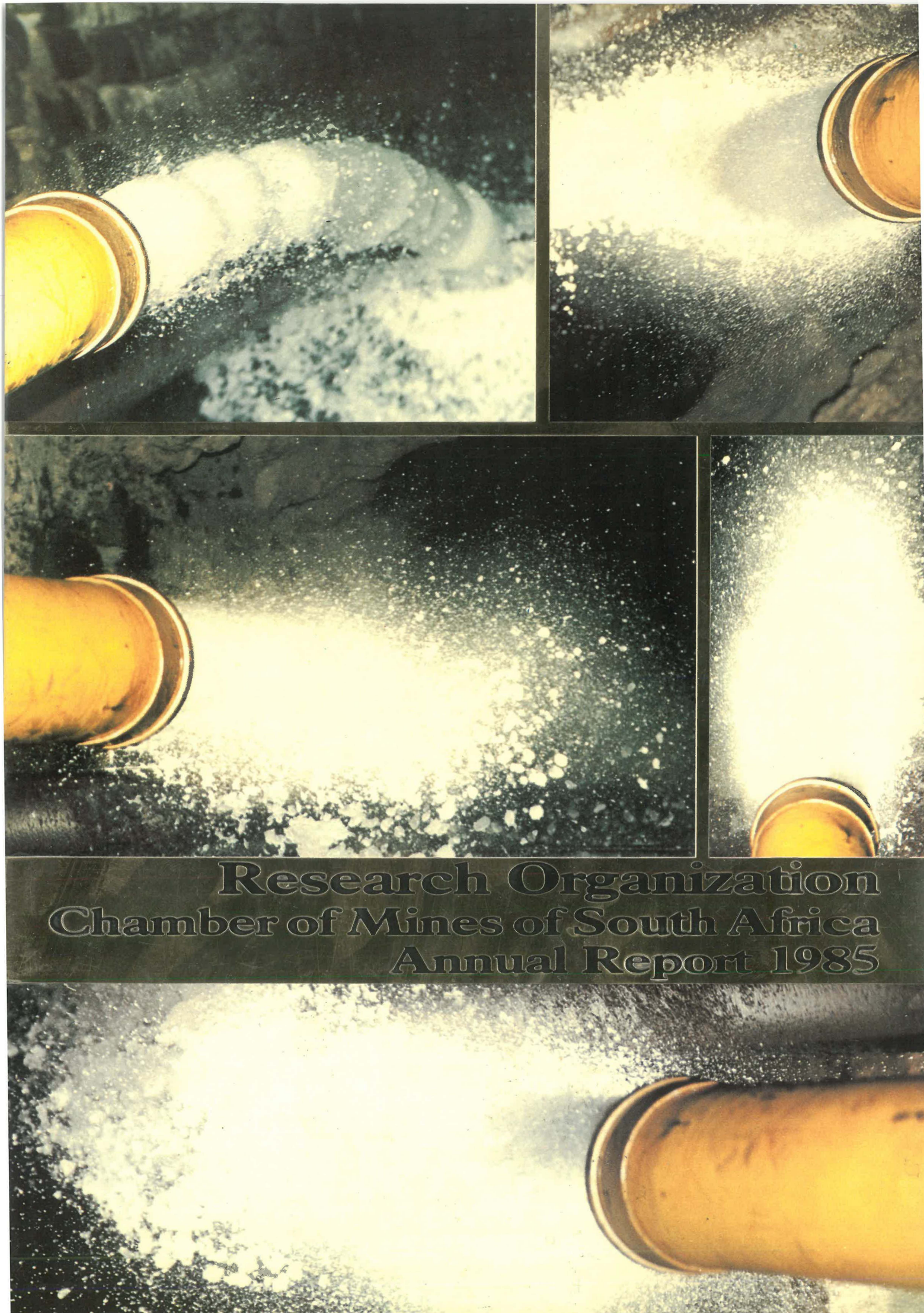


Research Organization
Chamber of Mines of South Africa
Annual Report 1985

Chamber of Mines of South Africa

The Research Organization of the Chamber of Mines of South Africa is the largest free-enterprise research establishment in Southern Africa and is financed directly by the members of the Chamber, comprising the mining groups and individual mines.

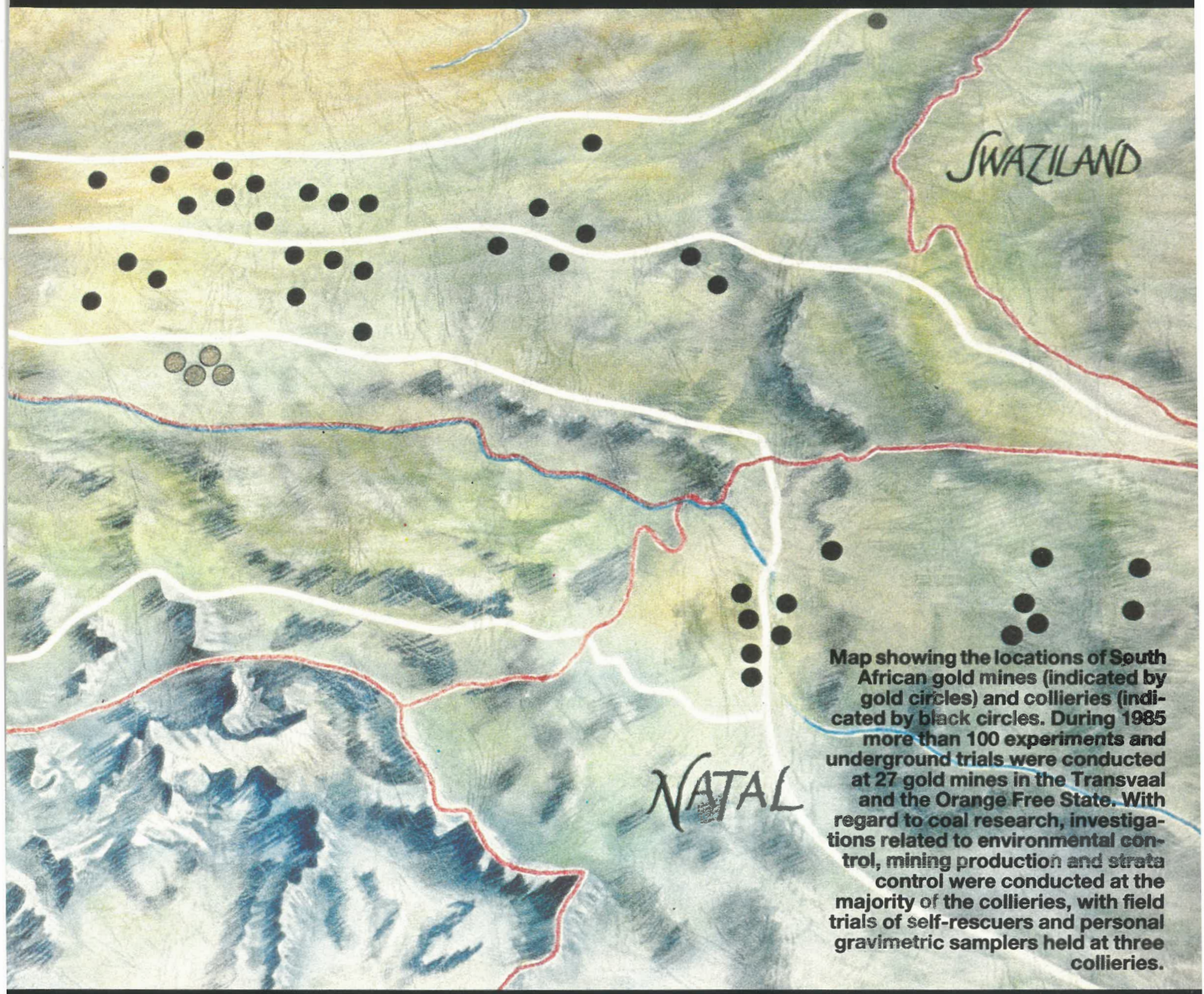
The cover shows ice emerging underground from a plastic pipeline. Tests have shown that ice can be conveyed underground successfully in a continuous plastic pipeline confirming the feasibility of ice as a primary mine coolant.

INTRODUCTION

The Research Organization of the Chamber of Mines conducts research on behalf of the gold and coal mining industries of South Africa. Research into gold mining is focused on five problem areas which are agreed by the Industry to be the most crucial and to have the most bearing on its future. These concern stoping, rock pressure, human, underground environment, and gold distribution and exploitation.

By contrast, the coal mining research effort is smaller in scale, focusing on those problems specific to the South African mining industry. This research is conducted under three problem areas: environmental, mining, and strata control.

Research Organization Annual Report 1985



Map showing the locations of South African gold mines (indicated by gold circles) and collieries (indicated by black circles. During 1985 more than 100 experiments and underground trials were conducted at 27 gold mines in the Transvaal and the Orange Free State. With regard to coal research, investigations related to environmental control, mining production and strata control were conducted at the majority of the collieries, with field trials of self-rescuers and personal gravimetric samplers held at three collieries.

STRUCTURE

The complexity of the problems investigated by the Research Organization is such that input is required from many disciplines. Consequently, the Organization's 12 laboratories and branches work together under the guidance of the Executive Office towards the solution of the specified problem areas.

Overall guidance and formulation of the research policy and direction is provided by the Research Advisory Committee (RAC) for gold, and the Collieries Research Advisory Committee (CRAC) for coal. These committees consist of senior officials from both the Industry and the Research Organization who meet regularly to review the progress achieved and decide on further directions to be taken.

In addition, a number of RAC and CRAC sub-committees meet regularly to deal with specific problem areas. These committees, which consist of Group representatives, the research advisory team and senior managers and directors of the Research Organization, act in an advisory capacity to RAC and CRAC.

Contents

Foreword

MDG SALAMON
Research Adviser

Safety and health of workers have always been a primary consideration in drawing up the research programme. Although issues related to safety may not appear to be an obvious feature of our research, almost every project has been conceived with the improvement of safety in mind. In 1985 a number of projects were completed in which this concern for increased safety is evident.

In tackling the rock pressure problem where safety of workers is the prime consideration, much effort continued to be expended in developing both improved mine designs to minimize the occurrence of rockbursts on a regional basis, and support systems to provide localized protection. Following on from breakthroughs made over the last two decades in mine design with the development of stress analysis programs for gold mines, Phase III of MINSIM-D was completed during 1985. This program can analyse complex stoping layouts in multiple or faulted reefs by calculating elastic stresses, displacements, and energy release rates around tabular excavations. Rock mechanics engineers, with this information, can then predict the areas likely to experience poor rock conditions and hence improve on layouts.

Microclimate acclimatization (MCA) was developed to its full potential in respect of all 'hot' underground zones, cooling jacket design and work categories. The success of the introduction of MCA is borne out by the reduction of 2,1 million man-shifts which would have been spent by men in arduous acclimatization.

The development and evaluation of both a special heat tolerance test and a protective cooling jacket for rescue brigadesmen were successfully concluded during the year. The test and the jacket constitute the twofold approach which was adopted to enhance the selection and physiological protection of rescue brigadesmen, and thus the safety of rescue operations. Besides the advantages offered to individual members, this approach also boosts psychological security as all team members are aware that the likelihood of a member developing a heat-related illness during rescue operations is significantly reduced.

Refinements were made to the system of controlled recirculation of ventilation air through the development of a safety system which will automatically shut down the recirculation fans should a fire occur. Recirculation was shown in 1983 to be an effective means of distributing refrigeration and controlling temperatures in the workings, and by the end of 1985, 16 recirculation systems were either operating or in the final stages of planning.

To provide greater protection of workers in collieries, the South African mining industry is preparing itself for the mandatory wearing of self rescuers at all times. In 1985 specifications for self-contained, self rescuers to protect workers against noxious fumes resulting from an explosion or fire were formulated, and field testing of prototype models commenced.

The Research Organization has become involved in an educational programme to alert colliery personnel to the importance of maintaining dust control systems installed in continuous miner sections as experience has shown that these systems are often rendered ineffective by inadequate maintenance. A 10 minute video was produced for collieries highlighting the necessity of maintaining these systems, the common troublespots and maintenance procedures.

Apart from these safety related developments, another achievement was the confirmation that ice can be used as a primary coolant in mines. The technical uncertainties about the large scale use of ice for mine cooling were resolved by developing practical methods of conveying ice and then devising ways of melting it underground. The first large ice plant was ordered by a mine during the year.

