

Safety in Mines Research Advisory Committee

Final Project Report

**Implementation of state-of-art mining
knowledge and technologies in design
and operation of a safe and efficient deep
gold mine stope for 21st Century**

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Executive Summary

Several new mining, rock engineering and environmental control technologies aimed at improving safety have been developed in the past decade or so. Since several of these developments have either not been implemented properly or only implemented at isolated instances, they have not led to any significant improvements in safety and health and efficiency on the mines.

The purpose of this project was to evaluate the suitability of currently available and potential mining technologies for integration into a mining system that would have superior safety, health and efficiency. The ultimate aim of the investigation is to implement and evaluate the derived mining system in a trial stope which could evolve into a benchmark stope for the most common geotechnical conditions in the Witwatersrand goldfields and for certain Bushveld mines. The underground evaluation of the proposed system is envisaged as a follow-up project.

To design the conceptual, integrated mining system, a broad range of expertise was required. Individuals or groups who could provide this expertise were identified and their views and recommendations are included in this report.

The optimal mining system was designed principally for the following conditions: mining depth - intermediate to deep level, thus catering for moderate to severe fracturing and potential seismicity; stoping width - from 1.0 m to 1.7 m; and faults in the stope face with throws up to 2.5 m and rolls where the slope angle changes by up to 20°.

The performance targets set for the system are a reduction in stope accidents of at least 50 % compared to the industry average, greater than 15 m face advance per month, dilution and gold losses reduced by 15 % compared to adjacent stoping, consistent provision of recommended environmental conditions and finally cost effectiveness.

The main areas of concern with current mining and which are attempted to be addressed by innovative combinations of appropriate technologies in this project are the following:

- Less than adequate support in the immediate face area particularly during the cleaning shift and making safe operations,

- Inadequate area coverage by support in the working area of panels and over gullies,
- Low cleaning rates in long strike gullies leading to accumulation of rock with resultant difficulties in access for men and materials and restricted ventilation flow,
- Timeous supply of materials to stope face area not ensured,
- No separation of water from rock in the cleaning process,
- Congestion in cross-cuts, and
- Recommended environmental conditions not ensured.

Other areas of concern where no reliable improved technologies were found are barring and face drilling. Mine wide issues such as training, appropriate reward schemes, organizational structures are not addressed in this project but preliminary investigations would be carried out in any implementation project.

The proposed conceptual mining system comprises the following equipment and technologies:

- Water powered, hand-held rock drills.
- Reliable sequential detonation blasting system – final decision of what system to be used will rely on latest information.
- Rapid yield hydraulic props with 0.8 m load spreaders. Lines of props aligned 70° to face to enhance drilling accuracy and limit interference with drilling.
- Safety nets suspended on the props where necessary.
- Roof bolts installed less than 0.5 m from face.
- Yielding mechanical props as temporary support during roof bolting.
- Diagonal blast barricades to facilitate water jetting.
- Fines barricade.
- Routine face-normal preconditioning to prevent face bursting and enhance advance per blast.
- Water jet assisted scraper face cleaning. Assists with preliminary barring and dust suppression.
- Gully shoulder support – constant yield force, low mass reinforced concrete packs or Fill-packs in backfilled stopes.

- Gully hangingwall support – roof bolts, shepherd's crooks or yielding tendons (depending on conditions) with lacing over membrane support to provide good areal coverage.
- Strike gully cleaning – scrapers, double-separated-scraper system for long pulls.
- Centre-gully – up dip rock transport by means of continuous scraper to a single, long box-hole with adequate bunkering. Water separated from rock.
- Separate men and material access. Mono-rope from x/cut storage bays – delivering to top gully/face intersection in overhand stope.
- Environmental control systems and equipment appropriate for local conditions.
- Initial geological and rock engineering assessment of ground control district. Geophysical probing of ground conditions ahead of the stope face where deemed necessary.

Developing technologies that could be added to the system once they have been finalized include the support system initiated under GAP708, mechanised rock breaking, the quiet rock drills and the plasma hole maker if permission is granted by the principals.

The above mining system remains a mere concept until implemented and evaluated underground. As part of this project consideration was given to the practicality and approximate costs of running a field trial of the proposed system. Three crucial issues were identified that need to be resolved before such a trial should proceed.

The first is to identify a willing mine that would enthusiastically champion the trial. Following discussions with AngloGold, it was concluded not to combine this proposed trial with that of AngloGold, as those results will not necessarily be made public to protect AngloGold's competitive position. Enquiries at Mine Manager's level indicated support for the project pending Head Office approval.

The second is to recruit or second necessary staff to the project. CSIR: Miningtek has the experienced researchers to design, monitor and evaluate the trial but no longer has sufficient production personnel nor technologists to run and service the site; suitable people to fill these positions would have to be either supplied by the mine or outsourced.

Thirdly, the cost, funding and revenue associated with the project need to be addressed by consultation and negotiation between the three parties concerned.

It is believed that none of the above problems are insurmountable and that an initial small project could be set up to finalize tripartite agreements. The successful outcome of the trial, benchmark stope could be of immense benefit to the industry in terms of technology transfer leading to significant improvements in safety, health and productivity.

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1 Introduction

1.1 Research problem

Assess the potential for underground implementation of state-of-art mining knowledge and technologies in the design and operation of a safe and efficient deep gold or platinum mine stope.

The primary output of this project is the evaluation of a concept of running a safe deep mining operation optimised in terms of design, working environment, stability of excavations, support and productivity / efficiency using mainly recently developed technology. The project assesses the viability of such a concept where a mining operation utilizes multi-disciplinary expertise available in both, the mining industry and research institutions, and is based on analysis of various technologies (current and developing) that could be incorporated into an optimised stoping system for intermediate and deep level stoping.

This project will evaluate newly developed technology for enhanced safety for practical implementation.

1.2 Objectives and aims of this study

The aim of SIMRAC project GAP 712 is to perform a brief feasibility study of a conceptual mine stope that will ensure a high degree of safety and good environmental conditions with optimal production.

Targets for the stoping system will be:

- stable gully access and stope working area,
- greater than 15 m face advance per month,
- dilution and gold losses reduced by over 15 %, and
- better than average deep level environmental conditions at all times.

As presented during a progress report meeting on 28 September, 2000 and accepted by the SIMRAC Committee, this project attempts to answer the question of the feasibility of a proposed deep mine stoping system through an analysis of critical skills required to design and run it, as well as an analysis of the technical and implementation potential of various existing and developing technologies.

The availability of required skills as well as the potential for implementation of certain selected technologies to design and operate a safe deep gold mine stope were also formulated in this project. Synergy that can be created by combining the expert knowledge, safe technologies and structural back-up available between the CSIR: Miningtek and a champion mine creates conditions where such a project can be successfully completed.

2 Research methodology

2.1 Enabling output 1: Analysis of required skills

Skills that are critical in a multi-disciplinary expert team of relevant personnel required to successfully design and run the operation of the “benchmark” deep mine stope were analysed and are identified in the project.

2.2 Enabling output 2: Analysis of technical and implementation potential of existing and newly developed technologies

An analysis of the technical appropriateness and implementation potential of various existing and newly developed technologies and whether they could be integrated into a successful stoping system was carried out using two fundamental qualifying criteria, i.e. improved safety and good environmental conditions.

Additional factors used in qualifying the relevant technologies were their proven technical capacity and practical availability for implementation. The potential benefits of partially developed technologies within this context are discussed briefly with the objective of highlighting those where development to a final product for practical evaluation should be encouraged.

2.3 Enabling output 3: The feasibility study of the concept

The concept of designing and operating a safe “benchmark” stope where state-of-the-art mining knowledge and technologies are implemented is feasible only if both a qualified research organization and a fully committed champion mine form an integrated team which would actively collaborate and participate in running such a project.

The feasibility study of the concept in terms of potential for continuation as Phase II was carried out and is presented in Appendix 1 of this report.

3 Analysis of required skills

A critical analysis of expertise and skills that are essential in designing and running a proposed “benchmark” stope has been carried out in this project.

Assuming that the orebody to be mined is made accessible through development excavations, an expert team that could implement the proposed concept would need to comprise specialists with complementary skills covering the entire spectrum of relevant activities. The skills that were identified are as follows:

- Management skills which would complement those available on a champion mine to organise the best structure for implementing the system and planning effective logistics.
- HR skills to determine fair rates of pay and appropriate bonus schemes; design effective training programmes; liaise with unions, etc.
- Expertise in mine planning/ systems/ layouts and costing.
- Expertise in risk assessment.
- Expertise in geology and mineralogy as well as use of modern technology to allow for advance delineation of the ore-body to be mined.
- Rock Engineering expertise to optimise the stress environment through the design of a safe mining layout, design and testing of large areal coverage supports for static and dynamic loading, and monitoring the stability of the rockmass/support system.
- Expertise in state-of-the-art raise, gully and stope support and thermal insulation products and their design, as well as specialist skills in support installation (including backfilling).
- Expertise in environmental control including design and operational skills with regard to cooling, ventilation, dust and noise control, as well as expertise in occupational health and safety.
- Drilling, blasting and cleaning expertise.
- Preconditioning expertise.
- Expertise in technology transfer and training.

Expertise as given above is available at CSIR: Miningtek and would be offered to a champion mine. When combined with relevant skills, structures and services which exist on such a mine, the expert teams would be formed to design, organise and monitor the system. A fully committed and actively participating champion mine is considered to be an essential part of the successful running of a safe and efficient deep stope.

It is envisaged that, in addition to operational and logistical functions, the mine would play an overall management role in the project.

There are several potential models available for this venture, ranging between:

- CSIR: Miningtek “leases” an area from a mine, assuming full legal responsibility for the venture;
- The mine retains the full responsibility, mining in a manner to be advised by CSIR: Miningtek

A complex variety of possibilities exists between these extremes. It is proposed that these be pursued further as an initial ‘go - no go’ investigation in Phase II, in consultation with potential champion mines.

4 Analysis of technical and implementation potential of existing technologies

4.1 Evaluation criteria

4.1.1 Safety criteria

The safety targets for the proposed conceptual stope are as follows:

- At least 50 % reduction in falls of ground compared to the average rate for the gold mining industry.
- At least 50 % reduction in rock related accident rate.

4.1.2 Environmental criteria

The environmental targets for the “benchmark” stope are as follows:

- Air pollutant levels (including dust) to be kept as low as practically achievable legislated values.
- Good temperature conditions where Wet Bulb Temperature (WBT) remains below 27 Deg C.
- Over 15 % reduction in noise exposure.

4.2 Stope design

4.2.1 The use of Geology and Geophysics in the design and operation of proposed stope.

The underlying control on all aspects of the implementation of various state-of-the-art mining tools and techniques is geology. Aspects from grade distribution (both vertically and laterally) through to rock mass behaviour and hence the type of support can only be properly determined if an accurate model of the geology is established. Several techniques have been developed and enhanced at CSIR: Miningtek for the creation of a geological model, for deep level gold mine stopes. These various detection and modelling techniques

are integrated to provide a realistic geological model that can be easily incorporated into a mine-planning process which enables the selection of the optimum methods for the various aspects of mining. The paragraphs below review some of the tools and techniques that are used in the creation of a geological model.

Gold content in the Witwatersrand reefs is controlled by the sedimentology of the deposit. It is thus essential to have an accurate picture of the sedimentary characteristics of the deposit, including the facies associations and their lateral and vertical interactions. This can be achieved through detailed underground mapping and the incorporation of this data into a numerical model for the determination of hydro-geological conditions. The speed and ease of underground mapping, and also its integration into the overall geological model, could be greatly enhanced through the use of digital photography and automated image processing (to allow for, for example, the determination of the maximum and mean pebble size).

The behavior of the rock mass around the excavation is determined by the type and composition of the reef and the hangingwall and footwall rocks. The composition of the various rock types determines the orientation and frequency of the mining induced fracturing. Often fractures will be associated with particular zones of geological weakness such as faults or dykes. In these areas the rock mass behaviour will be different, due to changes in the geological stresses, as well as changes in rock type (and hence for example its strength). To delineate these features ahead of mining, various high resolution geophysical techniques can be employed. These can be broadly divided into electromagnetic techniques and seismic techniques. The former includes ground penetrating radar (GPR) and borehole radar (BHR) and the latter mine seismic profiling (MSP).

GPR is typically a very high resolution tool, with limited probing range. With a 500 MHz antenna, a GPR system can resolve features in rock with a resolution of better than 20 cm, out to a range of about 5 m. It can image smooth interfaces between materials with contrasting electrical properties, and is particularly suited to mapping air or water filled fractures in rock, including mining induced fracturing ahead of the face. The combination of range and resolution make GPR ideally suited to near surface investigations of rock structure. The technique has been particularly successful in monitoring the effectiveness of preconditioning. Faces were scanned before and after a preconditioning blast, and GPR showed clearly the extent of the fracture cones around each preconditioning hole.

