environment at each mine. This diversity, combined with the high level of uncertainty that exists in the state of knowledge of the rock mass geotechnical conditions, should be recognised and taken into consideration when developing EGC strategies:

- The rock mass is not a continuum but is comprised of a large number of discontinuity bound potential blocks the size, shape, orientation, location and number of which are largely unknown;
- The forces or stresses acting in large volumes of the rock mass are generally unknown and are subject to variation (possibly as a result of block interactions or rock anisotropy), however "point" measurements of the rock stress field are possible;
- The strength of the rock mass is not well known and is difficult to measure in large volumes of rock; and large scale rock testing is difficult and expensive to conduct (however, it may be estimated by back analysis);
- The time dependent behaviour of the rock mass is not well known;
- Blast damage to the rock mass, particularly from large scale blasting operations, is an additional factor that has generally not been well quantified,
- Large scale caving/subsidence mechanisms are generally not well projected in advance of mining.

In view of the above uncertainties it is not surprising that even the most carefully planned and designed underground mines have to deal with the unexpected. Consequently, it would be wrong to suggest that there are rules of thumb or specific guidelines that are universally applicable in every situation, at any mine, in perpetuity.

Consequently, the mine operator, when developing effective ground control, should introduce design factors (of safety) and conservative mining practices that are reflective of both the level of uncertainty, and the perceived level of risk.

As stated previously, effective ground control can be attributed to the successful management of three factors; ground characteristics (GC) [as defined by the geotechnical model, mine planning and design (MPD) and ground support and reinforcement (GSR).

$$i.e. \qquad EGC \propto \int (SGC, MPD, GSR)$$

The interaction of various aspects of the MPD (e.g. damage due to blasting or cutting; and the size, number, shape, type and orientation of openings) with the host rock will determine the site ground conditions within a mine and ultimately the GSR required attaining EGC. Each of these factors has a large number of interrelated components (needing to be identified, qualified and well understood) that can influence or modify residual risks. Some examples of relevant risk modifiers are provided in the following sections.

3 SITE GROUND CHARACTERISTICS (SGC) / GEOTECHNICAL MODEL

A number of fundamental geotechnical characteristics of the ground/rock mass effectively determine ground movement and behaviour in and around a mine:

- Geological structure
- Rock stress
- Engineering properties of the ground/rock mass
- Groundwater

It is imperative that the potentially diverse range of ground characteristics around and within a mine, are recognised and well understood in order to achieve safe and cost effective ground control.

Consequently, the mine operator should develop a geotechnical model that quantitatively defines each of the above ground characteristics in all areas of the mine. The nature and form of the geotechnical model can be considered as a database that allows relevant and truly representative information to be readily distilled for critical design purposes such as GSR and MPD.

For mine wide-design purposes, the above rock mass characteristics should be used to divide the mine into volume domains of expected ground behaviour.

An example of the end use of a geotechnical model is the development of numerical models for specific areas of the mine or the mine as a whole.

3.1 Geological structure

Geological structure refers to all the natural planes of weakness in the rock mass that pre-date any mining activity and includes: joints, faults, shears, bedding planes, foliation and schistosity. Across these natural planes of weakness or discontinuities the rock mass has very little or no tensile strength. A discontinuity is any significant mechanical break or fracture of negligible tensile strength in a rock (Priest, 1993). Planes of weakness divide the rock mass up to a collection of potential blocks; the size, shape and orientation of which strongly influence rock stability conditions in underground mines. This assemblage of discontinuities is an important characteristic of any given rock mass.

Geological structure can have a range of risk modifying characteristics that the mine operator needs to understand - including:

- Orientation - usually specified by dip angle and dip direction
- Spacing
- Persistence or continuity
- Roughness

- Wall strength
- Aperture
- Filling
- Seepage, and
- Number of sets.

The important role that geological structures have in ground control cannot be over-emphasised. Thorough investigation and analysis (Priest 1993) of geological structure is vital to a good understanding of the major influence that geological structure exert in determining the ground conditions in underground mining. For instance, the combination of wide excavation spans and the presence of potentially difficult to detect flat dipping continuous planes of weakness in the mine roof/backs is particularly adverse for rock stability.

There should be a thorough understanding of the geological structure on both workplace-scale and the mine-wide-scales as a prerequisite for the successful management of ground control. Statistical records clearly demonstrate that the vast majority of hazardous ground movements result from the presence of geological structure, and the particular characteristics of each risk modifier listed above.

It is recommended that, to the extent that is reasonably practicable, systematic and on-going efforts should be made to understand genesis and other geotechnical characteristics of the geological structure by using a variety of standard geotechnical methods including:

- Identification of the geotechnical domains in the rock mass throughout the mine;
- Geotechnical scanline sampling (Priest, 1993) in selected development that is mutually orthogonal, in three dimensions, and/or oriented core logging, typical of each domain, to establish baseline geotechnical data on planes of weakness for each domain with a minimum of bias; Scanline sampling of planes of weakness should include: orientation, persistence, spacing, joint roughness, joint wall rock strength, joint aperture, joint infill and seepage;
- Regular geotechnical area or window sampling (Priest, 1993) in each heading or stope to confirm the existence of major joint sets and identify any changes;
- Use of computer based geological structure data plotting, analysis and presentation methods, e.g. DIPS (Diedrichs and Hoek, 1996), to determine the orientation, persistence, spacing and other characteristics of individual joint sets;
- The transfer of this data to geological plans and/or computer models for use in geotechnical engineering and mine design and development of the PHMP.

As the Code requires that ground control issues be considered during the whole life of a mining operation, it is essential that suitable steps are be taken to ensure that appropriate (and representative) data for geological structure are collected at all stages of mining.

It will be appreciated that in the early stages of exploration there may be comparatively few diamond core boreholes with detailed geotechnical logging. Once the potential for economic mining has been identified the mine operator should encourage geotechnical logging of a higher proportion of all diamond cored bore holes - as soon as the core becomes available (to avoid issues such as degradation of core samples).

Down-hole geophysical logging methods may be used to extract some geotechnical data from various types of drill hole walls. These down hole logging techniques should be calibrated in known ground conditions by comparing the results obtained from conventional geotechnical logging of whole diamond drill core with those obtained from down hole geophysical logging.

Regardless of the actual number of holes geotechnically logged, what is of fundamental importance is that those holes that are geotechnically logged constitute a representative sample of the ground conditions found in the ore zone(s) and the host rocks of a mine.

3.2 Rock Stress

In general, mines below the earth surface are excavated with a “confining environment” – defined by stresses in the earth’s crust. These inherent confinement stresses work in three dimensions around the mine void. The three dimensional rock stress, for design purposes, is typically simplified as having has both magnitude and direction in three principal, orthogonal stress directions.

Inherent stress at both regional and site scales and can vary considerably – largely due to geological structure. The potential for variation in stress environments within a mine, for the life of the mine must be suitably quantified in advance of the mining front.

In addition, an underground mine can be expected to influence the nature of the local stress field – largely depending on the size and orientation of the mine void in relation to the inherent stress field and local ground conditions (e.g. stiff intrusives can carry more strain energy/stress than a softer surrounding rock mass).

Rock stress in and around a mine can therefore be considered to consist of two parts:

1. Pre-mining stress field; and
2. Disturbance effects due to excavation (dimensions and shape).

$$i.e. \quad Rock\ stress \sim \int (virgin\ stress\ field, mining\ disturbance)$$

The pre-mining stress field primarily consists of two components:

1. Forces exerted by the weight of overlying rock mass; and
2. Lateral forces (tectonic forces) in the Earth's crust.

The importance of rock stress and its influence on underground mining activity should be recognised and understood. The rock stress field around an excavation provides the driving forces that can cause rock instability of considerable violence. There are two types of stress measurements that can be undertaken:

1. Absolute rock stress measurements; and
2. Stress change measurements.

Several methods can be used to estimate the magnitude and orientation of the rock stress field (Dunnicliff, 1993, Amadei and Stephansson, 1997, Hudson et al, 2003, Villaescusa et al, 2002), in terms of absolute stress levels or stress changes, see Table 1.

Table 1 EXAMPLES OF ROCK STRESS MEASUREMENT METHODS

ABSOLUTE STRESS MEASUREMENT	STRESS CHANGE MONITORING
Acoustic Emission CSIRO Hollow Inclusion cell (3D)	CSIRO Yoke gauge (2D)
Borehole slotter stressmeter (2D)	CSIRO Hollow Inclusion cell (3D)
USBM borehole deformation gauge (2D)	Vibrating wire stressmeter (1D)
Hydraulic fracturing method (2D)	Flat or cylindrical pressure cell (1D)
CSIR "doorstopper" (2D)	Seismic monitoring of a rock volume

Stress changes can occur in the rock mass in the vicinity of an excavation, particularly large stopes. The creation of a large void causes the rock stress field to “flow” around the void. The stress carried by the rock removed when the void was formed is redistributed to other areas of the rock mass around the void. This redistribution of stress around the void may cause stress increases in some areas and stress decreases in others. For example, the wall rocks in the central area of a high narrow stope and mine working excavated below shallow dipping extraction panels may experience a significant reduction in stress level. However, rock in the abutments of the stope, or crown pillar if one was formed, will probably experience an increase in stress level. These stress changes may be very subtle and can have a significant influence on the ground conditions.

It is not suggested that every mine should necessarily undertake a comprehensive programme of rock stress measurement. However, it is reasonable to expect that mine management does recognise that rock stress is an issue that cannot be ignored. When determining whether or not to undertake a rock stress measurement programme it may be necessary to consider a number of things including: size of the mine, mining depth, presence of stress related ground conditions, use of entry or non-entry mining method(s), major geological structure, production rates, mining history of the stope(s) and/or development heading(s), stope and pillar dimensions, presence or absence of fill, consequences of failure, etc.

It will be appreciated that all of these rock stress "measurement" methods require that strain, or some other parameters, are measured and then converted into a stress level by means of elastic or seismic theory. The reliable determination of the rock mass stress field magnitude and orientation is not something to be undertaken lightly or in haste. Considerable experience, technical skill, and appropriate equipment plus technical backup are required for success.

High rock stress conditions

Mines with rock stresses approaching rock strength are considered to be operating in high / elevated rock stress conditions. Under these conditions, rock "behaviour" can vary significantly to that expected in "low stress" environments. A term commonly used for high rock stress environments is seismic rock conditions.

Seismic rock conditions / mining seismicity, has been the subject of considerable international research and analysis for many years. Seismicity associated with underground mining operations is usually caused by the progressive build up of stress levels in the rock mass remaining around an excavation by the progressive removal of rock. Mine abutments and pillars are the main areas of a mine that attract high stress.

Under the right circumstances, seismic rock conditions can cause one of the following things to happen:

- sudden movement or slip occurs on pre-existing planes of weakness in the rock mass; and/or
- failure through the intact rock mass creating a new plane or planes of weakness on which movement can occur.

Movement of the rock mass allows the partial dissipation of high rock stress levels and allows the rock mass to regain a state of equilibrium. These movements of the rock mass can result in a wide variety of consequences including:

- Rock noise;
- Workplace-scale rock falls;
- Rock ejections into excavations at high velocity;
- Large-scale collapse or crushing of excavations; and
- Bursting of pillars or faces in development headings or stopes.

There is always potential for the workforce to be exposed to hazards associated with seismically active ground conditions where high rock stress levels exist. The use of appropriate mining practices when seismic rock conditions are encountered is an important issue that management should recognise and address.

The design and installation of ground support and reinforcement systems that are capable of withstanding dynamic loading caused by seismic rock conditions is a significant challenge for the mining industry. The design method adopted for each site (e.g. Kaiser etal, 1996) must be suited to local conditions, taking into considerations the "limitations" of each method, the limitations associated with GC and be capable of accounting for expected future stress regimes/seismic potential at various stages of mining.

3.3 Engineering properties of the ground/rock mass

Stating the obvious; the extent to which ground can be expected to move is primarily dependent on the mechanical properties / engineering characteristics of the rock / ground mass. Consequently, the mine operator of a mine will need to determine all the mechanical properties of the rock mass that are relevant to specific mechanisms of ground movement or failure expected at that minesite. Mechanical property tests typically include; unconfined compressive strength (UCS), unconfined tensile strength (UTS), Elastic Modulus, Poisson's ratio, flexural strength, shear strength, cohesive strength, angle of internal friction, bulk density, plastic index, porosity, permability etc. In some circumstances, it will be necessary to conduct post-failure / residual strength tests to determine potential outcomes in the event a volume of rock (e.g. a pillar) fails or slides on geological structure.

Although recognised/standard laboratory testing procedures are available to determine various intact rock strength parameters, it is most often the case that laboratory-determined mechanical properties will not be directly used for design purposes.

The strength of the rock mass is controlled by the complex interaction of a number of factors including:

- Intact rock substance strength;
- Geological structure (planes of weakness) - particularly orientation, persistence, spacing and shear strength parameters;
- Groundwater; and
- Alteration of minerals on exposure to air and/or water with time.

As a result of the complex interaction of the above factors, that can occur when rock is subject to load, it has also been found that the strength of rock, in general, is dependent on the volume of rock being loaded and the direction in which the load is applied. This volume and directional dependence of rock strength is not generally found in other engineering materials, e.g. well mixed concrete or steel.

Rock mass strength is probably the least well defined aspect of geotechnical engineering. There is a need to have a much better understanding of rock mass strength, ranging from small pieces of intact rock with a volume measured in tens of cubic centimetres to very large volumes of rock measured in tens of thousands of cubic metres. There are some obvious practical difficulties in conducting tests on large volumes of rock. The limitations that exist in this area of geotechnical engineering need to be recognised, particularly with regard to the use of numerical stress analysis techniques.

Published techniques exist (e.g. Hustralid, 1976; Hoek and Brown criteria - e.g. Hoek et al, 1997; Kramadibrata and Jones, 1993; and Stacey & Page, 1986) to assist the mine operator to estimate "downgraded" rock mass properties for various types of rock. Research by Misich, 1997, on the other hand suggests that, in certain circumstances, laboratory test results can be used to represent the mechanical properties of very weak rock masses.

Back analysis, typically of instrumented sections of a mine and/or failures, can be a very useful approach to estimating the rock mass strength (e.g. Pells, 2008). As the phrase suggests, the method can provide estimates of some of the input parameters of a system by analysing its behaviour under load. The method relies on instrumentation (Dunnicliff, 1993, Amadei and Stephansson, 1997) to determine, directly or by calculation, changes in displacements, strains, pressures and stresses during mining. This approach generally requires a good knowledge of the geometry of the situation, stress field, likely mode of failure, influence of geological structure, use of appropriate numerical model(s), etc for success.

Hard rock conditions

Hard rock conditions are generally the most common ground conditions encountered in underground mines in Australia. In this environment rock failure is primarily controlled by the presence of geological structure and the influence of gravity. The size and shape of the potentially unstable rock blocks depends primarily on the orientation, continuity and spacing of the planes of weakness in the rock mass plus the size, shape and orientation of the mining excavations. In hard rock mining conditions the strength of the intact rock is usually considerably greater than 25 MPa.

Soft rock conditions

The recognition of soft rock conditions is a very important geotechnical issue that overlaps the boundary between the usually separate geomechanics disciplines of soil mechanics and rock mechanics. Soft rock ground conditions may be identified as those where the rock (or backfill) has an unconfined compressive strength that ranges between approximately 0.5 to 25 MPa. There is a need for the combined application of both soil mechanics and rock mechanics methods for the analysis of soft rock materials.

Geological structure has potentially less influence on ground control in soft rock conditions. Hazards associated with occurrences such as pillar punching / foundation failure, roof collapse due to excessive shear and bending stress and potential problems with swelling clays (to name a few) need to be considered in these rockmass conditions.

The importance of high pore water pressures in soft rock conditions also needs to be recognised and addressed. The dissipation of excess pore water pressures in the soft rock mass, with time, may lead to movement of the rock mass into the excavation resulting in gradual closure of the excavation. The potential for time dependent behaviour (e.g. creep) of the rock mass should be addressed in a soft rock mining environment for issues such as the design of mine excavations, the design and installation of rock support and reinforcement, and mine abandonment. Such ground behaviour can also be observed at comparatively shallow depths of hard rock metalliferous mines in WA where the rock stress levels may be a substantial percentage of the intact rock strength.

3.4 Groundwater

The hydrogeological environment of an underground mine should be understood to an appropriate level of detail. This information can facilitate the prediction of seasonal changes of pumping requirements, the continued lateral and vertical expansion of the mine with time, and caving or subsidence of overlying aquifers. Groundwater is likely to be more of an issue in a new mine or new area(s) of a mine where very little of the rock mass has been actively dewatered by mining activity. It is recommended that the mine operator utilise exploration drilling as much as possible to assist with the defining of site hydrogeology – e.g. undertaking packer testing to determine various hydrological properties of the rock mass such as permeability and storativity, or simply noting the depth of any water loss or make during drilling.

Exploration drill holes intersected by underground openings can be a potential source of high pressure and/or high flow rates of water. The surveyed downhole path of all exploration holes should be known and plotted on plans and cross-sections, not just the collar and the toe positions. The sudden unexpected in-rush of water from a drill hole can jeopardise the safety of the underground workforce in the vicinity or more generally if the flow rate is sufficiently large. Having the correct size hole packers or stempipes on site can minimise uncontrolled water in-flow. Effective grouting of all exploration holes requires a good understanding of the source of the water likely to be transmitted by the hole, i.e. surface run-off and/or water contained within fractured zones in the rock mass. Development into new areas of the rock mass, with limited prior drilling information and/or where high pressure groundwater is suspected, should be treated with caution. Drilling long surveyed probe holes, e.g. diamond drill holes, ahead of the face, through a stem pipe fitted with a valve of appropriate pressure rating, is one approach that may be applicable.

The combination of groundwater and exposure to air may have an adverse influence on the rock mass strength, particularly in soft rock ground conditions. The potential for corrosion of the ground support and reinforcement by groundwater, in association with air and the particular minerals present, also needs to be recognised, investigated and if necessary remedied.

Water under pressure in the rock mass can reduce the normal force acting across the joint which results in a reduction in the shear resistance mobilized by friction. Briefly, the soil mechanics law of effective stress states that the total stress in saturated ground consists of two components:

- An effective stress component (the stress carried by the interparticle contacts in the ground); and
- Hydrostatic stress of the water in the voids (pore water pressure).

In soft rock, conditions the pore water pressure can be a significant percentage of the total stress, resulting in a significant reduction of the effective stress. This causes a significant reduction in the strength of the rock mass compared to the drained condition. In hard rock conditions, the reduction in the rock mass strength is considerably less because the intact rock strength is generally several orders of magnitude greater than the pore water pressure.

Some minerals and rock types, eg clays and argillaceous rocks, may exhibit a reduction in the strength of the rock mass on exposure to water or repeated wetting and drying. This behaviour may need to be considered in relation to the rock types selected as stope fill if hydraulic transport of the fill material is proposed.

4 MINE PLANNING AND DESIGN (MPD)

4.1 MPD approach

Simplistically, an underground mine may be considered to be an engineering structure that is made up of a two components:

- Mine voids (vertical/subvertical and lateral access development excavations and stopes both filled and unfilled (including caving methods);
- Pillars and abutments of various dimensions and orientations.

These excavations and regions of intact rock interact in subtle and often complex ways that can be difficult to predict; necessitating the application of soundly based geotechnical engineering methods to ensure acceptable levels of mine safety, productivity and economic efficiency.

The “design life”, size, shape, orientation, rock characteristics and purpose of each particular engineering structure must be suitably taken into account when designing a mine. As would be expected, voids with longer design life and higher degrees of inherent risk require significantly more demanding design criteria.

