SECTION 8

OVERVIEW OF DESIGN AND PLANNING STRATEGIES

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CONTENTS

Figures

8.1 INTRODUCTION

To quote More O'Ferrall (Budavari 1983); "The design engineer has a number of factors affecting strata control to consider when planning the layout of stopes…. The importance of these varies with the nature of the deposit.

In shallow deposits the effect of stress … is not critical and the stoping layout can be relatively flexible. However, the effects of stoping on surface structures must be considered. The nature of the roof, floor and seam rocks also tends to be of importance as the elastic convergence is small and in general stiff, permanent support must be used. The permanent support in this case is usually in the form of in situ pillars, their spacing depending on the strength of the seam or reef and the strength and jointing of the adjacent host rock.

With increasing depth of mining, the effects of stress on the workings become more important. As a result of generally high stresses, the rock around the workings fractures and at large mining spans the convergence of hanging- and footwalls in the stopes can be a significant portion of the stoping width. Therefore, the control of convergence and fractured rock has a paramount importance in deep level mining. One of the objectives in designing stope layouts is to minimise the effects of these high, mining induced stresses."

Lang (1998) summarised the legal status as"… the duty of care requires, in effect, that the generally available current technology be applied to reduce the risk of hazards to which the workforce is exposed. Consequently, it is incumbent on all mining and geotechnical engineering professionals to maintain a current awareness of these developments."

As stresses and the risk of seismicity increase, the importance of underground geotechnical engineering input into the design and planning strategies becomes increasingly important. Mining of seismically active and very high stress areas without such input would be unwise and management could not be seen as having followed their 'duty of care' obligations. Certain high stress remnants in seismically active mines would also be deemed unmineable without detailed geotechnical investigations, including detailed 3-Dimensional modelling, seismic analyses and rock mass characterisations etc.

Whilst this section briefly covers general aspects of planning, the main thrust is towards the geotechnical aspects, given their increased importance in highly stressed and seismically active mines.

8.1.1 STAGES OF MINE DESIGN AND PLANNING

Mine design and planning incorporates three separate areas;

pre-mining design and planning
operational planning and guidelines
short term modifications

These three stages of planning require similar input and background analyses. In reality the pre-mining stage will be conducted by a senior engineering team and the operation stage by less senior engineering staff in combination/negotiation with the production team.

8.1.1.1 Pre-mining Design and Planning

Pre-mining design and planning strategies are, in the vast majority of cases, conducted prior to the existence of development and stoping excavations. The information utilised is generally gained from diamond drill core and from experience with similar orebodies. The use of empirical geotechnical design methods is common at this stage but, as every orebody and mine varies, these methods have their limitations. Once mining commences, however, there is a rapid increase in the availability of geological and geotechnical data which in many (most?) cases requires adjustments to be made to the original planning.

8.1.2.1 Operational Planning and Guidelines

This stage of design and planning comes into effect when additional data from underground development and stoping excavations becomes available and is utilised. This data takes the form of mapping, rock tests, bulk sampling, support performance, and monitoring results.

The greatest increase in the rate of data available for planning and design purposes occurs during the initial stages of development and stoping. This additional data enables an improved correlation between the pre-mining estimates and the actual conditions to be made. Whether this additional data is available for inclusion into an updated long term (or annual) plan, or whether the data is only used in operational adjustments to the plan (eg monthly) depends entirely on the timing. Trial stoping, prior to full scale mining, is very advantageous for this purpose, and when undertaken can be used for adjustments to excavation design and support and reinforcement. Trial stoping can also be timed to provide input for annual, or more detailed long term planning (this is idealised – typically the mine will dive in to high production as soon as access is available).

Similarly the greatest benefits to be obtained from monitoring will be from instrumentation installed as early as possible in the mine life.

8.1.3.1 Short Term Modifications

The nature of mining typically requires frequent short term modifications to mining plans. This could be due to equipment or services failure, rockfalls, labour problems, or grade-tonnage variations.

Results of monitoring can also affect short term planning and production. In a highly stressed and/or seismically active mine this could include HI cell, seismic system, extensometer and closure monitoring. Rapid increases, or changes, in the readings of such instrumentation could trigger responses from geotechnical engineers such as delayed re-entry times following blasts, additional precautions, reduced production rates etc.. These types of ‘rapid response’ decisions require the presence of a full time geotechnical engineer on a mine to relate daily changes in monitoring and seismicity.

8.2.1 OBJECTIVES OF MINE DESIGN AND PLANNING

The objectives of mine planning and design in highly stressed and seismically active areas should not be dissimilar to those of low stress mines. The main objective is to produce a workable mining plan, utilising all available data and engineering skills, enabling the orebody to be extracted to the maximum benefit of the shareholders.

This would inherently incorporate maximum extraction, safety, employee motivation and continuity of production, and also optimum production rates and ore blending/grade control.

These factors in turn require detailed engineering design work to minimise dilution, eliminate falls of ground, maximise stability, and optimise support and reinforcement costs. Interpretation of “maximising stability’ is site dependent – if the whole mine collapses after the last tonne is mined, and after the last person has left, and if there is no risk of injury or damage to surface infrastructure, this could be construed as maximising/optimising stability.

The detailed objectives should include the production of a set of guidelines for;

tonnage and grade targets
the mining method(s)
access location
excavation dimensions, orientation and shape
excavation sequencing
support and reinforcement designs
safety (eg target = zero fatalities, zero LTI, ? MTI, ? MI)
and triggers for additional, more detailed investigations

The data required for building these guidelines will include more detail on economic and structural geological boundaries, rock mass property variances, stress (both pre-mining and mining induced), and on seismicity.