Borehole radar is GPR used in a borehole. It is applied at a lower frequency than GPR, so it has a poorer resolution, of about 1 m, and a substantially better range, better than 70 m in a good environment. Borehole radar is less sensitive to small fractures, but is ideally suited to mapping large fracture systems and geological structures. Borehole radar is an ideal research tool for correlating structure and fracture development to seismic events during the mining of a panel. If a borehole is drilled in the reef plane, on strike, toward the direction of mining, borehole radar can be used to monitor changes in the rockmass around the borehole as mining progresses. Changes can then be correlated to observed microseismic events.

Mine seismic profiling provides a flexible in-mine seismic system capable of delineating structures with a 2 m resolution for a 200 m by 200 m reef block in a single series of surveys. This technique is appropriate for the South African gold mining environment, taking into account the effect of support linings and mining induced fracturing. The MSP method is complementary to the electromagnetic methods (borehole radar and ground penetrating radar), having a greater range but poorer resolution than the electromagnetic techniques. Current project work (for DEEPMINE) entails a series of surveys to verify the ability of the MSP technique to map reef in regions where its structure and geometry are uncertain.

The information that these various tools and techniques (including sedimentological mapping and modelling, delineation of geological and mining induced discontinuities) provide can only be efficiently used if it is properly integrated into the mine planning and design. For this reason, the integrated geological model can be easily incorporated into common mine planning packages such as CADSMINE. This allows the planning and testing of various mining scenarios until the optimum safe extraction design can be realized.

Once a design has been developed and implemented, tools such as GPR and BHR can be used to determine its effectiveness by, for example, mapping out the fracture pattern around the excavation.

4.2.2 Mining layout

There are a number of mining methods for extracting tabular reefs at depth. The most commonly known are:

- Longwall with strike stabilizing pillars (LSP)
- Sequential grid mining with dip pillars (SGM)
- Sequential down-dip with dip pillars (SDD)
- Closely-spaced dip pillar method (CSDP)
- Scattered mining

Each of these methods offers advantages over the others, each application being preferred for certain geotechnical, operational and economical conditions. From preliminary evaluations still in progress, it cannot be stated that, overall, one particular method is better than the other.

For example: if evaluated from a rock engineering perspective alone, SDD could be seen as the preferred method when the measure of performance considered is the face ERR. Indeed, SDD has the lowest distribution of high values of ERR ahead of active faces over all the other methods. On the other hand, due to its very narrow spans and thus dispensing with the usage of backfill, the SDD method requires the highest cooling power of the four.

If ventilation and cooling considerations alone were to be taken into account, longwalling with strike pillars would be applied, as it appears to be the method with the most flexible ventilation control network. Longwalling, however, lacks flexibility to negotiate major geological features and requires a dense post-developed infrastructure which has both productivity and safety disadvantages.

On a pure economic front, for example, the CSDP method with its double-sided, non-constrained mining approach is preferable, as it is a method that has potential to deliver the fastest, most sustainable production output. As a result, the Net Present Value (NPV) of this type of layout is the most favourable making it, therefore, the layout of choice from an economic perspective.

Current single-sided mining sequential grid mining layouts, on the other hand, offer great flexibility in negotiating geological features in complex ore-bodies. A major constraint of this type of layout, once matured, however, is the very adverse effect of “flexibility” in that in the long run it may reduce the capacity to regenerate mineable face. This condition is brought

about by the stringent mining rules of the method which impact negatively on the economic viability of the mining method.

Although there is no perfect method, for the purpose of the exercise at hand, it may be feasible to consider a mining method that combines the benefits of CSDM and SGM, and a conceptual double-side grid mining layout with dip pillars is proposed (DSGM) (Vieira, 2000). However, discarding longwall and SDD at this stage does not mean these methods are not appropriate in certain circumstances.

The DSGM would be operated in the following manner:

- Pre-development of footwall infrastructure would be required, i.e. haulages, crosscuts and raises (advance delineation of orebody characteristics is thus possible)
- Concurrent ledging on both sides of raises (stress-relieving of orepasses during early stages is advantageous for their stability).
- Concurrent, double-side stoping of raise line panels would be carried out (double-side mining in controlled spans avoids stress-reversal effects in footwall excavations and improves production output).
- Breast mining towards pillar final positions. Panels are staggered to form an underhand overall face orientation. This orientation will be beneficial in that mining is always done toward solid ground.
- Dip orientated pillars separating stopes to be left in situ. Forty metre pillars at a span of 140 m up to a depth of 4500 m appear to be feasible, in so far as controlling the ERR ahead of faces is concerned.
- Narrow mining spans are advocated, possibly of the same order as the CSDP method, i.e. 140 m (thus resulting in an extraction ratio of 78 %). Narrow spans will control the energy released as well as the induced stresses in footwall excavations below pillars.
- Main footwall excavations such as haulages and return airways could be placed at a depth of 90 m below reef at least to avoid high stress concentrations due to mining above.
- One orepass for every two panels (originally SGM has one orepass for every panel).

- Initially conventional scraping to be used in order not to depart radically from current practice. However, continuous up scraping could be feasible in centre gullies. If the latter is considered, the number of orepasses required in a raise line would be only two.
- Advance rates are optional but 15 m / face / month is proposed. Note that this rate is currently attained but often not sustained for long periods.
- The application of backfill is recommended as this can have the combined effect of reducing ERR and seismicity. In addition, backfill has a positive effect on environmental control requirements in that it can reduce the overall cooling demand of the entire layout.

Note: These considerations are offered as examples only. The chosen mining method would be a function of the conditions at the champion mine.

The above is the preferred overall mining system but the stoping system could be evaluated in almost any breast mining operation. It is envisaged that a final decision on the matter will be made in close collaboration with the champion mine.

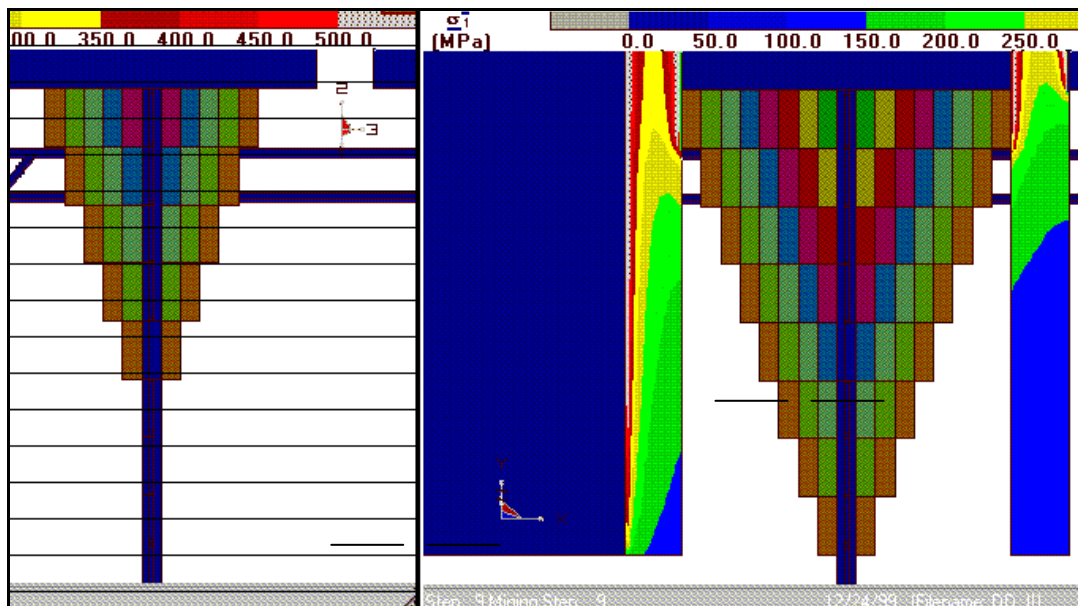


Figure 1. Concept of concurrent double-side grid mining (DSGM) (After Vieira, 2000).

4.3 Stope support technologies

Rock mass instabilities represent the single largest cause of injuries and fatalities suffered by the workforce in South African gold and platinum mines. The majority of rock-related fatalities ($\pm 56\%$) occur in the immediate vicinity of the stope face. Relatively few fatalities ($< 5\%$) are associated with the back areas. Stope support systems, typically consisting of combinations of tendons, props and packs or backfill, are used to stabilise the rock mass surrounding excavations and reduce the risk of rockfalls and rockbursts.

In response to the rock-related hazard, a significant research thrust was, and continues to be, directed at stope support, to combat the hazards of rockfalls and rockbursts. In spite of a considerable amount of research effort focused in the area of improved stope support, the trend in fatality rates over the past 10 years has shown only a marginal improvement. It is, therefore, unlikely that conventional support systems, as currently used, will result in a significant improvement in accident rates. New, alternative support systems and technologies strictly implemented according to standard procedures are required to significantly reduce the rock-related hazards associated with underground mining operations.

The stope face area is particularly difficult to support. Some deficiencies of current stope support systems include:

- poor area coverage,
- poor installation practices, and
- poor face area support during cleaning (almost 50 % of all stope fatalities involve people whose activity at time of incident is related to cleaning or making safe; Jager, 2000).

Any successful alternative stope support system would have to comply with certain rock engineering and operational requirements related to gold and platinum mining. The more important rock engineering requirements relate to the support resistance and energy absorption requirements, support/rock contact stresses (to prevent punching), yieldability of support, velocity of dynamic closure, post-rockburst stoping widths and the need for better areal coverage. The operational requirements include flexibility in terms of varying stoping widths, faults and reef rolls, ease of handling, and blast resistance. Another important operational consideration is that the system should not interfere with the cleaning and drilling operations.

It is also vital that any alternative support system should offer protection to workers during all phases of the production cycle, i.e. drilling, charging, cleaning, making safe and face preparation. It is further important to integrate the application and use of alternative support technologies into the production cycle. Thus, the proposed support system should take into account the space requirements and other factors related to barring, cleaning, drilling and blasting operations.

Examples of improved support technologies, which will be considered as stope support, will include the remotely advanced headboard system, the twin beam support system, hydraulic props integrated with backfill, and safety nets. These systems are reviewed in further detail below. Finally, a brief description of current elongate, pack and temporary support systems is given.

4.3.1 Remotely Advanced Headboard System

The remotely advanced headboard system was developed during SIMRAC Project GAP708. A detailed concept description is given by Daehnke et al. (2000), and only a short review follows below.

The remotely advanced headboard support system is remotely moved forward after each blast and provides a safe working environment within 3 m of the stope face. The system provides protection against both rockfalls and rockbursts. The primary components of the remotely advanced headboard system are three linked headboards, two hydraulic props and one temporary mechanical prop (typically a Camlok prop). The orientation of the headboards is in the strike direction, and multiple headboard-units are installed parallel to each other in the dip direction (with a centre-to-centre dip spacing of between 1.0 m and 1.5 m, depending on ground conditions).

Figure 2 gives an illustration of the main components of the remotely advanced headboard system. A plan and section view are given to indicate the linked headboards and hydraulic props. The illustration is drawn to scale. The steel sections indicated in Figure 2 are based on a 200 kN upward load at the beam centre, and 100 kN point loads at the ends.

As indicated in Figure 2, the three headboards are linked by 0.6 m-long solid rods (or link-bars), which are connected to sealed ball-joints. The ball-joints are off-the-shelf items and

are sealed for life, hence no maintenance is necessary. Should individual ball-joints or link-bars be damaged, it is a fairly simple procedure to replace individual components. The beam headboards have no moving parts, and, barring incorrect usage, are maintenance free. The hydraulic props are the only components which need to be serviced according to a regular maintenance schedule. With slight modifications to the existing 20/40 t hydraulic prop concept, the maintenance requirements of this prop system may be reduced.

The ball-joints and link-bars offer considerable flexibility to the proposed support system. The back section view, given in Figure 3, shows how the ball-joints allow downward, as well as forward rotational movement of the headboards during advancement. Note that the ball-jointed link-bar restricts the downward movement of the headboard being moved forward (by resting on the bottom edge of the stationary H-section headboard), and, hence, the retracted hydraulic prop is not dragged on the footwall.

A side section view, further illustrating the flexibility of the support system, is given in Figure 4. This lateral flexibility is important for the support system to negotiate uneven hangingwall conditions, as well as panel rolls, faults, and undercutting operations.

An alternative pre-stressing system makes use of heavy-duty rubber barrels, which are pressurised with water (estimated water pressure: 1.5 MPa for a pre-stress load of 200 kN). The barrels are placed on top of the headboards and are linked with connection tubes. This allows individual barrels to be replaced, should they be punctured. The main support element between the headboards and the footwall is a steel prop.