The handheld hydraulic rockdrill is now being tested by several mines following the successful conclusion of the rockdrill production trials in 1984. The Research Organization maintained a close involvement with these varying trials, providing assistance in the introduction of the drills and in the solution of teething problems as well as monitoring the performance closely, and providing support services. This implementation phase has required massive resources and has shown that development of equipment is not complete after conclusion of the field trial.

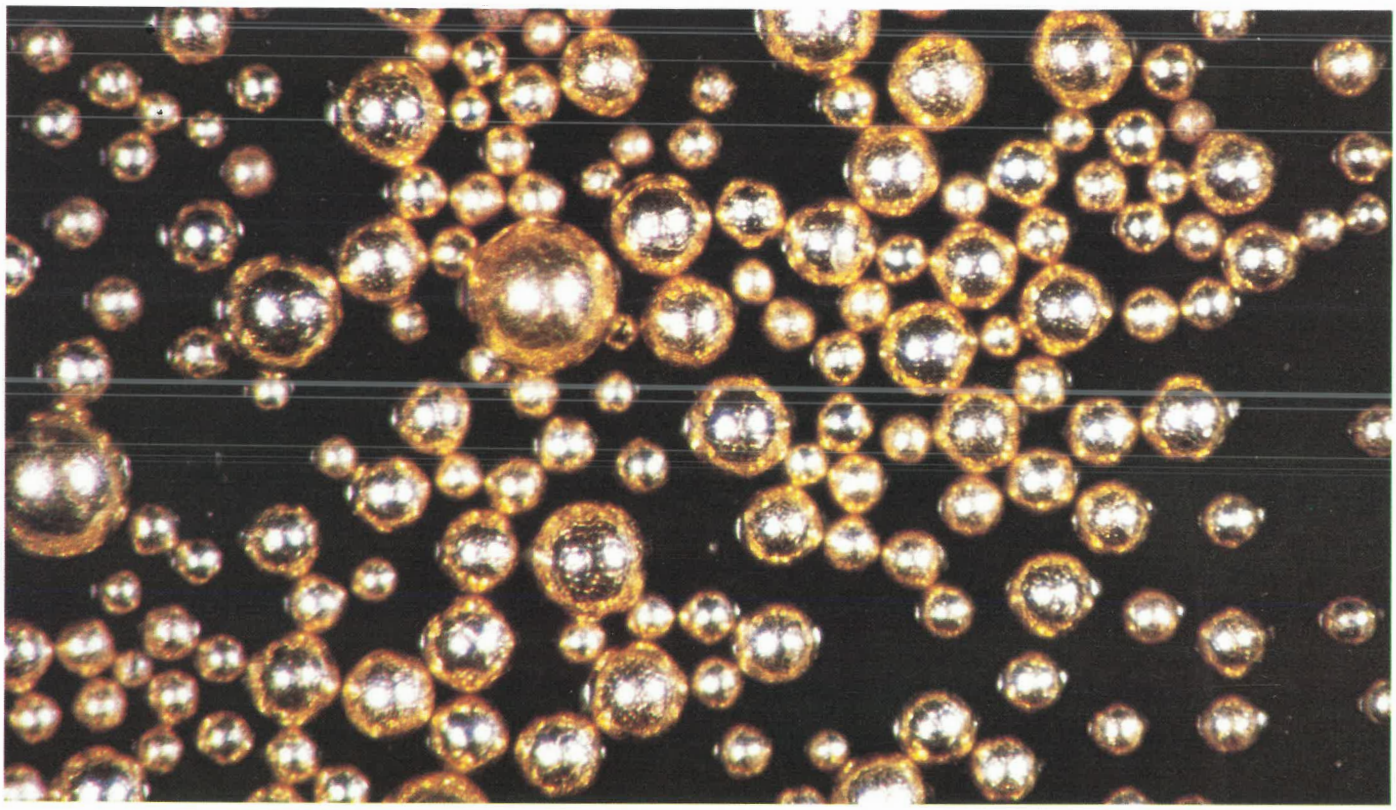
Efforts to improve existing rates of rockhandling in gullies concentrated on the continuous scraper which concluded its first underground trial in 1985. The trial results were promising with the scraper moving substantially more rock over greater distances than those achieved with conventional gully cleaning methods.

The pilot hydro-power system at Kloof gold mine continued to show promise. Water jets for stope cleaning were operated successfully and at the end of the year, the project was at the stage where other water powered equipment could be introduced into the stope.

Research into backfilling gathered momentum with the programme being broadened considerably to encompass all the backfilling methods being considered by the Industry. Although much still needs to be learnt, valuable knowledge was gained about the factors influencing the quality of the fill and progress was made in determining distribution and placement parameters needed for the different backfilling systems.

In the field of strata control for coal mining, pillars were designed according to the new squat pillar formula developed in 1984 for the design of pillars in deeper collieries. Field trials commenced in which the performance of these pillars is being monitored. In another part of the effort to optimize maximum extraction of coal reserves, further knowledge was gained about the factors which influence subsidence over total extraction. More work is however needed as this issue will have an impact on the future of coal mining in South Africa.

GOLD DISTRIBUTION AND EXPLOITATION



Gold spheres, made to model natural gold grains, for measurements in X-ray fluorescence and sedimentology

Much gold is lost or left unmined by current mining techniques. Optimal economic exploitation of the available ore reserves cannot be planned because the gold distribution within the reefs is not known with sufficient precision. In many cases considerable dilution of ore occurs and there are extensive low grade areas so techniques are needed to improve the profitability of mining in these situations. Gold extraction is further compromised by difficult mining conditions arising out of the irregular geology of the Witwatersrand Basin, and the depths at which mining takes place.

In addressing the gold distribution and exploitation problem three strategies are pursued. The first strategy, **valuation,** is aimed at developing reliable methods for predicting gold content, and its distribution in ground to be mined. The second, **upgrading ore,** is to devise techniques which will improve the profitability of mining by keeping waste rock underground. The third strategy is to develop **backfilling** as a method for improving the exploitation of available reserves under difficult mining conditions.

VALUATION

A sound understanding of the geology and mechanisms responsible for the formation of the Witwatersrand reefs is necessary for the precision and resolution of current valuation techniques to be improved. Geochemically and sedimentologically consistent regions of the reef need to be identified and models based on physical principles developed for predicting gold distribution patterns within those regions. Fundamental studies of a wide ranging nature therefore form an important part of the research programme. A complementary approach to improving the accuracy of measuring gold content involves the development of a portable gold analyser for in situ gold concentration measurements.

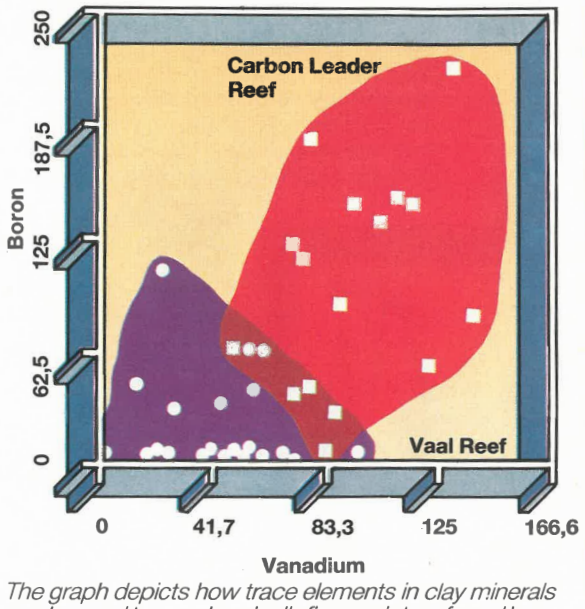
Placer Formation

Research during 1985 was aimed at gaining a clearer insight of the geology and processes responsible for the present distribution of gold within the Witwatersrand Basin. Some geological processes were active before and during sedimentation while others have subsequently affected the basin and reefs, but all can be expected to have had some effect on the gold and its distribution within the reefs. Much progress was made in evolving an age framework to provide an understanding of the duration and sequence of events which formed the gold bearing horizons. Detailed analysis of samples from Archaean granites and Witwatersrand reefs also substantiated earlier evidence that Archaean granite rocks were the source of Witwatersrand gold.

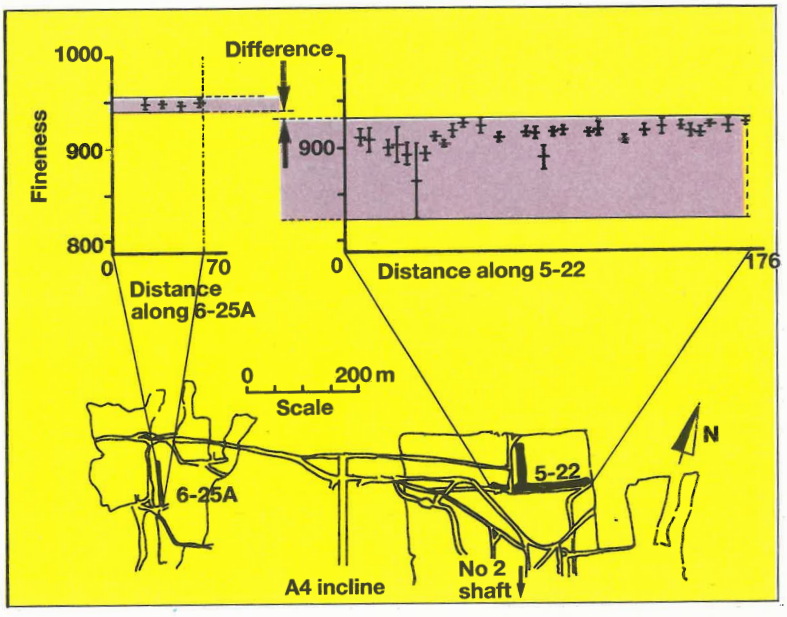
Geochemical Facies

Research in previous years has shown that within a single reef there are significant variations in the geochemistry of gold, pyrite and other heavy minerals. Systematic studies continued in 1985 to determine the effectiveness of geochemical techniques in identifying reef facies for valuation purposes. Work this year showed that not only do gold and pyrite differ within reefs, but so do clay minerals. First results from x-ray diffraction analysis conducted on various reef samples indicate that reefs or portions of reefs can be characterized by the type and relative proportion of clay minerals, as well as by the trace elements which are present.

Observed variations in gold particle fineness originally led to the hypothesis that the Witwatersrand reefs are complex formations with vertical and lateral variations due to differing near-basin sources of gold and associated elements. Systematic studies to extend existing data and to substantiate the hypothesis progressed steadily during 1985, while assistance was given to a number of mines in the use and interpretation of fineness measurements.



The graph depicts how trace elements in clay minerals can be used to geochemically fingerprint reefs and hence to indicate different depositional environments. Two of these elements, boron and vanadium, have previously been used to characterize sedimentary rocks, and as shown, when compared with samples from Vaal Reef and Carbon Leader Reef there is a significant separation of the two groups.

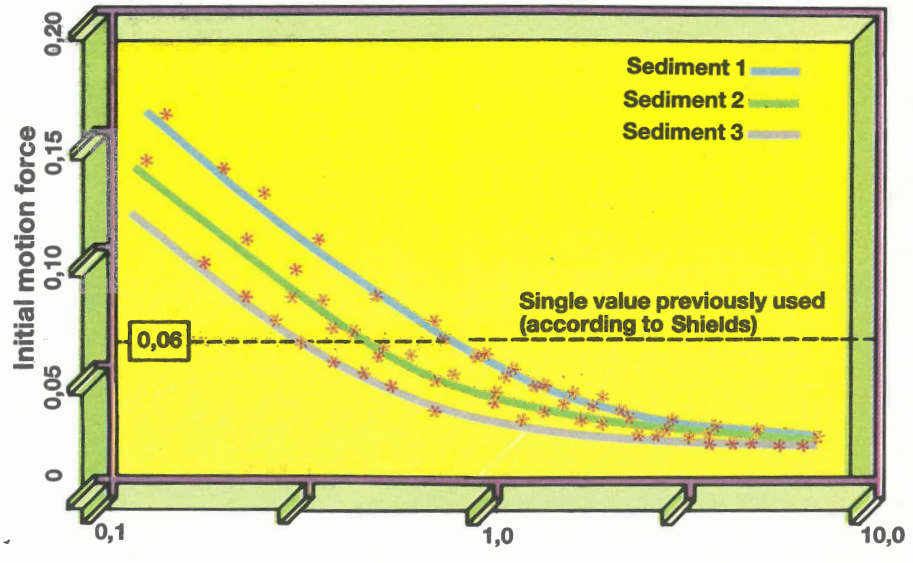


The above diagram shows a distinct difference in gold fineness between samples taken from two study sites on the Carbon Leader Reef at Blyvooruitzicht gold mine. This supports the results of previous gold particle measurements which have suggested that the reefs are made up of geochemical facies having different fineness. However, a programme of systematic studies involving more data from a number of long intersecting traverses is being conducted to enable more definitive conclusions to be drawn.