It follows that ore stoping / extraction methods selected by the mine operator will determine, to a large extent, each of the controlling factors mentioned above. These mining methods also greatly impact on the degree of exposure of mine personnel to hazards associated with those methods of mining. (For the purposes of this Code, stoping methods have been placed within two categories; entry and non-entry – see discussion below.)

Somewhat less obvious, but important components of MPD is extraction sequencing, production scheduling, and excavation methods (particularly where blasting is used) to develop mine openings throughout the mine. These components can significantly affect ground conditions in a number of ways (e.g. stand-up time, proximity to other workings, stress redistribution within and around the mine, and artificial damage to the rock mass). Further discussion on issues relevant to sequencing, production and excavation methods is provided later in this code.

Consequently, MPD is to be an iterative process, whereby the “hazardous products” of each mining method are compared to expected ground conditions and required stabilisation techniques to determine the most cost effective, safe approach to mining an orebody.

Mine Voids

For the purposes of this code, the design life of mine voids has been divided into two categories;

- Long term voids; and
- Temporary voids;

with long term voids having a design life of at least one year. Examples of the two types of openings are given in Table 2.

TABLE 2. EXAMPLES OF VARIOUS TYPES OF LONG TERM AND TEMPORARY VOIDS

LONG TERM VOIDS	TEMPORARY VOIDS
Shafts	Drill drives
Drifts, adits, declines, headings.	Cut-off rises
Main dip and level development	Mill holes (drawpoints)
Escape ways and refuge bays	Extraction drives
Intake & return airways	Working party magazines
Offices and lunch rooms	Stope ventilation rises,
Workshops and Electrical substations	Stope access drives
Crusher and conveyor excavations	
Main pump stations	
Main magazines and fuel storage bays	

From Table 2, it can be seen that there are a number of voids that could be classed as long term openings; suggesting that a proportionate number of openings in a mine require rigorous and detailed design.

The impact of each mine void on general mine stability can be further mitigated to varying extents; depending on GSR (Section 5) and the use of backfill (Section 4.1.3).

Pillars and abutments

A pillar is an area of ore (in contact with both hangingwall / roof and footwall / floor materials) that is left to support the overlying rock, hanging wall or backfill. These structures are an integral component for the continued safe operating conditions in most underground mines.

Pillars can be permanent - left in place for the life of the mine – or temporary - recovered sometime after their formation. Permanent pillars may also be stripped / reduced in size during the latter stages of a mine, when risk assessments allow.

Pillars can be designed for mine-wide stability (e.g. intra-panel pillars) or work-place stability (e.g. rib pillars in an airleg stope). “Crush pillars” can be considered to be permanent pillars, as they continue to provide support to roof and floor strata.

Mine abutments can be considered as areas of unmined rock at the edges of a mine void that carry may large regional loads. Abutments can also represent an integral component of mine stability; generally as a zone of support for ground arching - say from a mine pillar, across an extraction panel, to the abutment.

Similarly to the design approach for mine voids, the location, dimensions and orientation of mine pillars and abutments, the degree of detail, rigour and conservatism applied is based on risk assessment – should these structures fail or not provide adequate support as required by the initial design.

Issues to be considered when designing mine pillars include:

- Strength of materials – floor, pillar and roof – and their time dependent characteristics.
- Pillar cross-sectional area and aspect ratio.
- Variations (from pillar design) during to mining methods or spalling over time.
- Ground stress – natural, and stresses due to mine/pillar configuration or nearby mine voids.
- Orebody dip.
- Orebody depth.
- Geological defects.
- Shear strength at floor and roof contacts and influences of water at contacts.
- The use of GSR or backfill to improve pillar stability.
- The presence of important in-mine or other surface structures above the mine and the expected area of influence / angle of draw in the event of pillar failure.

Ore extraction mining methods

As mentioned above, the MPD processes used for stoping / ore extraction in a mine are largely dependent on the intended mining method and whether mine personnel are required to re-enter the stope.

<u>Entry mining methods</u>

Entry mining methods (Hartman, 1992) include cut and fill, room and pillar, bench and fill, gallery stoping and shrinkage stoping. They have the common feature that the workforce is exposed to the potential hazard of rock falls from or collapse of large areas of stope backs and walls, particularly in wide orebodies.

Entry mining methods typically require successive slices or lifts to be mined from the orebody, and hence require regular inspection and scaling and the installation of additional GSR for each lift. Therefore entry mining methods generally require a high level of effort in local-scale ground control; however this provides a benefit in greater control over such factors as ore grade, minimising dilution and maximising recovery as well as improving safety.

Ground conditions have a very strong influence on mining method selection and hence they should be well understood before a commitment is made to the development of multiple stopes. The mining of a trial stope is obviously one approach that could be used in a new mine where there may be some concern about the suitability of the mining method for the expected ground conditions.

Non-entry mining methods

Non-entry mining methods (Hartman, 1992) include open stoping, sub-level caving, block caving and longwall and Wongawilli mining on retreat. Where orebody geometry and ground conditions permit there is a general trend to the more productive non-entry mining methods. These mining methods require a much higher level of technical input into large-scale ground control primarily because of the large dimensions of the area being stoped or caved.

The exposure of the workforce to potentially hazardous conditions is reduced where the work is conducted in development size openings that are usually supported during initial development of the stope. However, the potential exists for large-scale pillar and/or wall collapse in open stope mining methods. Such occurrences may cause rapid flow of materials into nearby mine openings, air-blast problems, dilution and blockage of drawpoints.

Conversely, caving methods may hang-up or not cave in a controlled manner and result in a number of hazardous conditions; including potential for massive airblasts. In fact, hang-ups and irregular caving, particularly at larger distances from the extraction level, should be expected to varying extents – due to the variable nature of most rock masses – and systems must be put in place to detect caving irregularities before they become problematical to the mine.

The down-dip advance of the stope abutment can cause substantial adverse changes in the ground conditions, primarily because of increased mining induced stresses, to the possible detriment of existing or new development in these regions.

Engineered fill is an integral part of the design and operation of some non-entry mining methods. Where fill is used, the design duty, transport, placement and quality control aspects of the fill system should be addressed in a systematic manner to ensure adequate and consistent fill performance during the life of the mine. More discussion of mine fill is provided below.

A balanced geotechnical stope / extraction panel design process should involve the integrated consideration of a range of issues including:

- Orebody geometry;
- Orebody quality and geological variability;
- Ground conditions in the backs / roof and walls;
- Rock fragmentation requirements; and
- Ground support and reinforcement requirements.

Mine fill

Backfilling in mines has been used over many decades - generally for one of three purposes:-

i. Control of ground movements and stresses within the mining horizon
ii. Control of ground movements above the mine horizon (mining subsidence)
iii. Storage of waste materials.

The creation of large volumes of unfilled stope void can develop zones of high rock stress and exposure of significant geological structure to an extent that large-scale displacement (collapse or caving) occurs in an uncontrolled manner with little prior warning. Consequently, the inherent limitations of unfilled open stoping methods, particularly when combined with very high extraction ratios, poor quality ground conditions and a lack of geotechnical engineering need to be recognised by mine management. There are limits to the wall and/or back areas that can be exposed before significant levels of dilution, crown pillar collapse, caving and/or mining induced seismicity occur. The very short term advantages that can be associated with unfilled open stoping methods need to be carefully weighed against the potential requirement to introduce a stope fill transport and placement system, often at short notice, to fill large unplanned voids.

Where backfilling has been implemented as part of the general safe mining practice employed at a mine, there needs to be recognition that the mining process is not complete until the void has been filled within design limits with a suitable material.

Mine fill has a number of very important, but not widely understood, roles to play in large-scale ground control, including:

- Support of individual rock blocks on the surfaces of stope walls, pillar walls and backs (if tight filled) – preventing collapse of the immediate roof / hangingwall and also minimising mining subsidence ;
- Lateral confinement of the rock mass, thus increasing its compressive strength;
- Provision of an adequate working surface in entry stoping methods;
- Enabling secondary extraction by the exposure of backfill is capable of standing safely during the extraction of the adjacent rockmass; and
- Damping the vibrational response of the rock mass during seismic events (Glen, 1993).

The provision of small amounts of lateral confinement to the rock mass, by the fill, can have a very beneficial influence in improving the strength of the rock mass. This fact is demonstrated in triaxial testing of rock core where a small confining pressure can increase the strength of the rock. Fill has the potential to play a significant role in large-scale ground control by providing support over very large areas of stope walls. The importance of the role of fill in large-scale ground control is often under-estimated.

The systematic use of an appropriately engineered stope fill system in a mine can allow the mining of higher extraction ratios in a given orebody compared to a mine with no stope fill, assuming a non-caving method of mining is used. The improved safety conditions and higher extraction ratio are of direct benefit to the economic performance of the mine.

The most common forms of mine fill include cemented and uncemented waste rock fill, paste fill, hydraulic fill and sand fill. All fill types have their own set of hazards that need to be addressed during mine design, planning and scheduling, and during operations. Of all threats posed by mine fill in underground mines, the greatest threat would be from all fills reliant on water content (hydraulic and paste fills in particular). As mentioned previously, if not properly designed, implemented & monitored, these fills have significant potential to inundate large areas of the mine with catastrophic consequences. Inadequacies in any of the following can result in failure of the backfill to act as an engineering / supportive structure and potentially inundation of the mine:

- Fill design (fill specifications must suit purpose).
- Barricade design (must suit purpose).
- Filling strategy (pour-rest cycles, curing time).
- Quality control at process plant.
- Barricade construction (e.g. problems with local ground conditions, excessive drive dimensions, poor quality of materials used, personnel training)
- Overall management systems (e.g. fill request process, quality and performance monitoring strategies, including trigger action plan for out of specification fill or damaged barricades, blasting adjacent to uncured barricades or fill, tight filling/ overpressurising).
- Mining through or adjacent to uncured/ unconsolidated fill, causing collapse or flow of fill into workings.
- Water level and fill level control (including recharge of drained fill in old stopes due to ingress of mine/ ground water). For example, water should not be allowed to accumulate in filled stopes, particularly those filled with uncemented sand fill. The accumulation of water in sand filled stopes can potentially result in the following:
    - Liquefaction of the fill by dynamic loading;
    - Hydraulic pressure on fill bulkheads or barricades; and
    - Hydraulic pressure on lined ore passes or ventilation rises in the fill.

  The removal of crown pillars below filled stopes containing significant volumes of water should be treated with extreme caution and suitable measures to drain the water should be undertaken before the pillar is removed.

Clearly, it is important that the mine operator manage paste and hydraulic fills with extreme caution. A suitably qualified person with expertise in the area of paste and/or hydraulic fill should always be used for fill & barricade designs and implementation of fill systems. Fill systems should be monitored closely by operations personnel and should be overseen and reviewed by suitably qualified and experienced personnel.

Examples of backfill design, implementation and auditing strategies are available from numerous sources; for example; Potvin, Thomas and Fourie (2005).

Department of Mines and Petroleum WA Guidance material on auditing mine fill practices (http://www.dmp.wa.gov.au/6713.aspx#7255).

Extraction sequencing

The need to consider sequencing of stope extraction and filling (if appropriate) often stems from the requirement to minimise, as far as practical, adverse levels of stress concentrations in stope backs, walls, pillars, abutments and around development openings. These adverse levels of stress concentration take the form of very high compressive, very low compressive or possibly tensile stresses. If little regard is paid to the sequence of ore extraction, the end result may be adverse high stress concentrations in remaining ore reserve blocks, with the attendant problems of blast hole closure and mining induced seismicity in a high stress environment or ravelling of the stope walls in a low stress environment.

The comments made above in relation to numerical analysis methods apply equally to this section in regard to the determination of the stope extraction sequence. These methods can be used to compare various alternative extraction sequences with a view to selecting the most appropriate one.

Production schedules

A review of previous production schedules and mining history can provide valuable in-sights as to why particular geotechnical problems may have developed. Collection of geotechnical data, including regular visual observations of ground behaviour, during the various stages of extraction can be very useful in helping to calibrate initial MPD assumptions and strategies.

It is reasonable to expect a mine to have short term and long term production and development schedules, based on known ore reserves. These schedules should identify, amongst other things, areas requiring ground support and reinforcement, stope extraction and filling sequences and pillar formation for a range of time frames during the mine life. Accompanying this detailed production schedule should be a series of plans, or a computer based model, that show a range of issues including:

- Development requirements, priorities, ground conditions and predicted rock support and reinforcement requirements;
- Development and stope services requirements, e.g. ventilation, electric power, water and pumping, etc;
- Proposed stope and pillar extraction sequence; and
- Proposed stope filling sequence.

A LOM production schedule should also be available to present an over-view of mine development and production requirements for the total life of the mine. This schedule should highlight, for example, the formation of permanent and recoverable crown or rib pillars, propose pillar recovery sequences, access requirements and suggest possible mining methods for the recovery of non-permanent pillars.

Mine development excavation methods

Substantial and unwarranted damage can be caused to rock at the perimeter of an excavation through the use of inappropriate cutting or drilling and blasting practices. Indiscriminate cutting through selective roof strata, in coal mines for example, can expose weak materials and develop a cantilevered / overhanging slab is are invariably difficult to control with a standard GSR design. In metalliferous mines, there is a need to have standardised drilling and blasting patterns that have been determined using well founded and recognised blast design procedures (Persson et al, 1994). Rock damage due to the drilling and blasting process can be minimised by the use of a number of methods including:

- Use of correctly adjusted and operating automatic hole lookout angle control and hole parallelism functions on development jumbos;
- Selection of appropriate hole diameter, spacing and burden for the perimeter holes and all other holes in the blast (Persson et al, 1994);
- Use of suitable low energy explosives in the perimeter holes;
- Use of decoupled explosive charges, with a cartridge diameter less than the blast hole diameter, to minimise blast damage at the excavation perimeter;
- Consideration of the influence of the penultimate row of blast holes on rock damage and, where appropriate, modification of the explosive type used to charge these holes;
- Design of the cut and initiation sequence of the overall blast; and
- Where necessary, seeking the advice of the explosives manufacturer(s) on the appropriate use of various combinations of explosive(s) and initiation system(s).

The mine operator needs to ensure that the workforce is provided with on-going training in the safe and efficient handling and use of mining equipment and explosives and initiation devices. When blasting, it is necessary to implement soundly based development and production drilling and blasting practices that assist in minimising blast damage to the rock remaining at the perimeter of the excavation. The design of the blasting patterns should be optimised for the particular combination of ground conditions, initiation system, explosive product, initiation sequence, hole diameter, length of round and geometry of the opening. A critical review of drilling and blasting procedures is recommended on a regular basis to ensure that the minimum practical blast damage is occurring to the rock remaining at the perimeter of the excavation.

There are a number of commercially available, computer based, drilling and blasting design packages that may be used on a consulting basis. The application of recognised drilling and blasting design practices and procedures developed to suit local conditions should be an integral part of a balanced PHMP.

While consultation of the workforce on such matters is recommended, it is not appropriate that fundamental decisions on important aspects of blast design and practice be left in the hands of individual miners on the job, without any blast engineering support.

The aim of any well designed rock drilling and blasting process should be to achieve the required degree of rock fragmentation with the minimum damage to the remaining rock. Blast damage to the rock mass is an unavoidable consequence of conventional drill and blast mining methods. However, much can be done to minimise excessive blast damage to the rock mass by the use of controlled drilling and blasting practices (Persson et al, 1994). The factors that control the success of drilling and blasting include:

- Rock mass properties, primarily orientation, persistence and spacing of geological structure, presence of groundwater;
- Degree of confinement of the proposed blast;
- Degree of rock fragmentation required;
- Selection of the appropriate hole diameter, burden, spacing and length;
- Control of individual hole collar position, hole bearing, inclination and length;
- Placement of holes in a suitable pattern to achieve the required excavation geometry and/or development advance with each blast;
- Determination of the actual blast hole location in three dimensions compared to the design blast hole location, particularly in long hole mining methods, and verification that the actual blast hole location is within the design tolerance, e.g. automatic surveying of blast holes immediately after drilling, with re-drilling if necessary;
- Selection of the required expansion volume to allow for swell;
- Selection of appropriate initiation system(s);
- Initiation sequence of the blast or blasts to fragment the required volume of rock;
- Selection of appropriate explosive or combination of explosives with the required energy levels, effective product life in the blast holes and the appropriate distribution of the explosive through the rock mass;
- Compatibility of the initiation systems and the explosive(s);
- Control of explosive energy levels in the perimeter holes;
- Monitoring of blasts can provide valuable information which may assist in improving the blast design;
- Overbreak in the design size of development and stopes can result in increased waste rock handling and ground support costs in development, and a reduction in the mined ore grade via increased dilution in stopes. Both of these areas can have an adverse impact on the mine’s economic performance; and
- Use of well maintained drilling, explosives handling and charging equipment of appropriate capacity and reach.

The technique of drilling and blasting is a very large field that is constantly evolving and hence cannot be summarised in a few lines. Those interested in pursuing this matter further are referred to their suppliers of drilling equipment and explosives who are able to advise on drilling and blasting concerns.

Large stope blasts or extraction panels have a high potential to cause major damage to the rock in and around nearby development openings and to act as catalysts provoking seismic events. Non-entry stoping / excavation systems, e.g. long hole open stoping, and longwall retreat are much more suited to “mass” mining techniques. The location of permanent development openings, e.g. lateral or vertical accessways or workshops, in close proximity to non-entry extraction systems is undesirable from a consideration of blast vibration (due to explosives or large scale ground collapse) issues. Large-scale production blasts, in close proximity to permanent installations, may require the consideration of the effects of blast vibrations on the integrity of the openings and their associated ground support and reinforcement in the zone of influence of the blast.

There has been a considerable amount of work (Persson et al, 1994) done on the development of blast design tools by organisations such as the Julius Kruttschnitt Mineral Research Centre (JKMRC) in Brisbane, international research groups, consultants and explosives manufacturing companies. It is strongly recommended that mines give serious consideration to the use of one of these blasting design methods when designing large stope production blasts.

The detonation of explosives in the rock mass, particularly large stope blasts, can trigger seismic activity or audible rock noise. The occurrence of this should be recorded, noting for example the location, time, subjective description, number of events, any rock falls, etc. It may be possible to determine a reasonable explanation for these events. However, if the rock noise continues for some time, or occurs at unexpected times, then further investigation of the situation may be advisable as this could be a pre-cursor of more serious seismic activity in the future. These effects may, of course, be just natural re-adjustments in the rock mass and of no particular concern (so long as their cause and effects are understood). Typically, rock noise does not result in damage to the surface of openings or the installed ground support and reinforcement. The occurrence of rock noise does not necessarily mean that a seismic monitoring system should be installed immediately. However, if damage is occurring to the rock mass at the surface of openings and/or if the ground support and reinforcement is being damaged or broken, then further investigation of the seismic activity should be undertaken.

4.2 Mine design methods

Mine design methods generally in use by the mining industry include:

- Empirical methods (e.g. Bieniawski, 1989, Laubscher, 1990, Hoek et al, 1995, Hutchison et al, 1996) based on precedented experience; and
- Numerical analysis methods (e.g. Hoek et al, 1995, Brady and Brown, 1993, and Wyles, 2005).

In small scale mines with good ground conditions, it may be acceptable to use a combination of mining experience with one of the empirical design methods. In larger mines employing bulk mining methods, and in particular those with challenging ground conditions, it may be preferable to conduct a preliminary design using the empirical design methods in conjunction with one or more appropriate methods of numerical analysis, in conjunction with mining experience and stope monitoring techniques.