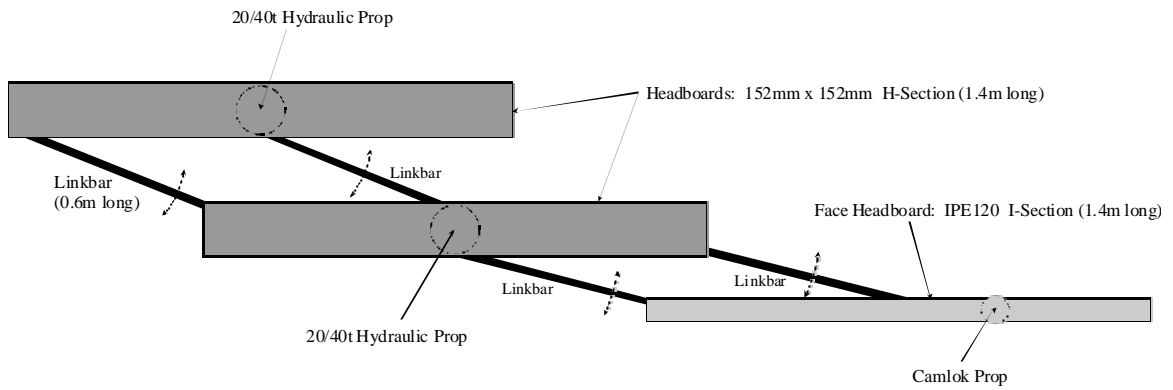
Quasi-static closure is accommodated by deformation of the rubber barrels. During dynamic closure, the steel prop is deformed in a controlled fashion and the rockburst energy can be dissipated. After the rockburst, the steel prop is discarded and replaced with a new unit.

The main advantages of the remotely advanced headboards are:

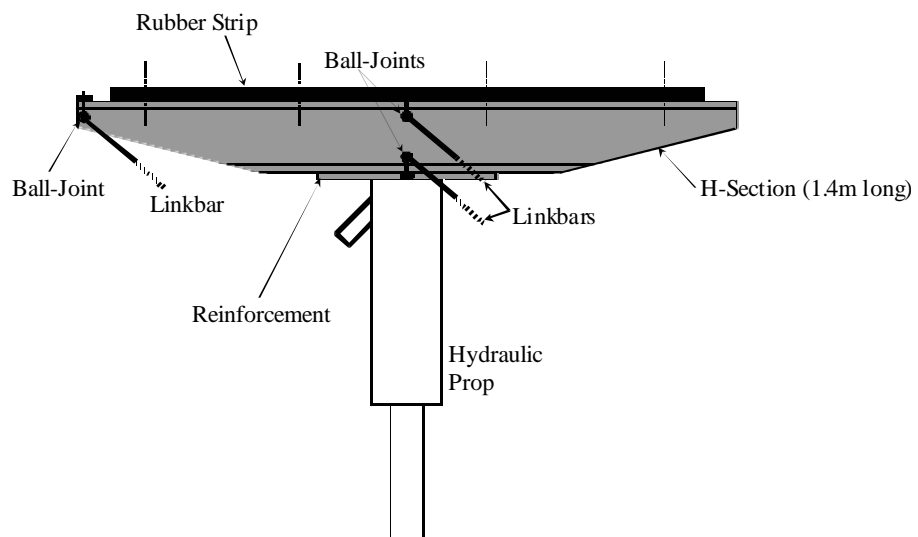
- Increased areal coverage.
- Active support within 3 m of the stope face.
- Safe and rapid advance of the support system from a remote position as the stope face is advanced.
- Integration of the support system with other support (e.g. nets, props, packs, tendons and backfill).

- Minimal physical labour to install and move temporary support systems.
- Reduced maintenance by making use of robust steel sections, linkages, joints, and hydraulic components.

Plan view:



Side section view (of single H-Section headboard):



Back section view:

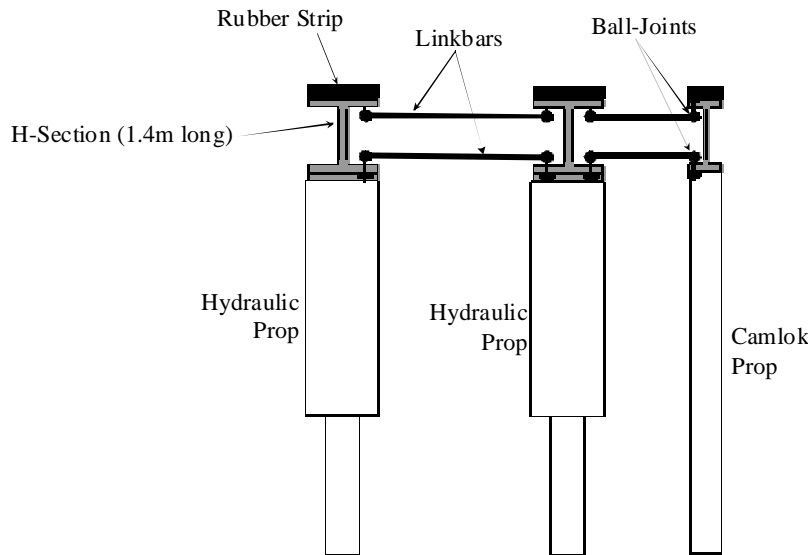


Figure 2. Schematic indicating the principal components of the remotely advanced headboard system.

- Provision for high degrees of flexibility to accommodate uneven hangingwall profiles, as well as undercutting operations and rolling panels.
- Simple and safe installation.

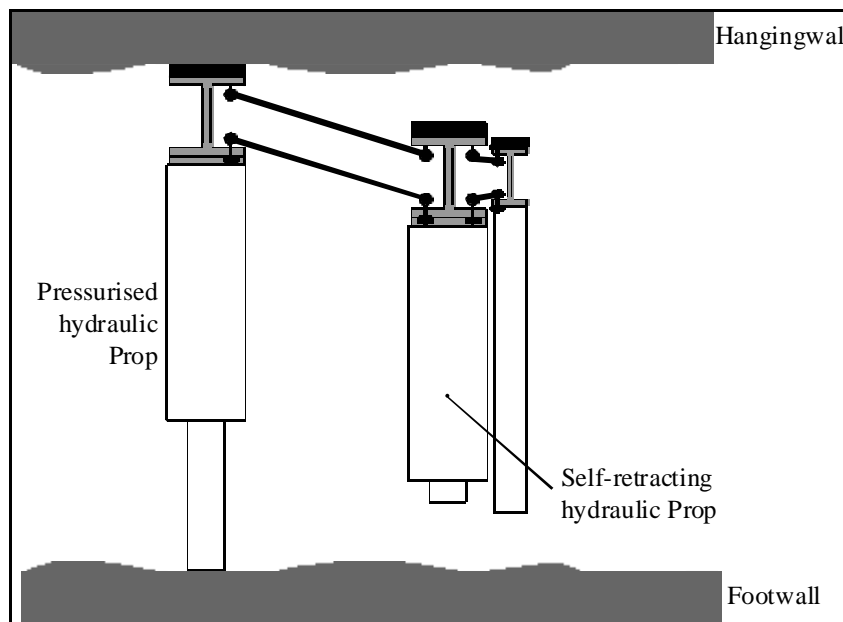


Figure 3. Back section view of the system being advanced. Note that the system makes use of self-retracting hydraulic props.

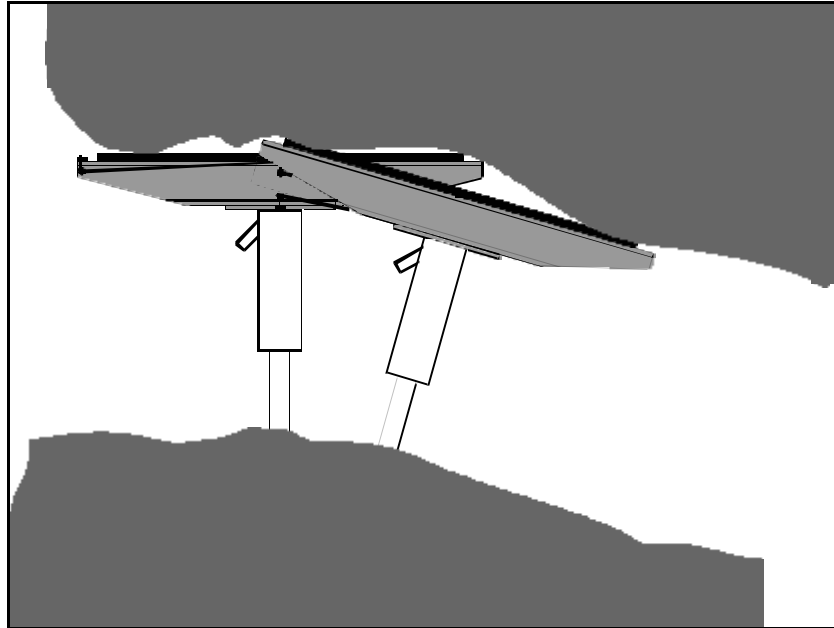


Figure 4. Side section view of the system being advanced, showing relative flexibility of H-Section headboards.

The disadvantages of the remotely advanced headboard system include:

- Maintenance of hydraulic props.
- Moderately high capital expenditure (approximately R 185 000 per 30 m panel; it has been shown, however, that after 12 months the remote headboard system becomes more cost-effective than a support system based on pre-stressed elongates).
- R & D work is required to fully develop the remotely advanced headboard system concept.

4.3.2 Twin Beam Support System

The twin beam support system consists of two conventional hydraulic props, which carry a steel beam during normal operating conditions. The concept is shown in Figure 5. The beam has rails from which the hydraulic props can be suspended, sequentially, when the system is moved. This greatly reduces the effort required to move the props, by allowing the hydraulic props to slide along the beams. The rear prop is drawn up to the front prop, to walk the structure forward. The beam also cantilevers ahead of the hydraulic props to provide areal support up to the face. The long axis of the beam will be installed perpendicular to the face and the mining-induced stress fractures. This will allow the

support of potentially unstable hangingwall blocks. Using this system, the hydraulic props and the beam can be moved with the mining cycle, while maintaining areal coverage.

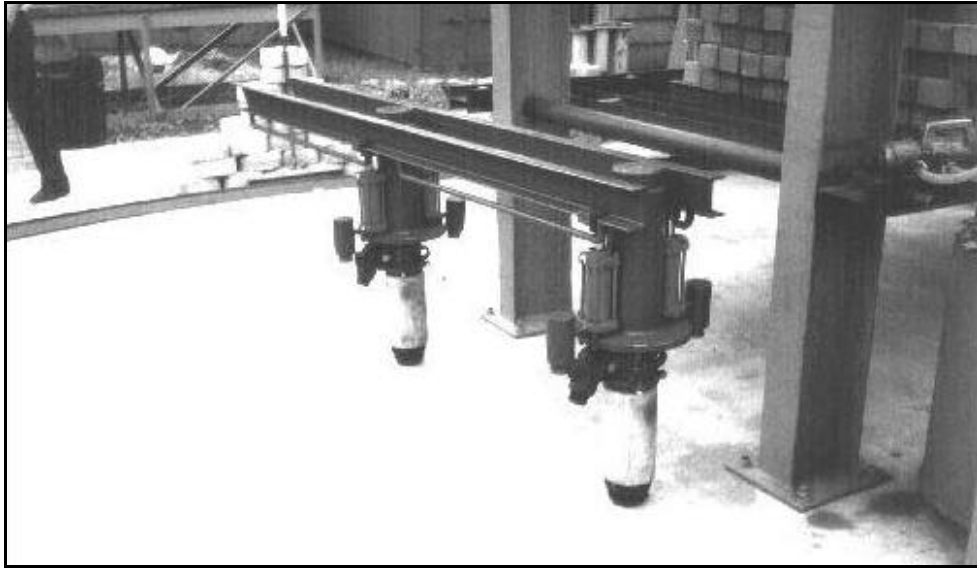


Figure 5. Photograph of the constructed twin beam support system prototype.

The preliminary models demonstrated a significant advantage, particularly in advancing the props. Hydraulic props are heavy, making the handling and advancing of these props after a blast in narrow stopes difficult. These props can also be hazardous if not installed properly. This new system alleviates these problems by allowing the beams to support the weight of the props. All the miner has to do is slide the props forward along the beams. The sliding action itself, either of the prop along the beams or vice versa, does not seem to be a problem, especially if linear guides are utilised. The concept is very useful and serious problems in the mechanism of operation are virtually non-existent, except for an increase in the number of tasks required to advance the props. Safety nets could be installed between beams in poor ground conditions.

The advantages of the twin beam support system are:

- Continuous active support, even whilst individual props or beams are moved forward.
- Robust components.
- A prototype has already been built and is ready for underground trials.
- Increased areal coverage.
- Integration of the support system with other support (e.g. nets, props, packs, tendons and backfill).

The main disadvantages of the twin beam support system include:

- Maintenance of hydraulic props.
- Moderately high capital expenditure (estimated as R 140 000 – R 180 000 per 30 m panel).
- The over-hanging headboards could interfere with the scraper cleaning operations. In this case the system has to be moved back from the face before installing the blast barricade, necessitating an additional step in the support cycle.

4.3.3 Hydraulic Props Integrated with Backfill

Hydraulic props, used in conjunction with headboards, have been used in the past to effectively stabilise the hangingwall in stopes prone to seismic activity. A possible support layout is shown in Figure 6. A further example of a blast-on face support system making use of hydraulic props, profile props, packs and diagonal blast barricades is given in Figure 7.