Prediction of Gold Distribution Patterns

To predict gold distribution patterns on a stope scale it is necessary to gain an understanding of the mechanisms responsible for concentrating gold. Flume and field studies continued in 1985 to both identify and quantify these mechanisms. Predictive models are the key to improving current valuation techniques, and the two models developed by the end of 1984 to simulate the hydraulic transportation and depositional processes responsible for the distribution of gold concentrations in Witwatersrand reefs were improved on. The development of a bed-load model to complement the two suspended sediment models was initiated towards the end of 1985.

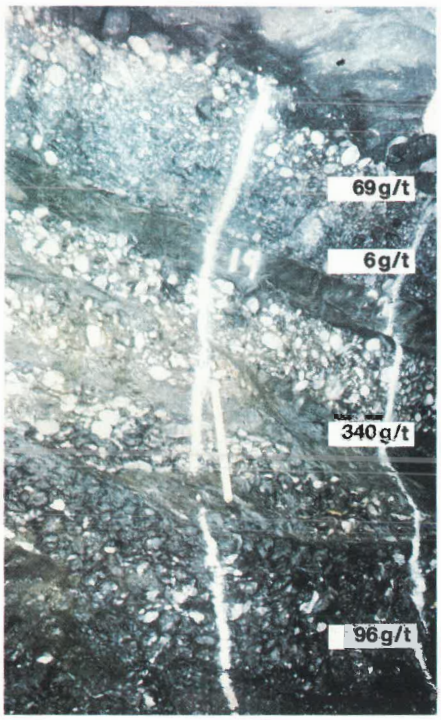
After completing modifications to the flume to allow for recirculation of water required for tests, a series of experiments was conducted to develop an important new criterion for the entrainment and transportation of particles. In addition to enhancing the accuracy of the predictive models, the criterion will yield an improved estimate of the hydraulic conditions responsible for reef formation.



This diagram clearly shows the inaccuracy resulting from the use of a single value for the initial motion parameter when calculating the onset of particle motion within a bed of particles of mixed size. The new entrainment criterion overcomes this problem; the curves indicate that the fluid force needed to move a grain in a non-uniform mixture depends on both the size of the grain and that of the particles in the surrounding mixture.

Observed Gold Distribution Patterns

Detailed mapping and sampling underground was carried out on two different types of reef during 1985. In a study of a carbon seam type reef it was found that the gold and uranium concentration patterns were controlled mainly by the channel distribution and by the presence of carbonaceous matter. This study revealed that without exception the major site of gold concentration was on the channel margin. This finding is consistent with the data from predictive models which also identify the channel margins and overbank sections to be the prime sites for gold concentrations. In a study of a banket type reef it was found however that deposition involved a number of sedimentation cycles, each having a marked variation in grade. The study revealed the difficulty of simulating the hydraulics responsible for forming such reefs, the practical problems of taking these variations into account when valuing the reef, and that studies of this nature are important in identifying aspects of the predictive models which require further development.

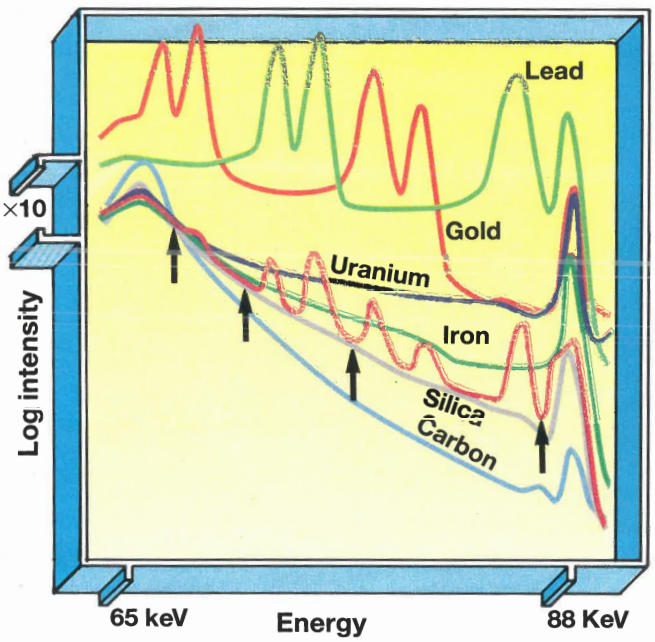


The variation of gold concentration within individual bands is shown in this section of a multiple pebble band placer from Kloof gold mine. The placer formed as a result of several phases of fluvial activity, the sorting processes during each of these activities being responsible for the variable concentration of gold. Detailed sample analyses and mapping has indicated also that in some situations a significant proportion of the gold was transported into the reefs within pyrite particles moving as a bed-load. This illustrates the importance of developing a mathematical model for bed-load particle transportation.

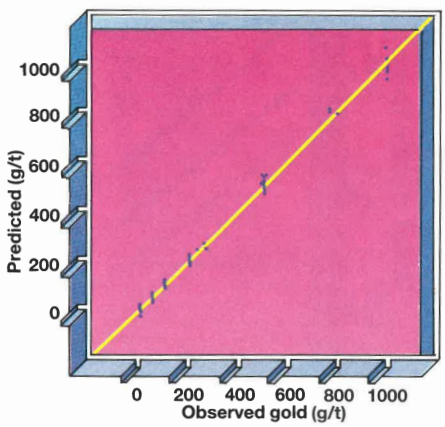
The Gold Analyser

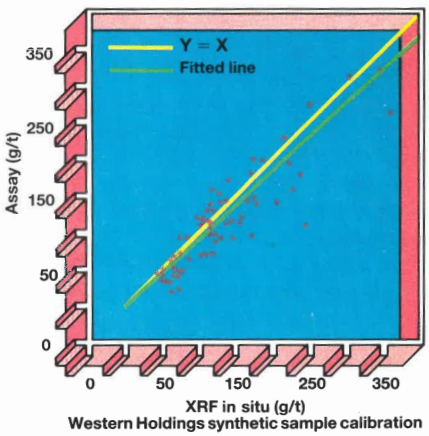
The development of the portable gold analyser is important for a number of reasons. The instrument has the potential to reduce labour requirements and speed-up the production of assay data required for decision making. More importantly the instrument should enable gold distribution patterns to be determined on a smaller scale, and with more precision because of the more extensive sampling which becomes practically possible. Work over the past two years has concentrated on identifying and quantifying the factors which need to be taken into account when using the instrument. Significant progress has been achieved in this regard.

In 1985 extensive laboratory investigations showed the way in which various elements in the reef affect the energy spectrum analysed by the instrument. Procedures were developed for analysing this spectrum to calculate the correct gold concentration and that of the other elements. Three instruments were modified and used in the field to successfully test these procedures. It was also established that the significant effect of gold particle shape and size could be overcome by field calibration of the instrument. The success achieved during 1985 with the instruments modified in-house made it possible to draw up specifications for the development of an improved production prototype model. In addition a start was made in developing optimum sampling strategies for different types of reef.



The red line in the graph indicates the energy spectrum seen by the gold analyser for a typical reef. This spectrum is a summation of the spectra of the different elements in the reef which affect the analyser (these are shown in the graph by the dotted lines). Note the very distinctly different characteristics of the various spectra. Having established the physics of how the spectra are combined, various techniques have been developed to calculate the gold concentration, as well as that of the other elements, from intensity measurements at selected energy levels in the spectrum (such as those indicated by the arrows).





The diagram at left shows the agreement achieved in the laboratory between gold analyser readings and the gold grade of synthetic samples containing a wide range of reef components. Modified analysers were successfully tested at four mines under conditions of extreme variations in mineralization to check laboratory findings. A comparison between gold analyser readings and assay values is illustrated at right. The scatter in the points is due primarily to the difference between the sample seen by the instrument in situ and that which is chipped. The scatter is much reduced if the analyser is used to measure the chipped sample.

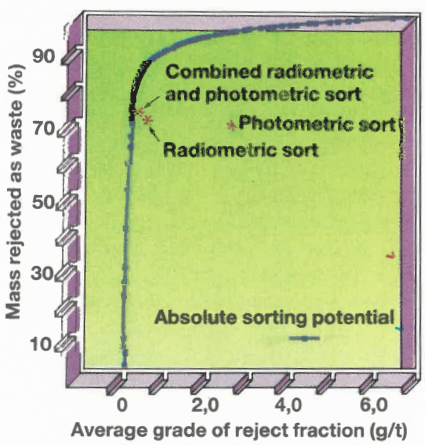
UPGRADING ORE

Achieving greater profitability by identifying and separating barren rock from gold ore close to the working face with a view to keeping the waste rock underground is the primary aim of this strategy. In previous work it was shown that upgrading ore by metallurgical means was not practical because of the fine grind that was needed to achieve acceptable levels of gold recovery. An alternative approach to the problem is that of mechanically separating the waste from the ore using sorting techniques. Test work has shown many Witwatersrand ores to have very good sorting potential, and, in principle, that the sorting could be done using automatic sorting machines. A preliminary economic analysis has shown this concept to be worth investigating and a systematic study of sorters and sorting technology, to determine their suitability for underground use, was initiated during the second half of 1985.

Sorting Techniques

Before the benefits to be gained from underground sorting can ultimately be assessed, the potential for sorting stoped ore on

different reef horizons must be established in conjunction with the effectiveness of various sorting techniques. Consequently, a wide variety of reefs and sorting techniques are being investigated, and results to date show that for some reefs a combination of the photometric and radiometric techniques should be efficient when ore is sorted away from the stopes. While in-stope sorting using specially designed mining methods may be attractive in some situations, attention in this strategy has been concentrated on evaluating automatic sorters located outside the stope. In-stope sorting of mechanically broken rock is receiving attention under the Stoping Problem. During 1985 the sorting efficiency of various automatic sorters available commercially was evaluated relative to optimum performance parameters established by assaying individual rocks. It was established that the efficiency of the sorters is significantly affected by relatively small ejector inefficiencies and that feed presentation to the sorter and ejector cycle times were, in this regard, the key factors.



The curve depicted in the graph establishes the lowest grade values which are theoretically possible for various fractions sorted as waste. It can be seen that a sorter combining radiometric and photometric methods of sorting leads to more than 70 per cent of the ore being rejected at a grade of 0,2 g/t. The high consequence of error occurring during the separation of ore by mechanical sorters is also depicted. If just five per cent of the mechanical separations are in error the reject grade would more than double to about 0,5 g/t. This grade increases nearly sevenfold, to 1,3 g/t, if the error rises to 10 per cent.

Economic Studies

Underground sorting affects the economics of mining in many significant ways. During 1985 a relatively simple cash flow analysis was done, in which most of these effects were taken into account, and the potential economic benefits of sorting and backfilling which emerged were sufficient to justify continuing with a systematic investigation of the concept.

Underground Sorting Plants

The location and size of sorting plants is being given systematic consideration. Preliminary design exercises were undertaken in 1985 to identify the range of practically possible plant locations and sizes. It was established that the cost of small plants located close to the stopes could be double that of a centralized plant located close to the shaft. The relative economics and engineering aspects of these possibilities continued to be investigated in order to assess their feasibility.

BACKFILL

The use of backfill has the potential to contribute directly or indirectly towards more extensive and efficient exploitation of available ore reserves. Benefits in this respect include an increased extraction due to a reduction in pillar requirements, increased reef hoisting capacity made possible by backfilling waste and hoisting reef in its place, improved strata control, support of middlings in multi-reef mining situations, and better face and hangingwall conditions thereby reducing the likelihood of falls of ground, particularly in the event of seismic disturbances. Other reasons for backfilling include the reduction of heat flow into stopes, better control of ventilation and a reduced fire hazard.

Because of these varied benefits, backfilling is being considered or used by mines for widely different reasons. One consequence of this is that a number of different backfilling systems have been or are being evaluated. The research programme is comprehensive and seeks to give fundamental consideration to the full range of possible methods.

The emphasis of the 1985 backfill research programme has been to achieve a quantified understanding of the factors which significantly affect fill performance. Laboratory and field measurements of backfill properties and fill behaviour under load have provided guidelines for the improvement of fills and fill placement methods; new data on the flow of fills was also obtained and a new crushed waste backfilling system was commissioned.

Evaluation of the benefits accruing to environmental control by the use of backfill is covered under the Underground Environment Problem, and work on quantifying the in situ performance of backfill is described under the Rock Pressure Problem.