Empirical methods

The empirical design methods allow mining experience in a particular set of ground conditions to be incorporated into the stope design process. The general methodology of empirical design methods is that, several geotechnical parameters are assessed and given a rating on the basis of simple index tests or visual observations and tabulated numerical values. The rating value is then used to design the “allowable” dimension of mine structure, based on observations / performance monitoring of the same geotechnical parameters with similar ratings in other mining areas.

For mine development and stope designs, these methods typically use one of the rock mass classification methods (Bieniawski, 1989), or a modified version thereof, to relate excavation geometry to the expected ground conditions. The stope geometry may be expressed in terms of "hydraulic radius" determined by dividing the exposed wall area by the wall perimeter. Several empirical design charts (e.g. Hoek etal, 1995, Hutchison and Diederichs, 1996) have been produced to aid the stope design process.

Similarly, several empirical pillar design methods are available in public domain – each having their own strengths and weakness in certain applications. Most are based on a mass-pillar strength, which is altered by a function of the pillar aspect ratio. In some situations, rules of thumb have been used, based on significant numbers of case data (e.g. acceptable pillar width to height minima for crown pillars, and the "indestructible squat pillar" theory for room and pillar-type structures), to derive pillar dimensions for mines.

Prior to using empirical methods to design mine openings, pillars (and GSR - see later), the mine operator needs to be aware that these methods have their limitations (e.g. Palstrom and Broch, 2006, Milne and Pakalnis, 1997, MOSHAB, 1997, and DMP, 1999). Potential exists for the inherent variability of the rock mass to be obscured by the need to make it conform to an arbitrary set of tabulated numbers.

Regular visual observation of stope and pillar performance and, where practicable, instrumentation of mining structures, should be used to verify the continued use of any empirical design process. Where observed performance conflicts with empirical predictions, the mine operator must undertake one of the following actions; modify the empirical method accordingly; use alternative design methods; or derive any verify specific limits for the continued use of that method in that mine.

Numerical analysis methods

Numerical methods of stress analysis or block behaviour, in two or three dimensions, allow the interaction of nearby stopes and development openings to be considered in much more detail than is the case with empirical design methods. The use of numerical methods generally requires considerably more input data including the geometry of development openings, stopes and pillars, extraction sequence, rock stress field, rock mass properties and location and orientation of geological structure.

The development of numerical methods has proceeded at a rapid rate during the past 10 years to the extent that there is currently available a wide range numerical modelling methods that can be run on most high-end personal computers.

The application of user-friendly numerical stress analysis codes may appear very straight forward at first sight. An appreciation of the challenges in: selecting the appropriate stress analysis code, having a sufficiently good model representation of the actual mine geometry being analysed (eg complex 3D geometry being poorly approximated by a 2D cross-section), the quality of the input data versus the inherent variability of the actual rock mass conditions, and having the mining experience and judgement required to correctly interpret the results in the context of actual underground observations; should all help to restrain the unthinking use of numerical stress analysis methods.

Considerable engineering knowledge and mining experience should be exercised to determine the appropriate numerical model for the task at hand; some numerical analysis methods have limited application due to their computational methods.

4.3 Mine Abandonment

By the time of mine closure, there should be adequate data to address all the long-term geotechnical concerns in regard to the abandonment of a mine.

Before underground mines can be legally abandoned, the Code requires that all long term drainage, environmental, and public safety/access issues are adequately considered and controlled.

Environmental requirements for abandoned mines are specified by the license conditions imposed by the relevant Government authorities during the mining project approval process.

5 GROUND SUPPORT AND REINFORCEMENT (GSR)

The terms ground support and ground reinforcement are often used interchangeably, however they refer to two different approaches to stabilising rock (Stillborg, 1994). Ground support is applied to the perimeter of the excavation to limit movement of the rock mass. These methods typically require the rock mass to move on to the support to generate loads in the support. Ground reinforcement is installed beyond the mine perimeter, into the rock, to limit movement of the rock mass.

Ground support and reinforcement includes all the various methods and techniques of both kinds that may be used to improve the stability of the ground.

There is a wide range of rock reinforcement and support methods available that can be used individually or in combination to stabilise underground mine workings – including:

- Rock bolts, and cables;
- Friction rock stabilisers;
- Cast concrete lining;
- Shotcrete (plain and fibre reinforced);
- Thin flexible surface coatings;
- Strapping.
- Timber props;
- Timber packs;
- Timber or steel sets;
- Yielding sets;
- Hydraulic props;
- Screw-jack type props;
- Mesh; and
- Backfill (plain and strength enhanced).

A description of each method is beyond the scope of this Code, however a brief outline of some of the more commonly used surface rock support methods is provided below. The use of reinforcement elements are discussed in more detail in Section 5.

Mesh

The installation of mesh on the backs and side walls of an excavation is a technique that can largely eliminate falls of small rocks.

Hoek, Kaiser and Bawden (1997) refer to this approach as a “safety” support system, the purpose of which is to prevent unexpected falls of small rocks.

This type of support system, however, is not designed to support large static or dynamic loads. It can be used in conjunction with other elements to be part of an integrated system for supporting large dynamic or static loads.

Providing that the mesh and the reinforcing elements do not become overloaded with loose rock fragments contained in the mesh, this system largely eliminates the need for regular check scaling.

These support systems may also be appropriate, irrespective of heading height, in regular travelways, places where the workforce regularly gather, and permanent installations containing specialised equipment or explosives; e.g. shafts, declines, main haulages, workshops, lunchrooms, offices, main pump stations, major electrical sub-stations, crushers, conveyors, main magazines, etc.

There is a variety of mesh available. The three main types are welded wire mesh, chain link mesh and non-metallic mesh. Chain link mesh has greater flexibility than weld mesh, while weld mesh is better suited for use with shotcrete. Where corrosive conditions exist, galvanised or non-metallic mesh is recommended.

Strapping

Strapping is sometimes used to extend the area of coverage of an array of rock bolts. This method may be suitable for restraining relatively large blocks and assisting with roof beam development. Recent developments in wire-mesh-type straps can withstand reasonably large – scale movement and seismic events.

Straps are usually installed in a linear or grid pattern along the side walls or the backs and can be installed in conjunction with other surface rock support.

Its use as a control method is limited, as the rock surface between the straps remains largely unsupported and blocks still may fall out.

Shotcreting

There are two types of shotcrete application - wet mix and dry mix. Each method has its particular use in surface rock support. The current trend is to use fibre-reinforced shotcrete, referred to as fibrecrete.

When designing a shotcrete program the following issues need to taken into consideration:

- Amount of shotcreting required;
- Shotcrete strength;
- Shotcrete thickness;
- Presence of groundwater (e.g. quantity, chemistry, pressure);
- Need for drainage of groundwater from behind the shotcrete;
- Water quality (potable);
- Type of shotcrete mix (wet or dry);
- Use of microsilica;
- Admixtures (plasticisers, etc);
- Accelerators (for wet mix);
- Fibre reinforcement;
- Curing (external or internal);
- Testing and monitoring;
- Correct spraying equipment; and
- Correct shotcrete application.

Other Surface Coatings

Recent developments include the use of synthetic rock surface coatings specifically designed for rock stabilisation in underground mines. Further work to develop these coatings may be required before they can be reliably and effectively used on a routine basis at minesites.

5.1 GSR Design

There are a number of ground control design methods that can be used. All these methods rely on having a good understanding of the prevailing ground conditions* before undertaking the design. Each method has its limitations and should only be applied to areas that are not impacted significantly by these limitations. The design methods that can be used include:

- empirical or experience based methods developed from extensive local information [e.g. RMR (Bieniawski, 1973), Q (Barton et al, 1974), MRMR (Laubscher, 1990), US Army Corps of Engineers (Stillborg, 1994), Stability graph method (Hutchison et al, 1996)];
- analytical/deterministic/limit equilibrium methods - using geotechnical parameters derived from either laboratory testing or back analysis of existing failures (e.g. composite beams (Peng 1978), support interaction analysis (Hoek et al, 1995);
- kinematic/stereographic and block analysis methods (e.g. SAFEX; Thompson and Windsor, 1996), UNWEDGE; Carvalho et al, 1996);
- numerical modelling (Hoek et al, 1995, Brady and Brown, 1993, Beck et al, 2010), and
- physical modelling (e.g. Player et al, 2009).
- Seismic criteria (e.g. ejection velocity (Ortlepp, 1992), allowable displacement, rock

damage criteria Kaiser et al, 1996).

Design criteria for each of these methods can differ; however, each design criterion is dependent on the level of acceptable risk of any particular failure and the degree of inherent uncertainty regarding the characteristics of the rock mass* and design method.

It is recommended that a sensitivity assessment be carried out to determine the effect of critical geotechnical parameters involved with mine stability. Any deficiencies that are highlighted in the analytical methods and sensitivity studies should encourage further work to remedy these matters, extend the use of the method or develop a new method.

The most common forms of design analysis are the empirical and kinematic or deterministic methods for which there are several packages available commercially. These methods are relatively simple to follow. Numerical modelling allows the design of underground workings to be considered in much more detail than is the case with empirical or deterministic design methods. One of the drawbacks for the use of numerical methods is that they generally require considerably more data input, which cannot always be adequately provided or accurately measured.

Computer-based numerical modelling packages have developed rapidly during the past 10 to 20 years and this trend is likely to continue. A wide range of design packages are currently available that can be run on most standard mine site computers. However, it must be recognised that differences exist between the solution methods used by the major numerical modelling techniques - e.g. finite element, finite difference, boundary element, and distinct element codes. These different solution procedures can give rise to some variation in computation of stresses and strains. The design engineer must acknowledge the differences and limitations between each of the numerical model codes with respect to the problem at hand.

The difficulty numerical model input data has in accurately representing the inherent variability of the complex rock mass* should also be recognised. It is therefore a prerequisite that significant mining experience and judgement is required to interpret and use the results correctly. It is also recommended that each numerical modelling technique be calibrated against observed ground response to mining for local conditions.

Considerable engineering judgement and mining experience is required to determine the appropriate levels and methods of geotechnical investigation required for the development of a geotechnical model of a particular mine, and to determine the method/s of analysis best suited for underground mine design.

Geotechnical data for design can be obtained from a number of sources including: published literature, natural outcrops, existing surface and underground excavations, chip and diamond drilling (for determining rock mass strength*, structure, and hydrogeological data), geophysical interpretations, seismic records, pump tests, field tests, trial pits, and experience. It would be a statement of the obvious to say that the quality and usefulness of these sources of data varies widely. However, qualitative information is better than none and, if nothing else, such data can be used to identify the areas requiring more detailed investigation and analysis.

The information gained from geotechnical investigations notably provides valuable information for mine design, but also assists with the development of a mineral resource estimate, and ultimately an ore reserve estimate. Particularly in marginal deposits, the geotechnical mine design limitations may define whether the resource can be classified as a reserve and therefore whether or not it should be mined. Again, all information used to establish effective ground control is to be maintained within the PHMP.

Obviously, the number, size, shape and orientation of the excavations and the ground conditions should be considered when selecting the most appropriate ground support and reinforcement system or systems.

It is suggested that the mine operator ensure that GSR requirements are derived from a combination of these methods; using a sensitivity-type analysis, taking into account local conditions and experience. Any deficiencies that are highlighted in the use of these design methods should encourage further work to remedy these matters, extend the use of the method or develop a new design method. As stated in Section 4, prior to using empirical methods, the mine operator needs to be aware that these methods have limitations (e.g. Milne and Pakalnis, 1997, MOSHAB, 1997, and Palstrom and Broch, 2006); consequently a reasonable degree of conservatism is needed when relying on these methods.

It is recognised that during the earlier design stages there is usually limited detail of the overall rock mass* available, and that it is necessary to make a number of assumptions/simplifications to arrive at a balanced mine design.

Rock support and reinforcement design methods must continue to evolve and develop as the mine matures. These methods, in keeping with the “engineering method”, do not present an exact closed form solution with one unique answer. Rather, they are based on underlying scientific principles, strength of materials concepts, engineering computational modelling, static and dynamic testing plus considerable observations of field performance to present a range of solutions.

Corrosion is an important factor that needs to be considered in the design and selection of the rock support and reinforcement. The influence of corrosion will mean that virtually none of the conventional forms of rock support and reinforcement can be considered to last indefinitely; they all have a finite design life. The two main causes of corrosion are: oxidation of the steel elements, and galvanic consumption of iron by more noble (inert) metals, for example copper. Ranasooriya et al, 1996 and Villescusa et al, 2007 provide more discussion on the corrosion of GSR elements. The groundwater or artificially introduced mine water, for example hydraulic fill water, needs to be checked to determine if it has the potential to cause corrosion of the rock support and reinforcement.

With respect to GSR design, it is important that the mine operator recognise that ground conditions can change during mining due to a number of factors and that the effectiveness of GSR may also change with time. Factors contributing to change in ground conditions include:

- Loosening of the rock mass due to blast vibrations;
- Drainage of water from soft rock formations and jointed rock;
- Deterioration of some rocks on exposure to air or water over time;
- Sudden changes in stope geometry, e.g. formation of a cut-off slot;

- Stress reductions, or stress shadows, near large stope/extraction panels; and
- High stress levels in abutments and pillars.

These changing conditions require ongoing assessment of GSR design strategies and systematic performance monitoring (further discussion is provided in Section 6.1.2).

5.2 GSR Installation

The timing of the installation of ground support and reinforcement should be considered as an integral part of the design to limit the potential for ravelling of the rock mass. In those headings or workplaces requiring control, the delay in the installation of the ground support should be minimized as far as is reasonably practical. It is recognised that several hours may elapse from the firing of a development face, before the heading is clear of post-detonation explosive fumes, watered down, scaled and cleaned out ready for the installation of ground support and reinforcement. Extended delays in the installation of GSR, in the order of weeks to months, may jeopardise the effectiveness of the ground control because of the rock mass loosening and consequent reduction in the shear strength that may occur. Significant changes can also occur in the rock stress field around stopes / extraction panels. These stress changes can have an important effect of the amount of radial confinement that is experienced by the rock reinforcement. A reduction in the confining stress, normal to a rock bolt, may adversely affect the load transfer capacity of the bolt (Hutchinson et al, 1996).

When the ground conditions are sufficiently poor, the available time that the excavation will remain open and stable (the stand-up time) may be considerably less than the 24 hours mentioned above. In these situations special measures may be required to promptly install ground support and reinforcement prior to the removal of broken rock from the face. Shotcrete applied to the exposed backs and walls, before the heading is cleaned out, is one approach that may be necessary or effective. Rapid placement of the ground support as soon as practicable after blasting, minimising the time that the ground has to stand unsupported, is likely to be important for successful mining in these ground conditions.

“Workplace” ground support and reinforcement should be installed (and tensioned, if appropriate) preferably on a hole by hole basis or at the very minimum on a row by row basis, before advancing. If the ground conditions are considered to be sufficiently poor, or the potential for failure of a block is judged to be high, then a hole by hole installation technique must be used. The drilling of a large number of holes, prior to the installation of the ground support, is not considered to be an appropriate system of work in these areas. GSR installed for the purpose of providing additional support (usually to account for expected large scale movements during the ore extraction stage) can be installed on a campaign basis with success.

For safety reasons alone, it is vital to ensure the design GSR is installed appropriately. Economically, the importance of correctly installing GSR is highlighted when one considers the marginal costs associated with the different types of GSR in comparison to the fixed costs associated with hole drilling, installation and grouting (e.g. equipment depreciation, drilling consumables, transportation, grouting and labour etc.).

It should be recognised that GSR, together with their ancillary fittings, combine to form an overall ground support and reinforcement system that consists of different layers. Each layer has its own unique contribution to make to the success of the system. The GSR design method used should ensure that the appropriate elements of support and reinforcement are combined in such a manner as to produce an effective overall support and reinforcement system that is matched to the ground conditions for the design life of the excavation.

Suppliers of GSR elements are encouraged to provide an appropriately detailed set of mechanical properties and instructions for the correct installation and testing for each element type.

The end user of the GSR must (at least) be able to demonstrate that they are following the manufacturer’s instructions for the correct installation of the equipment.

Training courses and materials should be readily available at each minesite to ensure that the workforce is fully conversant with the type(s) of GSR in use. There needs to be a thorough understanding, by all those concerned, with GSR usage, their strengths and limitations. Further discussion on training is provided in Chapter 7.

The equipment used to install GSR should, where practicable, be purpose designed and built for the particular range of GSR elements in use at the mine. For example, the use of development drill jumbos in narrow openings, where the GSR cannot be installed according to the design standards, is not considered good practice. Where the use of purpose-built installation equipment is not practicable, the mine operator must formally develop and implement appropriate GSR design and work/installation procedures to minimise risk to the workforce when installing GSR elements. Examples of issues to be considered in the formal design and installation procedures include:

- Knowledge of ground conditions in the area where the GSR elements are to be installed
- Timing of the reinforcement installation - taking account of the potential for early deterioration of ground conditions and the ability of the reinforcement to contain this
- Scaling requirements - prior, during and following the installation work
- Reach and capacity of the equipment - needs to be matched to the opening dimensions
- Placement of the GSR element(s), including mesh, on the equipment prior to installation to be carried out from a secure position
- Correct alignment of the support or reinforcing element relative to the orientation and shape of the excavation and local geology
- Appropriate operation of the insertion device - e.g. if a drifter is being used, the mode of drifter operation should be “percussion off” or “no percussion” while travelling up the slide
- When to use rotation only (no percussion) when installing rock bolts using a jumbo – e.g. no percussion when tensioning threaded reinforcement elements
- The required torque to be applied to a rock bolt or dowel nut etc. without damaging the individual components, and

- Personnel movement during the installation of GSR.

5.3 GSR Quality control

The importance of quality control to the successful design and installation of an adequate ground support and reinforcement system needs to be clearly recognised and proper quality control procedures put in place. The supplier of the rock support and reinforcement system elements should provide information on the factors that determine the quality of the installation.

The mine operator should formally develop and implement appropriate GSR quality control systems / procedures to ensure GSR design standards are being met. When designing a quality system the following issues (not excluding others) need to taken into consideration:

- Storage and handling strategies for GSR elements must effectively minimise damage and deterioration to the elements
- The suitability of GSR elements in variable ground conditions – e.g. expansion shell bolts are generally ineffective in soft rock - as are friction bolts where correct hole diameter cannot be maintained
- Correct hole length is drilled and holes are flushed clean of all drilling sludge
- Orientation of the hole is appropriate for the excavation geometry and expected block movement - axial tensile loading of the steel elements installed in the rock is generally preferred; shear loading should be avoided
- Hole should be drilled nearly perpendicular to the rock surface - use of hemispherical ball and domed plates may be required where this cannot be achieved
- Load capacity of the anchorage method, bar or tendon and surface restraint fittings should be appropriately matched to prevent the premature failure of any one component
- All steel and other components designed to be encapsulated in resin or cement grout should be clean of all oil, grease, fill, loose or flaking rust and any other materials deleterious to the grout
- Where full grout encapsulation of the steel elements is required, the method of grouting should show a grout return at the collar of the hole; other methods that can demonstrate complete hole filling may also be appropriate
- Correct tensioning or loading procedures should be used for the various rock support and reinforcement systems
- Plates and/or straps against the rock surface should have the required thickness to prevent nuts or barrel and wedge anchors being pulled through the plate and/or strap at the ultimate tensile strength of the tendon when loaded against the rock surrounding the bore hole
- Corrosion issues are recognised and remedied
- Blast vibrations may loosen threaded reinforcement systems
- Load tests are regularly carried out on point anchored rock bolts and friction anchored rock bolts
- Fully grouted reinforcement systems should be checked on a regular basis to ensure that the grout strength and encapsulated length of the bar or tendon is adequate

- Implement an action plan when it is found that the load capacity of the installed support or reinforcement system, grout strength and/or encapsulated length does not meet specifications
- Storage of resin grouts should be at the temperature range recommended by manufacturer
- Resin grouts are consumed before their "use by" date, or within a specified period of time
- Mixing of resin grouts should be for the recommended time and at the recommended speed - these should not be exceeded
- Cement grout is mixed at the recommended water: cement ratio, at the recommended angular speed in the specified equipment for the required time
- Water used for cement grout mixing is of the required quality or the cement used should be able to develop the required uniaxial compressive strength with the run of mine water supply
- Any additives (e.g. retarders, accelerators, fluidizers, etc) to the cement grout mix are added in the recommended amounts and at the specified time in the mixing and pumping process
- All grout mixing and pumping equipment to be cleaned and maintained on a regular basis
- Any pumping equipment used to pressurise rock support and reinforcement should be regularly maintained and operate at the recommended pressure
- Shotcrete mix specification should state the slump of the mix, the uniaxial compressive strength and a measure of the toughness of the product at specified time intervals prior to or following mine application, as appropriate
- Samples of the mine shotcrete mix should be collected at specified intervals, under normal mine operating conditions, and tested in a NATA registered concrete testing laboratory for compliance with the shotcrete design specifications, and
- Shotcrete thickness should be tested regularly during placement to ensure that the specified thickness has been applied - a means of permanently marking the shotcrete surface with a depth gauge probe may be appropriate.