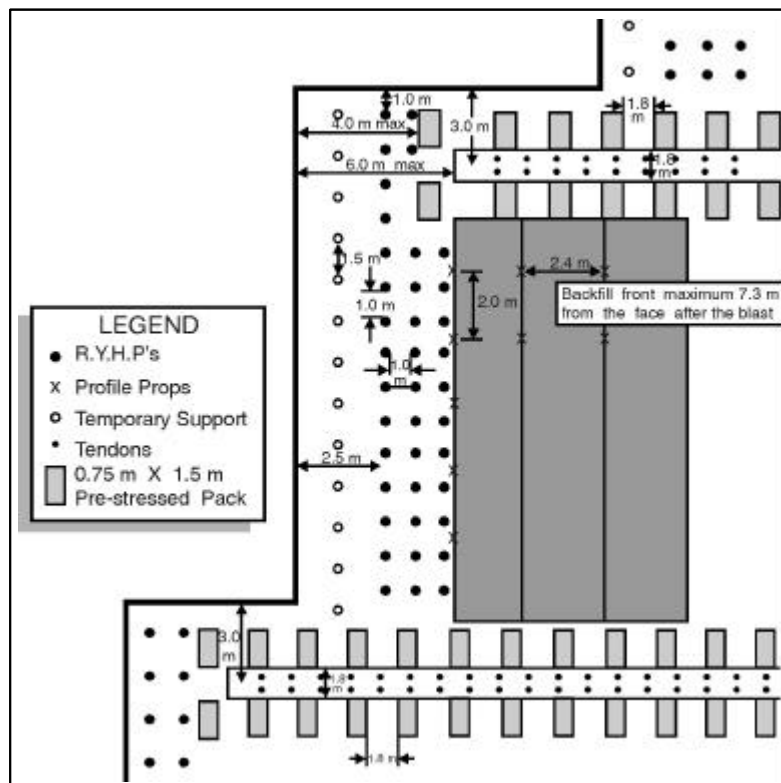


Figure 6. A backfill stope system employing three rows of hydraulic props (after Jager and Ryder, 1999).

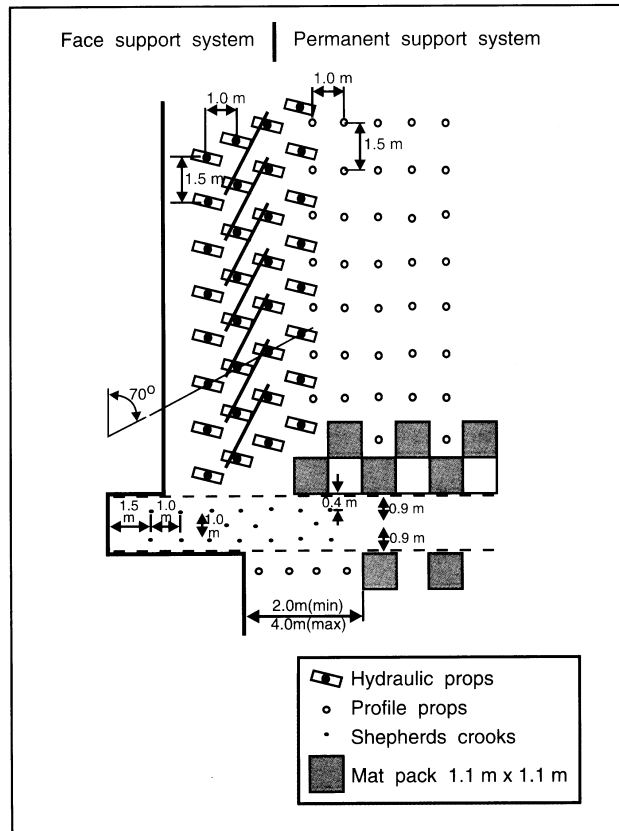


Figure 7. Blast-on face support system (after Jager and Ryder, 1999).

The advantages of hydraulic props are

- Reduced prop blast-out rate.
- Good stoping width control, resulting in reduced dilution.
- Rapid yielding capability during rockburst.
- Minimal interference with cleaning and sweeping operations.

The disadvantages of hydraulic props include:

- Props are heavy, hence handling difficulties are increased.
- Props require a rigorous maintenance schedule.

4.3.4 Safety Net

The safety net is rectangular in shape and has been tested for use in the stope face area. The net is used in conjunction with other stope support systems (e.g. remotely advanced headboards, twin beam support system, rapid yielding hydraulic props, elongates or tendons) and is placed as close to the hangingwall as possible to provide protection during barring, cleaning and drilling operations.

The safety net covers up to 85 % of the hangingwall and up to 2 tons of rock can be held. Furthermore, the safety net can be tailor-made to fit in between any dip and strike spacing of the main support system.

The net comprises two types of webbing, namely 2-ton and 4-ton webbing. The 4-ton webbing is used for the outer perimeter of the net. At each corner of the perimeter, a strap, made of 4-ton webbing, is attached with hooks or “D”-rings. The centre of the net has a number of 2-ton straps, woven and attached to the outer perimeter, forming a mat that can catch falling rocks.

When installing the net, the straps are attached to the stope support system. The net is tensioned by hand and is kept as close as possible to the hangingwall. The photographs in Figure 8 and Figure 9 show some installations of the safety net underground (used in conjunction with an elongate support system).

To summarise, the safety net is considered as a valuable passive auxiliary system to augment the main support system (comprising for example props, headboards, tendons, etc.). The net provides extensive areal coverage and is designed to protect the worker at the stope face from comparatively small falls of ground (up to two tons of rock). Research has shown (Jager, 2000) that a significant proportion of injuries and fatalities could be prevented by protecting the workers from these comparatively small falls of ground.

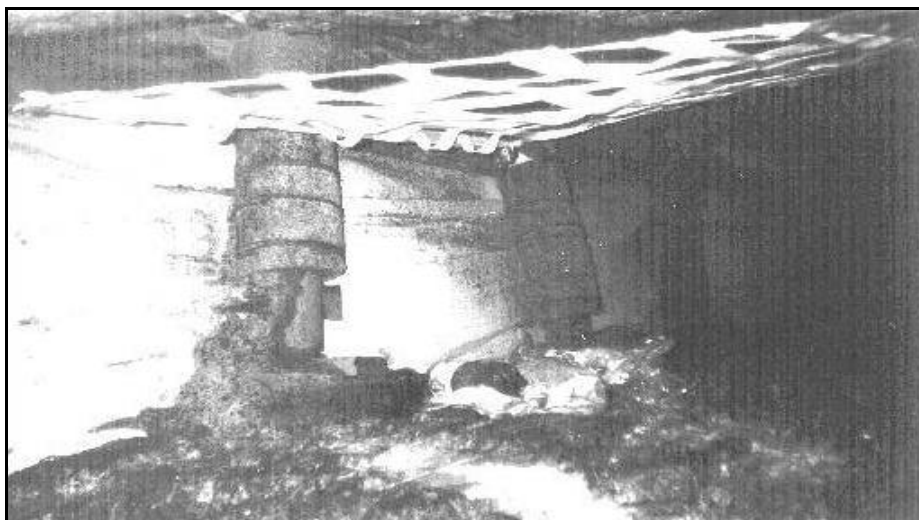


Figure 8. Underground installation of safety net used in conjunction with elongates.

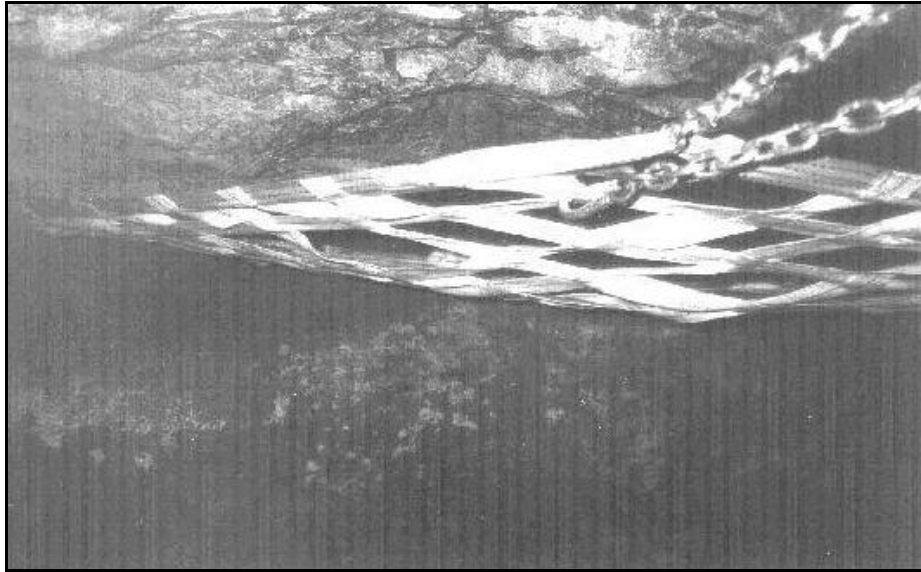


Figure 9. Safety net installed with chains.

The advantages of the safety net are:

- Low mass and simple installation and removal procedure.
- High areal coverage between support units.
- Ideal for panels with friable hangingwall conditions.
- Net can be re-used.

The disadvantages of the safety net are:

- Net can be damaged by scrapers (particularly when installed in low stoping widths).
- The net material has many applications outside the mining environment, and theft could be a problem.

4.3.5 Rock bolting in stopes

Rock bolting in stopes has a recognized potential to improve overall stability, particularly in the face area during cleaning and barring operations, and hence the safety of stoping operations. However, at present its application is limited to only a few shallow mines. Nevertheless, it is believed that this support method has a potential to be used in hard rock stopes industry wide.

Despite all recognized limitations of the pneumatic drilling equipment, encouraging results have been obtained with air-powered rock drills when used for rock bolting in stopes. Although not widely used in hard rock mines because of logistical problems with tendon installation in confined spaces, experience obtained on some mines indicate that rock

bolting in stopes has the potential to be successfully used in the proposed stope. Short drilling machines with specially designed airlegs are available and are used successfully in stopes with mining widths as low as about 1.2 m.

In hard rock environments (UCS >180 MPa) and for tendon's lengths of 0.9 m, up to 18 holes are drilled and rock bolts installed per worker per shift. Feedback from the mines that use rock bolting in stopes indicates that should a more efficient drilling technique be developed, for both solid and highly fractured ground, rock bolting would become a common support practice.

4.3.6 Yieldable anchors

Irrespective of the type of borehole drilling technology, a recent development, the simple, yieldable cable anchor which has been preliminarily and successfully evaluated in situ, has the potential to improve safety by facilitating rock tendon installation in confined spaces, including stopes and gullies, and by offering a well controlled support capacity, even under significant shear and dilation rock deformations. Relative ease of installation, including the potential for mechanising the operation, offers a user friendly, new rock bolting technology. This yielding cable tendon requires only a short grouted length which, together with the natural resilience of cables to shear loading, could make this new support an interesting rock bolting alternative for mine excavations under large quasi-static, dynamic and shear loading.

The necessity for only partial borehole grouting, without compromising on the tendon's performance, can ameliorate problems with ensuring quality of grouting, which in turn will result in enhanced safety of excavations. Examples of the in situ performance characteristics for both cement and resin grouted yieldable cable bolts, after only two hours of curing, are given in Figure 10.

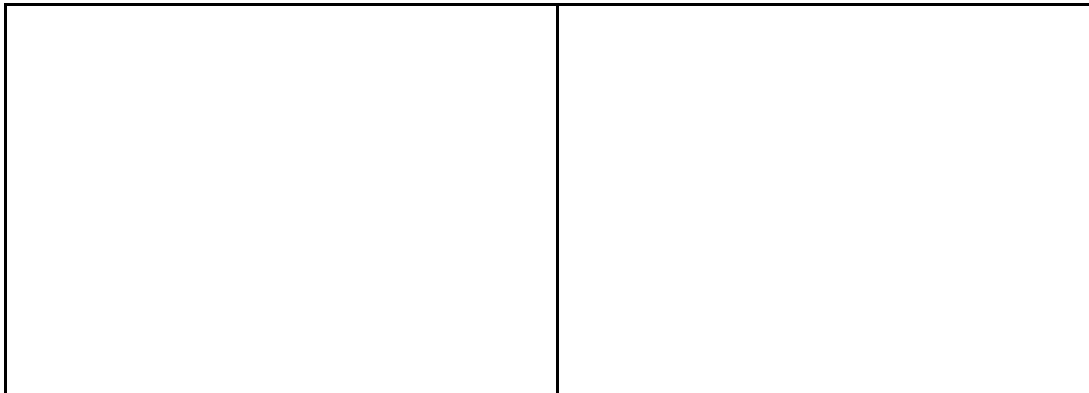
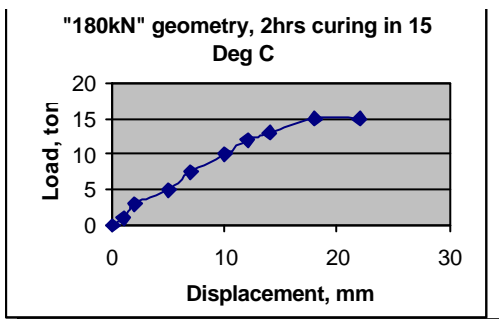


Figure 10. Performance characteristics of cement and resin grouted yieldable cable bolts.