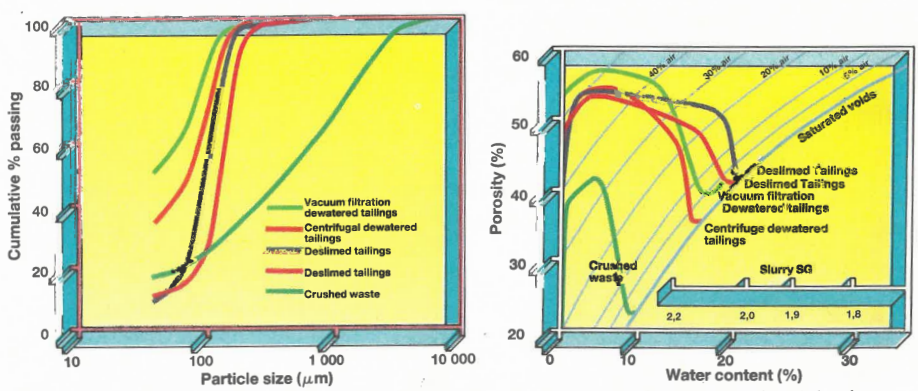
Placement Properties

The important difference between the various types of fill is the size, size range and shape of the constituent particles. These factors determine the potential maximum packing density, or minimum porosity of a fill material when it is hydraulically placed. The porosity of a material is the key parameter in regard to the load-bearing properties of that material, and a simple test was developed in 1985 to determine the minimum porosity possible with a given particle size distribution. Associated with this minimum porosity is an optimum water content for placement of the fill. This water content is well below that at which fills are currently being pumped and placed.

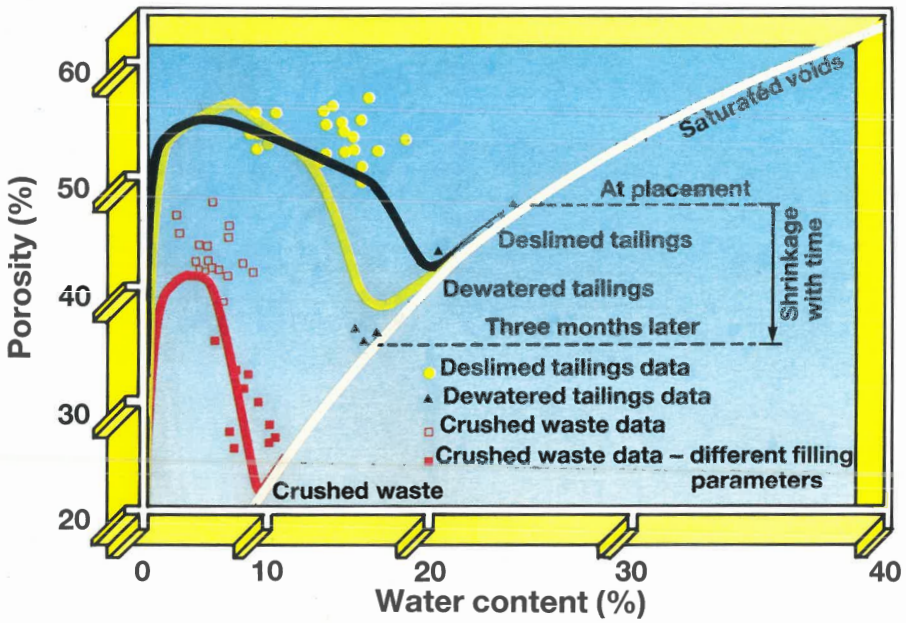
Placement procedures can substantially affect the quality of the backfill achieved in practice. Field measurements during the year showed that the in situ porosities of some materials were considerably above the potential minima and that, specifically, crushed waste and deslimed tailings were more porous than expected. Investigations also led to the important conclusion that fill should be placed as close to the optimum water content as possible.

Load - Bearing Properties

During the year the load-bearing properties of uncemented backfills were determined through the use of the new 25 MN compression-testing machine. An important result of the extensive testing carried out was the



The graph on the left shows the particle size distribution and the graph on the right the placement properties of various types of backfill: vacuum filtration dewatered tailings, centrifuge dewatered tailings, deslimed tailings and crushed waste. The graph on the right indicates the variation of porosity with water content of these materials under standard laboratory conditions. The curves show that each type of material has a clearly defined potential minimum porosity.



In the graph, curves representing the placement properties for three types of fill, as determined in the laboratory, are compared to the porosity and water content measured after placement underground. It can be seen from the data depicting crushed waste that changes in the filling parameters (rate of filling, moisture content of the placed slurry, paddock filter membrane) all significantly affect the porosity of the placed product. The data for deslimed tailings collected at the edges of the fill show that there is little consolidation or drainage at the edge of the fill after placement, thus indicating that an open structure is set up which prevents optimal settling. Samples taken from the edge of dewatered tailings indicate that consolidation and dewatering occur simultaneously. The decrease in porosity for this fill indicates the shrinkage that occurs.

formulation of a standard procedure for testing uncemented backfills. Tests confirmed and quantified the extent that porosity at placement affects the amount of strain an uncemented fill will experience before it starts to provide effective support. Furthermore, it was established in the laboratory that fills having a very high content of -38 μm particles (such as some dewatered tailings) spread laterally and provide almost no support if they are loaded rapidly. Investigations to ensure that fill will not behave in this way underground are being carried out with the aim of establishing specifications.

Distribution Systems

The design of a system for the minewide distribution of deslimed tailings commenced in collaboration with an engineering design company. Specific attention was given to deslimed tailings as a number of mines are planning to extend or install this type of fill system. One mine was selected as a study site but the results of the study are expected to be applicable to other mines. The pressure drop data for pipe system designs, urgently required for this study as well as by some mines, was obtained for deslimed tailings. Similar data is also being gathered for other slurries. Effective agitation systems were, in addition, developed during the year for storing and then re-adapting coarse slurries immediately prior to pumping.

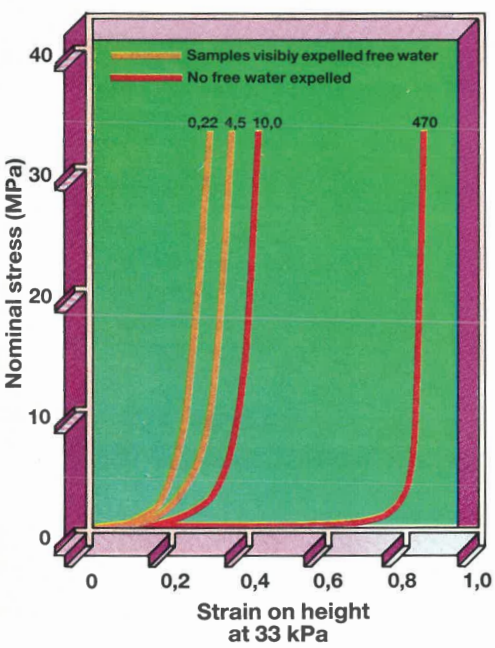
High valve wear rates in high pressure pumps were identified as a major problem when pumping quartzite slurries. A programme for the testing of valves and pumps in the Research Organization's surface test facility is underway.

Underground Systems

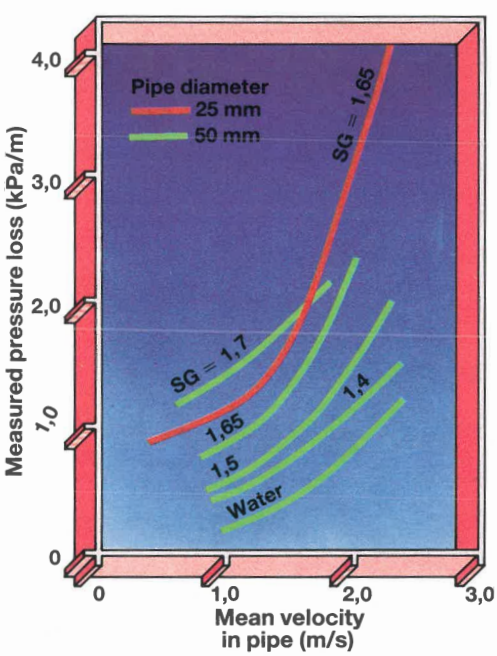
Different circumstances justify the use of different backfilling systems, and arrangements have been made to work with a number of mines on the identification and solution of system and equipment problems.

Assistance was provided to Western Deep Levels gold mine in the design, installation underground and commissioning of a new crushed waste backfilling plant capable of producing 30 tons of backfill per hour. It is a developed version of the plant tested on surface and is based on the use of conventional equipment, including a jaw crusher, cone crusher and rod mill.

The development of simpler and better backfill systems commenced during the year. Evaluation of alternative crushing equipment was initiated, and laboratory testing has revealed that scope exists for combining coarse crushed waste and tailings to obtain a low porosity fill which is easily pumped. Laboratory testing to identify optimum blends of these materials was also initiated.

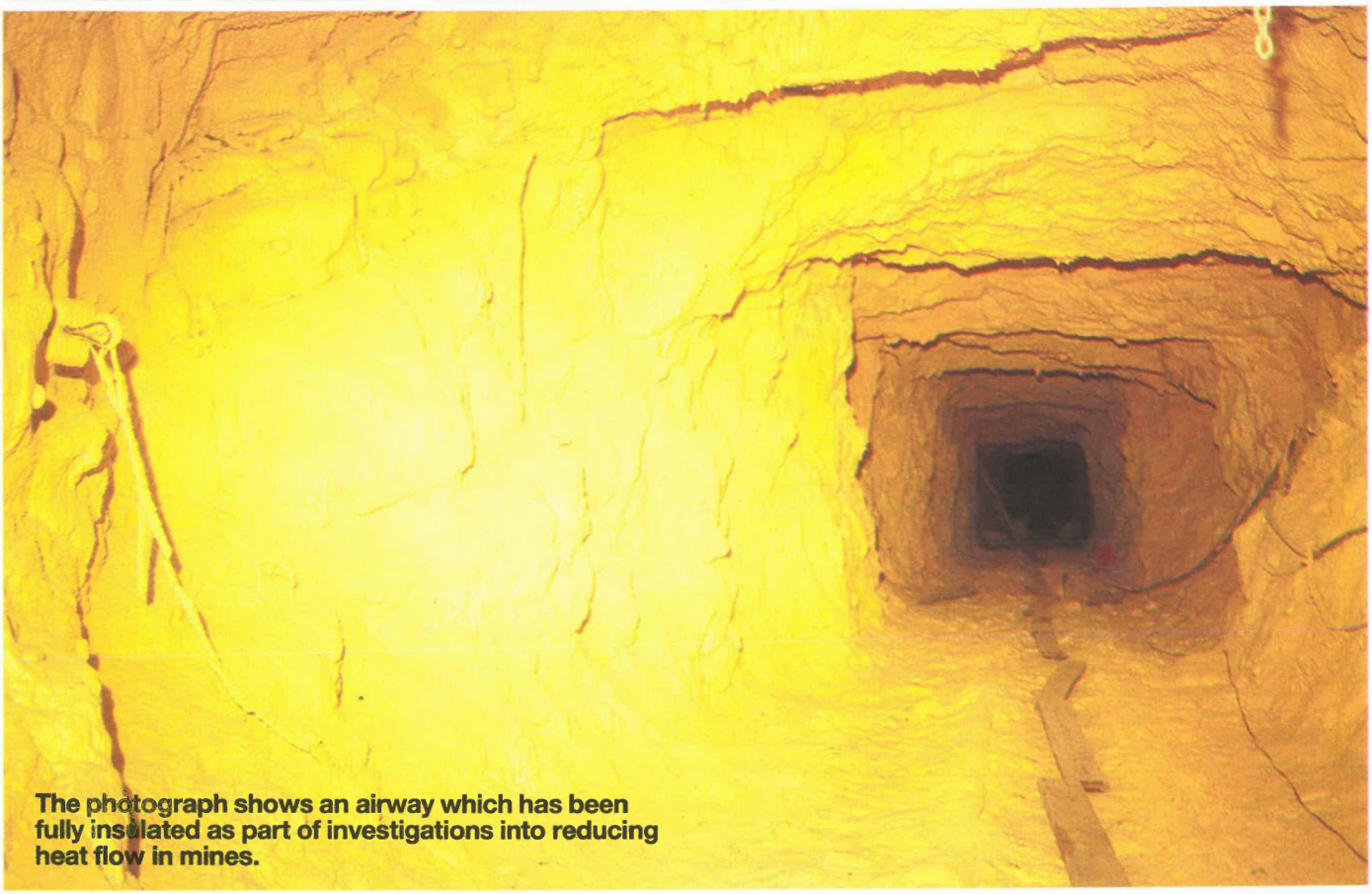


These load deformation curves obtained from dewatered tailings (vacuum filtered) at different rates of closure show that even at only a moderately fast rate of closure (470 mm/h) the fill provides almost no resistance to deformation until as much as 80 per cent closure has occurred. At closure rates above 100 mm/h the water remained trapped within the fill which spread laterally. The results indicated some factors to be considered in selecting fill material.