6 OPERATIONAL/ONGOING CONSIDERATIONS

At commencement of mining, it is necessary that the formal effective ground control (EGC) and risk assessment strategies, established in the feasibility stage of a mine (see above), are used as an integral part of the mining process. As mining progresses, however, these tools are to be continuously improved and formally updated as required during the life of mine. The "vehicle" for maintaining formal records of MPD, EGC and risk assessment is the ground control management plan (GCMP), which forms part of the overall PHMP.

It is recommended that the PHMP and GCMP be produced for a mine using a combination of in-house and outside expertise in the field of geotechnical engineering. Both management plans should be critically reviewed at least annually, or more frequently if necessary, to correct areas of deficiency exposed by mining experience or changes to the intended mine plan.

Development of the GCMP may be facilitated by the use of qualitative risk assessment techniques (Joy, 1994). These techniques can assist in identifying the high risk aspects of a mine and develop a range of appropriate controls to effectively manage the risks. The successful implementation, review and, where necessary, modification of the GCMP is the responsibility of the mine operator and the mine management team.

A balanced GCMP should recognise and address the "downside" as well as the "upside" of possible courses of action. The open informed discussion of the potential risks associated with alternative courses of action, practices, methods, equipment, technology, limitations of knowledge or data, and any other deficiencies, is considered central to sound geotechnical engineering practice. Those with knowledge and experience in geotechnical engineering have a duty of care to inform their colleagues or client(s) of the inherent strengths and weaknesses of any preferred course of action in an objective and unbiased manner. Responsible risk management practice requires those having sound knowledge of geotechnical engineering to communicate that knowledge. Similarly, mine operator should take timely, balanced and documented decisions regarding the application of that knowledge and ensure that these decisions are promptly communicated to the relevant people.

The GCMP should also serve as a tool to improve geotechnical knowledge and databases (the geotechnical model. This on-going assessment is required because of the relative paucity of data that is usually available when the mine design (and PHMP) is first formulated. An example of the on-going review of geotechnical databases is mapping of geological/geotechnical features (e.g. the orientation, spacing and length of planes of weakness – discussed further in Section 3) as mine faces/walls/ribs and backs/roof are exposed, or when additional exploration / confirmation drilling is undertaken.

The size, scope and type of mining operation will obviously be major factors in determining the amount of effort and the resources that are required to develop, implement and improve the PHMP. With experience, it will be possible to successively refine the plan over time to address the ground control issues identified as important to the maintenance of an acceptable standard of working conditions. It will be necessary to apply considerable mining experience and professional judgement when establishing the PHMP and GCMP at a mine for the first time.

The GCMP should recognise the importance of developing an underground mining culture in the workforce that understands the vital importance of the rock mass, as well as the people and equipment, to a viable mine. Consequently, it is necessary to adopt a team approach, involving the whole underground workforce, if ground control challenges are to be overcome in a safe and cost effective manner. Additionally, the GCMP should be structured to contain all the relevant information for persons working in the mine to design, attain and maintain safe mining conditions. Examples of the issues to be included are listed below:

- monitoring strategies (e.g. monitoring of ground movements, seismic monitoring, and recording general ground performance),
- safe working procedures relevant to ground control, and emergency action procedures.
- depth and operating life of mining projects
- potential for changes in expected ground conditions in the rock mass (eg. rock strength, earthquake events, rock stress, rock type etc.)
- production rate
- size, number, shape and orientation of the excavations
- the location of major infrastructure and transportation routes
- potential for surface water and groundwater* problems
- the equipment to be used, excavation/mining methods (e.g. entry/non-entry stopes or advance/retreat longwall mining, and handling of ore and waste
- the presence of nearby surface features (e.g. public roads, railways, pipelines, natural drainage channels or public buildings)
- the potential for the general public to inadvertently gain access to the mine void during and after mining, and
- Engineering qualities of the rock mass, including time dependent characteristics of the rock mass.

6.1 Performance Monitoring

As stated on several occasions previously, a mine operator should acknowledge that all geotechnical design methods intrinsically include assumptions of the true engineering nature of the rock mass, and as a consequence, each design method has limitations. Should rock mass characteristics change during the process of mining, it is likely that the “standard geotechnical design” will not be well suited to the change in ground.

In operating mines, information from mine inspections and monitoring programs can be incorporated into the ground control risk assessment methodology first developed prior to mining. [Regular inspections and monitoring (see Chapter 2) of the mine shall be carried out in a manner consistent with sound geotechnical engineering practice (Priest, 1993).]

Consequently, during operation, it is necessary to monitor the performance of mine excavations over time to identify changes to the rock / ground surrounding the mine that either:

1. Require immediate attention (e.g. scaling loose slabs of rock), or
2. Indicate that, should the existing ground control strategies be left unattended, hazardous mining environments will eventually develop (e.g. increasing rock noise, rates of ground movement, or deformation of GSR etc.).

The determination of the timing and nature of corrective actions required in both scenarios will be dependent on a number of influencing factors; including mine access, production and development scheduling, the nature of the hazard and residual risk. Again, the determination of appropriate actions will require significant engineering evaluation and judgement.

In order to ensure that the performance monitoring data collection and analysis strategies are suitably implemented and remain suited to an ever-changing rock mass, the mine operator will need to formally develop and implement procedures that specify the nature and frequency of data to be collected, the data collection and analysis methods, the responsibilities of relevant personnel and trigger-action plans for each form of monitoring and/or analysis method.

Examples of formalised performance monitoring activities that can be undertaken on a regular basis include:

- Regular inspections and assessment of general workplace stability conditions;
- Regular photographic record of walls, backs, pillars, drawpoint conditions and fragmentation; the date should be recorded on the photograph;
- Definition and updating of geotechnical domains to classify volumes of rock with similar geotechnical properties;
- Use of displacement monitoring equipment (eg extensometers, tensioned wires across drive walls or 3D imaging) to measure displacement of exposed rock - where it is considered necessary (e.g. caving processing above stopes / extraction panels, changes in mine rod movement with encroaching nearby development and/or concerns about the ability of the stope walls to remain stable for a sufficient length of time to complete extraction and fill the stope);
- Real-time seismic monitoring and associated data analysis methods (discussed further in Section 6.1.2);
- Use of absolute and/or incremental rock stress measurement techniques in large, complex and/or seismically active mining environments to determine the pre-mining rock stress field and/or changes in the rock stress field; particularly where there is the potential for rock instability involving large volumes of rock in critical locations, eg open stope crown pillars below filled stope(s) and barrier pillars and coal pillars within access drives and extraction panels;
- Laser surveying techniques, (e.g. the Cavity Measurement System (CMS)) to determine the extent of over-break, under-break and non-break in large open stopes; may also be of use in determining the three dimensional void shape and/or volume where caving and/or collapse voids have formed; re-surveying on a regular basis may also be required;

- Surface subsidence monitoring – e.g. surveying of subsidence pegs, satellite imaging.
- Use of longitudinal projection(s) to summarise stope geometry changes during blasting, date and number of rings fired, estimate of tonnage broken, estimate of extent and depth of wall sloughing - preferably using laser surveying techniques (eg CMS) or by visual estimate, plus observations of ground conditions; and
- Comparison of the observed ground conditions and instrumentation monitoring results with the results of numerical modelling to verify that the observed ground conditions and those predicted by numerical modelling are in reasonable agreement; if not then measures should be taken to determine the reasons for the apparent discrepancies of stope and pillar dimensions and the best actions to take within the MPD process.
- The use of a standard rock failure report form (see Appendix 3) to analyse factors contributing to failure (Laubscher, 1990) – such as: failure location, failure dimensions, induced stress change, rock failure mode, geotechnical features, rock mass quality, excavation details, rock support and reinforcement details this should include monitoring information of monitoring strategies. The use of this form will improve the understanding of rock failure modes which should further assist in the development of remedial measures and modification requirements to the GSR design methodology.

In addition to helping with assessment of the suitability of the existing GSR strategies, regular collection of geotechnical data is also useful for evaluating possible impacts of any mining approaching an existing workplace.

Seismic monitoring

The field of microseismic monitoring has been evolving rapidly in recent years in Australia; however, many issues such as the exact timing required for seismic monitoring to be installed in mines are yet to be fully resolved. Although seismic monitoring data has several benefits with respect to performance monitoring of GSR, and SGC, several factors exist that can impact negatively on the use of seismic monitoring. The mine operator should be aware of all issues relevant to this form of performance monitoring when designing an appropriate microseismic monitoring system. Factors to be considered when deciding to use or designing seismic monitoring systems include:

- Sensors need to be capable of determining magnitude and source parameters (eg S:P ratio) to determine mechanisms of seismic responses.
- The orientation of sensors within the mine and expected sources of seismicity.
- The number of seismic sensors required to get reliable seismic source parameters is somewhat dependent of the size/expanse of the mine.
- The benefits of uniaxial and triaxial sensors.
- The sensors need to be attuned with the expected magnitude of and frequency of seismic events.

- Seismic event filtration protocol to remove various mine noise (e.g. vibration from ore passes, ventilation fans, crushers). (It is recommended that filtered data is not completely deleted.)
- Location of sensors preferably away from ore passes and other sources of background noise.
- Power/UPS backup systems for full seismic monitoring coverage.
- Location of the digitiser/communications computer with respect to, close to the sensors for cleaner waveforms.
- The need to put some far field monitoring and need redundancy in the system – for cases where sensor saturation/ overload occurs.
- The need to develop a template for seismic damage investigations.
- Specification of triggers that activate the Emergency Response Plan.
- Seismic systems are to be setup and operated by suitably qualified and experienced persons.
- The need to develop a monthly reporting system for seismic monitoring to compare periods of mining activities, expected behaviour and assess trends.

Some benefits from the seismic monitoring data include:

- Early use of seismic systems can assist with the development of a “beta chart” (number of events versus local magnitude) to determine “a/b” and $M_{max.}$
- Look at spatial zoning of data. Clustering helps to understand sources of seismicity. Seismic clusters - should have similar S:P, b-value, a/b (M_{max}), Time-Magnitude frequency and spatial trends.
- List M_{max} for all groups (seismic sources), seismic sources and mechanisms (eg fault slip on X fault) to assess future demands of GSR. Analytical techniques such as the Gutenberg-Richter frequency-magnitude chart can also assist with assessment of potential future demand.
- Examine cause-effect seismic response to blasting. The seismic “system” can be partially calibrated by monitoring various blasts (e.g. P & S wave velocities can be determined by monitoring a single blast in the mine, knowing its location and time and watching the sensor responses).
- Use analytical methods such as the Omori Analysis (number of events/hour versus hrs after blast) to estimate preferred re-entry periods.

Routine back analyses of seismic events will allow the mine operator to increasingly better understand seismic sources and ultimately devise effective seismic risk management plans (SRMP) as required.

6.2 Stability checks and ongoing remediation

The mine operator should expect that, over time, loose rock will develop at certain locations within the mine. Consequently, during LOM operations, regular checks will be required to determine the ongoing stability of workplaces. At some time, it is to be expected that certain workplaces will require remedial work to re-establish safe working conditions.

Workplace inspections need to be scheduled at a rate equivalent to the noted rate of change in ground conditions at each locality.

The mine operator is required to maintain records of workplace inspections and the scope of work required to remediate any unsafe areas. These records should also be signed off when appropriate remedial work has been satisfactorily completed.

Scaling

Scaling is the most commonly applied technique to control workplace hazards. Scaling involves removing loose rock from the walls, face and backs of an excavation. Whilst the act of scaling is relatively straightforward, careful attention should be paid to the following:

- Identifying the ground conditions;
- Manual scaling procedures;
- Mechanised scaling procedures;
- Scaling procedures for large potentially unstable blocks;
- Scaling procedures in ravelling ground;
- Progressive scaling and installation of support;
- Scaling in high headings;
- Scaling in narrow headings; and
- Regular check scaling of main travelways

Further discussion on scaling is contained in the DMP Guideline Underground Barring Down and Scaling.

7 TRAINING

Obviously, it is the exposure of the workforce to hazards resulting from ineffective ground control that may result in the occurrence of accidents and fatalities. The level of risk, both in human and economic terms, will be substantially increased if the ground conditions and ground control requirements are not well understood. Consequently, each worker must have a sound understanding of identifying hazardous ground conditions and safe mining practices to keep them safe.

In order to ensure the workforce have suitable awareness of all safety issues relevant to ground control, throughout the LOM, it is necessary that the mine operator develop, implement and maintain appropriate training systems. These training systems need to be attuned to the level of exposure of particular workers to various forms of ground movement.

Minesites throughout Australia have addressed this issue with varying degrees of rigour and success. This Code requires the mine operator to formalise each training program to an extent that subsequent management and workers can readily follow the process and maintain “accreditation” for working in underground mines. Several training models exist within the industry (e.g. Jaeger and Ryder 1999 – Chapter 12) – each will need to be assessed for local conditions / restrictions before being accepted.

8 SELF AUDITING

As mentioned throughout this code, a mine operator should expect that rock mass characteristics will change during the process of mining; as a consequence, it is likely that the first-pass "standard EGC system" may not be well suited for the LOM. Consequently, during operation, it is necessary for the mine operator to undertake regular audits of the ECG system to ensure continued validity of all components within the system and formally modify the process as indicated by the audit.

To assist the reader with the development of an internal audit, an example audit has been provided (for metalliferous mines) in Appendix 4. In this example, the audit process has been divided into seven geotechnical elements of underground mine operation with respect to EGC;

Element 1 – Mine Planning and Design

Mine planning and design processes seek to establish if the geotechnical issues or hazards at the mine have been identified and suitably addressed during the design stage of the mine. Management has, in effect, a duty of care to verify that the geotechnical considerations are addressed in a manner appropriate to the risk profile of the mine. The requirement to identify and control hazards through mine design will vary from mine to mine and also within each mine.

Element 2 – Development and maintenance of a geotechnical model

Refers to the ongoing management of geotechnical databases – used initially to derive mining strategies, and then to verify the assumptions made to develop these strategies. This includes the development and implementation of a "ground control management plan" (PHMP) that specifies the roles of various personnel with respect to mining safely near drop-offs and existing underground and open pit voids and dump slopes, and provides controls required to mine responsibly near other stakeholders. The PHMP will also include suitable detail of the design and implementation processes used to manage geotechnical issues relevant to a particular mine.

Element 3 – Operations – Mining Control

Refers to the control measures used by the mine operator to ensure all issues relevant to EGC for short, medium and long term mine planning and design are routinely addressed.

Element 4 – Operations – Performance monitoring

Performance monitoring refers to the quality control and performance monitoring of geotechnical issues relevant to particular mines. Ground support and monitoring methods used must be installed/implemented in a suitable manner in relation to the particular mining environment at any location in a mine. The monitoring data needs to be systematically recorded to build up a good understanding of how the mine is performing with time. Monitoring data also needs to be conveyed to the workforce in a timely and clear fashion, explaining the risks and actions needed to be taken.

Element 5 – Operations – GSR

GSR applies only to mines that require rock reinforcement and support to supplement the safe design of open pit walls. The rock support and reinforcement installed in the mine should be matched to the ground conditions, wall geometry and rate of mining. Ground support (and reinforcement) should be installed, using appropriate methods, as soon as practicable after walls have been fired to minimize loosening of the rock mass. Ground conditions can deteriorate with time by exposure to the atmosphere, water, gravity, repeated blast vibrations, seismic events, etc.

Element 6 – Operations – management of unstable rock

Addresses techniques to be used for rehabilitating areas of the mine where loose or potentially unstable rock represents a hazard to the workforce.

Element 7 – Drill and Blast

Addresses geotechnical issues specific to drilling and charging workplaces. Blast damage to the rock mass should be reduced as far as practicable and suitable sub-drill practices used to improve the workplace ground conditions. Excessive damage to the rock mass in the walls will result in additional ground control work (i.e. scaling and ground support). Drill and blast practices must be able to deliver, within acceptable tolerance limits, site specific and overall void geometry. The quality of the drilling and the charging components must be recognised and addressed.

Element 8 – Design confirmation / back analysis

Refers to the process of geotechnical model and mine design confirmation. An underground mine will be designed (initially) according to assumptions of the rock mass and ore reserves made during feasibility studies. This design needs to be ratified against performance monitoring and actual as-mined geometries to determine whether the current mine design can ensure a continued safe working environment for the life of the mine. Any rock or rock reinforcement failures occurring during the mining process should be back analysed to assist with the design confirmation process.

Element 9 – Training and competency.

Requires that the mine operator has developed training modules for the workforce appropriate to the geotechnical hazards at a particular minesite and systematically implements these training modules and assess workforce competency.

APPENDIX A – OTHER RELEVANT INFORMATION

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APPENDIX B - GLOSSARY OF TERMS

The following brief explanations of some geotechnical and mining terms are not intended to be dictionary definitions or detailed technical explanations.

Abutment. The areas of unmined rock at the edges of a stoping block that carry may large regional loads. Generally a zone of support for ground arching.

Arching. The transfer of rock stress or load from an active mining area, eg stope back, to a more stable area or abutment; this may result in the release of rock blocks.

Backs. The section of an underground excavation which comprises the overhead rock (in coal mining it is called the "roof").

Bedding plane slip. The relative movement or slip of continuous bedding planes or foliation planes in response to large areas of stope wall moving into a void, filled or unfilled. May be observed in areas where extensive stoping has been carried out in a well bedded rock mass.

Bedding planes. Parallel beds or planes of weakness in the rock formed when there was a change in the deposition of minerals under water.

Cable bolts. One or more steel reinforcing strands placed in a hole drilled in rock, with cement or other grout pumped into the hole over the full length of the cable. A steel face plate, in contact with the excavation perimeter, is usually attached to the cable by a barrel and wedge anchor. The cable(s) may be tensioned or untensioned. The steel rope strand may be plain strand or modified to improve the load transfer between the grout and the steel strand.

Competent person. Means a person who is appointed or designated by the employer to perform specified duties which the person is qualified to perform by knowledge, training and experience.