These guidelines would generally be updated and improved as more data is obtained, and analysed, from the day to day operation of the mine. Such data would include mapping (geological and geotechnical), CMS surveys, geotechnical monitoring results (eg closure pegs, extensometers, stress cells), seismic analyses, grade distributions and numerical modelling results etc.

Effective mine planning would ensure reduced occurrences of situations where the following exist;

decreasing pillar sizes (eg mining towards voids, or stopes mining towards each other)
large scale mining with faces parallel to major, active structures
mining back towards central accesses
vast mined out areas without fill
insufficient pillar dimensions
lack of regional pillars

These poor mining practices as a result of poor planning and design can in turn result in;

out of control hangingwall collapses or caving
unplanned production delays due to seismicity or falls of ground
excessive dilution
increased accidents and incidents

8.3.1 DATABASE

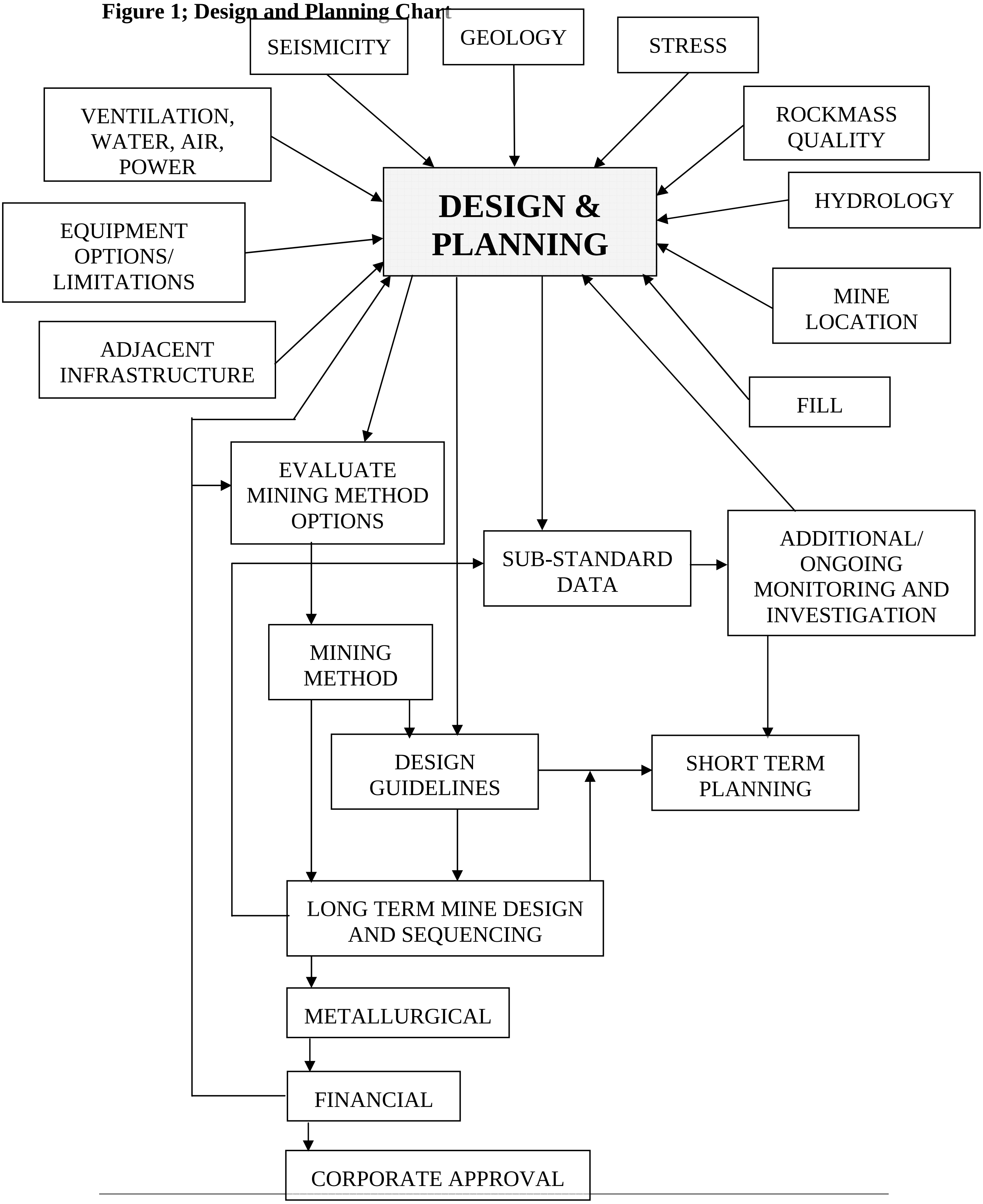
Accumulation of data for mine planning purposes should always be fully documented and referenced. This is especially the case where staff turnover is high – the cost of man-hours expended (time wasted), looking for 'missing' data, and even duplicating work, far outweighs the cost of organising data in the early stages.

The database should include data on the following sections.

Structural Geology
Economic Geology
Geotechnical
Hydrology
Services
Mining Equipment
Mine Location and Infrastructure
Fill Availability
Legal, Contractual and Corporate Obligations

This data is used in the complex relationships involved in mine design and planning, an example attached as Figure 1.

Figure 1; Design and Planning Chart



8.3.1.1 Structural Geology

Structures in a highly stressed and/or seismically active mine can have a major impact on the stability and hence safety and economics.