The yieldable anchors have been developed and evaluated to the extent that they are considered suitable for consideration for inclusion in the final stoping system design. Only minor modifications to installation equipment could be required to match site specific conditions.

4.3.7 Structural membrane support

To improve safety and overall stability of mine excavations, by addressing the problem of insufficient rock areal coverage by conventional support, a new generation of large areal coverage supports are rapidly being developed around the mining world. These membrane support technologies are compatible with rock bolting, are thin, strong and flexible, adhere well to rock surfaces and are spray applied. Given these advantages, they could soon offer, in a number of applications, a safe, attractive and cost efficient alternative to conventional support measures, such as shotcrete and/or wire mesh. It is believed that international collaboration in the development of standards for testing of structural membranes, as well as for the refining of this new technology will benefit a variety of support and other applications, such as insulating, sealing, etc.

An interesting variation of the sprayable membrane that was recently developed and tested in South Africa is the low density product called Evertherm. In addition to its thermal insulation capacity, where the "k" ratio = 0.05 W/m (which is about 2 times smaller than

the specified requirements for mine insulation products of 0.1 W/m K), it also offers a measure of support capacity with a UTS of about 0.5 MPa and a UCS of about 1 MPa. A more detailed description of the Evertherm technology is given in Chapter 4.8.

It appears that the advantages offered by some of the latest developments of structural membranes should ensure their application in a proposed “benchmark” stope.

4.3.8 Overview of current elongate, pack and temporary support systems

4.3.8.1 Elongate support systems

Pres-stressable elongates (PSEs) provide an alternative to rapid yielding hydraulic props. Their fundamental advantage is that they do not have to be removed for re-installation, nor do they require maintenance. An example of a PSE (in this case a profile prop) is given in Figure 11.

There are, nevertheless, two technological disadvantages of most current PSEs with respect to hydraulic props: these have to do with areal coverage and consistency of performance. Firstly, no load-spreader for PSEs approaches the strength and dimensions of those available for hydraulic props. Secondly, as the majority of PSEs are based on timber props, their consistency of performance cannot approach that of hydraulic steel props. This issue is currently being addressed by a substantial testing programme and statistical analysis of results, which provide a performance characteristic for each type of PSE, guaranteed to some probability level of achievement.

4.3.8.2 Packs

A large variety of pack types are available, with widely diverse load-deformation characteristics. The options range from relatively soft and weak skeleton packs, through mat and solid timber packs, combinations of concrete blocks and timber (composite and sandwich packs), grout packs with the grout gravitated from a surface preparation plant, combinations of elongates and a framework of timber slabs (EPS packs), to the more recent innovations of combinations of end-grained timber blocks with parallel-grained slabs and lightweight foamed concrete, reinforced with either annealed steel mesh or wood fibres. These latter two types are supplied in modular sections, which interlock and can be

engineered to provide a wide range of combinations of initial stiffness, yield force and strength.

The characteristics of packs, which account for their widespread usage are: high strength, at least 50 % yieldability in most cases, structural integrity when subjected to eccentric loading, and relatively large direct areal coverage compared to prop types.

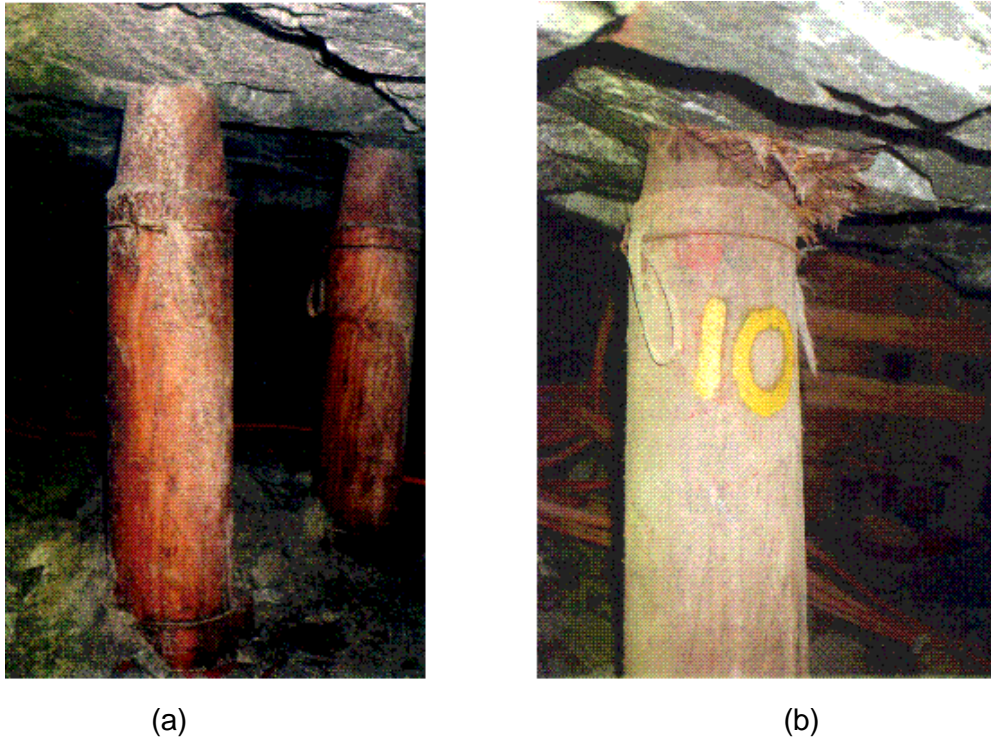


Figure 11. Examples of an installed turned profile prop (note brushing of prop top in b)

4.3.8.3 Temporary support systems

Camlok props are examples of temporary support types which can be installed at the face during barring, cleaning and drilling operations. Their usage is widespread, and they offer interim support until the permanent support system is installed. Yieldable Camlok props were developed recently to provide support during rapid compression (i.e. rockburst) conditions.

4.3.9 Backfill

Backfilling in a proposed conceptual stope would be looked at as a potential alternative to other technologies with the potential to address safety and stability problems.

Significant knowledge of the effects of backfill has been obtained through SIMRAC and other research programmes such as DEEPMINE. Relevant investigations have been carried out for over 10 years in order to quantify the potential of backfill to achieve its local and regional support effects.

A survey of rockfall and rockburst accidents in conventional and backfilled stopes provided convincing evidence to the effectiveness of backfill as local support. It was shown that the accident rate due to hangingwall instability in backfilled stopes is greatly reduced if a significant proportion (greater than 60 %) of the mined out area is backfilled, compared to the accident rate in conventional stopes. In panels where only small areas (20 to 30 %) had been filled, the rockfall accident rate increased over that in conventional stopes. Thus, the work indicated that, to obtain consistent local support from backfill, at least 60 % of the mined out area should be filled, and to minimize the risk of fall-outs and resulting accidents at the face area, backfill to face distance must be kept to minimum, preferably 6 m or less.

Backfill has an important role in maintaining ERR at low levels in deep level mining scenarios, as well as in stabilising the surrounding rockmass in the event of a rockburst. Research has indicated that backfill is superior to other support types in terms of reducing rockburst damage in most current deep level gold mines. It is also expected to be a better support medium at ultra depth as closure rates would be greater. To reduce rockburst damage, un-cemented backfill only requires backfill stresses of between 2-4 MPa to activate itself to become an effective local support.

Backfill would be considered as a potential medium for effective local support in the deep level mining scenario under consideration (i.e. 140 m span and 40 m pillar). In this scenario, backfill could play an important role in reducing stresses on stabilising pillars and, it was concluded, the cost of backfill compared to conventional timber back area support is about 16 % lower at a 1.2 m stoping width (Deepmine Task 4.4.2).

It should be emphasised that good backfill practice is highly dependant on a high level of commitment from mine management and rock mechanics personnel. In several cases, poor ground conditions and accident rates were incorrectly attributed to the presence of backfill, where in fact poor backfilling and mining practices were to blame.

4.3.10 Gully support

For some years it has become increasingly apparent that one of the essential requirements to improve the safety and stability of highly fractured stope gullies is better control of the support characteristics of gully packs.

Problems with maintaining stability of stope gullies are not confined to high stress environments but are also experienced in shallow mines, particularly those located in a disturbed rock mass. Such conditions occur in South African platinum mines.

Problems with stability of stope gullies result in falls of ground and lead to loss of and disruptions to production, in addition to the significant number of accidents that occur in gullies. Available statistical data indicate that approximately 14.6 % and 5 % of all rock related fatalities in stopes occur in strike and centre gullies, respectively (Jaku, 2000).

Currently gully support designs include various support unit types, mainly rectangular packs, with variations in spacing and support dimensions. Only a number of these systems are optimized while the rest are either being over or under-designed. Rock bolting is fairly commonly used in the hangingwall over the gully.

In addition to the few, proven supports and technologies such as Durapack, which have been specifically designed for gullies, a new, promising gully support concept has been developed and preliminary tests carried out. Initial evaluation of performance characteristics of this new support technology, a water inflatable gully/stope support, indicates that it has the potential for application in a “benchmark” stope by replacing various timber gully packs.

Some of the characteristics of the inflatable gully support are:

- Water-inflatable units have a support stiffness ranging from 32 - 50 kN per 1 mm deflection, and a yield force that can be set by choosing a suitable yield valve. It is envisaged that once a gully has been vamped and is no longer required, the units could be deflated and used again thus improving their cost-effectiveness.
- A preliminary cost benefit analysis indicates that there could be major cost savings arising from the use of inflatable support units. They would provide improved

control of ventilation air, and require less support installation. The benefits are however highly dependant on the re-usability of the support units.

- If installed 'face-to-face', inflatable units could not only improve the efficiency of mine ventilation but also reduce heat inflow into excavations, thus reducing energy requirements for air conditioning of hot excavations in gold and platinum mines and improve working conditions.

It should be noted that any savings in rehabilitation and reduced loss of production due to gully support failure have not been included in the evaluation, and these benefits are likely to be considerable.

Figure 12 shows an example load-deformation characteristic of a prototype water inflated unit. The dotted line indicates a controlled yield force, the magnitude of which can be pre-selected. It can thus meet the gully support requirements derived in SIMRAC project GAP032.

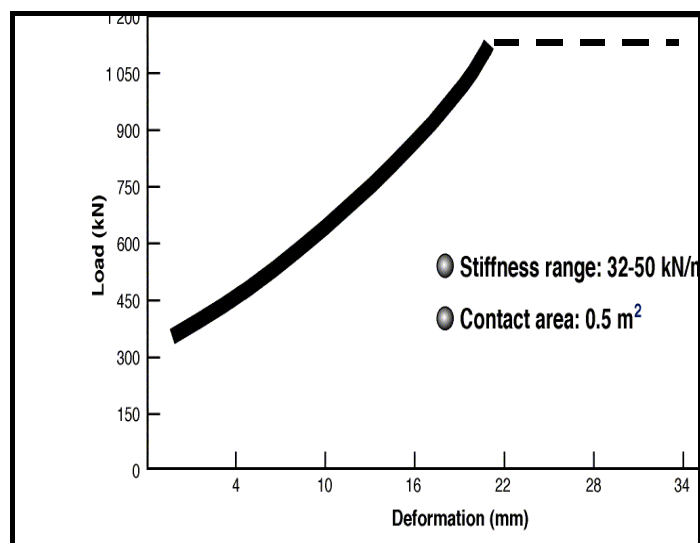


Figure 12. Example of the Load-Deformation characteristic of a water inflated unit.

This type of unit needs development beyond the prototype units before it could be considered for the “benchmark” stope.

4.4 Optimisation of in-stope logistics

Well designed and optimised in-stope logistics play a significant role in creating a safe and efficient working environment. It is envisaged that in a “benchmark” stope such an optimisation would include (Rupprecht, 2000)

- Optimising movement of men, material, and rock in terms of: establishing optimal T-way sizes and designs for men + material; and re-generation of x/cut; establishing ledging rate to match orepass capacity; and orepass configuration to minimize their number and allow for three shift tramming.
- Integration of geophysics for the advanced detection of rolls, faults and dykes.
- Use of systems/models (such as MIDAS) to estimate grade ahead of stope faces and optimise pillar layout.
- Evaluation of transport technologies for the proposed stoping environment for the movement of rock and material from stope to x/cut.
- Active involvement/presence of staff with managerial capabilities such as Mine Manager Certificate, Mine Overseer Certificate, Professional Mining Engineer, and Mechanical Engineer (while an operation in progress).

4.4.1 Stope design aspects

Design the optimal face length based on the stope layout as determined by the Rock Engineer in terms of stabilizing pillars (strike or dip). By planning the face length properly, the blasted rock can be removed from the face and from the strike gully within the time constraints established by the planned face advance and effective shift times. This way the strike gully will maintain a proper height, which will facilitate worker access to the face and easy rescue operations if necessary.