Pipe friction data for deslimed tailings was measured for a range of flow rates, concentrations and pipe sizes in the test loop at the Research Organization's backfill test facility located at Western Deep Levels. The graph provides information on deslimed tailings flowing in two pipe sizes at various slurry densities. Underground measurements indicated that a high pressure loss of 6 kPa/m of pipe results in -3 mm slurries in a 50 mm diameter pipeline at a mean velocity of 2 m/s and SG of 1,65.

UNDERGROUND ENVIRONMENT



The photograph shows an airway which has been fully insulated as part of investigations into reducing heat flow in mines.

Efficient mining operations are inhibited by the underground environment which is frequently hot and humid and may be polluted. Mining depths are continually increasing and the task of providing satisfactory environmental conditions underground becomes progressively more difficult and expensive. With planning already in progress for mining depths of 4 000 m below surface and corresponding virgin rock temperatures of more than 60 °C, the removal of heat from the workings constitutes a particularly critical consideration for the future.

Two strategies have been adopted to overcome the environmental problem. The first is to devise methods for **reduction,** at the source, of the heat and pollutant loads on the underground environment, and the second is to devise improved methods for **conditioning** the underground environment.

REDUCTION

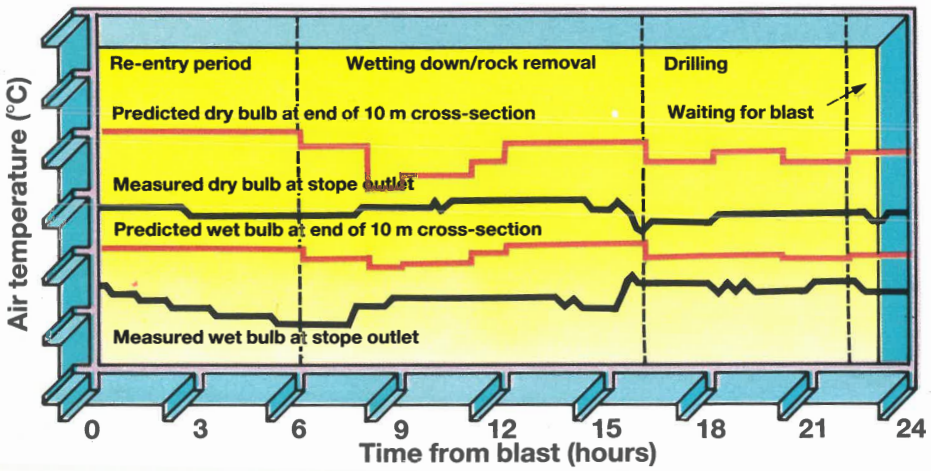
During 1985 work was directed at an overall strategy of the reduction of heat flow from the rock into mine workings. Potentially the most significant reductions in heat flow lie in alternative approaches to the design of mining layouts as well as the mining method, and the choice of cooling strategy. High priority is being assigned to both measuring and predicting theoretically the various components of mine heat loads to develop computer programs which can be used by the industry for the planning and design of mine layouts and ventilation and refrigeration systems. In addition, two direct methods of reducing the heat flow, namely, the use of insulation to coat exposed rock surfaces, and the use of backfill in stopes, were investigated. Included in the on-going research into reducing rock heat flow is a compilation of all available geothermal data from the Witwatersrand Basin. This was completed in 1985 and is considered to be the most comprehensive data bank of its type in the world. The results enhance understanding of regional virgin rock temperatures and crustal heat flow patterns.

Mine Heat Loads

The development of a flexible interactive program for use on a micro-computer is underway and will enable a mine to be simulated in terms of heat flow components. It will be possible to calculate minewide heat loads for different mine layouts, and monitor the effects of the cooling strategy employed. In developing the interactive program the various components of heat flow are being re-examined in detail. Emphasis during 1985 concentrated on generating quantities of sound empirical data which will be used to correct the theoretical models which form the basis of subroutines within the interactive program. The first edition of the flexible program has been developed.

Heat Flow into Stopes

Stope heat flow is usually the most important mine heat load component and it is also the most difficult to predict. Accurate prediction of the stope heat load is essential for economic planning of the ventilation and refrigeration systems. Field measurements were successfully taken in 1985 and theoretical modelling continued. A field measurement exercise was completed in a working stope which had one intake and one return airway, and was located in a scattered mining area. Eleven flow and temperature parameters together with the power from seven selected winches and the main power, were monitored and logged on a micro-computer at 15-minute intervals over two months. An energy balance was then performed to assess the amount of heat flowing from the rock.

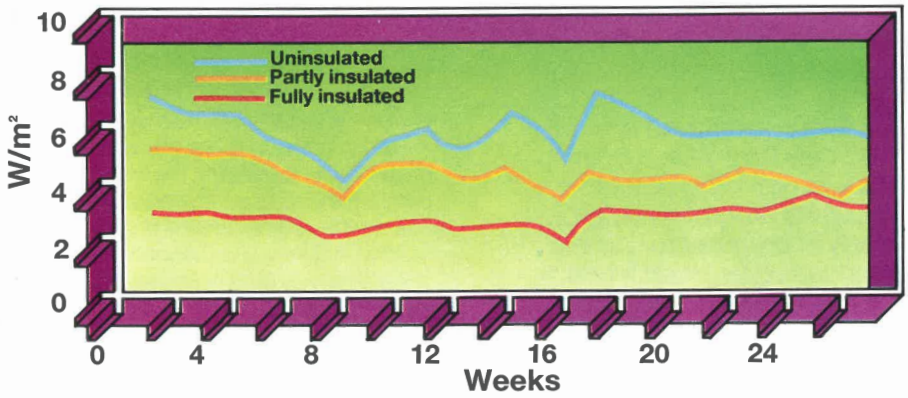


A theoretical two-dimensional finite element heat flow model for an advancing stope face is being used to generate a large data base of heat and moisture transfer information for different activities of the stoping cycle. An initial set of data for a 24-hour mining cycle has been generated and further calculations are continuing. The diagram shows a comparison between the temperatures predicted at the end of a 10 m cross section through finite element analysis and those actually measured at the stope outlet. For clarity, the measured and predicted temperatures have been moved from their actual positions relative to each other.

Insulation of Airways

A field trial was completed in 1985 which confirmed theoretical predictions of the heat flow reduction that can be achieved by coating airway surfaces with thermal insulation material.

The thermal properties of various backfills are being tested and conductivity tests were completed in 1985 on dry backfill materials of the types encountered in the Industry. A case study based on an existing mine has also commenced and attempts will be made to quantify the benefits of backfill on a



Experimental results showing differences in measured heat flux for uninsulated, partly insulated and fully insulated sections of an airway. Temperature measurements were obtained from 144 thermometer probes installed in the rock. Results showed a reduction in heat flow of 50 per cent for a fully insulated airway and 25 per cent if the footwall is not insulated. Detailed theoretical studies evaluating the effects of airway length, conductivity, insulation thickness, and dampness have been completed for both the fully and partially insulated sections. Various types of insulation materials are being evaluated in terms of structural strength and durability, thermal conductivity, fire resistance, ease of application, and price. The measured data obtained, in conjunction with the theoretical analysis and the results of the material assessment, are being used to evaluate the feasibility and economic viability of large-scale insulation.

Heat Flow Reduction by Backfilling

The environmental effects of backfilling are being examined closely, and significant reductions in heat flow may be expected as well as better ventilation control. Predictions have indicated that by backfilling, the rock heat flow in a typical stoping zone can be reduced by 25 per cent to 50 per cent. The extent of the reduction depends primarily on the distance of the fill from the face and the rate of face advance.

minewide basis by examining complete environmental control system designs with and without backfill. In addition, a field measurement exercise has begun which will monitor the heat flowing into a backfilled stope.

Research conducted in 1985 on backfill preparation and placement is considered in detail under the Gold Distribution and Exploitation Problem and research investigating the effectiveness of backfill as a regional and local support is considered under the Rock Pressure Problem.

CONDITIONING

In view of the continually increasing depths of mining, the development of more cost-effective systems and equipment for cooling the underground workings to acceptable ambient temperatures has been directed towards rationalizing the designs of air and water systems to optimize air and water usage. Concurrent with this approach is the need to integrate new developments in environmental control with technological developments in other areas, such as backfilling, hydro-power and water treatment.

Refrigeration in Mines

Greater mining depths and rising working standards have necessitated significant increases in refrigeration requirements. The cost of providing an acceptable working environment is estimated at typically 15 per cent of the total operating costs of a gold mine, rising to perhaps 25 per cent in future deep mines. Efforts continued throughout 1985 to advance the technology of cooling deep mines through the development of a new generation of more efficient refrigeration systems.

To assist in evaluating overall system performance, a computer program is being finalized that will predict the performance of water chilling installations operating under varying conditions. As far as investigations into unconventional cooling systems are concerned feasibility studies have begun into the use of air-cycle systems and closed circuit coolant systems.

The economic benefits to be derived from combining certain processes are under investigation; studies into the expected performance of dual-purpose machines for producing ice for cooling and simultaneously desalinating the inlet mine water have begun. In addition, a study into the implications of combining hydro-power and mine cooling using a common water system was begun with a case study based on Kloof gold mine.

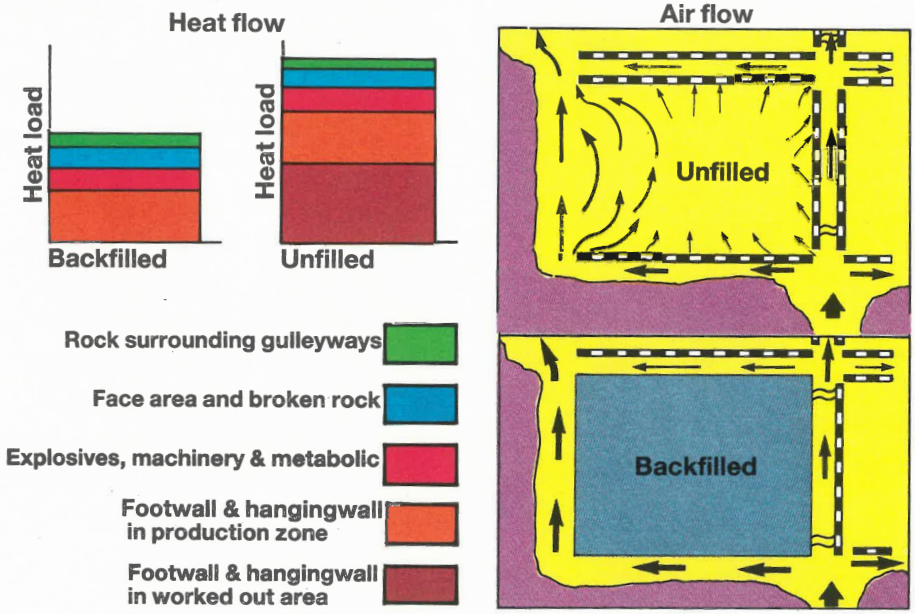
Ice for Cooling Mines

Practical methods of conveying ice pneumatically to the depths of a mine, as well as melting it underground, have been developed and successfully tested, confirming the feasibility of ice as a primary mine coolant.

Considering the high costs of manufacturing ice the possibility is being investigated of combining this process with that of the desalination of mine water.