Compressive stress. A stress or pressure that tends to push or clamp objects together. The state of stress found in the rock mass before mining occurs. Tends to hold the rock mass together.

Controlled blasting. The art of minimising rock damage during blasting. It requires the accurate placement and initiation of minimal explosive charges in the perimeter holes to achieve efficient rock breakage with least damage to the remaining rock around an excavation.

Destressed zone. A zone of rock around the perimeter of an excavation where the rock stress field has exceeded the strength of the rock mass at some time during its mining history. The rock mass is in a post-peak loading condition and it may be capable of carrying significant loads with low levels of lateral confinement being provided by reinforcement.

Dilution. The contamination of ore with barren wall rock during stoping operations.

Dip. The angle a plane makes with the horizontal.

Discontinuity. Any significant mechanical break or fracture of negligible tensile strength in a rock.

Dowel. An untensioned rock bolt, anchored by full column or point anchor grouting, generally with a face plate in contact with the rock surface.

Earthquake. The local shaking, trembling or undulation of the ground surface and the radiated seismic energy caused most commonly by sudden fault slip, volcanic activity or other sudden stress changes in the Earth.

Elastic limit. See yield point.

Elastic. Capable of sustaining stress without permanent deformation. Tending to return to its original shape or state when the applied stress is removed.

Entry-method stoping. Entry-method stoping typically proceeds upward through the orebody with a series of cuts or slices, mining through the previously installed ground support.

Fault. A naturally occurring plane or zone of weakness in the rock along which there has been movement. The amount of movement can vary widely.

Fill. Waste sand or rock, cemented or uncemented in any way, used either for support, to fill stope voids underground, or to provide a working platform or floor.

Foliation. Alignment of minerals into parallel layers; can be planes of weakness in rocks.

Footwall. The rock below the orebody.

Friction rock stabilisers. Steel reinforcing elements, typically a "C" shaped shell, that are forced into holes drilled in the rock. Frictional forces between the side of the hole and the element to generate forces to limit rock movement. The anchorage capacity of the device depends on the anchorage length above any plane of weakness and the frictional interference between the bore hole wall and the outer surface of the shell. Anchorage capacity is dependent on the hole diameter and the effective anchorage length in solid ground.

Geological structure. A general term that describes the arrangement of rock formations. Also refers to the folds, joints, faults, foliation, schistosity, bedding planes and other planes of weakness in rock.

Geology. The scientific study of the Earth, the rock of which it is composed and the changes which it has undergone or is undergoing.

Geotechnical engineering. The application of engineering geology, hydrogeology, soil mechanics, rock mechanics and mining seismology to the practical solution of ground control challenges.

Ground. Ground refers to rock in all the possible forms that it may take from a fresh, high strength material to an extremely weathered, very low strength, essentially soil like material. This term also includes all (back)fill materials, both cemented/stabilised in any way, or uncemented.

Ground control. The ability to predict and influence the behaviour of rock in a mining environment, having due regard for the safety of the workforce and the required serviceability and design life of the openings.

Ground Support. In respect to this Code, includes both rock reinforcement and surface rock support.

Hanging wall. The rock above the orebody.

Hard rock. Hard rock refers to rock where the compressive strength of the intact rock is >25 MPa. In this environment rock failure is usually controlled by the presence of geological structure. The size and shape of the potentially unstable rock blocks depends primarily on the orientation, continuity and spacing of the planes of weakness in the rock mass plus the size, shape and orientation of the mining excavations.

High Heading. Heading with a height exceeding a nominal 3.5m.

Induced stress. The stress that is due to the presence of an excavation. The induced stress depends on the level of the in-situ stress and the shape of the excavation.

In-situ stress. The stress or pressure that exists within the rock mass before any mining has altered the stress field.

Instability. Condition resulting from failure of the intact rock material or geological structure in the rock mass.

Joint. A naturally occurring plane of weakness or break in the rock, along which there has been no visible movement parallel to the plane.

Kinematic analysis. Considers the ability or freedom of objects to move without reference to the forces involved.

Loose. Rock that should be removed by scaling to make the workplace safe.

Mineral resource. An in-situ mineral occurrence quantified on the basis of geological data and an assumed cut-off grade only. More correctly referred to as an Identified Mineral Resource. Strict professional and technical criteria exist for the determination of mineral resources.

Mining induced seismicity. The occurrence of seismic events in close proximity to mining operations. During and following blast times there is usually a significant increase in the amount of seismic activity in a mine. Mining induced seismicity is commonly associated with volumes of highly stressed rock, sudden movement on faults or intact failure of the rock mass.

Ore reserve. That part of a mineral resource that is considered to mineable in terms of tonnage and grade following an appropriately detailed study of the technical and economic criteria and data. The plural may also used to refer to a list of known ore zones that a mine has identified as being suitable for mining at some time in the future. Strict professional and technical criteria exist for the determination of ore reserves.

Ore. Part of an ore reserve. See ore reserve.

Overbreak. The excess rock broken outside the design perimeter of an underground excavation. Overbreak increases the amount of rock to be moved and may reduce mining efficiency. It may also increase the amount of barring down and ground support required.

Pillar. An area of ore left to support the overlying rock, hanging wall or backfill. Pillars can be permanent - left in place for the life of the mine – or temporary - recovered at sometime after formation. Permanent pillars may also be stripped / reduced in size during the latter stages of a mine, when risk assessments allow.

Plane of weakness. A naturally occurring crack or break in the rock mass along which movement can occur.

Plastic. Capable of deformation at constant stress once the yield point is exceeded. The ability of a material to undergo permanent deformation without returning to its original shape or failing.

Ravelling. The gradual failure of the rock mass by rock blocks falling/sliding from the opening perimeter under the action of gravity, blast vibrations or deterioration of rock strength. A gradual failure process that may go un-noticed. The term unravelling is also used to mean the same thing.

Reinforcement. The use of tensioned rock bolts and cable bolts, placed inside the rock, to apply large stabilising forces to the rock surface or across a joint tending to open. The aim of reinforcement is to develop the inherent strength of the rock and make it self-supporting. Reinforcement is primarily applied internally to the rock mass.

Release of load. Excavation of rock during mining removes or releases the load that the rock was carrying. This allows the rock remaining to expand slightly due to the elastic properties of the rock.

Rock bolt. A tensioned bar or hollow cylinder, usually steel, that is inserted into a drill hole in the rock and anchored by an expansion shell anchor at one end and a steel face plate and a nut at the other end. The steel face plate is in contact with the rock surface.

Rock mass strength. Refers to the overall physical and mechanical properties of a large volume of rock which is controlled by the intact rock material properties, groundwater and any joints or other planes of weakness present. One of the least well understood aspects of geotechnical engineering.

Rock mass. The sum total of the rock as it exists in place, taking into account the intact rock material, groundwater, as well as joints, faults and other natural planes of weakness that can divide the rock into interlocking blocks of varying sizes and shapes.

Rock mechanics. The scientific study of the mechanical behaviour of rock and rock masses under the influence of force fields.

Rock noise. Sounds emitted by the rock during failure, may be described as cracking, popping, tearing and banging.

Rock Reinforcement. The use of rock bolts and cable bolts, placed inside the rock, to apply large stabilising forces to the rock surface or across a joint tending to open. The aim of reinforcement is to develop the inherent strength of the rock and make it self-supporting. Reinforcement is primarily applied internally to the rock mass.

Rockburst. The instantaneous failure of rock causing a sudden violent expulsion of rock material at the surface of an excavation. Can be a serious hazard to people and equipment. Sometimes used to describe a seismic disturbance to a surface or underground mine where damage results to the mine structure or equipment.

Scaling bar. A solid steel bar with a straight chisel point at one end and a heel and toe chisel point at the other end, used to remove loose potentially unstable rock. Hollow aluminium bars, fitted with steel chisel tips at each end, can provide longer reach in high headings.

Scaling. The art and function of making the ground safe using a scaling bar to locate and remove loose rock from the walls, face and backs of the workplace. Loose or potentially unstable rock is prised off the rock surface with a scaling bar. Also referred to as barring down.

Seismic event. Earthquakes or vibrations caused by sudden failure of rock releasing stored strain energy. Not all seismic events produce damage to the mine structure, hence all seismic events are not necessarily rockbursts.

Seismicity. The geographic and historical distribution of earthquakes.

Seismology. The scientific study of earthquakes by the analysis of vibrations transmitted through rock and soil materials. The study includes the dynamic analysis of forces, energy, stress, duration, location, orientation, periodicity and other characteristics.

Shear stress. A stress that tends to cause an object to slide.

Shear. A mode of failure where two objects or pieces of rock tend to slide past each other.

Shotcrete. Pneumatically applied cement, water, sand and fine aggregate mix that is sprayed at high velocity on the rock surface and is thus compacted dynamically. Tends to inhibit blocks ravelling from the backs, walls and face of an excavation.

Slabbing. Unstable slabs of rock formed by close spaced foliation or bedding planes in the backs or walls. Can also be caused by high stress levels that produce flat slabs parallel to the walls or backs.

Smooth blasting. The use of closely spaced parallel perimeter holes charged with low strength explosives, fired after the main round. Can be used to reduce blast damage to the rock mass and improve rock stability.

Spalling. Stress induced failure of the rock mass that results in small, thin, curved, sharp edged pieces of rock ejected or falling from the backs or walls of an excavation. Generally accompanied by rock noise, usually associated with high rock stress.

Stope. An excavation where ore is extracted on a large scale.

Stope lift. A horizontal slice of ore mined from the back of a stope. Generally applied to cut and fill stoping methods.

Strain. The change in length per unit length of a body resulting from an applied force. Within the elastic limit strain is proportional to stress.

Strength. The largest stress that an object can carry without breaking. Common usage is the stress at failure.

Stress field. A descriptive term to indicate the pattern of the rock stress (magnitude and orientation) in a particular area.

Stress shadow. An area of low stress level due to the flow of stress around a nearby excavation, eg a large stope. May result in joints opening up causing rock falls.

Stress. May be thought of as the internal resistance of an object to an applied load. When an external load is applied to an object, a force inside the object resists the external load. The terms stress and pressure refer to the same thing. Stress is calculated by dividing the force acting by the original area over which it acts. Stress has both magnitude and orientation.

Strike. The bearing of a horizontal line in a plane or a joint.

Support. The use of steel or timber sets, concrete lining, steel liners, etc that are placed in contact with the rock surface to limit rock movement. The rock mass has to move on to the support before large stabilizing forces are generated. Support is applied externally to the rock mass.

Surface Rock Support. The use of mesh, strapping, shotcrete, thin flexible spray-on coatings, steel or timber sets, concrete lining, steel liners, etc that are placed in contact with the rock surface to limit rock movement.

Tectonic forces. Forces acting in the Earth's crust over very large areas to produce high horizontal stresses which cause can earthquakes. Tectonic forces are associated with the rock deforming processes in the Earth's crust.

Tensile stress. A stress that tends to cause a material to stretch. Can cause joints to open and may release blocks causing rock falls.

Ultramafic rock. Typically, dark coloured rocks that have been intruded into the Earth or extruded underwater in a marine environment. May have been altered by heat and pressure producing foliation in the rock. Typically associated with nickel and gold deposits in WA. They can be low strength, sheared and altered and a potential source of challenging ground conditions.

Wedge. A block of rock bounded by joints on three or more sides that can fall or slide out under the action of gravity, unless supported.

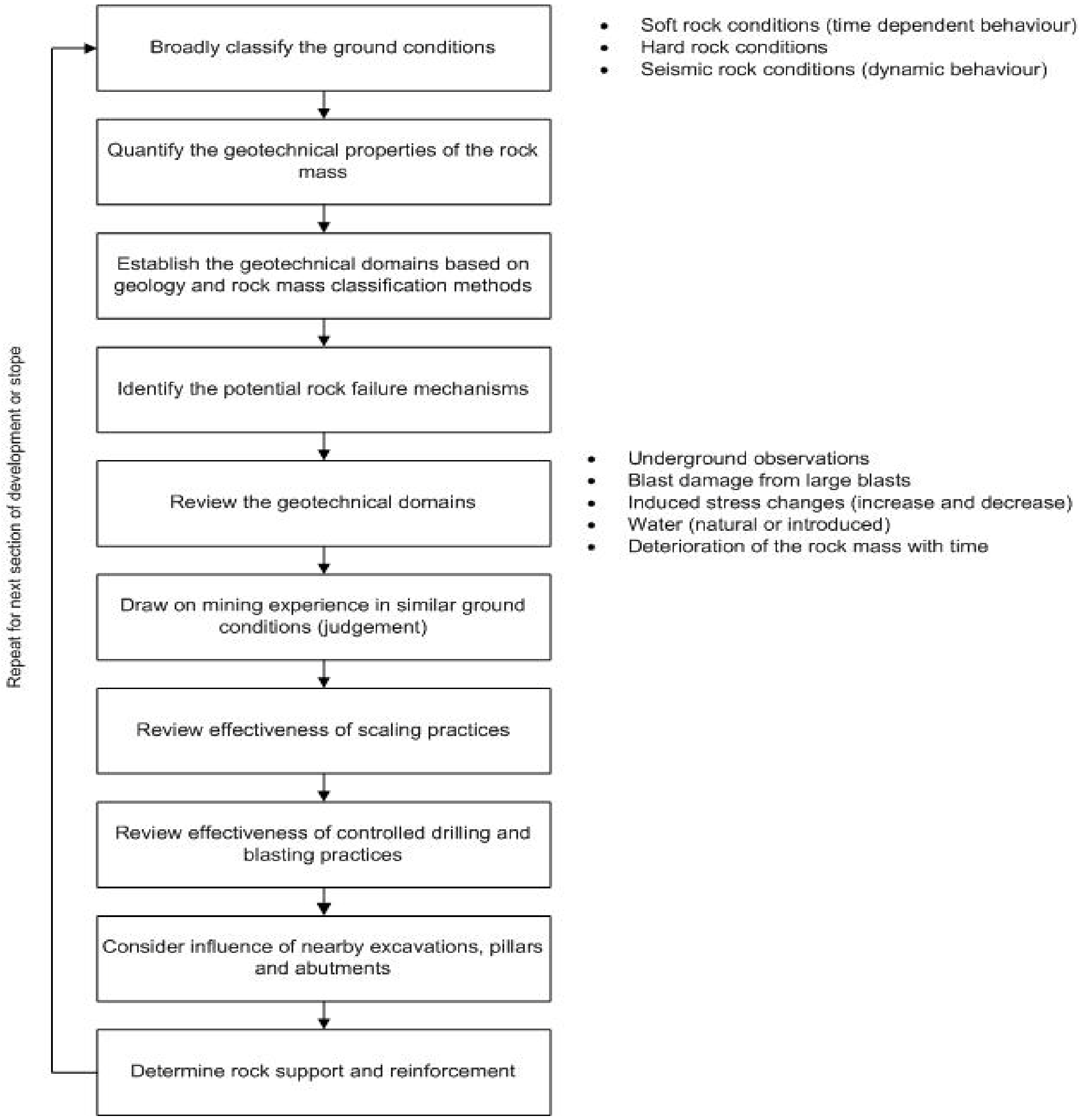
Yield point. The maximum stress that a material can sustain without permanent deformation or rupture. The limit of proportionality between stress and strain. Also known as the elastic limit.

APPENDIX C - TEN-STEP GEOTECHNICAL RISK ASSESSMENT FOR DEVELOPMENT HEADINGS AND ENTRY STOPING METHODS IN METALLIFEROUS MINES

The geotechnical risk assessment should be carried out by competent persons, including geologists, mining engineers, supervisors, safety and health representatives and underground workers exposed to the risk.

Specialist goetechnical advice from appropriately qualified and experienced professionals should be sought when complex, variable and difficult or unusual ground conditions are found.

The frequency and scope of the geotechnical risk assessment shall reflect the level of risk and shall be documented.


Broadly classify the ground conditions
Quantify the geotechnical properties of the rock mass
Establish the geotechnical domains based on geology and rock mass classification methods
Identify the potential rock failure mechanisms
Review the geotechnical domains
Draw on mining experience in similar ground conditions (judgement)
Review effectiveness of scaling practices
Review effectiveness of controlled drilling and blasting practices
Consider influence of nearby excavations, pillars and abutments
Determine rock support and reinforcement
Repeat for next section of development or stope
Soft rock conditions (time dependent behaviour)
Hard rock conditions
Seismic rock conditions (dynamic behaviour)
Underground observations
Blast damage from large blasts
Induced stress changes (increase and decrease)
Water (natural or introduced)
Deterioration of the rock mass with time

APPENDIX D - EXAMPLE ROCK FALL REPORT FORM

COMPLETE THIS SECTION FOR ALL OCCURRENCES INVOLVING A SIGNIFICANT SEISMIC EVENT AND/OR FALL OF GROUND (FOG)

TIME, LOCATION & EXTENT OF FOG/ DAMAGED ROCKMASS/ DAMAGED SUPPORT						
Time & Extent	Time of FOG?	FOG Tonnes (t)	Damaged Area - Depth (m)	Damaged Area – Width (m)	Damaged Area - Length (m)	
	DD/MM/YY HH:MM AM/PM	*<numeric>*	*<numeric>*	*< numeric>*	*< numeric>*	
Depth (m below surface)	Mine (deepest active stopes)		At Fall of Ground (FOG)			
	<text description>		*<text description>*			
Location of Damage Site *<Attach screen dump from mine software showing development, stopes & major structures>*	Lode/Block Name		Northing	Easting		
	<text description>		*<text description>*	*<text description>*		

EXCAVATION DESIGN (For Damaged Development/ Accessway)				
Excavation Details – in area of FOG/damage	Date Mined	Development Width/Span (m)	Development Height (m)	Perimeter Blasting used?
	DD/MM/YY	*<numeric>*	*<numeric>*	Y/N

SUMMARY DESCRIPTION OF FOG/ DAMAGED ROCKMASS						
Damage Site Description	*<text description> Eg stope brow*					
Site Geology, Structures, Stress Conditions, Presence of Water (l/s) *<describe>*	*<text description> Eg porphyry dyke contact with ultramafics, high stress at brow, dry.*					
Kaiser Rock Damage Scale (See Table 1) (tick 1 box)	R0 (no rockmass damage)	R1 (minor new fractures)	R2 (minor damage <<1t displaced)	R3 (<1t displaced)	R4 (1-10t displaced)	R5 (>10t displaced)
	√					

Failure Mode (Tick correct box)	Static	Seismic (Ref: ACG Generic SRMP)				
	Wedge Sliding Block Toppling Unravelling	Strain Burst (incl bulking)	Buckling	Face Crush/ Pillar Burst	Shear Rupture/ Fault Slip	Shakedown
					√	

SEISMICITY (Fill in this section only if a Seismic Event has occurred)					
Source Mechanism (eg high S:P = fault slip)	*<text description> Eg ' Jog Fault' slip, observed displacement/ heave of 300mm*				
Seismic Event Hypocentre	Time of Event	Level/ RL/ mBS	Northing	Easting	Distance from damage site(s)?
	DD/MM/YY HH:MM AM/PM	*<numeric>*	*<numeric>*	*<numeric>*	*<numeric>*
Magnitude	Seismic System		Local (M_L) (ESG)	Richter Equivalent (M_R) (ISS)	S:P energy ratio
	ISS/ESG/other		*<numeric>*	*<numeric>*	*<numeric>*

BLASTING (Provide details of last blast before the FOG/seismic event)					
Most Recent Blast Details	Time of Blast	Blast Tonnes	Blast Type (Stope production/ development/other?)	Exclusion Zone Details (Part of mine closed)	Re-entry Period (hours after blast) [based on Omori Chart analyses]
	DD/MM/YY HH:MM AM/PM	*<numeric>*	Prod/Dev/Other	*<text description>*	*<Hours>*

SUPPORT DAMAGE RATING IN FOG/ DAMAGED AREA						
Kaiser Support Damage Rating (See Table 2) (tick 1 box)	S0 (no damage)	S1 (1st signs of distress)	S2 (loaded, plates deformed, mesh bagged but OK)	S3 (heavy loaded, few broken, mesh bagged, some torn/open)	S4 (major damage, many broken bolts, mesh failed or bagged to capacity, rock ejected between bolts)	S5 (complete failure of support components)
				√		
	SC0 (no damage)	SC1 (1st cracks in shotcrete)	SC2 (shotcrete cracked & loaded)	SC3 (shotcrete fractured, debonding, some fragments)	SC4 (shotcrete heavily fractured, large pieces fallen)	SC5 (shotcrete non-functional)
				√		

INSTALLED GROUND SUPPORT IN FOG/DAMAGED AREA								
Order of Installation	1	2	3	4	5	6	7	8
Support Type <bolt/ reinforcement name>								
Black/ Galvanised?								
Bolt length (m)								
Pattern (burden x spacing, m)								
Bolt Load Capacity (t)								
Bolt Energy Capacity (kJ/bolt)								
Displacement Limit (mm)								
Age of support (months)								
Condition/ corrosion?								
Mesh	Sheet size (W x L, m)	Aperture (mm)	Gauge (mm)	Energy (kJ/m^2)	Overlap Pinned?	Coverage		
	<W x L>	*<numeric>*	*<numeric>*	*<numeric>*	Y/N	Backs/ Shoulder/ Grade Line		
Shotcrete/ Fibrecrete	Design Thickness (mm)	Actual Thickness (mm)	Energy (kJ/m^2)	Fibre Dosage (kg/m^3)	UCS (MPa)	Coverage		
	<numeric>	*<numeric>*	*<numeric>*	*<numeric>*	*<numeric>*	Backs/ Shoulder/ Grade Line		

GENERAL COMMENTS & REMEDIAL ACTIONS

Provide further relevant information. Describe immediate rectifications/ actions as a result of this event.
Please attach relevant photos, investigation memos, seismic history & data analyses.