Design the layout to utilize a minimum number of ore-passes. The use of the continuous scraper or an up-dip scraping design will enable water to be prevented from entering orepasses, and thus reduce the chance of mud rushes. The use of a single orepass at the top of the connection will allow the layout to be designed such that the box front can be positioned so that it does not interfere with men and material handling, as seen in Figure 13. A single box front also facilitates the installation of a well-designed box which will minimise spillage (derailments). As only one orepass is required per stope, tramming can be facilitated as the ore-pass will be capable of bunkering a full days production.

Design layouts that facilitate the separation of men and material in the stoping horizon. Properly designed and implemented travelling ways which account for the closure and horizontal ride for the life of the stope will mean that persons will be able to travel much more easily than is currently experienced in deep level gold mines. Two idealized travelling ways are shown in Figure 14 and Figure 15.

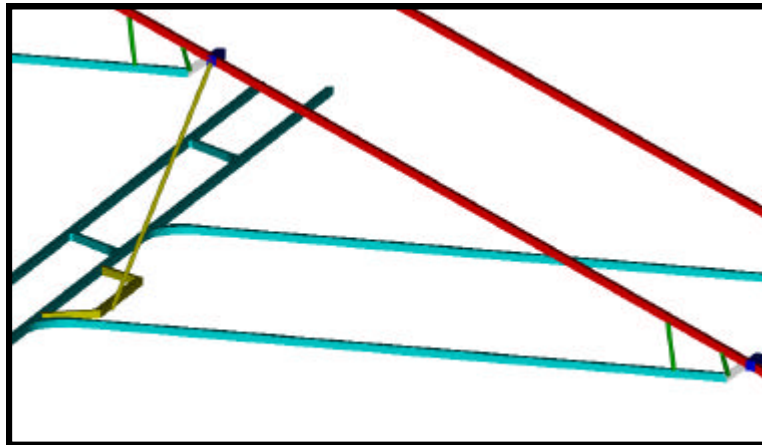


Figure 13. Ore-pass layout utilising one primary ore-pass and a tramming loop.

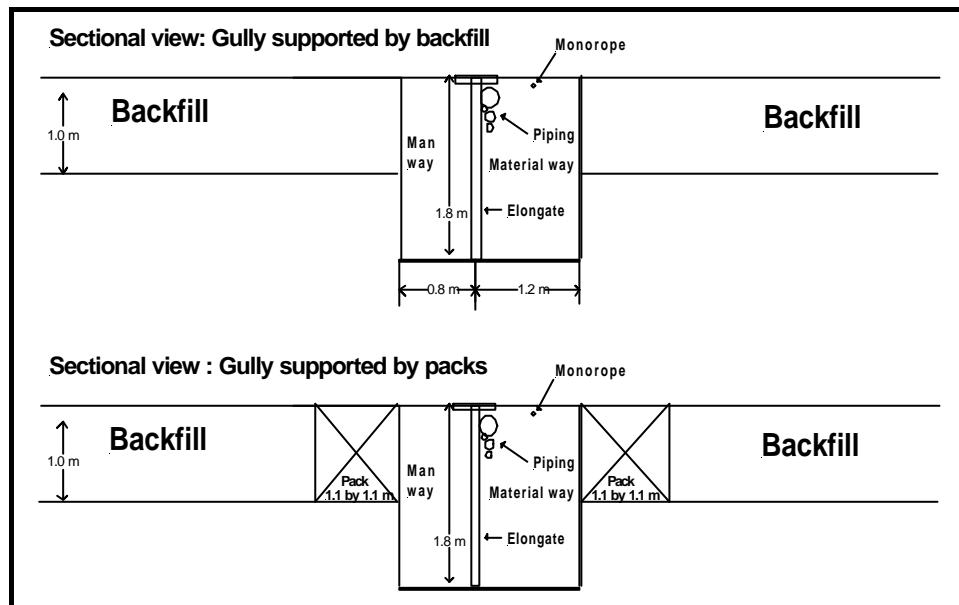


Figure 14. Dip travelling way.

Blast design is an area currently being investigated by the industry where unconventional explosive methods are being tried which would preclude specific blasting times and ventilation re-entry times. Stope designs based on this approach can be applied to remove toxic gases from the environment and allow for a continuous operation. Similar blast

designs could be considered to minimise hangingwall damage, thus creating a safer mining environment.

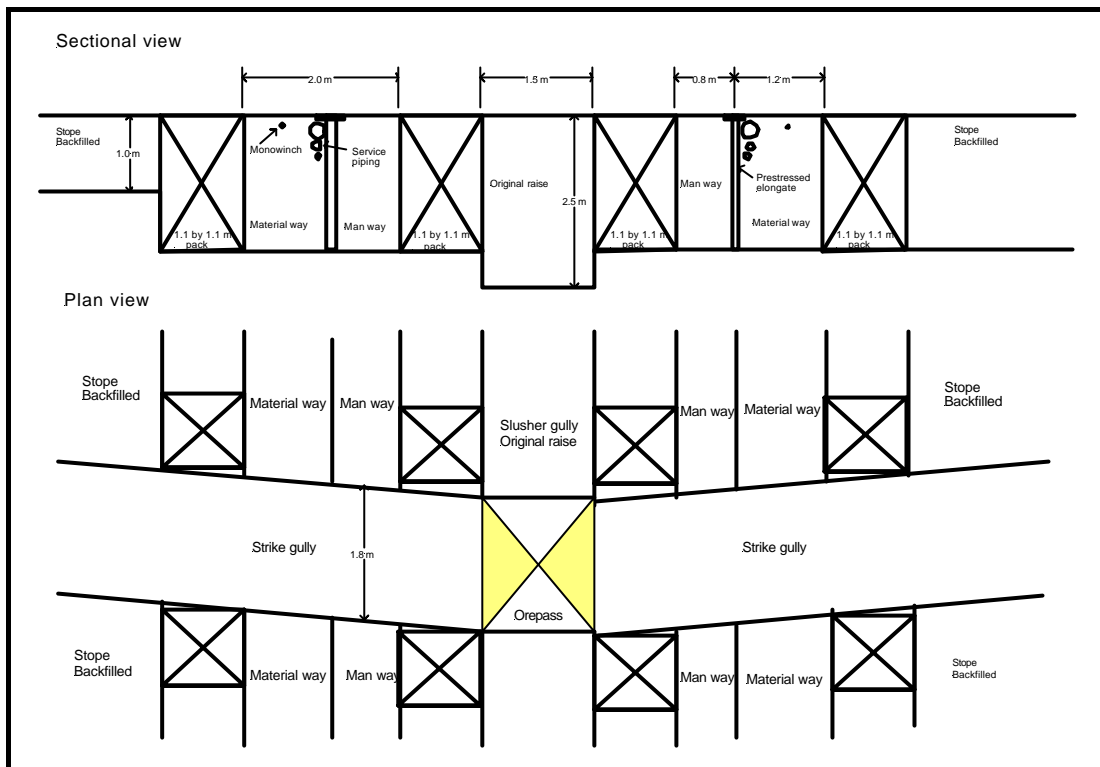


Figure 15. Twin travelling way system for use when dip gully scraping takes place.

4.5 Drilling and blasting technologies

Well designed and executed drilling and blasting in stopes should meet three fundamental objectives:

- use correct amount and type of explosive,
- use the explosive in the right place, i.e. properly positioned blast holes, and
- detonate the explosive in the correct sequence.

4.5.1 Drilling

Two types of drilling machines are used in stopes, the first utilises compressed air and the second utilises high pressure water. Electric rock drilling holds promise with the development of compact motors and may become commercially available in the foreseeable future. Hand held drilling is still the predominant means of drilling in narrow

tabular ore bodies, however stope drill rigs are beginning to be utilised and will become more predominant in the next few years.

Hand held pneumatic drills have been successfully used by the industry for over 50 years and, although considerable resources have been invested to improving pneumatic drilling, the benefits achieved to date have become marginal with the overall efficiencies of compressed air systems and the rock drills themselves remaining very low. Furthermore, the performance of pneumatic rockdrills decreases in the increasingly fractured rock conditions encountered in deeper level mines.

Pneumatic rockdrills typically operate at noise levels of 120 dB. There is a 41 % probability for those exposed to such high noise levels of becoming compensably deaf within five years which, at 1990 compensation levels, equated to an annual compensation cost of close to R30 million. Most recent data obtained indicate that the industry spends approximately R147 million on compensation for hearing loss per annum. The noise produced by rock drills not only places a large number of men at risk of lost hearing, but, additionally, compromises safety in the stope by seriously inhibiting communication.

In recognition of this problem, the South African mining industry, rock drill manufacturers, and other interested parties have, over the past three decades, expended considerable effort in developing methods to reduce the noise level of blast-hole drilling systems. This has resulted in a prototype quiet rockdrill which has achieved average noise levels of 92-93 dB during collaring and 90-92 dB during drilling, while maintaining the drilling rate of a standard pneumatic rockdrill.

Hydraulic powered rockdrills, with their higher power output, can overcome the disadvantages of pneumatic drills and provide further advantages of lower noise levels and the elimination of the fogging associated with the exhaust air of pneumatic drills. However, a combination of increased, industry wide focus on noise exposure, the limited availability of drillers and the current level of profitability has emphasized the need for improved blast-hole drilling systems.

4.5.2 Blasting

4.5.2.1 Fuse and Igniter cord

Fuse and igniter cord systems are popular due to their low costs, however they offer low reliability and thus often cause poor face shapes.

4.5.2.2 Shock tube initiation

The shock tube system allows for a reliable and consistent initiation system improving hangingwall conditions, stope width control and face advance.

4.5.2.3 Electric initiation system

The electric initiation system allows for a proper firing sequence and delays can be programmed on the face using an electronic control box. The system allows the blast to be monitored, which links into the knowledge management systems being implemented on the mines.

4.5.3 Summary

Various methods can be utilised for drill and blast design and should be workshopped with the 'champion' mine as several options exist. Stope drill rigs and electronic detonators are systems of the near future and offer safe operating systems.

At present, explosives and detonators are well covered by existing technologies. Therefore, the most important need to obtain more effective blasting in stopes requires reliable and correct drilling of blast holes.

4.6 Non-conventional drilling and rock breaking technologies

4.6.1 Impact Ripper

The Impact Ripper is a fully non-explosive face mining system capable of continuous operation. It operates with low pressure water (20 MPa) as the working medium, with the

water derived from a hydro-power column or pump chamber. The system comprises a hydraulically operated hammer (with a blow energy of 4500 J at a cycling frequency of 5 Hz), a main frame onto which the hammer is mounted (which serves as a platform to support all the necessary movements of the hammer), a reciprocating flight conveyor (capable of transporting 30 t of rock per hour) and a traction unit to allow the machine to traverse along the reciprocating flight conveyor. All the functions of the machine are achieved through the use of the 20 MPa supply water.

The machine is designed to exploit the mining-induced stress fractures which develop parallel to the face. Since the hammer action is also roughly parallel to the stope face, it can wedge open the stress fractures. Once the rock has been removed from the face, the hammer is used to facilitate loading of the rock onto the reciprocating flight conveyor.

The advantages of such a mining system are:

- Full-face stoping combined with non-explosive mining operation.
- Low grade energy suitable for workers being present in the stope.
- Concentrated mining with no blast effects.
- Environment friendly (no dust or fumes).
- Mining operations and installation of roof support may be conducted simultaneously.
- While skilled operators are required to operate the equipment, training is easily accomplished with workers who show sufficient potential to be trained as operators.

The disadvantages of such a mining system are:

- Only suitable in geotechnical areas which have sufficient mining-induced stress fracturing.
- Unable to mine hard patches which sometimes occur in gold-bearing reef. This requires blasting on a small scale to pre-fracture the rock before the Impact Ripper may proceed.

4.6.2 Water-Pulse Gun

The Water-Pulse Gun is a device which is used to induce high pressure shock waves into drilled holes in a stope face, for the purposes of stoping. The application of these high pressure water pulses is seen as a potentially viable alternative to drilling and blasting.

The device was originally derived for use in surface quarrying and demolition and has been adapted for use in an underground stoping environment. It consists of a thick-walled cylinder which is filled with water and pressurised to 3000 bar. A hole is drilled into the stope face parallel to a free face. The nozzle of the Water-Pulse Gun is then inserted into the hole, and the hole filled with water prior to discharging the Water-Pulse Gun. The high pressure water pulses fracture and heave the rock in a safe manner, i.e. there is no fly rock.

The advantages of the Water-Pulse Gun are:

- Operates with water as the working medium, so is environmentally friendly.
- Does not result in fly rock, so personnel do not require to be removed from the area during firing.
- May be used for continuous mining.
- No dust produced.
- Low noise levels.
- The energy stored in the compressed water is safely contained, and any small leak results in rapid pressure loss in the system. Hence, there is little chance for the cylinder to rupture and high energy debris to be produced. It is therefore safe for use in a stoping environment.
- The device has been shown to break fractured and unfractured quartzitic rock with burdens up to 350 mm.