Cooling and Hydro-power

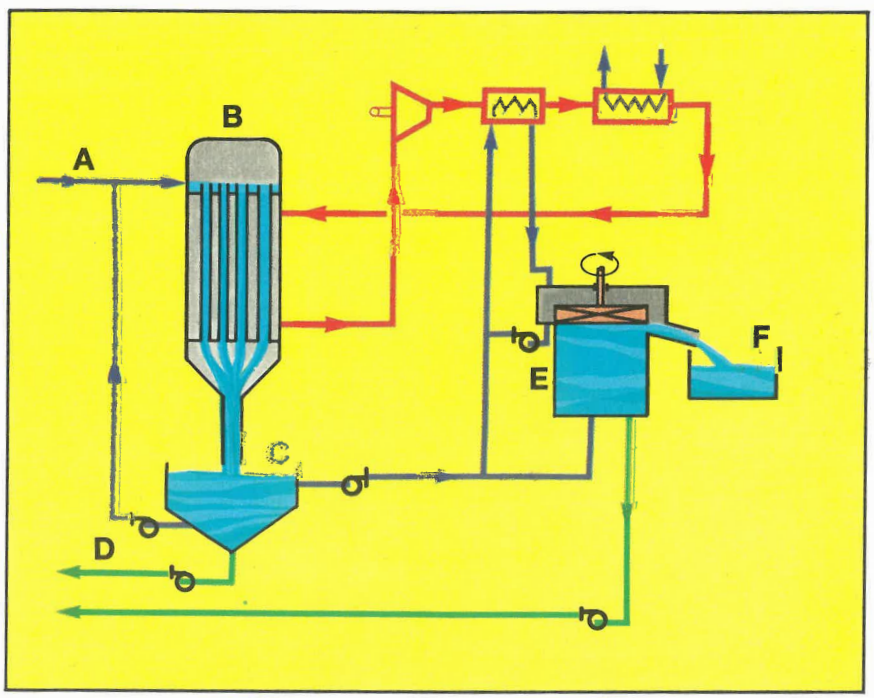
In future deep mines which make use of hydro-power water will serve two distinct purposes, namely, cooling the mine and powering stoping equipment. A study of the



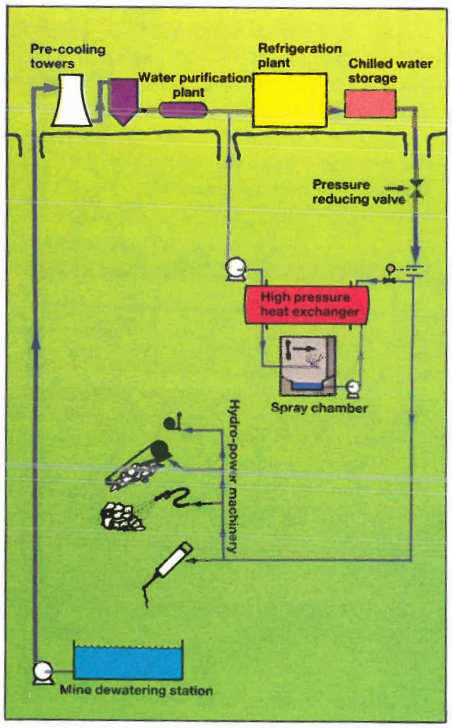
implications of hydro-power on the design of mine cooling systems commenced in 1985, and a number of system designs which are compatible with hydro-power are being evaluated. Two systems which show promise are those including either high pressure heat exchangers or energy recovery turbines to provide the cold water for the spray coolers. Additional systems, such as the hydrotransformer, are being investigated.

A comparison of heat pick-up and ventilation paths between filled and unfilled stopes. Where the worked-out area is fully backfilled this serves as an effective barrier in preventing leakage of the ventilation air through to the worked-out area, and also greatly reduces the surface area of exposed rock and hence the heat flowing from the rock. Higher face velocities can then be maintained for the same overall air flow rate.

Conveying tests have shown that ice can be transported without problem through a continuous pipeline having a vertical length in the shaft of 1 800 m and a horizontal section underground of 1 000 m. Results have indicated that the flow of both tube ice and flake ice can be sustained without blockages through a plastic (not steel) pipeline; no form of boosting is required underground, and the pressures inside the pipe remain low at all points. In addition, flow in the underground pipeline is not affected by the type of pneumatic conveying system used on surface. Two types of surface conveying systems have been tested successfully, namely, a blow-through rotary valve, and blow vessels; in both cases the ice is blown from the end of the pipe underground in a series of dense-phase spurts.



Combined ice-making and freeze desalination process. Saline mine water enters at (A) and is partially frozen in heat exchanger (B); the resultant ice slurry (C) enters a separating vessel from which a concentrated brine effluent is removed (D). Ice slurry is then pumped to washer (E), and the final product which emerges (F) is a dense, desalinated slurry. Apart from the important cooling benefit, the advantages of freeze desalination compared with other processes include insensitivity to the inlet water composition, and a very high recovery of clean water. A pilot installation of 0,1 kg/s capacity has been ordered by the Research Organization for testing at a mine.



Illustrated is a hydro-power/cooling system which makes use of high pressure water-to-water heat exchangers and bulk spray coolers. The high pressure heat exchangers allow cooling to be distributed from surface to the conventional low-pressure air coolers without reducing the static pressure of the water. Energy recovery turbines can be used in place of the high pressure heat exchanger, thus dropping the pressure and recovering the energy. In either case the electrical pumping costs are reduced.

The concept of hydro-power together with the design of the system are considered in detail under the Stoping Problem.

Air coolers

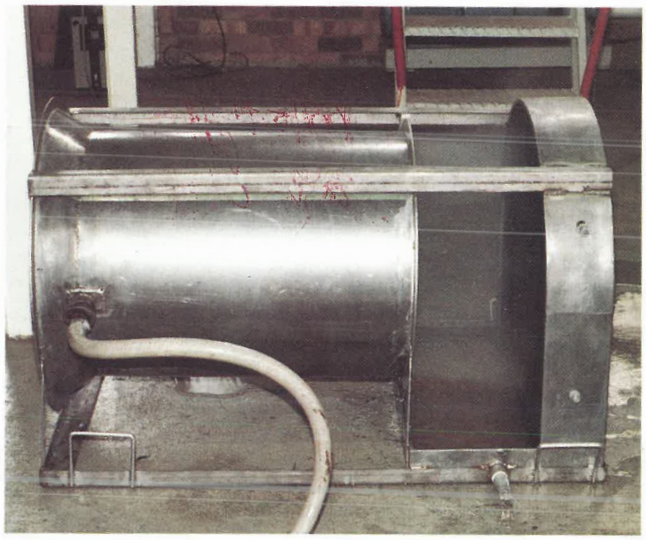
In deep mines over 25 per cent of the heat produced arises at the working face, and there is a need for stope air coolers which are not powered by electricity since the heat generated from this source would add to the heat load. Work proceeded in 1985 on developing air coolers powered by chilled water sprays.

Testing capabilities at the Heat Exchanger Test Centre were extended during 1985 to accommodate the development of larger air coolers for a variety of underground applications. The air flow was increased from 12 m^3/s to 15 m^3/s to enable higher air velocities to be achieved, and refrigeration capacity was increased from 230 kW to 300 kW.

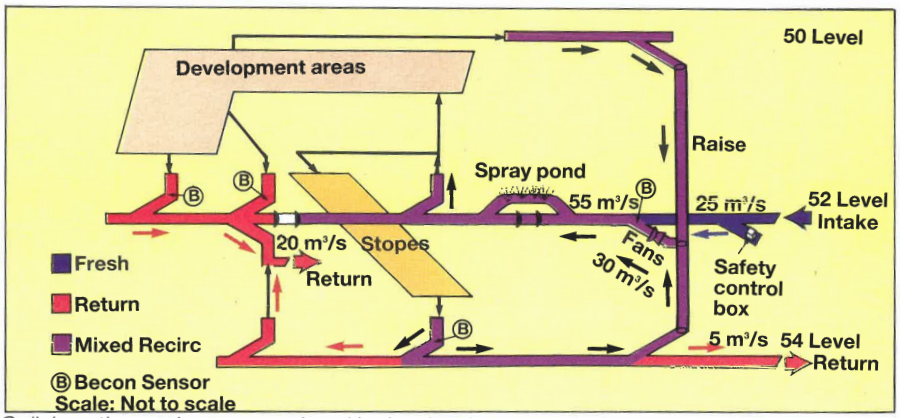
Recirculation of Ventilation Air

The controlled recirculation of ventilation air was confirmed in 1983 to be an effective means of distributing refrigeration and consequently controlling temperatures within working areas, and in certain circumstances to offer advantages over normal ventilation practices. There is a growing application of this method on South African gold mines. The total quantity of air involved in the schemes which are currently being planned or considered amounts to 12 per cent of all the ventilation air presently supplied in the gold mines. Work was completed in 1985 in developing a safety system designed to shut down recirculation fans automatically in the event of a fire.

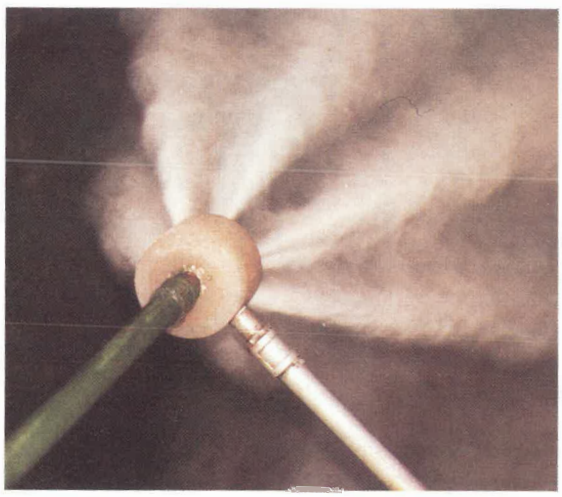
The benefits of using controlled recirculation would be further enhanced if practical means can be developed to reduce the levels of respirable dust in the recirculated air.



A prototype stope air cooler has been developed which makes use of 0,5 ℓ/s water sprays at normal stope pressures of 400 kPa to 700 kPa. The water sprays induce an air flow of between 0,5 m^3/s and 1 m^3/s. Various designs incorporating full cone or hollow cone nozzles together with various arrangements of heat transfer packing have been tested, with promising results.



Collaborative work was completed in the development of a Recirculation Safety System, and a prototype was installed underground; fire and alarm tests have begun under various operating conditions. The control unit in the system relies on signals from the mine-proven Becon fire detectors and is designed to stop recirculation as soon as possible after a fire is detected. The unit is completely self-contained and does not need to be installed in an air-conditioned room. The system shown here monitored four Becon sensors but can accept up to eight sensors by slotting in additional modules.



Research continued into suitable means of dust filtration and particularly the testing of a wet dust scrubber (shown left) for recirculation circuits. Underground gravimetric measurements and experimental work showed that normal direct-contact bulk air coolers are unsuitable for respirable dust filtration purposes. Tests have shown that special water atomizing nozzles that use compressed air to break up the water stream into small droplets are more effective. Tests began towards the end of 1985 on an experimental unit installed in a return airway and preliminary results have indicated optimum operating parameters.

HUMAN

Despite increased automation and mechanization human resources remain the most strategic and important asset in the labour intensive South African mining industry. There is a shortage of both skilled and semi-skilled manpower and scope exists for the level of human productivity to be considerably improved. The likelihood of injury and ill-health arising out of mining operations cannot be discounted nor can the possibility of sporadic unrest and disharmony on mines. Although significant progress has been made in reducing the risk of ill-health and injury, the decision makers in the Industry still need to be constantly informed about the changing needs of the workforce and the Industry's manpower requirements.

Four strategies have been adopted to address the problems in this area. The first concerns **manpower planning** for the Industry. The second deals with the **quality of life** on mines. The third strategy addresses the important area of **work performance** and the fourth concerns the **selection** and subsequent **protection** of workers on mines.

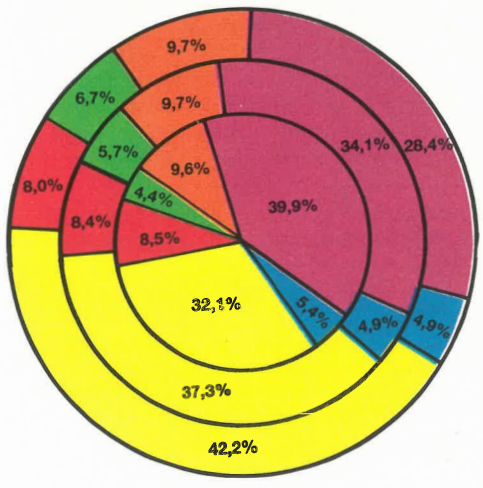
MANPOWER STUDIES

The mining sector has to compete in a national labour market where demand for skilled personnel outstrips supply. Strategies are required for ensuring the supply of qualified skilled manpower and counteracting the effects of the low rate of retention of such personnel.

Part of the research effort during 1985 was directed at examining the long-term complements in the skilled occupations in gold mining by means of occupational projections to the year 2000 – an exercise which revealed a significant trend. In addition, the problem of retaining skilled employees was addressed in studies which identified those factors leading to the high turnover of skilled personnel, together with proposals for ensuring employment stability.

Future Manpower Demands

The process of industrialization internationally has led to a gradual change in the occupational structure of the labour force with increasing employment opportunities for skilled workers and a decreasing demand for unskilled workers. This process is now becoming evident in South Africa, and to assess the implications for the gold mining industry, occupational trends within the Industry were analysed during 1985 and revealed a changing demand for skilled personnel. Implied at the same time was the training effort that would be required to meet this changing pattern.