One major point to note is the detrimental impact of shotcrete on structural mapping. Shotcrete is generally applied in the areas requiring more detailed structural mapping! This problem should be discussed with geologists at mine sites and solutions found – face mapping could be conducted prior to shotcrete being applied and could be extended to cover the backs and walls (from under supported ground, 2m from the face for example). Structures hidden by shotcrete can be time bombs waiting for an increase in shear stress, and knowledge of such structures, especially in combination with seismic data, could be very beneficial.

This knowledge can be used for support/reinforcement designs per mining area and can also be used for pillar locations. Locating permanent pillars in structurally complex areas of an orebody can be of benefit to a mine. The risk of pillar instability plus mining the adjacent good ground should be compared to the cost of alternatively leaving a pillar in good ground and mining the complex area under difficult conditions. The information required for this type of decision is unavailable prior to mining, or early on in the mine life, as the performance of different structures under high stress conditions can vary considerably, eg will the features move and will they move seismically or aseismically?

Planar or sub-planar structures in the orebody, footwall and hangingwall and crossing the orebody, could be mobilised under certain stress/shear stress/seismic conditions. Quality structural mapping can be extremely useful in the prevention of major damaging movements if incorporated and used in the planning and design processes.

8.3.2.1 Economic Geology

Highly stressed and seismically active mines can have increased requirements for permanent pillars and can require site specific adjustments to ore drive geometries. This can lead to stope production drilling from difficult and restricted locations/at less than optimum angles. The economic models should include additional grade information in areas of possible dilution (planned and unplanned).

Locating permanent pillars in low grade and/or narrow width sections of orebodies makes obvious economic sense but in many mines the detailed width/grade data is not available.

As another example, highly stressed uphole retreat stope planners could be faced with an option of undercutting the hangingwall or footwall at the oredriving stage, with an additional option of cablebolting. The impact of low-grade material could affect this type of decision.

8.3.3.1 Geotechnical

The geotechnical database in highly stressed and/or seismically active mines should generally be more comprehensive than in low stress mines. More factors can affect the stability of excavations and these require quantifying, where possible. Geotechnical data should be documented in Mine Ground Control Management plan, with summarised data also included in a Mine Management Planning Control document (eg Mine Operating Plan). The geotechnical section of the database should include details on at least the following items.

Rock Testing
Rock Mass Quality
Stress
Seismicity
Support Performance
Rock Mass Deformation and Failure

8.3.3.1.1 Rock Testing

Rock testing of the major rock types to be exposed during mining should be conducted. A sufficient number of tests per rock type would be required to give statistical sound results. A complete list of tests would provide information to be used in modelling (an integral part of planning in high stress/seismic mines), and would also help determine which of the rock types would be susceptible to strainbursts, for example. Rock tests should include;

Density
P-wave Velocity
S-wave Velocity
Young’s Modulus
Poisson’s Ratio
UCS
UTS
Fracture Toughness

Additional tests are available for more specialised rock failure mechanisms, such as swelling strain and slake durability etc., for rocks susceptible to deterioration and swelling on contact with water, air, carbon dioxide etc..

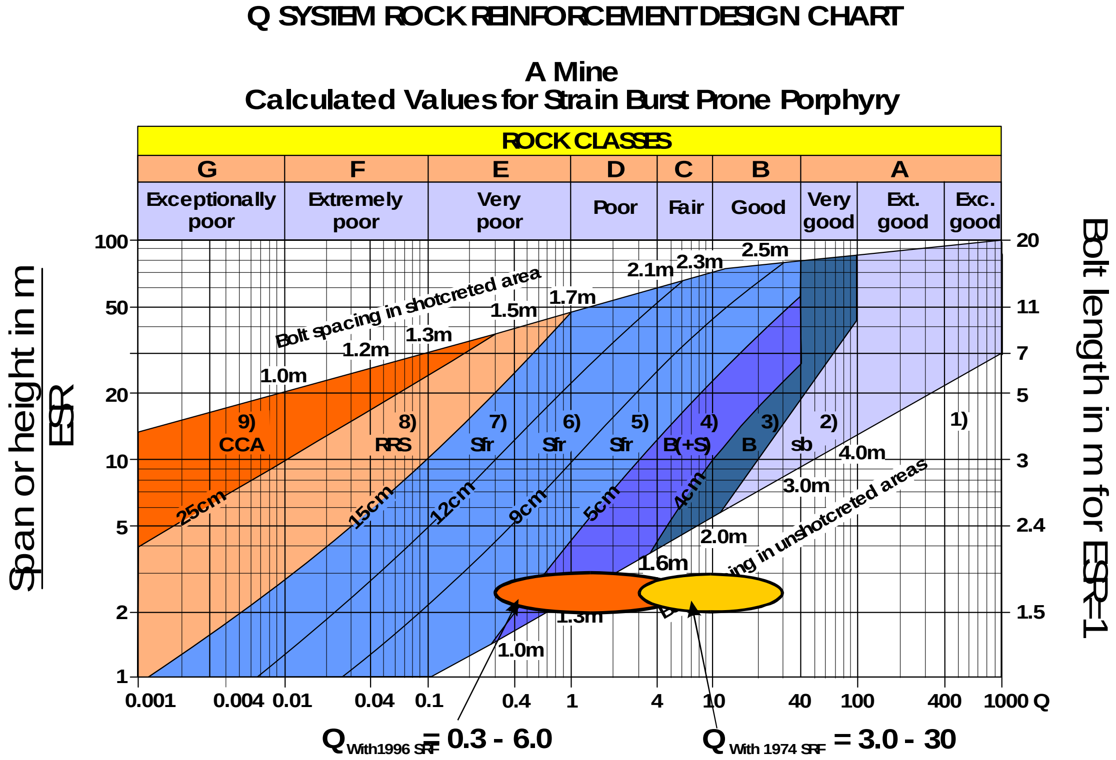
8.3.3.1.2 Rock Mass Quality

The section should include the results of classification investigations. These results can be used for both excavation/stable span design and for excavation support and reinforcement estimation.