Table 1: ROCK DAMAGE SCALE

Ref: Kaiser, P.K., Tannant, D.D., McCreath, D. R. and Jesenak, P. 1992 "Rockburst damage assessment procedure" in Rock Support in Underground Mining and Construction, Kaiser and McCreath (eds), Balkema, Rotterdam pp639-647.

Source: Generic Seismic Risk Management Plan, ACG, 2008.

Table 1 - Rock Damage Scale (RDS) from Kaiser *et al* (1992).

Damage Level	General Description	Rockmass / Excavation Damage
R0	Conditions unchanged	No new damage due to rockburst
R1	Excavations undamaged but first signs of distress detectable	Rock shows fresh but minor, small fractures and cracks (possibly behind 'loose') Small shards of rock may have been displaced
R2	Slight damage to excavations Only 'loose' displaced	Slight sloughing from back and walls of unsupported excavations (only 'loose' rock displaced, little freshly broken rock) Small shards and a few chunks of rock displaced in supported excavations (possibly retained by mesh) Rockmass shows only minor new fracturing
R3	Minor damage to excavations 'Loose' displaced and new rock failure	Unsupported drifts sustain damage with <200 kg of rock displaced from either a fall of ground or due to newly generated fracturing of rock (spalling) In drifts supported with only rockbolts and mesh, small to large pieces and occasional blocks (totalling < 1000 kg) of rock dislodged Moderate new bagging of mesh by fractured and displaced rock Clear evidence of newly fractured rock, possibly displaced violently
R4	Moderate to considerable damage to excavations Violent displacement of 'loose' and freshly broken rock	Unsupported drifts sustain damage at multiple locations Drifts supported with only rockbolts and mesh are damaged with substantial rock displaced (<10000 kg) but are still passable Rock is heavily fractured and displaced violently
R5	Serious or severe damage to excavations Opening collapsed	Unsupported drifts completely closed Drifts supported with only rockbolts and mesh heavily damaged and unpassable Substantial amounts of rock displaced (> 10000 kg) Rock is highly broken and fractured

Notes: 1) The damage indicators listed in this table describe damage that is new and was caused by the rockburst. If the observer cannot ascertain that the damage was inflicted by the rockburst then the damage should be ignored for the purposes of damage classification.
2) The mass of displaced rock serves only as a rough guide and should not be used alone to establish the degree of rockburst damage. Other qualitative descriptions are equally important when deciding on the degree of damage.
3) One or more damage scales may be observed in the same area and should be recorded separately.
4) 'Loose' is rock that could be scaled down by hand without much effort.

TABLE 2: SUPPORT DAMAGE SCALE

Ref: Kaiser, P.K., Tannant, D.D., McCreath, D. R. and Jesenak, P. 1992 "Rockburst damage assessment procedure" in Rock Support in Underground Mining and Construction, Kaiser and McCreath (eds), Balkema, Rotterdam pp639-647.

Table 1 - Support Damage Scale (SDS) from Kaiser *et al* (1992).

Damage Level	General Description	Support Damage	Shotcrete Damage
S0	Conditions unchanged	No new damage or loading	No new damage or loading
S1	Support undamaged but **first signs of distress** detectable	No damage to any support component	Shotcrete shows new cracks, very fine or widely distributed
S2	**Slight damage** to support **Loading clearly evident but full functionality maintained**	Plates and wooden washers on some rockbolts are deformed, showing loading Individual strands in mesh broken Mesh bagged but retains material well	Shotcrete cracked, minor flakes dislodged Shotcrete is clearly taking load from broken rock mass (mostly drummy)
S3	**Moderate damage** to support Support shows **significant loading and local loss of functionality**; retaining function primarily lost (except in laced or shotcreted areas)	Plates, wooden washers, and wood blocking on rockbolts are heavily deformed, showing significant loading; bolt heads may be "sucked" into rock Mesh torn near bolt heads with some strands broken and mesh torn or opened at overlapping edges Moderate bagging of mesh and isolated failures of rockbolts Cable lacing performs well	Shotcrete fractured, often debonded from rock and/or reinforcement Major flakes possibly dislodged Holding elements mostly intact
S4	**Substantial damage** to support **More extensive loss of retaining and holding functions** (except for lacing systems)	Mesh is often torn and pulled over rockbolt plates; if it did not fail, it is substantially bagged (at capacity) Many rockbolts failed Rock ejected between support components Cable lacing is heavily loaded with bagged mesh	Shotcrete heavily fractured and broken, often separated from the rock mass with pieces lying on the ground or hanging from reinforcement (Connections to holding elements often failed or holding elements failed locally)
S5	**Severe damage** to support Support **retaining, holding, and reinforcing functions failed**	Most ground support components broken or damaged Most rockbolts fail and rock peels off cable bolts Shotcrete non-functional Mesh without cable lacing heavily torn and damaged Cable lacing systems heavily stressed and often failed	For damage level S5, shotcrete fails to be functional and the left-hand column applies

Notes: 1) The damage indicators listed in this table describe damage that is new and was caused by the rockburst. If the observer cannot ascertain that the damage was inflicted by the rockburst then the damage should be ignored for the purposes of damage classification.

2) One or more damage scales may be observed in same section and should be recorded separately.

3) Rock and support damage levels need not correspond.

4) Because the function of shotcrete support is somewhat different and more complex than for other support systems, a separate column of indicators is provided over the range of S0 to S4. It is important to record where shotcrete is present and when it has been used to determine the support damage level.

5) Failure of rockbolt applies to failure of nut, plate, anchor or shank.

APPENDIX E - EXAMPLE EGC AUDIT – UNDERGROUND METALLIFEROUS

	MINE PLANNING AND DESIGN	Guideline
1.01	The design life of the mine and economic limits of the orebody have been determined.	Intent: To verify that mine management is capable of developing the optimal life of mine (LOM) design for the full extent of the orebody (eg. perennial 2 year LOM plan is not considered appropriate). Personnel: Registered manager, chief geologist. Method: Sight 3D geological model with LOM stoping overlay. The geological model will need to illustrate economic limits of the orebody beyond limits provided in the LOM design.
1.02	Mine management has a documented LOM design.	Intent: To verify that mine management is capable of identifying potential future geotechnical problems with current mine plans / designs well in advance of problems occurring. Personnel: Registered manager, manager mining, underground manager, chief mining engineer, technical services manager, chief geologist. Method: Sight LOM design plans or 3D model with estimated scheduling encoded on the LOM design.
1.03	Senior mine management has demonstrated a clear understanding and commitment to address the geotechnical issues in underground mining using sound geotechnical engineering practice.	Intent: To verify that mine management has sufficient knowledge of potential geotechnical hazards and associated risks and has provided clear committment to address these issues. Personnel: Registered manager, manager mining, underground manager, chief mining engineer, technical services manager, chief geologist. Method: Sight budgetary commitments. Sight a site-wide geotechnical hazard register and risk assessment for all safety issues related to ground control, and minutes of senior management meetings. Has senior management commissioned geotechnical investigations which consider worker exposure to rock failure hazards and recent rock failure incidents?
1.04	A set of development planning and design guidelines have been drawn up to provide general guidance in mine planning and design.	Intent: To verify that a consistent approach to development planning and design, particularly during absence of key personnel from site and high personnel turn-over. Personnel: Registered manager, manager mining, underground manager, chief mining engineer, technical services manager, chief geologist. Method: Sight documentation from mine planning and design meetings. Are the meetings minuted or recorded in some way? Sight examples of approved mine plans and accompanying notes or memoranda. Are they stored and accessible for future reference or review. Have mine design standards (eg drainage, camber, gradient, subdrill, ground support services etc) been set and are they documented? .
1.05	Mine management has established a "geotechnical model of the mine".	Intent: To verify that the characteristics of the rockmass within the immediate surrounds of the mine that can have an influence on mine performance have been recognised, quantified and grouped into an effective database (representing the "geotechnical model"). Personnel: Geologist, mining engineer, geotechnical engineer. Method: Sight geotechnical model/database. For the LOM design note; geological boundaries, geological structure, ranges of mechanical strength properties of all rockmass types, hydrogeology and insitu stress assessments.
1.06	The designed number, types, operating life and dimensions of all openings have been based on a suitable "geotechnical model of the mine".	Intent: To determine that mine management has identified the full range of mine openings to be excavated at the mine with respect to LOM design, hydrogeology and ground stability. Personnel: Registered manager, manager mining, underground manager, chief mining engineer, technical services manager, chief geologist. Method: Sight a database that contains the full range of void geometry and expected rock types within the perimeter of each void with geotechnical verification that each void can be suitably stabilised for the LOM. Applicable two/three dimensional stress analysis techniques are used to determine the interaction, dimensions, and sequencing of mine excavations. These designs have been derived by competent persons and formally documented.
1.07	The number, types, design life, dimensions, orientation and spacing of all pillars have been determined by geotechnical methods.	Intent: To determine that mine management has identified the full range of mine pillars to be developed at the mine with respect to LOM design and ground stability. Personnel: Registered manager, manager mining, underground manager, chief mining engineer, technical services manager, chief geologist. Method: Sight a database that contains the full range of pillar geometry and expected rock types within each pillar with geotechnical verification (by competent person/s) that each void can be suitably stabilised for the LOM.
1.08	Geotechnical domains are used to divide the rock mass into volumes of similar expected ground behaviour.	Intent: To ensure that the variation in ground conditions has been recognised and quantified. Personnel: Geologist, mining engineer, geotechnical engineer. Method: Sight plans, sections, longitudinal projections that show the expected range of ground conditions. Have these been contoured, shaded or otherwise identified? Have the different ground conditions been graded or classed in some way, eg A, B, C, … ; class 1, class 2, etc? Is the data represented in three dimensions, using justifiable local design criteria or using one or more of the recognised rock mass classification methods.
1.09	A justifiable design criteria exists for mining beneath / near surface water or water-filled mine workings according to the ground conditions, the mine plan and size of openinings and mine access.	Intent: To verify that the mine has conducted appropriate geotechnical appraisal of the potential for water inundation into the underground workings (from various sources). Personnel: Registered manager, manager mining, underground manager, chief mining engineer, technical services manager, chief geologist. Method: Sight relevant investigation/design documentation. (E.g. Due consideration has been taken of the potential for caving /stoping on contacting overlying bodies of water, nearby surface water drainage paths flooding into the portal at the base of a box-cut or open pit.) If there is no perceived source of water, there should be a formal statement (eg. within the PHMP) explaining why.
1.10	The mine uses a formalised approach for the design of rock support and reinforcement (GSR) for all types of mine openings in all geotechnical domains.	Intent: To verify that there is a reasoned explanation for the rock support and reinforcement being used in the mine. Personnel: Underground manager, mining engineer, geologist, geotechnical engineer, mine planning engineer. Method: Interview personnel. Which, if any, of the rock support and reinforcement design methods have been used (see page 18 of the Guidelines Geotechnical Considerations in Underground Mines)? Does the design method specifically refer to the type of support and reinforcement elements proposed (eg friction rock stabilisers)? Or has something else been substituted? Does the mine use an estimated maximum dynamic energy event, to design sesmic resistant GSR? The GSR design takes is based on published or peer review research.
1.11	The mine has developed a ground control management plan (PHMP) relevant to the local ground conditions and mining strategies	Intent: To verify that there is a formalised "live" document that summarises strategies used for managing all issues relating to ground control at the mine. Personnel: Registered manager, manager mining, underground manager, chief mining engineer, technical services manager, chief geologist. Method: Sight PHMP, is it up to date, does it contain reference to mine history with a description of mining methods and how they were selected, mine planning and design guidelines, mine backfill systems, SWPs, geological environment, hydrogeology, geotechnical qualities, worker responsibilities, GSR requirements etc.

1.12	The mining method, design and positioning of mine infrastructure have taken into consideration the long term stability/viability of nearby tenements and any surface features.	Intent: To verify that the mine can be abandoned without impacting on the long-term safety of nearby stakeholders. Personnel: Registered manager, manager mining, underground manager, chief mining engineer, technical services manager, chief geologist. Method: Sight a closure plan that addresses potential long term impacts on the surrounding environment and land owners / stakeholders. The closure plan needs to address issues such as extraction methods used in shallow or weathered rock (subsidence potential), waste dumps, drainage / diversions etc.
	DEVELOPMENT & MAINTENANCE OF GEOTECHNICAL MODEL	**Guideline**
2.01	The range of geological structure (planes of weakness) within the proximity of the mine have been defined, given geotechnical qualification and kept up to date in a suitable structural database.	Intent: To verify that there is a good understanding of local planes of weakness in rock within and immediately surrounding the mine, so better decisions can be made with respect to mine design and planning. Personnel: Registered manager, manager mining, underground manager, chief mining engineer, technical services manager, chief geologist. Method: Sight database with known geological structure, describing origin, trends and continuity. Can these be readily presented in 3D across the LOM design. Must be either included within or referred to by the PHMP.
2.02	Geotechnical mapping is being carried out on a regular basis in all 'active' and accessible mine voids.	Intent: To verify that up to date geotechnical data has been used to quantify and verify the ground conditions and that all records are kept up to date, commensurate with the rate of mining. Personnel: Geologist, geotechnical engineer. Method: Sight geotechnical mapping records. Have geotechnical software packages (eg DIPS or other similar program) or manual plotting methods been used to process the data? Have the geotechnical properties of the planes of weakness been determined (eg number and orientation (dip and dip direction) of joint sets; persistence (length), spacing and joint surface properties (eg roughness, planarity), etc)? Have these properties been plotted and summarised?
2.03	The pre-mining rock stress magnitude and orientation in the mine has been quantified and is updated at suitable intervals commensurate with the rate of mining.	Intent: To verify that the mine has sufficient data to quantify the variation in pre-mining stress fields within the rock through all stages of mining. Personnel: Underground manager, mining engineer, geotechnical engineer, mine planning engineer. Method: Interview personnel. Sight results of rock stress measurement and interpretations of principal stresses in the local rockmass. What method was used to determine the rock stress magnitude and orientation and have the limitations of this method been formalised and taken into account when used for design purposes? Has the mine determined a rock stress relationship with increasing depth, and/or is there localised stress variation dependent on geological structures/environments.
2.04	The rock mass strength and deformation characteristics within each geotechnical domain in the mine have been quantified and engineering properties understood.	Intent: To verify that the strength and deformation characteristics of the rock mass have been determined. Personnel: Underground manager, mining engineer, geotechnical engineer, mine planning engineer. Method: Interview personnel. Have the rock strength and deformation properties been determined for the various geotechnical domains? Sight a summary of the estimated rock mass strength and deformation properties (eg. compressive and tensile strength, Young's modulus, Poisson's ratio etc) for the various geotechnical domains. Note: This information may have been determined by laboratory testing of rock core samples or from biaxial tests carried out during rock stress measurement, ie using intact rock samples. Has the mine determined the extent to which these results need to be adjusted (typically reduced) to take account of jointing and microfractures etc. in the rock mass. These data may also have been estimated by using stress analysis techniques to "back-analyse" a particular mining geometry.
2.05	Local hydrogeology has been quanitified and ongoing measures taken to verify these assumptions.	Intent: To verify that hydrogeological data is collected and stored in a database that is readily available for further processing. Personnel: Geologist, geotechnical engineer Method: Sight hydrogeological database. Does the database have all the required information to allow the interpretation of the extent of aquifers, likely heads of pressure, water quality and potential inflows of water.
2.06	Geotechnical diamond drill core logging is used as a tool for ongoing confirmation of mine-wide geological/structural models in conjunction with scanline and area mapping models.	Intent: To ensure that borehole data is used to provide information to help maintain the geotechnical model in advance of mining (relying solely on mapping of areas already exposed may be problematical). Personnel: Geologist, geotechnical engineer Method: Are exploration holes (in-mine) or specific geotechnical holes being planned and used for advance confirmation of the geotechnical model? Are these holes oriented? The database used could be part of the geological drill hole database. View a sample of the geotechnical database by selecting typical holes chosen at random. Borehole data has more application for predictive work, and should be incorporated in the model verification process to ensure there are no surprises if mining towards a potential geotechnical anomoly. This diamond drill data is regularly entered into an appropriate database that allows easy interrogation of data and trends.
2.07	A comprehensive database is maintained that includes all geotechnical data (eg rock mass properties,) relevant to the local geological and mining characteristics.	Intent: To verify that geotechnical data collected is stored in a single database that is readily available for further processing such as 3D numerical/stress modelling or hazard mapping. Personnel: Geologist, geotechnical engineer Method: Sight geotechnical database. Reference must be made to this in the PHMP. Does the database have representative data for all parameters (in each domain) required for use in a numerical model appropriate to the mine site. (UCS, E, v, Sig1,2,3, unit weight, fault/defect properties, shear strength and modulus as required etc.) Sight site geotechnical hazard map. This database must be included within or be referred to in the PHMP.
2.08	A hazard map for existing and future areas of the mine has been developed.	Intent: To ensure that hazard mapping is undertaken at the mine to highlight areas of concern in existing areas of the mine and subsequent mining areas and that these are maintained in an appropriate database for future records. Personnel: Geologist, geotechnical engineer Method: Sight geotechnical hazard map / database. This database must be included within or be referred to in the PHMP.
2.09	A numerical modelling development process has been developed and numerical model/s exists for the mine, taking into account the nature of the mine, the geotechnical conditions and perceived hazards.	Intent: To ensure that all relevant data is being used or can be used in short notice for stress modelling to assess perceived problem areas in the mine or to modify mine planning and design - particularly in deep mines - and that these are maintained in an appropriate database for future records. A prescribed modelling "philosophy" should be formally specified for future reference. Personnel: Geologist, geotechnical engineer Method: Sight numerical model and modelling philosophy documentation. This documentation must be included within or be referred to in the PHMP.