Inner circle 1970, middle circle 1984, outer circle 2000

Past and projected distribution of employment in skilled occupations in gold mining are represented in the diagram. As a result of technological changes, there has been a structural shift within skilled occupations in terms of demand, in particular, between mining and engineering. Employment in mining occupations relative to all skilled occupations is declining, and if past trends continue is projected to decline even further by the year 2000. In contrast, the proportion employed in engineering occupations will, according to past trends, continue to rise.

Employment Stability

Since the demand for skilled staff greatly outstrips supply, it is expedient for employers to concentrate more effort on retaining the services of skilled personnel. Ideally, management requires an early indication of an employee's perceived propensity to leave service. The concept of propensity, applied initially during 1984, was developed further during 1985 studying electricians and fitters in the gold mining industry. The analysis involves a dual approach, namely, quantitative in which the formal conditions of employment offered in mining occupations are compared with those in equivalent jobs in the labour market, and qualitative where employees' perceptions of their formal and informal employment conditions are compared with those they perceive to be offered in the labour market. This approach assists in identifying factors such as low salary, or lack of promotional opportunity, which could lead to a high turnover. Understanding of these aspects would enable management to pre-empt staff loss through re-design of work situations, and/or formal conditions of service.

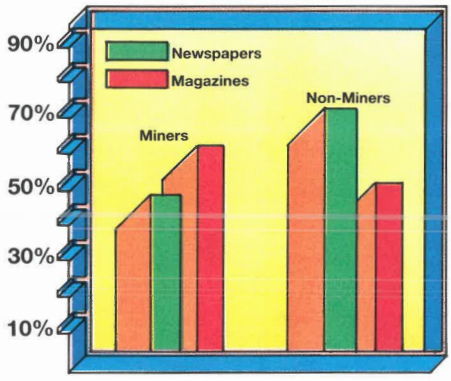
QUALITY OF LIFE

The changing socio-political climate in South Africa, and particularly the recognition and formation of trade unions, have impacted upon labour relations within the gold mining industry in terms of employee perceptions and aspirations. A variety of employment issues are being brought into formal negotiation by representatives, of employers and employees alike, adding a new dimension in communication within the Industry and highlighting the importance of a sound industrial relations system.

To assist the Industry in adequately managing and resolving conflict, contributions have been made to the development of an overall communications strategy intended to assist mine management in improving employer-employee relations. During 1985 employee preferences for printed media were investigated, and a monitoring procedure to elicit employee opinion was designed to assess the industrial relations climate on mines. Work also continued on enhancing employees' quality of life, with particular emphasis being given to improving counselling services for employees with legal and consumer-related problems, and remedying hoisting difficulties on mines.

Communications

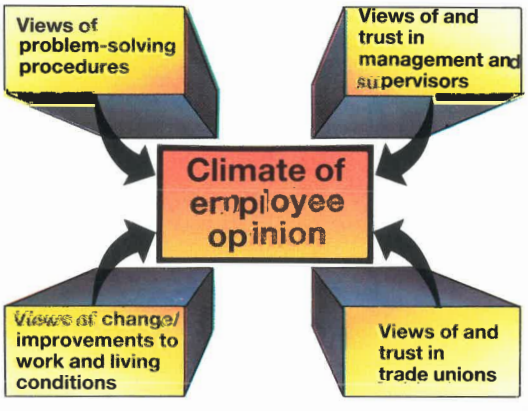
For a communications strategy to be effective it is necessary in the first instance to determine the most appropriate medium for communicating with the workforce by assessing employees' receptiveness to and preferences for the various media. Printed media offer a viable means for conveying information and during 1985 black mineworkers attendance to such media was investigated and compared with that of non-miners. Results of the media analysis indicated that black mineworkers do not differ from other black industrial workers in the extent of their reading; over one-third of mineworkers read or scanned magazines and newspapers regularly and consistently.



Compared with other industrial workers, black mineworkers displayed a relatively high preference for publications of magazine format (as opposed to newspapers), particularly magazines printed in vernacular languages and English.

Labour Relations

In the interests of preserving industrial peace, effective direct lines of communication between management and employees are being developed and maintained to assist in detecting or anticipating work-related factors which could cause dissatisfaction. The development of a procedure for indicating general trends in mine employees' perceptions of and attitudes towards management, trade unions and the process of change was finalized during 1985.



The Industrial Relations Climate Monitor incorporates four major dimensions of employee opinion (illustrated) which have been identified and for which individual interviewing modules are being developed. The main thrust of this work is to provide individual mines with a means of obtaining an objective assessment of their current labour climate to assist in formulating appropriate communication and labour relations policies. This approach was applied successfully on two gold mines during 1985; the findings were conveyed to management, and certain recommendations incorporated into strategic industrial relations policies.

Work and Social Life

Arising from legal and consumer problems encountered by mineworkers, attention was focused on improving employee counselling services on mines, specifically the problems arising from employee involvement in private contracts such as hire purchase and credit agreements which can affect morale and work attendance. Guidelines for improving employee counselling on mines were developed.

Arrangements for the lowering and hoisting of men and materials were reviewed with a view to addressing administrative delays and difficulties. Special attention was paid to the role of the onsetter, the transport of production materials, and the conveyance of men between the shaft and their living quarters. The introduction of zoning procedures to improve hoisting on one mine was also evaluated.

WORK PERFORMANCE

The shortage of skilled manpower and oversupply of unskilled workers in the mining industry is accompanied by a low level of productivity. In order to overcome the latter every effort is being made to identify people with potential for more skilled employment, to develop this potential through training, and to ensure that employees achieve their optimum levels of performance within the organization.

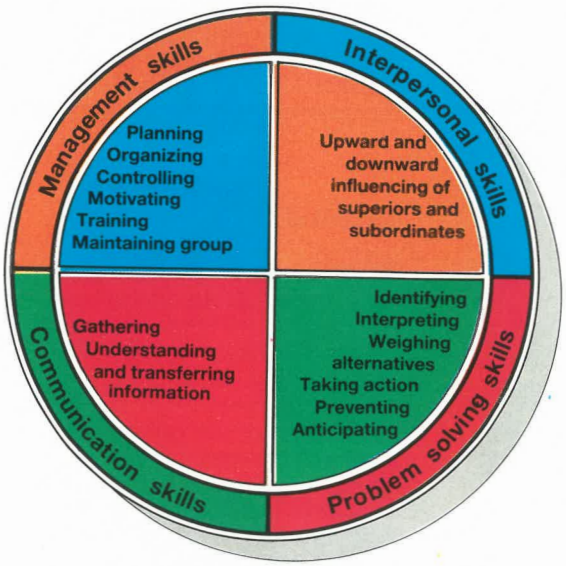
Productivity

During 1985 much effort was directed at investigating and providing means of improving human productivity in gold mine stopes. Research was conducted comparing stope productivity of the down-dip stoping method and the conventional breast stoping method on one gold mine in the Carletonville area. The experiment indicated that the down-dip stoping method resulted in the more effective utilization of labour and equipment and therefore increased labour productivity. The down-dip stoping method was perceived by the workforce to produce a safer, more attractive working environment and greater job satisfaction in terms of easier drilling and cleaning, less crowding, fewer accidents, and better bonuses.

Leadership

Effective leadership has a significantly positive influence on productivity. Past research

has indicated the importance of the Stope Production Team Leader whose leadership skills can considerably improve productivity levels of workers. For this reason guidelines for the improvement of current training practices are being formulated, and are aimed at developing the leadership skills required of the Stope Production Team Leader in performing his duties effectively. Training methods which could be used for this purpose have been identified.



A training needs analysis of leadership skills required by the Stope Production Team Leader was finalized during 1985. Areas identified as requiring training were: Management, Communication, Interpersonal and Problem Solving Skills (illustrated). The development of leadership training modules stressing appropriate 'leadership' behaviours has commenced.

Psychological Testing

An important aspect of manpower utilization in the mining industry is the use of psychological tests for the placement of mineworkers in appropriate occupations. Since the early 1970s use has been made of the Classification Test Battery (CTB) as the primary screening medium for the placement of semi-skilled black employees. In view of progressive demographic changes in urbanization and education of the workforce, as well as the effects of repeated exposure of employees to the battery, it was recognized that the CTB had become outmoded. The testing of newly constructed batteries aimed at identifying a broader range of cognitive abilities, as well as elementary literacy and numeracy levels was carried out.

A 

clock	television	wire	telephone	number

B 47+15−18=

80	34	54	58	44

A battery of new psychological tests was developed during 1985 and applied in a pilot study. Two test examples are shown which establish literacy level (A), and numeracy level (B). Both tests use a multiple choice format involving no writing skill and the testee is required to place a cross over the correct answer. The test scores assist in identifying those incumbents with potential for advancement to more skilled and supervisory levels. Further testing may be required to determine specific ability levels and possible career paths.

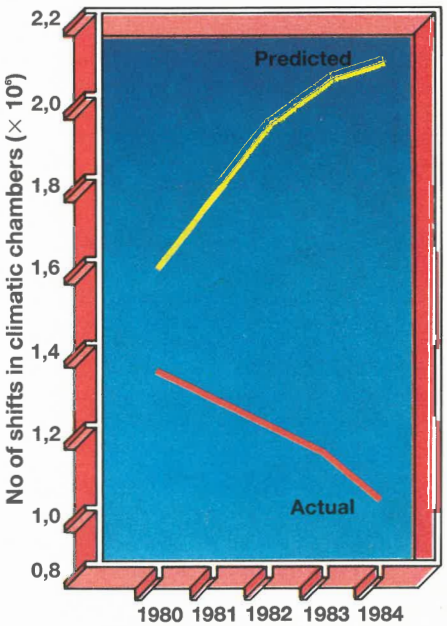
SELECTION AND PROTECTION

Research is continuously directed towards developing and improving methods of safeguarding workers against health and safety hazards which can be associated with mining, particularly those of heat and noise. Given the unusually deep levels of mining, South African experience in heat physiology and acclimatization remains unique in the world, and during 1985 emphasis was placed on further improving physiological selection procedures. Improved protection of rescue brigadesmen, and progress towards formalizing a hearing conservation programme were achieved. The effects on employees of atmospheric pressure changes, treatment of heat stroke, and improved design of the miners cap lamp were also investigated.

Heat Acclimatization

Where mine cooling strategies are directed at effecting an acceptable overall work environment, formal heat acclimatization practices and procedures are directed specifically at individual workers and contribute substantially to improved health and safety standards. The introduction of the Heat Tolerance Test (HTT) and implementation of microclimate acclimatization (MCA) have been instrumental in achieving a substantial decrease in unproductive shifts despite an increase in the number of workers entering hot areas underground.

During 1985 MCA was developed to its full potential in respect of all 'hot' underground zones, cooling jacket design and suitable work categories. It has the potential to replace conventional climatic room acclimatization (CRA) on all mines except those on which the entire underground work force is required to work in wet bulb temperatures of 27,5 °C and above. The success of MCA is illustrated by the fact that the number of unproductive man-shifts required for acclimatization purposes has decreased dramatically from 4,8 to 2,7 million over the period 1980-1984.



Analysis of MCA data during 1985 revealed a substantial reduction in the number of shifts spent in climatic chambers as a result of the implementation of HTT and MCA for the period 1980-1984 (illustrated). This is compared in the graph to the shifts predicted on the basis of the growing labour force without the implementation of the HTT and MCA.

Barometric Pressure

As mining operations are carried out at unusually deep levels in South Africa experimental work regarding the immediate effect on employees of exposure to daily oscillations in barometric pressures was completed at Western Deep Levels gold mine during 1985. During the experiment rates of change in pressure, the absolute pressure itself, and the duration of exposure were taken into consideration. Preliminary analyses of the results suggested no demonstrable detrimental physiological effect upon employees. Indeed, it was found that at high

work rates workers are less likely to become fatigued underground than on surface since the air underground is more dense which increases the availability of oxygen.