These empirical methods are very generalised and the conditions at a particular site could be outside the applicability of the methods. These methods also use a limited number of rock/rock mass properties, sometimes far less than required to fully describe a rock mass.

The use of the SRF factors detailed in the Barton (1996) is recommended in highly stressed areas susceptible to seismicity. The difference these factors make when used in support and reinforcement estimates can be seen in Figure 2.

Figure 2; Q System Rock Reinforcement Design Chart – SRF Comparison



$$\text{Rock mass quality } Q = \frac{RQD}{Jn} \times \frac{Jr}{Ja} \times \frac{Jw}{SRF}$$

REINFORCEMENT CATEGORIES

1) Unsupported
2) Spot Bolting, sb
3) Systematic Bolting, B
4) Systematic bolting (and unreinforced shotcrete, 4-5cm), B (+S)
5) Fibre reinforced shotcrete and bolting, 5-9cm, Sfr +B
6) Fibre reinforced shotcrete and bolting, 9-12cm, Sfr + B
7) Fibre reinforced shotcrete and bolting, 12-15cm, Sfr +B
8) Fibre reinforced shotcrete >15cm, reinforced ribs of shotcrete and bolting, Sfr, RRS+B
9) Cast Concrete lining, CCA

(after Grimstad et al., 1993)

8.3.3.1.3 Stress

Stress measurements should be an integral part of the geotechnical database in highly stressed and/or seismically active mines. The choice of stress measurement sites is critical to obtaining representative results for use in modelling. Measurements in the wrong location can give very misleading results and too many measurements can generate confusion. Stress fields can be extremely variable due to the influence of geological structures and history. This should always be noted when interpreting stress fields into new areas, especially where relatively large scale faults, shears or severe folding is encountered. Results of stress measurement tests should be requested in the most suitable format for the simulation program(s) being used. This could be principal stresses, with dip and direction, or the six stress components relative to a mine grid.

Mine designs should take into account both the initial stress regime, to determine the expected initial magnitude of rock mass deformation and susceptibility to seismicity, and the expected stress changes, for subsequent deformations and seismicity etc.. Maximum Principal Stress levels approaching UCS/2 should indicate that rock mass deformations could be a critical aspect when designing pillars and support.

The results of stress measurements are used in numerical modelling, using software such as MAP3D. These programs are initially used to back analyse stress levels in relation to ground conditions and seismicity and to indicate threshold levels for damage, changes in support, mining method variations, final remnant situations etc. The numerical simulation programs, such as MAP3D, are then run to assess predicted stress levels for future mining, and hence to estimate expected conditions.

8.3.3.1.4 Seismicity

Data required on seismicity starts with information from national and regional networks such as the AGSO (Mundaring for WA), which can indicate if there is a history of large scale seismicity (natural and mining induced).

Seismic data from neighbouring mines, or mines in the same mining region, should also be documented. Information on which sets of structures are seismically active in the region should be determined prior to mining if at all possible.

Actual seismic data on mine can really only be accumulated once a seismic system is installed. The initial system could be a single triaxial unit located on surface. A more advanced system could involve an 8 station portable unit located underground once development reaches a possible seismic threshold depth, or intersects certain structures or the orebody.

Installation of a full scale system, at $200000 to $300000 or more, should only be required once it has been determined there is seismicity.

Data required from a system should include;

Location (x, y, z)
Time
and a relative magnitude (even if only related to wave amplitude or the number of sensors used)

More detailed information such as;

Energy
Frequency-Magnitude Relationships
Spatial Distribution
Time Relationships

can also be essential for planning purposes. Production of this type of information requires additional man-hours. Some large systems require full time seismologists for in depth result analyses.

Ideally the seismic data should be used in planning guidelines. This could include, for example, which structures are active (including those not picked up by mapping), and at what shear stress levels (from MAP3D for example) they become critical. Another example is at which size, and in which rock type, pillars become seismically active, stress levels also being related to modelling results and possible HI or vibrating wire stress cell monitoring.

8.3.3.1.5 Support Performance

The performance of support installed underground, including pull test data, grout cube tests, laboratory test results etc. should all be stored, readily available for access and updated as more results are acquired.

The failure mode of rock in situations where support systems or elements failed is also extremely useful.

The underground performance of bolts and support systems in rockbursts and under high stress and high deformation conditions can sometimes only be recorded using photographs. ‘Before’ and ‘after’ pictures are invaluable in assessing which elements performed, which failed, and which combinations work best.

Support and rock reinforcement capabilities have to be matched with expected rock mass deformations over the life of the excavation. Trials and comparison of various support elements and systems in high stress and seismically active mines or mining areas should also incorporate rock mass deformation monitoring. This will provide information required to determine at which point in a mining cycle the installation of stiff support is acceptable, if at all (eg. fully grouted Gewi bars, CT-bolts, grouted split sets etc.).

8.3.3.1.6 Rock Mass Deformation and Failure

A database of monitoring results should be maintained in a central location (ie not in small, easily lost, individual files all over a mine). Centralised libraries and high capacity file servers are suitable – there should also be a comprehensive referencing system. All results and analyses of closure monitoring, extensometers, CMS surveys, subsidence monitoring, crack surveys etc. should be maintained throughout the life of the mine.

Monitoring systems and stations should ideally be set up prior to mining. In too many cases a fair proportion of the displacements/events have occurred prior to installation. The changes in displacements and seismicity will be of greater magnitude if installed early and this facilitates more accurate back analyses of numerical simulations using programs such as MAP3D.