	OPERATIONS - mining control	Guideline
3.01	A system is in place which ensures that short, medium and long term planning and scheduling are compatible with one another and reviewed concurrently.	Intent: To verify that the mine has established a systematic approach whereby short term development and production schedules can deliver required long term plans/schedules. Personnel: Registered manager, manager mining, underground manager, chief mining engineer, technical services manager, chief geologist. Method: Sight long term and short term development and production schedules and notes of meetings and sign-off on each schedule.
3.02	Mine design drawings are signed off by the underground manager and all relevant geology, surveying and engineering professionals.	Intent: To verify management accountability for the proposed mine plan. Personnel: Registered manager, manager mining, underground manager, chief mining engineer, technical services manager, chief geologist, mine planning engineer. Method: Sight approved mine design drawings and check that signatures and dates are present. The sign-off process must meet with accepted auditing standards and not readily tampered with after the event.
3.03	Mine planning and design meetings are held monthly or more frequently.	Intent: To verify that mine planning and design is an on-going process and not a series of ad hoc crisis meetings. The mine planning and design process should lead production, not the reverse. Personnel: Manager mining, underground manager, chief mining engineer, technical services manager, chief geologist, mine planning engineer, mine geologist, mine surveyor, electrical engineer, mechanical engineer, maintenance engineer (as required). Method: Sight minutes of mine planning and design meetings. When was the last meeting held?
3.04	Mine planning and design matters are regularly discussed with the underground workforce.	Intent: To verify that the underground workforce are made aware of the reasons why mining work is being carried out in various areas of the mine. Personnel: Underground workforce. Method: Ask the workforce about their understanding of the reasons why certain headings are being developed, why stoping blocks are being mined and what difficulties are expected in say the next 6 months. What do they know about the possible causes of the ground control problems, if any, that the mine has experienced recently (eg seismic events, rockbursts, rock falls, etc)? Sight minutes of meetings.
3.05	For recoverable pillars, an appropriate pillar recovery plan exists and is implemented.	Intent: To verify that a suitable process has been developed that takes into account localised stresses, unsupported spans, interaction with other voids and geological structure etc when extracting pillars. Personnel: Registered manager, manager mining, underground manager, chief mining engineer, technical services manager, chief geologist. Method: Sight pillar recovery strategy document.
3.06	The mine has a formalised, clear definition of "unsupported ground" and has derived a formal protocol with respect to persons working near these areas.	Intent: To verify that clear definitions of "unsupported ground exist" that are appropriate for all forms and sequences of mining. Personnel: Geotechnical engineer, underground manager, underground mining personnel. Method: Sight formal definition. Must be included in the PHMP. May have slighly different definitions in different mine areas/mining methods - eg airleg mining, raise boring. Must be accompanied by acceptable safe working practices when working near these locations.
3.07	The mine has established tolerance limits / trigger points for mine planning/scheduling and trigger-action plans relevant to major geotechnical hazards.	Intent: To verify that the mine understands various tolerance limits for mine design and scheduling a standard protocol is developed that defines the actions and decision making processes of all relevant personnel when particular trigger points are reached for ground movement and seismic activity. Personnel: Registered manager, manager mining, underground manager, chief mining engineer, technical services manager, chief geologist. Method: Sight registry of geotechnical hazards that influence mine design and scheduling strategies (eg. extraction sequences to maintain a "chevron" shaped advancing stope face to control mining induced stresses; minimum pillar dimensions when retreat mining to a central pillar, or to limit exposure times in weak rocktypes etc). Sight standardised strategies for cases when certain trigger points have been exceeded.
3.08	The mine has formalised procedures for preventing inadvertent access to vertical openings and unsupported ground - as required.	Intent: To verify that formal procedures exist that ensure safe, consistent approach to prevent personnel inadvertently accessing these hazards (from below and/or above). Personnel: ReGeotechnical engineer, underground manager, geologists, surveyors, relevant underground personnel (e.g. bogger drivers). Method: Sight relevant documents - must be referred to or included directly within the PHMP. Interview mining personnel. Reference must be made to regular checks by nominated persons to ensure these procedures are being consistently and adequately followed. Refer: MSIR 10.28(1)
3.09	Appropriate strategies/designs have been developed and implemented to maintain safe working conditions when working near unsupported ground and portal access via open pits - as required	Intent: To verify that formal procedures exist that ensure safe, consistent approach by all relevant personnel when working near these hazards (eg. surveyors, bogger operators etc). Personnel: Registered manager, manager mining, underground manager, chief mining engineer, technical services manager, chief geologist. Method: Sight relevant documents - must be referred to or included directly within the PHMP. Interview mining personnel.
3.10	Waste dumping procedures (surface and underground) have been developed to take into account the full range of materials being dumped and ground/surface water conditions in all areas at both the tip head and toe of the dumping points.	Intent: To verify, where relevant, that procedures and geotechnical assessment exists for the dumping of waste rock at the surface for the range of foundation and drainage conditions, dump materials, dump geometry, and other local hazards. Personnel: Registered manager, manager mining, underground manager, chief mining engineer, technical services manager, chief geologist. Method: Sight waste dump design and management documents.
	OPERATIONS - Performance monitoring	**Guideline**

4.01	The mine has formally established monitoring requirements for all potential geotechnical hazards.	Intent: To verify that the mine understands the mechanisms of the propagation of geotechnical hazards and concomitently understands the appropriate methods required to monitor such hazards before they become problematical. Personnel: Registered manager, manager mining, underground manager, chief mining engineer, technical services manager, chief geologist. Method: Sight register of geotechnical monitoring requirements.
4.02	The mine has established tolerance limits / trigger points for all forms of geotechnical performance monitoring and has formalised appropriate trigger-action plans.	Intent: To verify that the mine understands the tolerance limits for all forms of performance monitoring and that a standard protocol has been developed that defines the actions and decision making processes of all relevant personnel when particular trigger points are reached (e.g. for ground movement, seismic activity, water pressure etc). Personnel: Registered manager, manager mining, underground manager, chief mining engineer, technical services manager, chief geologist. Method: Sight documentation prescribing trigger points and concomitent action plans for all forms of monitoring. Does the minesite posses an emergency response plan that describes emergency actions or protocols to be taken by persons working in/near areas where a specific trigger event occurs (eg. potential high risk ground movement and/or seismic event) and for re-entry into those areas.
4.03	There are regular geotechnical inspections of the as-mined conditions of the relevant mine GSR, openings and their surroundings.	Intent: To verify that the geotechnical hazards are continuously assessed at the mine. Personnel: Manager mining, underground manager, chief mining engineer, technical services manager, chief geologist. Method: Sight records of geotechnical hazard assessment, mining history and any changes in the observed ground conditions, GSR status or requirements and perceived potential hazard assessments. This may include the identified geotechnical hazards being ranked according to severity. Who undertakes these inspections? How frequently are they done? Does the mine have its own geotechnical engineer- if not, does the mine have regular visits from a representative of a consulting geotechnical organization? Is a summary produced that is reported to management with recommendations?
4.04	An on-going photographic record of important geotechnical events, with written notes of observations, is maintained and regularly updated.	Intent: To verify that there is a record of important geotechnical events in the mine. Personnel: Underground manager, mining engineer, geologist, geotechnical engineer, mine planning engineer. Method: Interview personnel. Sight photographs with notes summarising events. Have these events been interpreted? What are their implications for future mining? Note: Later review of these history data may provide improved insights into what was occurring at the time. This may not be readily apparent, during mining, due to production demands and/or a lack of appreciation of the full magnitude of the event.
4.05	Absolute and/or incremental rock stress measurement techniques are used where appropriate.	Intent: To verify that the mine can quantify if there has been any change (increase or decrease, orientation) in the rock stress field magnitude as a result of mining. Personnel: Mining engineer, geologist, geotechnical engineer, mine planning engineer. Method: Interview personnel. Sight results and interpretation of the rock stress measurements (absolute or incremental change). Note: Large changes in the mine geometry, eg mass blasting, can cause significant changes in the rock stress field. Generally more applicable in non-entry mining methods, eg longhole open stoping, sub-level caving, block caving and vertical retreat mining.
4.06	Appropriate surveying techniques are used to monitor as-mined void and pillar geometry.	Intent: To verify that the extent of overbreak, underbreak or non-break in all production and development voids can be quantified. Personnel: Underground manager, surveyor, mining engineer, geologist, geotechnical engineer, mine planning engineer. Method: Interview personnel. Sight results from laser surveying techniques and determination of actual stope profile (plans and cross-sections may be useful) and overlying or nearby development. Have these results been recorded in a suitable 3D database? Has there been large scale wall collapse in open stopes? Is active caving occurring within the stope? Is nearby development likely to be effected by the caving front? How is the situation being managed? Note: The survey data can be useful in calculating wall rock or fill dilution. Results are used to assess stopes that are caving or self mining upwards towards the surface, overlying development or other filled stopes and for confirmation of design criteria (See Section 8 in this audit)
4.07	Displacement monitoring instrumentation is used where appropriate.	Intent: To verify that movement that is occurring in stope walls, on faults, floor settlement, etc is monitored. Personnel: Underground manager, mining engineer, geologist, surveyor, geotechnical engineer, mine planning engineer. Method: Interview personnel. Sight graphical summary of results from extensometers, monitoring pins, convergence monitoring, precise levelling, etc. Sight plans showing monitoring instrument locations, development and stope voids. How often are the monitoring instrument read? How are they read (ie manually or automatically)? Who is responsible for ensuring that they are read? How are these data used? Where access to the underground workings is via a portal in an open pit or deep box-cut, suitable monitoring and preventative actions are taken to limit potential for loose rock to subside onto travelways.
4.08	Appropriate seismic monitoring is undertaken where potential exists for rockburst activity to damage mine openings and/or the GSR systems in the mine.	Intent: To verify that a seismic monitoring system is installed in seismically active mines and / or that sufficient information exists that formally explains why/how seismic monitoring systems are not required. Personnel: Registered manager, underground manager, mining engineer, geologist, geotechnical engineer, mine planning engineer. Method: Refer to PHMP, sight reference to a seismic monitoring strategy or a formal (up-to-date) statement that supports the non-requrement of seismic monitoring. Ascertain from records of mine observations whether seimically induced damage has occurred regularly to mine excavations and the installed ground support? If yes, then a seismic monitoring system should be installed. Interview underground personnel to check the current level of seismic activity in the mine. Does the information from underground personnel compare well with the perceived level of risk and management and monitoring strategies in place at the mine.
4.09	The installed seismic monitoring system is capable of detecting, processing and displaying a representative sample of the range of seismic events occurring in real time - including during power outages.	Intent: To verify that the installed seismic monitoring system is capable of monitoring a representative sample of the seismic events and rockbursts at the mine. Personnel: Registered manager, underground manager, geologist, geotechnical engineer, mine planning engineer. Method: Interview personnel. Has the seismic system been supplied by a reputable supplier with experience in the mining industry? Has the supplier conducted test work underground to determine the P and S wave velocities? Has the supplier prepared a report recommending a particular seismic monitoring system, sensor type (ie geophone or accelerometer) and locations of sensors underground? Has this recommendation been accepted in its entirety by the mine? Can the seismic monitoring system carry out the required quantitative seismological processing in real time? Can the system discriminate between blasts and seismic events occurring very soon (ie preferably within seconds to minutes) after blasting?
4.10	The seismic system is capable of providing coverage to all areas of the mine that persons work for the full range of events used to determine the performance of the mine.	Intent: To verify that suitable processes exist that define the areal limitations of existing seismic monitoing in relation to the accuracy and range of seismic data required and strategies and schedules for upgrading or relocating monitoring points. Personnel: Registered manager, manager mining, underground manager, chief mining engineer, technical services manager, chief geologist. Method: Sight design documentation that supports the current configuration of the seismic monitoring system and provides recommended further development of the system with respect to ongoing mine expansion and mining methods.

4.11	The results from all forms of monitoring have been used to assess trends of movement or seismic activity .	Intent: To verify that systems are in place whereby all forms of monitoring are systematically reviewed and interpretations made of the causes and likely outcomes and potential impacts on mine safety reported. Personnel: Registered manager, manager mining, underground manager, chief mining engineer, technical services manager, chief geologist. Method: Sight memorandums / reports that include monitoring results and recommendations of actions to be taken in response to the monitoring data/trends (e.g. Guttenburg / Richter plots for prediction of potential maximum magnitude, or Omori charts used for re-entry restrictions; influence of geologic structure, sesimic or failure mechanisms, influence of mine void geometry etc.)
4.12	ALL forms of monitoring results (underground and where applicable surface) and interpretations are regularly communicated to the workforce.	Intent: To verify that management have informed the workforce of monitoring results etc. at suitably frequent intervals or immediately after significant trigger events have occurred. Personnel: Underground manager, supervision, mining engineer, geologist, surveyor, geotechnical engineer, mine planning engineer, all underground workforce. Method: Interview personnel. Are regular meetings are held with all members of the workforce who work underground? Is ground behaviour information shared with the workforce at these meetings? Are the results of seismic monitoring displayed on plans or longitudinal projections that are readily accessible to the workforce and are explained by cause/effect interpretations? Management should verify that the workforce are informed of potentially adverse ground behaviour that is occurring or may occur in the mine. Essential to reduce the element of surprise for the workforce.
	OPERATIONS - Ground support and reinforcement (GSR)	**Guideline**
5.01	Load capacity of the individual elements (anchorage, bar or tendon and surface restraint) are appropriately matched to prevent premature failure of any one component for various modes of failure.	Intent: To verify that there is no weak link in the support system. For example if the mine uses expansion shell rock bolts, then will the intact rock strength permit the full tensile strength of the bar to be achieved in a load-displacement test; bolts should not be able to pull through plates; mesh should be capable of holding expected loads as well as reinforcement holding the mesh. Personnel: Mining engineer, geotechnical engineer, supervision, rock support and reinforcement crew. Method: Interview personnel. Has load testing been carried out on the support? Sight results of load tests. Does the bar or strand fail before the anchorage method (expansion shell, grout, frictional interference fit)? Does the bar fail before the nut or ring pulls through the plate? What support failures, if any, have been observed?. What failed - anchorage method; bar/tube/strand or threaded end/ring/plate/nut/ barrel and wedge anchor?
5.02	The mining cycle has been adapted to the ground conditions to take into account the effect of time dependent behaviour of the rock mass and LOM void design.	Intent: To verify that management recognise that ground conditions do not remain the same for ever and that GSR needs to be installed prior to critical rock movement occurring (eg minimising the delay in installing the ground support and sequencing of cable bolt installation in wide spans) and also be capable of withstanding the expected ground movement and stresses over the active life of the mine void. Personnel: Underground manager, mining engineer, geotechnical engineer, supervision, rock support and reinforcement crew. Method: Interview personnel. Has time dependent deterioration of the ground conditions been experienced at this mine? If so, sight of records kept by the mine, eg photographic records, results of simple convergence monitors and regular observations/inspections of suspect areas, preferably noted in a record book. Has the mine carried out any three dimensional stress analyses of each mining stage? This may help to pin point areas of stress decrease/increase and hence possible deterioration of ground conditions. Note: Subtle changes in the rock stress field, particularly stress decreases and stress increases, (as a result of nearby mining) may trigger a deterioration in the ground conditions.
5.03	A technical specification exists for all the GSR systems in use, taking into consideration design and performance requirements.	Intent: To verify that the mine has its own technical specifications for the various types of rock support and reinforcement in use. Personnel: Underground manager, mining engineer, geotechnical engineer, mine planning engineer. Method: Interview personnel. Sight a copy of the rock support and reinforcement technical specifications prepared by the mine. The rock support and reinforcement specification states the load capacities (support resistance) and the energy absorption capacities of the various elements in the system. Reference should be made to this in the PHMP.
5.04	The mine has, uses and enforces written standard work procedures for installation of all the various types of GSR in use at the mine.	Intent: To verify that written standard work procedures exist that describe how the rock support and reinforcement is to be installed and that they are enforced. (e.g. Do procedures such as bolt hole diameter tolerance etc. comply with manufacturer's recommendations?. Personnel: Underground manager, supervision, mining engineer and operators. Method: Interview personnel.Observe installation. Sight copy of standard work procedures. Compare observed work procedures with those in the standard. Are they in agreement? If not, what explanation can be provided? Interview personnel, Have the diameters of holes drilled in the rock for support been measured? Are the re-sharpened drill bits graded according to diameter range? Are the re-sharpened drill bits colour coded to indicate a range of bit diameters? Have support load tests been done using holes drilled with different bit sizes? Has the support load capacity been related to bit size ranges for each geotechnical domain ? Note: This audit point is particularly important with friction rock stabilisers (eg Split Sets) where the load capacity is very sensitive to the correct hole diameter range. Observe holes being drilled. Where appropriate, are the correct hole lengths being drilled (this should not be an issue for spilt sets)? For upholes, was the drilling water left on after the bit stopped drilling for say a few seconds? Was the return water clean? For down holes, it is much more important to blow the hole out with compressed air (if available) and water to remove all drilling sludge. This is very important for long down holes drilled for cablebolts.
5.05	The storage and handling of rock support and reinforcement elements is such that deterioration with time is minimised.	Intent: To verify that deterioration of support and reinforcement components is minimised. Personnel: Supervision, mining engineer, stores officer. Method: Inspect the surface and underground locations where the rock support and reinforcement equipment is stored. Are the components, particularly threaded components, protected from rain, groundwater, contamination during storage and general damage during transport? Are resin cartridges protected from direct sunlight and high temperatures and used before the prescribed expiry date? Are pallets of bagged cement shrink wrapped? Note: Ground support and reinforcement should be stored "like with like" to avoid mis-match of components, eg putting friction rock stabiliser plates on expansion shell rock bolts.
5.06	The drill hole orientation is appropriate for the excavation geometry and expected block movement.	Intent: To verify that the full effective length of the support is used. Personnel: Supervision, mining engineer, rock support and reinforcement crew. Method: Observe hole being drilled in the backs and walls, particularly in development headings. Are the holes generally perpendicular to the excavation surface? Note angle of boom to backs and walls. Is it perpendicular to the rock surface? Does the boom length, relative to height or width of the excavation, make it difficult to drill perpendicularly to the rock surface? Note: Very flat holes seriously reduce the "effective" length of the support (proportional to the cosine of the included angle).