The disadvantages of the Water-Pulse Gun are:

- Application of water pulses into holes sloping upwards requires a mechanism to keep the flushing water in the hole prior to discharging the Water-Pulse Gun.
- The device is fairly large and cumbersome.
- Requires drilled holes in the stope face which may have potentially harmful side effects in noise and air-pollution.

4.6.3 Hydropower

Water is used underground for cooling / cleaning / drilling etc. In deep mines, the column used to gravitate this water underground may be as long as 2 km, resulting in a pressure of 20 MPa at the base of the column. This pressurized water was identified as a source of power, called 'hydropower'.

Hydropower is a convenient source of power as it is clean, readily available (as deep level mines all require cooling), and may be used in operations that require pressurized water, such as water-powered rockdrills, water-jet assisted stope cleaning, Impact Ripping, turbine energy recovery, etc.

In the context of stoping operations, high pressure water is suitable for:

- water-powered rockdrills (which have shown the potential to reduce noise and pollution levels in stopes, as well as drill faster than conventional pneumatic drills, and cool the surrounding environment),
- water-jet assisted cleaning (especially to assist removal of fines),
- Impact Ripping (which uses high pressure water to operate the impact hammer, reciprocating flight conveyor, wheel traction unit, and positioning cylinders).

The advantages of hydropower are:

- recuperation of otherwise lost energy,
- clean, non-polluting source of power,
- water-powered rockdrills are quieter, environmentally friendly, and drill faster than pneumatic rockdrills,

- relies on natural head of water to generate the pressure (i.e. no surface pumping equipment required to produce the pressure),
- mining by means of Impact Ripping may be carried out continuously.

The disadvantages of hydropower are:

- large initial capital outlay required (since water column is now made of thick-walled material),
- water column requires control system to prevent potentially hazardous water-hammer situations,
- not suitable for shallow mining operations (less than 2 km) as these will not result in a sufficient head of pressure, or effective usage of the energy.

4.6.4 Plasma Hole-maker

The concept of roofbolts to prevent falls of ground in the stope area emerged during late 1991 and early 1992 at Kinross mine. The main idea behind this technology was to move away from a totally passive support system at the face (mine poles with headboards) to a system of active support (pre-tensioned steel tendons), offering immediate support resistance close to the face where most falls-of-ground accidents occurred. Unfortunately, while the installation of roofbolts produces significant advantages in large stoping widths, their application to narrow stoping widths (as low as 800 mm to 1 m) has been impaired by inadequate practical drilling techniques.

Thus, the concept of the Plasma Hole Maker (PHM) was developed to provide an economic method of generating long roofbolt holes in narrow stopes. The benefits from this new support tool are very significant. First, the unsupported span at the face can be reduced to half the present possible value, which allows for much better control of the hanging and thereby reduced dilution. Second, since props near the face can be avoided, safer mechanized mining methods become more practical. Mechanization is viewed as being crucial to sustaining the mining industry into the future.

The economic benefits of using roofbolts are reduced numbers of lost shifts, increased safety, higher face advance rates per blast and reduced dilution. Once the technology is developed for this purpose, it is possible that the cost could reduce with time and be competitive for drilling blast holes. Further advantages of this method of rock drilling are the low noise emissions and the significant reduction or elimination of compressed air supplies in stopes. No new power supply infrastructure needs to be installed since the system currently used for winches can be utilized. Electric pulsed power technology could also be applied as a full-face mining method in very narrow reefs, making man-free operation in ultra-deep mines possible.

In addition, South Africa has large reserves in the form of shallow mines and low grade ore that cannot be mined using current technology, and it is envisaged that the culmination of this technology into a full face electric mining system will facilitate (through its efficiency and automation capabilities) the economic extraction of these reserves. Further, its application is not limited to South Africa but extends to the greater SADC region and the rest of the world.

4.7 Stope cleaning technologies

There are four primary means of moving rock in the stoping environment. The first is by heave or throwing the reef itself. The second is face cleaning, the third is by strike gully scraping and the fourth is the removal of the rock through the ore pass. An additional system can be required for layouts requiring dip gully scraping, e.g. the Kloof SDD method and the Driefontein continuous scraping method.

One potential alternative to the stope layout is to utilise throw blasting combined with water jet cleaning. This would entail shorter panels in the order of 12 to 15 m long.

Another potential solution is drilling long holes on dip from strike gully to strike gully and then blasting. The blasted rock is then water jettted to the strike gully and the back area filled with backfill. Thus workers are removed from the face.

4.7.1 Face Cleaning

4.7.1.1 Scrapers

Utilising conventional scrapers, a cleaning rate of 250 t-m/hr to 500 t-m/hr can be achieved. Mine planning is essential to ensure panel lengths are optimised so that blasted rock can be removed from the stope in the required periods (period based on face advance and other parameters).

4.7.1.2 Mechanical conveyors

Mechanical conveyors i.e. reciprocating flight conveyors can be utilised on the face where non-explosive mining takes place and have been utilised in the past with the impact ripper. At this time, it is doubtful whether the project stope would utilise mechanical conveyors.

4.7.1.3 Water Jetting

Water jetting can reduce face cleaning time in half when used in conjunction with scraper cleaning of the face. It is possible to clean panels with water jetting alone. Tau Lekoa are cleaning panels 15 – 20 m in length and at Northam, panel lengths of 25 – 30 m are being cleaned. Water jetting could play an important role in whatever stoping layout is chosen.

4.7.2 Strike gully cleaning

4.7.2.1 Scraping

Current scraping equipment can achieve cleaning rates in the order of 800 to 900 t-m/hr. The strike gully length remains the critical factor in deciding the length of the panel as the ability to clean a panel over 90 m can take over 12 hours or three shifts.

Because the strike gully also serves as a primary access for men and material, it is important that stope layouts account for the total removal of the rock for the entire length of the strike gully so that men and material have access to the stope face.

Due to the fact that the strike gully is always being moved forward, it is doubtful that a conveyor or continuous scraper will be suitable. Strike gully cleaning can be seen as a barrier that may limit face advance. Trackless strike gully cleaning may be one way to achieve higher face advance but this would require changes to current mining layouts.

4.7.3 Dip gully cleaning

4.7.3.1 Up dip scraping

Both conventional scraping and continuous scrapers may be considered for up dip scraping. Conventional scraping is capable of achieving 600 to 700 t-m/hr over short pull lengths, while the continuous scraper is capable of rates of up to 400 t per hour over long pull lengths. Both methods offer the advantage of separating water from the rock and the continuous scraper offers the ability to utilise single orepasses in the stope layouts.

4.7.3.2 Down dip scraping

Down dip scraping provides a cleaning rate of 1100 to 1300 t-m/hr. Down dip scraping over long distances is cumbersome and may require several overlaps, thus down dip scraping is generally limited to lengths less than 90 m.

4.8 Environmental control technologies

The proposed design and operation of a modern gold mine stope requires the integration and co-operation of different skills and knowledge. From an occupational environment control perspective, the significant requirement of this project is to provide environmental conditions adequate to attain high productivity targets while maintaining consistently high standards of health and safety.

Given the apparent divergence on mines in the emphasis on efficiency and on safety and health, it is necessary that environmental control aspects form part of both design and operational stages of this project.

Adequate design and operation of the environmental system infrastructure in the footwall leading to the stope is as important to the control of environmental conditions in the reef horizon as are the control measures in the stope itself. In addition, in order to attain the objectives of this project, it is important that the various environmental control systems near and within the reef plane be operated without excessive interference with mining operations.

In order to attain the proposed objectives, it is deemed essential to include experts with both design and operational experience of environmental control systems in the proposed multi-disciplinary expert team from the initial stages of the project's life.

It is stressed that the incorporation of effective environmental control system design is essential to ensure the attainment of adequate temperature and humidity levels and safe and acceptable air quality standards with respect to gas and dust contamination.

In addition, it is important that the environmental control systems be operated efficiently to reduce capital and operational costs, without compromising the protection afforded to workers.

The following environmental control components are considered to be controllable within the scope of this project:

- The design and operation of a “mini” air handling unit located in the crosscut that will attain the stope inlet design air quality (temperature humidity and aerosol content). This will obviate the need for in-stope cooling at these depths.
- The design and maintenance of centre gully brattices to ensure the target air utilization.
- Design of air inlet(s) into the stope that will allow maximum air flow with minimum air resistance.
- Design and implementation of equipment and systems that will minimize the liberation and dispersion of dust in the atmosphere.

In terms of environmental condition objectives, the following are proposed:

- | | |
|--|------------------------|
| • Minimum stope air utilization : | 75 % |
| • Maximum air quantity (per side at 1.5 m stoping width) | 10.0 m ³ /s |
| • Maximum face wet bulb temperature | 27.0 °C |
| • Minimum air cooling power | 335 W/m ² |
| • Maximum air quality index (AQI) | 0.5 |
| • Maximum chilled service water usage | 1.0 t/ton mined |

It is estimated that the proposed air power savings that can be achieved will result in net savings of approximately R8/m² mined (Biffi, 2000)

The newly developed thermal insulation technology, Evertherm, has the potential to contribute to achieving required environmental condition objectives (Wojno et al. 2000).

Development of this technology was a continuation of a wide-ranging research programme by CSIR: Miningtek concerned with developing safe and user friendly technologies to address support and ventilation problems experienced on the mines.

The Evertherm thermal insulation coating and its application technology were specifically developed to address the problem of excessive heat loads in the excavations. Measurements of thermal conductivity for the Evertherm insulating coating indicate that its "k" ratio is about two times smaller than specified (0.1 W/m K). In practice, this means that a significantly thinner layer of the material will be sufficient to effectively reduce heat loads in excavations insulated with this material.

Evertherm's Uniaxial Compressive Strength (UCS) is about 1 MPa and its Uniaxial Tensile Strength (UTS) is about 0.4 MPa, indicating that, in addition to its good thermal insulating properties, it also appears to have a "bonus" support capacity.

One of the main requirements for thermal insulating coatings is that they must be user and application friendly. Quick covering of large rock surface areas is best achieved by spray application. To meet the requirements, mixing + spray application equipment was developed and tested. Figure 16 illustrates the application of the Evertherm coating to a test panel.



Figure 16. Spray application of Evertherm to a test panel.

4.9 Other safety measures

4.9.1 Preconditioning

To improve safety by ameliorating problems related to rockbursts and to improve overall hangingwall stability, it is envisaged that preconditioning would be used routinely in the proposed stope. An extensive research programme to address the issue of rockburst control was carried out as part of the SIMRAC Projects GAP 030 and GAP 336 where preconditioning was developed and found to be a very effective rockburst control technique.

Preconditioning involves regularly setting off carefully tailored blasts in the fractured rock immediately ahead of a mining face, so as to encourage slip on pre-existing fractures, in order to prevent the accumulation of high strain energy density in the rock mass. The effectiveness of preconditioning was proven in situ, including areas where this technique prevented face bursting, despite several large seismic events occurring close to the subject faces.

An improvement in hangingwall stability and face advance per blast (typically 50 % in VCR stopes) has also been noted in properly preconditioned areas.

In order to ensure successful implementation of the techniques into the mining environment, a structured implementation process has also been developed. Owing to the benefits of preconditioning in safety and productivity, the technique should be considered as an integral part of any given deep level mining operation. Preconditioning is also cost efficient because it results in an increased face advance per blast as mentioned above. Relevant expertise exists at CSIR: Miningtek and is readily available.

5 Proposed Mining System

Having taken into account the advantages and disadvantages of the discussed technologies and their potential for effective integration, the conceptual mining system, comprising the following equipment and technologies, is proposed:

- Water powered, hand-held rock drills.
- Reliable sequential detonation blasting system – final decision of which system to be used will rely on latest information.
- Rapid yield hydraulic props with 0.8 m load spreaders. Lines of props aligned 70° to face to enhance drilling accuracy and limit interference with drilling.
- Safety nets suspended on the props where necessary.
- Roof bolts installed less than 0.5 m from face.
- Yielding mechanical props as temporary support during roof bolting.
- Diagonal blast barricades to facilitate water jetting.
- Fines barricade.
- Routine face-normal preconditioning to prevent face bursting and enhance advance per blast.
- Water jet assisted scraper face cleaning. Water system - high pressure, low volume. Assists with preliminary barring and dust suppression.
- Gully shoulder support – constant yield force, low mass reinforced concrete packs or Fill-packs in backfilled stopes.
- Gully hangingwall support – roof bolts, shepherd's crooks or yielding tendons (depending on conditions) with lacing over membrane support to provide good areal coverage.
- Strike gully cleaning – scrapers, double-separated-scraper system for long pulls.
- Centre-gully – up dip rock transport by means of continuous scraper to single long box-hole with adequate bunkering. Water separated from rock.
- Separate men and material access dip gully equipped with mono-rope from x/cut storage bays – delivering to top gully/face intersection in overhand stope.
- Environmental control systems and equipment appropriate for local conditions.
- Initial geological and rock engineering assessment of ground control district. Geophysical probing of ground conditions ahead of the stope face where deemed necessary.