Examples and investigations into rock mass failure should also be documented. Previous failure modes can give a very good indication of what could occur under similar conditions in the future.

8.3.4.1 Hydrology

Data on the hydrological regime of the area should include details on aquifers, water bearing structures, the results of quality testing at various locations, rainfall history, evaporation rates, storm frequencies, regional water flow data and recharge rates (surface and underground). Expected or measured inflow rates and water quality are also required for underground excavations. Data with an impact on support and excavation stability would include underground groundwater flow rates, pressures and corrosiveness (how long will a split set last?).

8.3.5.1 Services

Ventilation, service water, potable water, compressed air, and electrical reticulation need addressing as in a low stress mine. If strain bursting is accepted as a norm, and areas are not supported accordingly damage could be expected to these services.

8.3.6.1 Mining Equipment

Excavations in high stress and seismically active areas should be as small as practically possible, but must take into consideration all the equipment which could feasibly be required to work in the area. The database should include a list of equipment purchased or available, or a list of equipment suitable for the operation. High stress and seismically active areas undergo closure, of stopes, ore drives and other excavations – this should also be considered. Telescopic booms for support installation will normally be required where drive height or widths are 4m or less.

Jumbos, shotcrete machines, scaling machines and boggers will also require operator protection from rocks ejected at high velocity from the face and sidewalls in seismically active mines. If a decision is made not to utilise scaling machines, procedures and rules would be required for alternative, safe, means of scaling faces, backs and sidewalls in areas which could be spitting rock.

Longhole drilling in high stress areas, with hole closure, sometimes requires higher powered drills to prevent loss of drill rods, bits etc. Consideration should also be given to uphole, blind, raiseboring machines for rising as ‘one-shot’ can be problematic at both the drilling and charging stage in highly stressed rock.

8.3.7.1 Mine Location and Infrastructure

The mine location can be critical to the design of the mine and mining method. This is applicable in all mines, but in seismically active mines there could be a concern regarding possible damage to surface infrastructure. The database should include detailed surface plans covering the area overlying the orebody, and which could be affected by mining operations, and should show public buildings, roads, railway lines, electrical transmission lines, water and gas pipelines, treatment plants, and especially existing and proposed tailings dams.

8.3.8.1 Fill Availability

The results of fill studies, including the availability and suitability of fill for various mining methods should be detailed. Documentation and referencing of such studies is critical – there are many instances where work has had to be duplicated at additional expense.

Fill can function as both a local and regional support element in high stress areas and can assist by absorbing seismic energy during periods of seismicity. A wider range of tests including tests on increased cement content, are generally required for very high stress and seismically active conditions. Some open stoping and underhand cut and fill operations, for example, use 12-15% cement, with accelerators to facilitate high early load bearing/load transfer capabilities. Closure in highly stressed open stopes can cause failure of cemented which was designed using free-standing height rules.

8.3.9.1 Legal, Contractual and Corporate Obligations

The database for legal, contractual and corporate obligations could include requirements for minimum stoping tonnages, development metres, grades, costs, and equipment and labour limitations.

The dates by which monthly planning reports, annual planning recommendations and the contents of such reports could be detailed.

Requirements could also exist for seismic systems – if there is, or could be, seismicity, a seismic system should be installed to at least locate the activity. This sort of logic is being implied on mines in WA, as in South Africa and Canada.

Corporate requirements could be in position for support and planning guidelines in certain high stress and seismically active situations (for example corporate guidelines governing crown pillars in some WMC operations).

In South Africa there are also additional precautions required by corporations for highly stressed remnants. These precautions include rules covering access by visitors, limitations on the total number of persons in an area at any time, minimum supervisory presence, increased support, re-entry times, remote blasting, and procedures for re-entry after long weekends etc.

8.4.1 MINING METHOD SELECTION

Mining method options include entry stoping, non-entry stoping and caving. For high stress and seismically active mines, or mining areas, non-entry stoping methods are the safest. Safety is the primary factor governing mining method selection.

8.4.1.1 Entry Mining

Entry mining methods include cut and fill, shrinkage and room and pillar. Many variations are available to these methods for mining in high stress and seismic environments. The fact that operators are required to undertake drilling and blasting operations within the stope void inherently increases the risk of injury, compared to non-entry stopes.

Support systems can be designed to protect operators from localised strain bursts and rock bursts. No support system will protect crews from major events where significant closure, rockmass and support system damage occurs. Sequencing of extraction to reduce the stress changes which trigger large events is therefore extremely critical to entry stoping in high stress and seismically active areas.

The risk to operators in entry stoping methods can also be reduced by the use of fill close to the face/working area. Stiff fill such as high cement, low water content tailings or graded waste fill with cement, or with both tailings and cement, are all great improvements on plain development waste fill. Stiff fill builds up a load bearing capacity with limited convergence and serves to transmit stress through the mined out areas, away from working faces.

8.4.2.1 Non-Entry Mining

Non-entry mining methods include the various types of open stoping such as bench stoping, Avoca, uphole retreat, etc.. Operators are not required to enter the stope void, with production drilling operations conducted from drill drives and bogging conducted using remote controlled units.

Critical design aspects include;

- maximum stable spans (crowns and hangingwall)
- regional extraction sequencing
- hangingwall and crown reinforcing for stability and dilution control
- re-entry delays in seismically active areas
- pillar dimensions
- permanent or recoverable pillar
- fill – cemented/waste/tailings
- drawpoint support
- sub-level interval
- orebody variability/geological model accuracy
- longhole drilling capabilities accuracy
- handheld remote or tele-remote

This list does not cover all aspects to be covered during the design process but gives an idea of the possible complexity of the decision making process.