5.07	All components to be encapsulated in resin or cement grout are clean and free of deleterious materials.	Intent: To verify that the support element is able to development the full bond strength between itself and the grout. Personnel: Mining engineer, geotechnical engineer, supervision, rock support and reinforcement crew. Method: Inspect installation procedure. Are the support elements (particularly bar, tube or strand) free of loose flaking rust, oil, grease, paint, fill?
5.08	Records are kept that fully grouted elements are actually fully grouted.	Intent: To verify that the element is fully encapsulated in grout. Personnel: Mining engineer, geotechnical engineer, supervision, rock support and reinforcement crew. Method: Observe installation of grouted support. Where support is installed in the hole first and then grouted: is there a grout return at the hole collar? Alternatively, where grout is placed in the hole first and the support is then pushed through the grout: is some of the grout displaced from the hole collar? This is considered to be the same as a grout return.
5.09	Retensioning of relevant anchor rock reinforcement is carried out and/or records are kept to verify that retensioning is not required.	Intent: To verify that tension in point anchored reinforcement systems is maintained. Personnel: Mining engineer, geotechnical engineer, supervision, rock support and reinforcement crew. Method: Interview personnel. Does the recommended support installation procedure require that the tension be checked? Is retensioning or torque testing of point anchor reinforcement carried out on a random basis?. Are the reinforcement manufacturer's instructions being followed?
5.10	GSR is protected against corrosion for the design life of the opening.	Intent: To verify that the design life of rock support and reinforcement and the openings are matched. Corrosion issues should be addressed and remedied in permanent openings (see page 17 of the Guidelines Geotechnical Considerations in Underground Mines). Personnel: Underground manager, mining engineer, geotechnical engineer. Method: Interview personnel. Does the mine have areas where corrosion is likely to be a problem? Is the corrosion in these areas likely to be adverse for the support load capacity? What corrosion protection has been incorporated into the support technical specification? Does the installed support meet the required specification for corrosion protection.
5.11	The mine has formalised procedures to ensure that the quality control of resins and grouts (including shotcrete and fibrecrete) satisfy design requirements at all times.	Intent: To verify that management recognise that rock performance is heavily dependent on quality control of all materials used as a fixative or "cementing agent" to rock. Personnel: Mining engineer, geotechnical engineer, supervision, rock support and reinforcement crew. Method: Interview personnel. Sight formailsed procedures for assessing installation quality of resins and grouts. Issues to be addressed include: reference to "use by date" of the resin, resin mix and delay time, specification of the water:cement ratio, whether potable (drinking quality) water is to be used to mix the cement grout (e.g. impurities in the water (eg chloride salts) may adversely effect the grout compressive strength and corrode the steel in contact with the grout). Sight quality control testing of the "cementing agent" (eg slump, UCS tests etc) .
5.12	All equipment used for cementitious applications, pressurising swellex-type bolts and tensioning is maintained on a regular basis.	Intent: To verify that management recognize that poorly maintained equipment may not correctly inflate Swellex type reinforcement. The anchorage capacity of such reinforcement with be less when not inflated in accordance with the manufacturers recommendations. Personnel: Mining engineer, geotechnical engineer, supervision, rock support and reinforcement crew. Method: Interview personnel.Is equipment maintained in accordance with the manufacturer's instructions? Is the equipment operated at the recommended pressure? . The anchorage capacity of such reinforcement with be less when not inflated in accordance with the specification. Sight results of test work conducted by NATA laboratory on mine shotcrete samples. Do the results comply with the shotcrete specification?
5.13	Shotcrete/fibrecrete thickness testing is regularly undertaken to ensure that the specified thickness has been applied.	Intent: To verify that the shotcrete thickness complies with the technical specification (see audit point 5.38). Personnel: Underground manager, mining engineer, geotechnical engineer, supervision, rock support and reinforcement crew, shotcrete contractor. Method: Interview personnel. What method is used to determine the shotcrete thickness? How often is testing carried out at each location where shotcrete is applied? Does the shotcrete thickness comply with the technical specification? Does the mine have an action plan to rectify this if the shotcrete thickness specification is not achieved? If the shotcrete is too thin it may fail prematurely.
5.14	Regular load versus displacement testing is conducted for all types of rock reinforcement used in the mine.	Intent: To verify the installed rock reinforcement load-displacement performance complies with the technical specification for all rock conditions (including seismic) at all times. Personnel: Mining engineer, geotechnical engineer, supervision, rock support and reinforcement crew. Method: Sight results of load-displacement tests conducted during the previous 12 months on the various types of rock reinforcement used in the mine. The test equipment and procedure to be as per the ISRM suggested methods of testing or suitable adaptation thereof. Do the results of the load versus displacement testing comply with the support technical specifications? Note: The load-displacement tests could be incorporated into the rock support and reinforcement supply contract. Reinforcement elements tested shall be installed in the mine by mine workforce using mine equipment and usual work procedures (ie not one off specials). The annual minimum number of load-displacement tests should be approximately 1% of the total number installed for each type of support or a minimum of 5, which ever is the larger, for each geotechnical domain.
5.15	The equipment being used to install the rock support and reinforcement has formal confirmation that it is suitable for that purpose from both installation safety and quality assurance perspectives.	Intent: To verify that the equipment used is purpose designed and built for installing rock support and reinforcement. Personnel: Underground manager, supervision, mining engineer. Method: Interview personnel. Sight the manufacturer's description of the intended use of the equipment. Is this how the equipment is being used? If not, has the mine discussed with the manufacturer the use of the equipment in the manner proposed? How is the equipment maintained and by whom. Is the frequency of maintenance work in line with that specified by the manufacturer?
	OPERATIONS - Management of unstable rock	**Guideline**
6.01	The mine has developed and enforces a scaling policy to be adapted in each area within the mine.	Intent: To verify that a formal policy exists that specifies the strategic approach to scaling in all areas of the mine. Personnel: Registered manager, manager mining, underground manager, chief mining engineer, technical services manager, chief geologist. Method: Sight scaling policy documentation.
6.02	The mine has developed and enforces a standard work procedure for all forms of scaling used in the mine.	Intent: To verify that formal procedures exist that specify the frequency and methods of scaling to be appropriately implemented in all areas of the mine. Personnel: Registered manager, manager mining, underground manager, chief mining engineer, technical services manager, chief geologist. Method: Sight scaling documentation.

6.03	The mine conducts on-going regular checks for scaling / rehabilitation requirements of all main access ways.	Intent: To verify that all working areas are checked for scaling requirements at regular intervals, commensurate with the rate of rock loosening and perceived magnitude of hazard. Personnel: Registered manager, manager mining, underground manager, chief mining engineer, technical services manager, chief geologist. Method: Check scaling scheduling documentation. Interview mining personnel. Observe underground.
6.04	Records are kept of all scaling / rehabilitation required and these records are placed into a suitable database for future reference.	Intent: To verify that each area requiring scaling has been recorded and signed off as being completed to the required standard and that scheduled scaling intervals are well matched to the frequency and amount of scaling required in particular areas. Personnel: Registered manager, manager mining, underground manager, chief mining engineer, technical services manager, chief geologist. Method: Sight scaling records documentation. Interview personnel. Observe underground.
6.05	The mine has a standard specification for scaling bars and other forms of scaling equipment (eg mechanised scaling units and work platforms).	Intent: To verify that the scaling equipment in use is suited to the purpose, extent, and local ground conditions and do not introduce additional hazards to the job at hand. Personnel: Registered manager, manager mining, underground manager, chief mining engineer, technical services manager, chief geologist. Method: Sight documentation listing specifications for scaling equipment and formal verification that the specifications adequately meet with the requirements for all areas in the mine.
6.06	The mine has developed and enforces a standard work procedure for removal of loose rock (as required) that is too hazardous to be scaled or removed by normal methods.	Intent: To verify that the mine is capable of safely managing large or dangerously positioned loose rock (eg beyond stope brows or potential removal of a "key block" that may cause unravelling above the person scaling). Personnel: Registered manager, manager mining, underground manager, chief mining engineer, technical services manager, chief geologist. Method: Sight relevant documentation (eg procedure specifies identification, reporting hierachy, risk assessment, actions taken etc.). Interview underground personnel.
6.07	The mine has a trigger-action plan that is implemented when it is found that the tested load capacity or visual degradation (eg. "bagging" of mesh, "popped" plates etc) of the installed GSR system does not meet the required standard.	Intent: To verify that any deficiencies identified in the load capacity of the installed support systems are rectified. Personnel: Underground manager, mining engineer, geotechnical engineer, supervision. Method: Interview personnel. Does the mine have an action plan? Sight a copy of the proposed action plan. Has the plan ever been implemented? The "required standard" is the technical specification. Does the mine have a standard definition of how much bagging can be tolerated, and a SWP dealing with "bleeding" of mesh - as required. Similarly, Does the mine have a standard definition of how much damage/deformation of reinforcement can be tolerated before remediation actions are undertaken. Is there a SWP for remediating these areas?
6.08	Where appropriate, additional illumination is available and used while the scaling or checking is in progress.	Intent: To verify that suitable lighting is available for personnel on foot when checking whether scaling is required in high areas. Personnel: Registered manager, manager mining, underground manager, chief mining engineer, technical services manager, chief geologist. Method: Interview personnel.
	OPERATIONS - Drill and blast	
7.01	The mine has, uses and enforces standard design procedures for drilling and blasting in rises and development.	Intent: To verify the achievement of optimum fragmentation and minimum overbreak per excavation blast with the minimum blast damage to the remaining perimeter rock. Personnel: Underground manager, mining engineer, supervision. Method: Interview personnel. Does the mine have a blast design procedure? Is it largely based on practical experience? Sight examples of use of blast design procedures in use. Have the blast designs been prepared by consultants or in-house expertise? How often are the blast designs reviewed? How do they incorporate changes in the ground conditions? How is back and wall damage minimised? Sight standard work procedure for various blast types. Were they produced using the blast design procedure? Sight reference to preferred powder factors, burden, stemming etc for each domain.
7.02	The mine has, uses and enforces standard design procedures for drilling and blasting in stopes.	Intent: To verify the mine has taken due consideration of the effect of stope blasts on the stability of stope walls and backs and floor and nearby voids and pillars (low/high stresses, vibrations etc). Personnel: Underground manager, mining engineer, supervision. Method: Interview personnel. Does the mine have a blast design procedure? Is it largely based on practical experience? Sight examples of use of blast design procedures in use. Have the blast designs been prepared by consultants or in-house expertise? How often are the blast designs reviewed? How do they incorporate changes in the ground conditions? How is stope wall damage minimised? Sight standard work procedure for various blast types. Sight stope etc charging sheet. Were they produced using the blast design procedure? Sight reference to preferred powder factors, burden, stemming etc for each domain.
7.03	A standard drilling and blasting pattern exists for all forms of blasting (and is always available to endusers) for each geotechnical domain.	Intent: To ensure that a design standard is available for "standard" void types and geotechnical domains. Personnel: Registered manager, manager mining, underground manager, chief mining engineer, technical services manager, chief geologist. Method: Sight standard patterns, interview personnel, observe underground.
7.04	The drilling and blasting crew(s) understand the importance of correct drilling and blasting work procedures.	Intent: To verify that the drilling and charging crews understand that correct work procedures are essential for a quality excavation. Personnel: Lateral and vertical development mining crews, air-leg miners etc. Method: Interview the drilling and charging personnel, inspect work places. For example, in hard rock conditions, half hole barrels can be seen in the backs and side walls on a regular basis, particularly in cross-cuts or where prominent planes of weakness are perpendicular to the direction of mining. What problems, if any, have the crew experienced?

7.05	All drilling equipment can deliver required hole parallelism at appropriate gradients and operators are capable of achieving this.	Intent: To verify that the development rounds are drilled correctly. Personnel: Supervision, lateral development crews, maintenance crews. Method: Observe drill hole barrel parallelism back from the face and drilling practices at the face.
7.06	The mine implements blast strategies to minimise blast damage to the perimeter of all excavations in all geotechnical domains and ensures that these strategies (eg. modified perimeter blasting) are followed rigorously underground.	Intent: To verify that the explosives, blast initiation strategy and drill patterns used minimise blast damage to the rock mass in the walls and backs. Personnel: Supervision, lateral development crews, air-leg miners. Method: Observe drilling and charging of the face, note explosive used in the perimeter holes. Is this the explosive specified in the standard work procedure? (Note: it is preferable that decoupled cylindrical cartridges are used.) This may also be an issue for the penultimate row of holes. Note: In hard rock conditions, half hole barrels are indicative of "good" mining practice.
7.07	Overbreak at the excavation perimeters is monitored.	Intent: To verify that measuring of overbreak occurs to maintain quality of excavation. Personnel: Underground manager, mining engineer, surveyor, development crews. Method: Enquire as to whether the mine has a policy on the maximum percentage of overbreak that is acceptable? Is the percentage overbreak regularly determined? Sight a copy of fortnightly or monthly summary of the percentage overbreak, as calculated by the surveyor, for each heading. Is this information permanently recorded by the mine and contractor? Is the overbreak information regularly given to the development crews?
7.08	A system exists to correct mining techniques where excess overbreak is encountered.	Intent: To verify that changes in void span due to overbreak variations encountered in the production/stoping or development stage are geotechnically assessed to ensure that the support and / or void design iremains within tolerance limits for the prevailing ground conditions. Personnel: Underground manager, mine planning engineer, geologist, geotechnical engineer. Method: Interview personnel establish whether rock mass classification, block analysis, stress analysis or other recognised methods been used to determine maximum opening spans that can be mined?
7.09	The mine uses appropriate blast monitoring techniques in development, rises and stopes to verify blasting performance on an regular basis.	Intent: To verify the stope blast design parameters are monitored (eg fragmentation, vibration, general observation and overgreak). Personnel: Underground manager, mining engineer. Method: Interview personnel. Sight a stope blast monitoring report. Have stope blasts been performing according to design?
7.10	Blasting in the immediate vicinity of stopes that contain wet fill is not permitted.	Intent: To verify procedures exist that prevent liquefaction of the saturated fill ((eg uncured paste fill, undrained hydraulic fill and uncured cement hydraulic fill) by dynamic loading from blasting. Personnel: Registered manager, manager mining, underground manager mine planning engineer. Method: Interview personnel. Sight records of stope blasts and stope filling (eg on a longitudinal section) Estimate the minimum time period between the completion of the filling process and firing of adjacent stopes. What basis is there for the minimum time. Has fill liquefaction occurred at the site. How is the potential for fill liquefaction managed.
	DESIGN CONFIRMATION/BACK ANALYSIS	
8.01	The mine has conducted back-analyses/comparisons of as-mined void geometry (Section 4) to justify the mine's short term design and planning strategies.	Intent: To verify that mine design/planning techniques used remain valid over time and that any discrepancies between observations and design criteria are satisfactorily resolved. Personnel: Registered manager, manager mining, underground manager, chief mining engineer, technical services manager, chief geologist. Method: Interview personnel. Observe backanalysis documentation, note comparisons made between actual stope and/or pillar dimensions and ground / rock performance monitoring (eg falls of ground, seismicity) and predicted/designed mine geometry and behaviour].
8.02	The mine has conducted back-analyses/comparisons of as-mined performance monitoring (Section 4) against existing numerical or empirical design criteria to validate existing geotechnical models and justify the mine's short-term design and planning strategies.	Intent: To verify that appropriate techniques exist and that any discrepancies between observations (eg ground stresses or displacements) and geotechnical modelling are satisfactorily resolved. Personnel: Registered manager, manager mining, underground manager, chief mining engineer, technical services manager, chief geologist. Method: Interview personnel. Observe backanalysis documentation, note comparisons made between actual stope and/or pillar dimensions and ground / rock performance monitoring (eg falls of ground, seismicity) and predicted/designed mine geometry and behaviour. Does the geological / structural model require modification or confer with numerical or empirical techniques?
8.03	The mine has conducted back-analyses/comparisons of the as-installed performance of GSR (Section 4) against minesite design criteria to validate existing geotechnical models and justify the mine's GSR short term design strategies.	Intent: To verify that appropriate GSR design confirmation techniques exist and that any discrepancies between observations and design are satisfactorily resolved. Personnel: Registered manager, manager mining, underground manager, chief mining engineer, technical services manager, chief geologist. Method: Interview personnel. Observe backanalysis documentation.

8.04	Methods exist to confirm that existing assumptions for the potential for corrosion/degredation of the GSR system, cement products and other relevant mine infrastructure can be expected to remain appropriate in all areas of a potentially changing hydrogeological environment.	Intent: To verify that design assumptions regarding the expected life and quality of GSR etc. remain valid for all areas of the mine, for the LOM. Personnel: Registered manager, manager mining, underground manager, chief mining engineer, technical services manager, chief geologist. Method: Interview personnel. Is groundwater acidic or highly saline, and is there sufficient knowledge of the distribution of groundwater throughout the mine. Is potable (drinking quality) water used to mix the cement grout? Note: Impurities in the water (eg chloride salts) may adversely effect the grout compressive strength and corrode the steel in contact with the grout. Water quality should be stated in the technical specifications.
8.05	A procedure exists to ensure that formal records of any changes in the geotechnical model (resulting from backanalysis/confirmation processes) are maintained.	Intent: To verify that the mine design guideline remains current and that factors contiributing to change in mine design / planning (in an ever changing environment) are well understood and that adequate records are kept for future personnel to use for continued safe mine design and planning of the mine. All changes should be given reference in the PHMP. Personnel: Registered manager, manager mining, underground manager, chief mining engineer, technical services manager, chief geologist, mine planning engineer. Method: Sight notes, memoranda or technical reports accompanying approved mine plans. Have the design decisions been documented. Have the design assumptions, if any, been clearly and unambiguously stated? Have the results of the evaluation of existing geotechnical models and planning / design criteria against performance monitoring been suitably documented for future reference.
8.06	Backanalysis / design confirmation data is used to verify that the existing geotechnical models and mine design / planning methods can be expected to remain appropriate for LOM designs.	Intent: To verify that appropriate techniques exist to allow the mine to determine that GSR and general mine design strategies and design criteria can be expected to remain adequate for the LOM. (Eg. the ongoing practice of leaving large open stopes or extracting stopes to a central pillar, and issues such as dewatering requirements etc. is regularly justified using performance monitoring and relevant modelling / assessment techniques) Personnel: Registered manager, manager mining, underground manager, chief mining engineer, technical services manager, chief geologist. Method: Interview personnel. Observe backanalysis / "mine performance" documentation that compares all forms of geotechnical performance monitoring (eg rock quality, seismic, absolute stress, convergence, GSR performance etc and notes of observations) against expected behaviour at the initial design phase and projects comparisons for LOM performance using current/planned mining strategies. Reference to this document should be contained in the PHMP.
	TRAINING AND COMPETENCY	
9.01	The workforce receives on the job training and ongoing competancy assessment of issuescovering the recognition and factors involved in rockfall hazards in the underground workplace.	Intent: To verify that the workforce receives on the job training and assessment covering the recognition of geotechnical hazards and to understand the importance of geological structure and its influence on rock stability Personnel: manager mining, Training manager. Method: Sight training and assessment records. Interview personnel.
9.02	The workforce receives on the job training and ongoing competancy assessment of issuescovering general ground awareness when working near vertical openings, and other areas of unsupported ground.	Intent: To verify that the workforce receives on the job training and assessment covering general ground awareness when working near drop-offs, ore and waste stockpiles, open stopes and other areas of unsupported ground. Personnel: manager mining, Training manager. Method: Sight training and assessment records. Interview personnel.
9.03	The workforce receives on the job training and ongoing competancy assessment of issuescovering the importance of the correct drilling and blasting work procedures.	Intent: To verify that the workforce receives on the job training and assessment covering the importance of the correct drilling and blasting work procedures. Personnel: manager mining, Training manager. Method: Sight training and assessment records. Interview personnel.
9.04	The workforce receives on the job training and ongoing competancy assessment of issuescovering general ground awareness with respect to assessing scaling requirements and safe scaling practices	Intent: To verify that the workforce receives on the job training and assessment covering general ground awareness with respect to assessing scaling requirements and safe scaling practices. Personnel: manager mining, Training manager. Method: Sight training and assessment records. Interview personnel.
9.05	The workforce receives on the job training and ongoing competancy assessment of issuescovering the importance of the correct GSR installation procedures.	Intent: To verify that the workforce receives on the job training and assessment covering the importance of the correct GSR installation procedures. Personnel: manager mining, Training manager. Method: Sight training and assessment records. Interview personnel.