Figure 17 schematically illustrates the layout and positions of various types of support and the other equipment in the proposed stope.

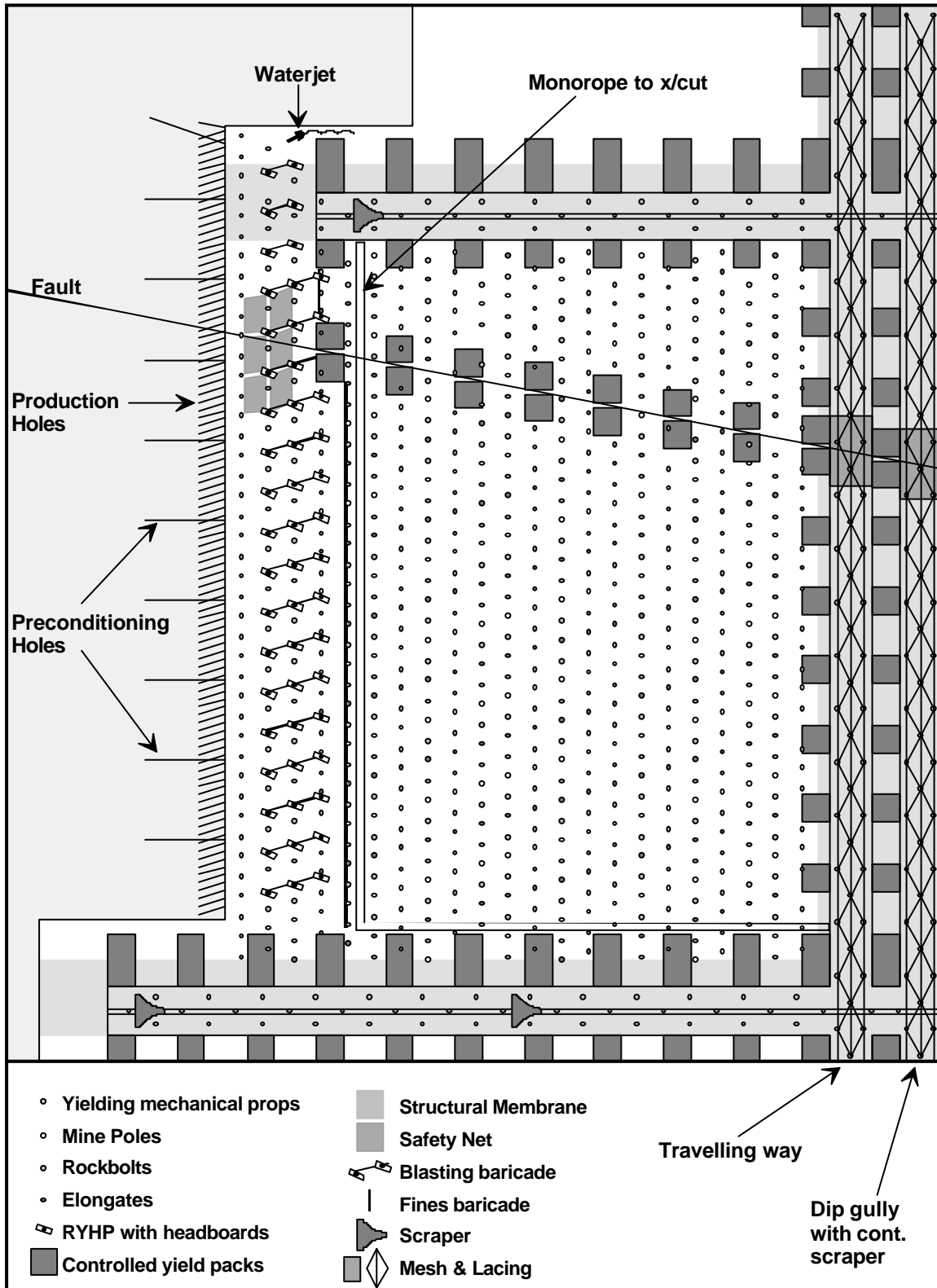


Figure 17. Schematic layout and positions of various types of support in the proposed stope.

6 Potential for continuation as Phase II

The mining system as introduced in chapter 5 remains a mere concept until implemented and evaluated underground. As part of this project, consideration was given to the practicality and approximate costs of running a field trial of the proposed system. Three crucial issues were identified that need to be resolved before such a trial should proceed. The first is to identify a willing mine that will enthusiastically champion the trial. The second is to recruit or second necessary staff to the project. CSIR: Miningtek has the experienced researchers to design, monitor and evaluate the trial, but no longer has production personnel nor technologists to run and service the site; suitable people to fill these positions would have to be either supplied by the mine or outsourced. Thirdly, the cost, funding and revenue associated with the project need to be addressed by consultation and negotiation between the three parties concerned.

It is believed that none of the above problems are insurmountable and that an initial small project could be set up to finalize tripartite agreements. The successful outcome of the trial, benchmark stope could be of immense benefit to the industry in terms of technology transfer, leading to significant improvements in safety, health and productivity.

It should be re-emphasised that a fully committed and actively participating champion mine is essential to the success of the project. It is envisaged that, in addition to operational and logistical functions, the “champion mine” would play an overall management role in the proposed “benchmark” stope project.

7 Conclusions and recommendations

7.1 Conclusions

7.1.1 Conformance with contractual project outputs

7.1.1.1 Enabling output 1: Analysis of required skills

- A range of critical skills that are essential to create the multi-disciplinary expert team required to successfully implement the proposed “benchmark” deep gold mine stope was identified and analysed.
- It was found that the expert teams could be formed from a combination of the expertise available at CSIR: Miningtek, as described in Chapter 3 of this report, with relevant structures and services which would routinely exist on a champion mine. However, experience obtained by CSIR: Miningtek during similar projects in the past (Hartebeestfontein, Doornfontein and West Driefontein mines) strongly indicates that an absolutely essential component of any successful technology implementation project are technical and supervisory teams from CSIR: Miningtek that are recognized by mine personnel, are familiar with a specific mine (preferably ex-mine employees) and would be identified on the mine as “natural allies”.

7.1.1.2 Enabling output 2: Analysis of technical and implementation potential of existing technologies

Analysis of the technical and implementation potential of various technologies indicates that they can be allocated to two groups:

- technologies that are immediately available for full implementation, and
- technologies that require some refinement and “trouble shooting” through gradual implementation and evaluation in the proposed benchmark stope.

The proposed technologies are listed in Chapter 5 of this report. It is envisaged that, in the first stage of the implementation project, the following technologies would be used:

- Technologies to optimise drilling and blasting with respect to throw, fragmentation, advance per blast, stoping width control and limiting damage to hangingwall.
- Routine preconditioning.
- Initially hydraulic props and elongates as face support, with safety nets between prop support and gradually implementing yieldable rock bolting (bar type and cable anchors) and structural membranes.
- Initially packs with defined maximum yield force as gully support and gradually supplementing with rock bolting and structural membranes and lacing.
- Scrapers optimised for site specific conditions and supplemented with water jetting to clean rock from the face, together with diagonal blast barricades.
- Scrapers (double scraper system for long pulls) and/or conveyors optimised for site specific conditions to move rock along gullies.

It is envisaged that other technologies with promising implementation potential, but still requiring some refinement and “trouble shooting” in situ, such as those related to mechanisation and hydropower, would be gradually implemented in the course of the second stage of the proposed Phase II. These technologies are as follows:

- Face area support system emanating from project GAP 708.
- Plasma Hole Maker (with the proviso that permission is obtained from intellectual property holders Amplats).
- Hydropower for borehole drilling and other applications.
- Impact Ripper (if proven to be a viable system by then).
- Water inflatable gully support.

The safety issues addressed in this conceptual design include:

- Rockfalls during the cleaning shift and making safe operations.
- Casualties caused by rockbursts and rockfalls between support units.
- Rock related casualties in the gullies.
- Exposure of personnel to danger from moving equipment such as scrapers, conveyors, etc.
- Unreliable supply of support materials to the face area.

- Reduced alertness of personnel to hazardous situations caused by poor environmental conditions.

7.1.1.3 Enabling output 3: The feasibility study of the concept

A feasibility study of the proposed concept (i.e. implement proposed technologies on a champion mine) was performed as Phase II of this project and is presented in Appendix I.

Analysis of the availability of critical skills required to successfully run a safe “benchmark” stope, together with the implementation potential of some of the state-of-the-art proven technologies, indicates that, from a technical perspective, such a project can be feasible.

7.2 Recommendations

It is recommended to continue this project into the field-trial stage. A small project should be set up to firstly identify a potential champion mine; to secondly determine costs and to negotiate the funding and revenue associated with the trial, as well as the roles and responsibilities of the various parties; and to thirdly recruit suitable production personnel and technologists required to run the site. As these people are not available at CSIR: Miningtek, they should be either seconded from the mine or outsourced.

Discussions were held with the personnel responsible for a similar trial by AngloGold, with a view to combine the projects. However, it was stated that the AngloGold trial is aimed at improving the Group’s competitive advantage and that the results would not necessarily be made public. This is clearly not acceptable to a SIMRAC project, it was decided not to combine the projects. However, it was resolved that all safety related developments would be openly shared by the two projects.

Further discussions with individual mine managers indicated strong support for the project, but the managers felt that their participation should be the subject of Head Office negotiations. The team subsequently felt that SIMRAC approval for continuation should be sought first, following which the implementation would be taken further with a selected mining group at Head Office level.

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Appendix 1

Feasibility of continuation as Phase II

The required skills and many of the existing technologies that can realise the running of the proposed stope were listed and briefly explained in the main report. However, the 'champion' mine is required to join and accommodate such a project. The authorities and the responsibilities of the participating parties (The 'champion' mine, CSIR: Miningtek, SIMRAC and those who provide various technologies) must be clearly identified and agreed upon prior to commencement of Phase II. Without active participation of the 'champion' mine the second phase of this project (i.e. the implementation of proposed technologies) cannot be accomplished.

It is intended that relevant proven technologies be implemented one at a time unless prior experience has demonstrated compatibility. Once an acceptable confidence is gained on the proper integration of a specific technology into a mining cycle, the effects of this integration may be quantified and tested to establish whether it serves the ultimate objectives of this project. Then the following technologies, in turn, can be taken through the same process of implementation and integration. In order to prevent incompatibility of these technologies, the entire implementation process must be properly sequenced.

Most of the technologies mentioned in the report have been implemented separately in different mining environments and their benefits, in terms of improving the safety records, were assessed. This project intends to implement and integrate the selected and proven technologies into one single stope and to create a benchmark for stoping operations in South African deep level gold mining. The potential for success of this project is high and the benefits of a successful implementation of the most promising technologies can be significant. However, it will require a great deal of both technical and financial commitment from all participating parties.

The implementation of some of the technologies will require substantial capital costs. On the other hand, this project involves high human resources cost as detailed in Table 1.

Such cost will be markedly higher if mechanisation-related technologies are implemented. These costs are given in Table 2.

Table 1. Estimated Human Resources cost for Phase II (with conventional drilling and blasting and assuming a total of 2 years involvement)

Area	Activities	Man Days	Cost (kR)
Rock Engineering	Project management and coordination of activities	500	2000
	Layout Design	20	80
	Consultation Support Design and Implementation (incl. Evaluations)	120	480
	Consultation on Preconditioning	60	120
	Instrumentation and monitoring	100	300
	Reporting on safety aspects (reports, seminars, workshops, etc.)	40	160
Environmental Control	Consultation and long term planning	25	120
	Medium / short term planning, equipment installations, etc.	120	200
	Measurements, observations and surveys	100	165
Mining Systems (Backfill system *)	Initial Backfill system design	15	45
	Quality control audits and maintenance of backfill system, if used.	25	75
	Consultation on Fill Pack system if backfill used*	10	39
Mining Systems (Mechanisation)	Consultation	30	120
Mining Systems (Geology and Geophysics)	Consultation	30	150
	Monitoring (e.g. Mine Seismic Profiling, Borehole Radar, Ground Penetrating Radar)	50	150
Mining Systems (Stope design)	Consultation on stope design	20	66
	Planning and monitoring performance and costs	100	330

TOTAL HR		1365	4600
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* Subject to backfill technology used on the mine.

Table 2. Estimated additional Human Resources cost for Phase II (with non-conventional rock breaking and assuming a total of 2 years involvement)

Area	Activities	Man Days	Cost (kR)
Mining Systems (mechanisation)	Consultation	70	280
	Consultation on Impact Ripper	300	1500
	Consultation on Water Pulse Gun	200	540
	Consultation on Plasma hole maker	300	630
	Measurements, observations and survey	100	180
Mining Systems (hydropower)	Consultation	24	70
TOTAL HR		994	3200

It is proposed that these costs be off-set by the income arising from mining. This income is not shown in the tables.

No detailed estimate of the running costs of the proposed benchmark stope has been carried out. It is possible that the costs would be higher than industry average. It is envisaged that the improved face advance rate and reduced dilution would more than cover these additional costs and the overall system will be more cost effective.