8.4.3.1 Caving

Caving in highly stressed and seismically active mines requires complex 3-Dimensional geotechnical, grade-tonnage and cave strategy modelling to assess the suitability of such a method. Stress re-distributions and concentrations can be extremely severe, with problems at drawpoints, and in adjacent access development.

Closures in cross-cuts at Premier diamond mine and Perseverance nickel mine have exceeded 2m, and the seismic activity at El Teniente are examples of the effects of stress re-distributions adjacent to cave zones.

In summary, block and sub-level caving methods are complex and sometimes difficult when high stresses and seismicity are present. Considering the capital investment required for these methods there should usually be ample funding for the complex modelling required.

8.5.1 MODELLING

Computer modelling of the orebody and surrounding rock becomes more critical when high stresses and seismicity are involved. The penalties for mining parallel to major structures and longhole blasting into the hangingwall can become rapidly severe, therefore controlled mining is critical.

8.5.1.1 Geological

Geological modelling requirements for mines in high stress environments should not necessarily vary from modelling in low stress environments. The onset of dilution, caving and possible seismicity can be far more rapid if mining is conducted outside the optimum geological boundaries in high stress environments.

The mapping of structural features which could be mobilised by mining induced stresses, seismically or aseismically, becomes more critical in highly stressed and seismically active mines.

Models should be built with the maximum grade and structural content, including hangingwall and footwall regions where possible planned or unplanned dilution could occur.

8.5.2.1 Geotechnical

Geotechnical modelling should be an integral part of the mine planning process in mines with high stresses and/or seismicity.

The stress regime, incorporating magnitudes and direction, can change considerably with the commencement of, and during, stoping operations. This can sometimes be extreme close to large stoping excavations in high stress areas and where rock mass properties vary considerably (eg stiff porphyry dykes intersecting ‘soft’ ultramafics, or shear zones passing through metasediments). Mining induced stress changes can be estimated using programs such as MAP3D. Relating these stress changes to rock mass deformations and movement should indicate the most suitable reinforcing and/or support systems. Calibration of numerical modelling results with the results of underground rock mass deformation monitoring enables more accurate prediction of deformation.

The total expected stress regime during the planned life of a stope access excavation could typically include periods of increasing stress, changes in stress direction, peak stresses and finally stress relaxation. This series of changes could cause different modes of failure of the rockmass. Areal support in the form of mesh is critical in these environments.

Only a handful of different stress regimes can practically be used, in a limited number of domains, in single models in programs such as MAP3D, but this an improvement on many other boundary element programs. Modelling will, however, not take into account local variations in stress regimes, as experienced in certain Western Australian mines.

A summary of typical geotechnical modelling strategy framework for planning purposes follows;

1. Rationalise rock property data
2. Rationalise stress data
3. Determine most suitable/practical modelling program (depends on the availability of skills, the extent and spread of mining, variability of orebody thickness and the variation in virgin stress and rock properties)
4. Simulate previous mining (if available) with a number of relevant mining steps
5. Benchmark previous mining conditions to stress levels (principal, normal, shear stresses, and energy release rates). Previous conditions should ideally include very good, good, average, poor, very poor, seismic and unmineable in order to cover a complete range of conditions.
6. Produce a plan of future mining, with a number of mining steps, ie. face/stope positions, at 3-6 monthly intervals
7. Run MAP3D simulation
8. Assess results relative to benchmarked levels, enabling future conditions to be predicted
9. Adjust mining plan to reduce stresses and improve conditions
10. Re-run simulation
11. Assess results
12. Continue adjusting and re-running simulation until mining plan and conditions are optimised (or options limited, or time runs out, which is typically the case with corporate deadlines)

8.6.1 PLANNING GUIDELINES

Guidelines should be determined for a typical, expected range of conditions and these should be signed off, fully documented and included as part of a Mine Management Planning Control document (eg Mine Operating Plan).

Guidelines should include the following;

Mining Methods
Stope Designs
Stope Extraction Sequencing
Excavation Location
Development Dimensions and Profiles
Blast Designs
Excavation Orientation
Excavation Life
Intersections/Breakaways
Fill
Pillar Mining Strategy
Support and Reinforcement Systems
Risk Assessment

8.6.1.1 Mining Methods

Guidelines for mining methods should be covered in planning, including the logic by which the methods were chosen. The numerical approach by Nicholas (1981) is an option. A knowledge of the expected rock mass deformation in and around the orebody is required, along with the stress regime, structural features and stope limit options. Modelling (eg with MAP3D) is useful for comparing stress redistribution around alternative mining methods.

8.6.2.1 Stope Designs

Stope design guidelines should cover dimensions of access development and stope voids, mining/stoping directions (eg top-down, north-south etc) and references to associated fill requirements, pillar designs, drilling and blasting designs, and support and reinforcement designs.

8.6.3.1 Stope Extraction Sequencing

The objective of stope extraction sequencing should be to minimise stress and seismicity related problems. In highly stressed mines the idealised requirements for consistent grade and 100% extraction can be over-ruled by the requirement to mine safely, with reduced dilution, collapses and seismicity.

The guidelines should cover in detail which stopes should be mined when, using specified methods, and in which direction they should advance. Modelling, using

MAP3D for example, will have analysed various stope sequencing options and the final sequence in the guidelines should be the optimum regarding stress and seismic related aspects. This could include optimisation of maximum principal stresses, shear stresses, normal stresses, energy, stiffness, deformation etc. Consideration should also have been given to major infrastructure – the mining sequence should not cause stress related damage to workshops, declines, shafts, pump stations etc.

Many options are available to design and planning engineers for stope extraction designs and sequencing – a few will be discussed in the talk and by the following speaker.

8.6.4.1 Excavation Location

Excavation location can be critical to stability in highly stressed and seismically active mines. Abutment stresses adjacent to large mines out voids can be significantly elevated. Similarly there will be elevated stresses adjacent to solid pillars. The distance from the orebody to major footwall drives, orepasses, shafts, or declines etc., requires specifying in the guidelines. This type of guideline can be generated following analyses of life of mine simulation results (eg MAP3D).

The distance between excavations also requires specifying – and should be backed up by geotechnical simulations, and monitoring results if available.

As with all mines there should be guidelines covering the non-location of excavations in poor ground conditions, and long term access usually located in the footwall of orebodies (although this is site dependent – footwall rock properties could be exceptionally weak).

8.6.5.1 Development Dimensions and Profiles

Excavation dimensions should generally be minimised in high stress and seismically active areas, but have also to take into account the equipment and ventilation/services required. Support and reinforcement systems in these conditions are generally not cheap, and reducing the area to be supported can result in considerable savings.

The profile of the backs of development excavations can also have a major impact on stability, especially in highly stressed areas. Square back profiles are generally less stable than rounded, and rounded less stable than arched. The optimum profile can vary depending on the orientation and on the exposed joint sets and foliation. Shanty backed profiles in ore drives are also more stable in high stress areas than square/flat backed profiles.

Large excavations expose more structural weaknesses and, in high stress environments, the depth of fracturing may be pushed further into the rock mass. This could lead to a requirement for longer/deeper reinforcement. On the other hand narrow excavations may also limit the choice of support elements due to equipment and space limitations.

Narrow excavations could also open up options to include as hand installed units, hydraulic props etc. The shape of excavations in relation to foliation could require support elements in the back to be installed at an angle other than perpendicular to the wall. Bolts installed along foliation are not as effective as across foliation and designs should always bear this in mind.

8.6.6.1 Blast Designs

Guidelines covering both production and development should include drill designs, charging and initiation details. Drill designs should include hole lengths, spacings or patterns, angles and diameters.

Poor blasting in highly stresses and seismically active areas can cause extensive damage to the rock mass, leading to a greater volume of failed rock, possible increases in seismicity and increased support requirements. Blasting techniques such as reduced peripheral hole charge densities, well designed drilling patterns, explosive charges and hole timing can reduce support requirements by facilitating the self supporting properties of the rock mass. Quality blasting also reduces damage to support elements such as mesh and shotcrete, installed close to the face as a necessity in high stress and/or seismically active areas.

Triggers for implementing changes to blast designs, or changing to alternative designs should also be included. Reduced round lengths in poor ground conditions are beneficial for example, minimising the unsupported distance between the previous support and the face during blasting, bogging and support operations.

Centralised blasting, from a single secure location (on surface for example), should also be considered in seismically active mines.

8.6.7.1 Excavation Orientation

Excavations can be more stable in one orientation than another. If previous experience or geotechnical information indicates this is the case guidelines should include this aspect. Generally excavations are less stable in highly stressed and seismically active areas when orientated with their long axis perpendicular to the major principal stress and along foliation. The nature of jointing also has a major effect on stability and there could be specific excavation orientations to be avoided.

The orientation of steep excavations such as orepasses can also seriously affect stability – if there are a few options and local stress measurements are available, life of mine modelling could be used to compare stabilities. Dog-earing of raisebored passes can be severe in highly stressed areas and this in turn can cause wear in the pass to accelerate, which in turn could cause more failure and possible seismicity. Local experience is worth a lot in these circumstances – and could help in deciding what is the optimum angle at which the passes should dip, relative to the maximum principal stress and/or structures.

8.6.8.1 Excavation Life

The planned life and function of an excavation must be considered during planning to enable the most suitable support system to be designed and installed. Premature failure of support elements and complete systems due to time dependent rock mass deformation and/or corrosion leads to expensive re-support and rehabilitation of excavations.

The workable life of an excavation could vary from only a few months to many tens of years. Support and reinforcement systems, service reticulation, roadway quality and blasting techniques could all vary, depending on the excavation life.

8.6.9.1 Intersections/Breakaways

The guidelines should include details on how to plan and approach the excavation of intersections. Intersections and breakaways should not be located opposite each other. The effective size of excavations increases considerably at intersections, especially 4-way intersections, and this consequently greatly increases the reinforcing requirements – with a requirement for additional cables.

Excavation of intersections should generally involve developing past the breakaway position, installing standard support on the way, mapping the area for joints and major structures, installing cables or longer bolts opposite the breakaway site, and then developing the breakaway, followed by the rest of the longer support.

The angle of breakaways to the main drives should also be included in guidelines – thin pillars caused by breaking away at too acute an angle can cause problems for many years in highly stressed and seismically active mines. An angle of 45° could be taken as the minimum.

8.6.10.1 Fill

Guidelines covering the fill to be used in certain stopes should be included. This could include the source of rock/tailings or the blend of both, the cement content, other details and specifications and minimum and maximum fill rates. The guidelines for fill should incorporate the final results of previous investigations and should reference data sources.

8.6.11.1 Pillar Mining Strategy

Guidelines covering pillar mining would be included if a decision has been made to mine pillars. This type of decision should be made early on in the mine life in highly stressed and seismically active mines – pillars to be mined at a later stage would be designed larger than those which would not be considered for mining.

Guidelines would include the requirement to mine from a higher stress towards a lower stress, unless a sacrificial satellite pillar remnant is planned. Pillars mining can be a very high risk operation and seismic systems, destressing, low production rates, teleremote drilling and bogging, and high cement content backfill could all be required.

8.6.12.1 Support and Reinforcement Systems

Assuming availability of a wide variety of support and reinforcement elements and geotechnical engineers, and minimal storage/stockholding costs, the most economic support and reinforcement systems for a mine would include a possibly large number of different designs. These designs would be dependent on excavation types, excavation life, rock types, stress environments, seismicity etc...

The guidelines should include a manageable number of different support and reinforcement designs (manageable could vary from 3 in one mine to 20 in another).

The design methodology behind the support and reinforcement guidelines should be fully referenced and auditable.

8.6.13.1 Risk Assessment

Probability-consequence matrices should be constructed for stoping and development areas for critical risk activities/fields within short, medium and long term planning.

Critical fields could include (with examples);

1. Geotechnical (seismic, rockfall, support failure, stress slabbing etc)
2. Geological (grade variances, boundary variance, tonnage/grade/model confidence)
3. Major Engineering (power outages, hoist breakdown, fan breakdown)
4. Mobile Equipment (availability, fuel, road maintenance, service rosters)
5. Mining (misfires, ventilation, poor fragmentation, consumables)
6. Labour (availability, industrial action, sickness, transport, skills)

These individual matrix scores can be summed and each stope or development area given an overall risk index.

8.7.1 References

Barton N (1996). Investigation, Design and Support of Major Road Tunnels in Jointed Rock using NMT Principles. IX Australian Tunnelling Conference, Sydney, Australia, August.

Bieniawski ZT (1976). Rock Mass Classification in Rock Engineering. Proceedings of the Symposium on Exploration for Rock Engineering, Johannesburg.

Brady BHG, and Brown ET (1993). Rock Mechanics for Underground Mining. Chapman and Hall, London.

Bronkhorst D, Rheault J, and Ley GMM (1993). Geotechnical principles governing mine design at the Williams Mine, Innovative Mine Design for the 21st Century, Bawden and Archibald (eds) Balkema, Rotterdam.

Budavari S (1983). Rock Mechanics in Mining Practice, SAIMM Publications, South Africa.

CAMIRO (1995). Canadian Rockburst Research Program 1990-1995, CAMIRO mining Division, Sudbury, Canada.

COMRO (1988). An Industry Guide to Methods of Ameliorating the Hazards of ROCKFALLS AND ROCKBURSTS - 1988 Edition, South Africa.

Grimstad E and Barton N (1993). Updating the Q-System for NMT. Proceedings of International Symposium on Sprayed Concrete – the Modern Use of Wet Mix Sprayed Concrete for Underground Support. Fagernes (eds Kompen, Opsahl and Berg), Oslo: Norwegian Concrete Association.

Grimstad E, Barton N and Løset F (1993). NMT Tunnel Support Design, World Tunnelling, September 1993, Page 270.

Hall BE (1993). Development of a computerised mine planning system at Mount Isa Mines, Innovative Mine Design for the 21st Century, Bawden and Archibald (eds) Balkema, Rotterdam.

Hedley DGF (1992). Rockburst Handbook for Ontario Hardrock Mines, Canmet Special Report SP92-1E, ISBN 0-660-14549-9

Hedley DGF, and Grant F (1972). Stope and Pillar Design for the Elliot Lake Uranium Mines. CIM Bulletin, Vol 65, No 723 pp 37-44.

Hoek E and Brown ET (1980). Underground Excavations in Rock. Institution of Mining and Metallurgy, London

Hoek E, Kaiser PK and Bawden WF (1995). Support of Underground Excavations in Hard Rock, Balkema Publishers, Rotterdam, Netherlands.

Hutchinson DJ and Diederichs MS (1996). Cablebolting in Underground Mines (BiTech Publishers, British Columbia, Canada).

Kaiser PK, McCreath DR and Tannant DD (1996). Canadian Rockburst Support Handbook, GRC, Sudbury, Canada.

Kazakidis VN, (1997). Do's and Don'ts in Sill Pillar Design at Depth. 13th Mine Operators Conference, Sudbury, Ontario, Canada, February.

Lang A (1998). How does this relate to Western Australia? Mine Seismicity and Rockburst Risk Management in U/G Mines, Australian Centre for Geomechanics short course No 9804, March.

Laubscher DH (1990). A geomechanics classification system for the rating of rock mass in mine design, Journal of SAIMM, vol 90, No 10, October.

MacGregor S (1998). Development and Application of Strata Management Systems in Coal Mines. International Conference on Geomechanics/Ground Control in Mining and Underground Construction, Wollongong, NSW, Australia, July.

McCreath DR and Kaiser PK (1992). Current support practices in burst prone ground (task 1), report to Mining Research Directorate, Sudbury, Canada.

Nicholas DE (1981). Method Selection – A Numerical Approach. Design and operation of Caving and Sub-level Stoping Mines, SME of AIME, pp 30-53.

Ogilvie ML (1998). The Consistent and Systematic Management of Hazards – Development of Management Plans. International Conference on Geomechanics/ Ground Control in Mining and Underground Construction, Wollongong, NSW, Australia, July.

Ortlepp, WD (1983). The Design of Support for Rockburst Prone Tunnels. Proceedings of the Symposium on Rock Mechanics in the Design of Tunnels, ISRM, South African National Group.

Salamon MDG and Oravecz KI (1976). Rock Mechanics in Coal Mining, COMRO, South Africa (ISBN 0 620 00232 8).

Stacey TR and Page CH (1986). Practical Handbook for Underground Rock Mechanics, Trans Tech Publications, Germany.

Stillborg B (1994). Professional Users Handbook for Rock Bolting, Trans Tech Publishers, Germany.