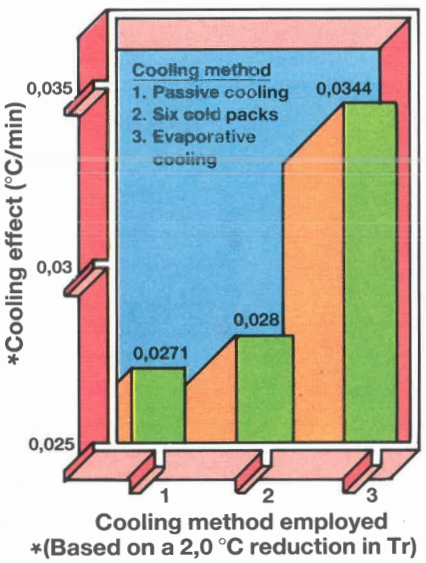
Rescue Brigadesmen

The supranormal thermal conditions under which rescue brigadesmen perform their duties have necessitated a dual approach for enhancing their selection and physiological protection. The development and evaluation of both a special heat tolerance test, and a cooling jacket were concluded during 1985; in combination they assist in minimizing the risk of heat fatigue or heat stroke during rescue operations.

The heat tolerance test is a carefully planned regimen performed under controlled conditions and is designed to identify those individuals who are at risk when working strenuously in excessive heat. The design of the body cooling jacket was modified during 1985 to increase comfort and in the acceptability trials, which were conducted underground for the first time, these protective garments successfully provided cooling during an entire rescue operation in a hot environment.

Reducing Hyperthermia

When successfully treating heat stroke the prime consideration is to rapidly reduce body temperatures to normal levels through the correct use of effective body cooling methods. A recent analysis of heat stroke statistics revealed the need for improved education and training of personnel in utilizing and effectively applying body cooling methods. During 1985, various body cooling techniques were reviewed, compared and evaluated; results confirmed that evaporative cooling as currently practiced in the South African mining industry is the best method of reducing hyperthermia, in conjunction with a special water/air nozzle which increases the rate of cooling. The latter refinement is similar to body cooling systems used in Mecca for treating heat stroke during religious pilgrimages.



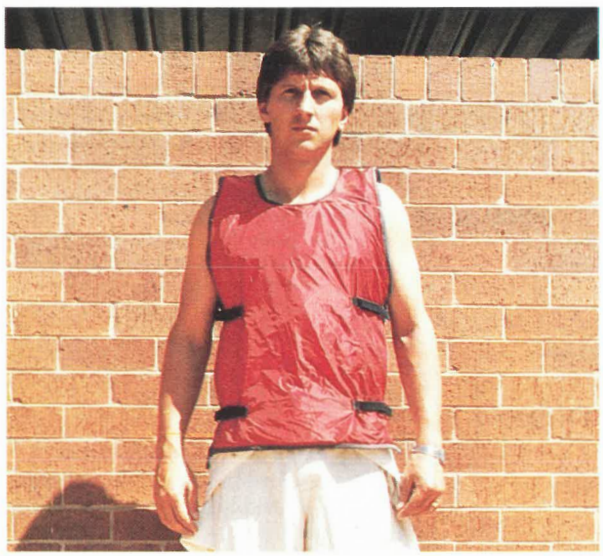
Different techniques to reduce hyperthermia were evaluated in 1985. From the results illustrated above it can be seen that the evaporative cooling technique is by far the most effective and surpasses the cold pack technique where six cold packs are placed over the large arteries of the neck, axillae and groin, as advocated in the scientific press.

Miners Cap Lamp

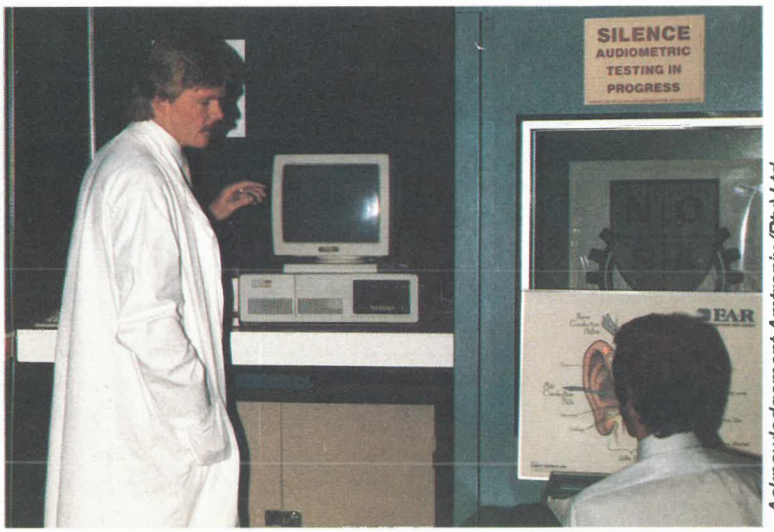
Most of the working areas in gold mine stopes do not have permanent illumination, the only light source being that produced from miners cap lamps. As these must supply sufficient illumination for workers to perform their various tasks accurately and safely, methods for resolving illumination inadequacies through improved cap lamp design have been investigated. Specifically, a pilot study was completed which investigated the visual requirements of a cap lamp in terms of the visual acuity of the worker, visual requirements of various tasks, and degree/level of illumination required of the cap lamp for both general and specialized use.

Hearing Conservation

The compilation of a guide on the implementation and control of a hearing conservation programme in the South African mining industry was finalized during 1985 and is presently under consideration. The ultimate criterion of success of such a programme is expressed in terms of hearing acuity. Industrial audiometry provides the means for measuring the programme's effectiveness, since it establishes quantitatively the hearing status of an individual and monitors hearing acuity during his period of employment so as to control the risk of occupational hearing loss. The guide further addresses the uniqueness of the South African mining industry in terms of the logistics associated with implementing an audiometric programme for a labour force approaching 500 000 workers; appropriate computerized systems have been especially developed for this purpose.



The body cooling jacket for rescue brigadesmen uses readily available solid carbon dioxide (dry ice) as a coolant; blocks of the dry ice are contained in 25 pockets on the inside of the jacket and provide cooling for at least two hours. The jacket, manufactured locally, is compact, light and of rugged construction; it is worn next to the skin under a specially designed boiler suit. The total mass of the jacket and coolant at the beginning of a two-hour rescue operation is 5,7 kg, decreasing to approximately 2 kg.



A fully computerized audiometric system has been developed in South Africa and is being applied successfully on several mines. A typical system is shown together with a printout depicting hearing levels for workers in a specified work category. An audiometric programme involves pre-employment tests followed by tests at regular intervals and/or at the end of a worker's contract thereby creating individual case histories; audiometric records are kept for the duration of the employee's period of employment and for three years thereafter. The computer program, for use on a desk top computer, is designed to record, analyse, categorise and validate each audiogram. A further facility enables comparisons with previously recorded audiograms.

Acknowledgement Amtronix (Pty) Ltd

ROCK PRESSURE

Rockbursts and rockfalls continue to be one of the main problems affecting the safety and productivity of gold mining operations. The task of alleviating the problem is intensified as mines become deeper because the rock pressure increases with depth. This high pressure around the deep excavations causes extensive and sometimes violent fracturing of the surrounding rock. While significant progress has been made in understanding the way rock fractures and deforms, and in controlling the fractured rock by the design of good mine layouts and support systems, the effects of rock pressure still require the most urgent attention.

Three strategies have been adopted for alleviating the rock pressure problem. The first concerns the design of deep underground mines so as to avoid unfavourable rock pressure conditions. The second deals with the development of support systems to minimize the effects of high rock pressure on underground excavations. The third strategy deals with the fundamental aspects of rock fracturing to acquire a better understanding of the processes which control it.

DESIGN OF MINE EXCAVATIONS

The objective of this strategy is to design mine excavations in a manner which ensures favourable rock pressure conditions so as to minimize the development of extensive rock fracturing of excavation walls, and excessive rock deformations. To achieve this objective many factors have to be considered. The shape of the excavation, its position relative to other excavations, the sequence in which it is developed and the rock formation in which it is situated are among the more important. The presence of faults, dykes and other geological discontinuities are further factors which have to be taken into account when designing mine excavations.

In order to achieve the objectives of good mine design it is necessary to develop design procedures and to establish design criteria. This, together with monitoring of the excavation's performance, forms an essential part in an integrated design approach to the rock pressure problem. Research during 1985 addressed all three aspects of mine design. In addition specific design investigations were conducted for water barrier pillars and shaft protection.

Design procedures

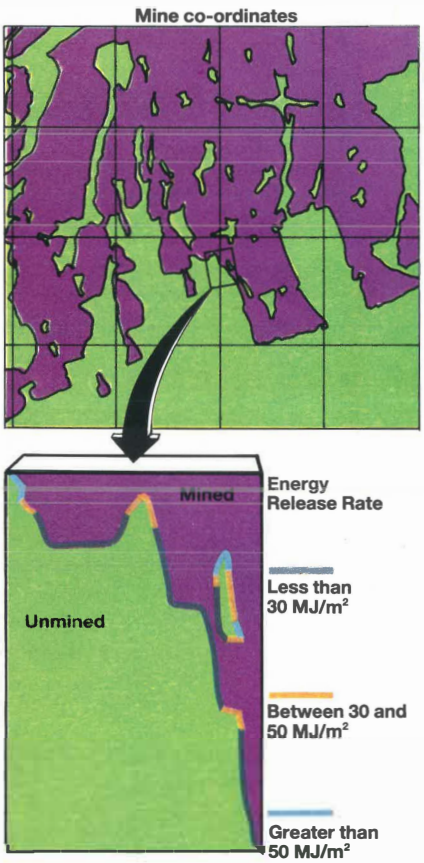
The MINSIM-D computer program, a three dimensional stress analyser for tabular ore bodies, was developed successfully and implemented. The program is capable of analysing complex stoping layouts in multiple or faulted reefs by calculating elastic stresses, displacements, and energy release rates around the tabular excavations. The program is written in FORTRAN and is transportable to mini- or mainframe computers.

Specific features of the program are improved accuracy and solution times, and user friendliness. The program has been made available to the mines, and Industry rock mechanics personnel have been trained in its use.

Development of two-dimensional, finite element, stress analysis programs to model the inelastic behaviour of rock structures was continued during 1985. The development of the GOLD-suite of finite element programs by an overseas university collaborator has reached an advanced stage. The purpose of these programs is to analyse in further detail the effect of rock fracturing and geological structures such as joint sets, faults and layered material on the distribution of stress around excavations. The programs are being used to study support requirements for stopes, highly stressed tunnels and large excavations, as well as to examine pillars, and to analyse the results of laboratory tests.

Criteria

The well known Energy Release Rate (ERR) and critical field stress concepts ($^{\sigma}$CR) have been the design criteria used by rock mechanics practitioners in the Industry for stoping and service excavations respec-



A typical example of a MINSIM application is shown (above). The complex mining layout above can be recorded quickly and easily from a mine plan by means of a digitizer. This becomes the essential input information for running the MINSIM-D program and the scaling feature enables small areas of a mine (below) to be examined in detail to determine, for example, the energy release rate (ERR).

tively. Experience gained over many years has shown that these design criteria were useful provided the reefs to be stoped were relatively free from faults and dykes, and the dimensions of service excavations were comparable to that of typical gold mine tunnels.

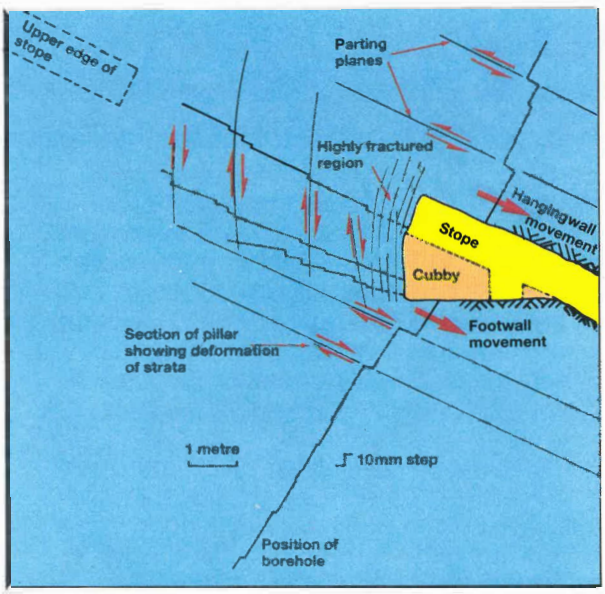
During 1985 good progress was made in developing a new design concept for stoping excavations in geologically disturbed ground. This concept is based on the observation that mining induced stress changes can result in movement occurring along geological discontinuities. The probability of such movement is closely linked to a quantity which has been termed Excess Shear Stress (ESS) and which compares the shear stresses acting in the plane of the discontinuity with the frictional resistance to movement. Following encouraging results in the application of this concept, ESS has been included as an optional feature in the MINSIM-D program.

Work on the development of a rock mass classification system to assist with the design and support of highly stressed large service excavations commenced during 1985. Initial results indicate that the presence of parting and bedding planes has a significant influence on the effective strength of excavation walls.

Performance monitoring

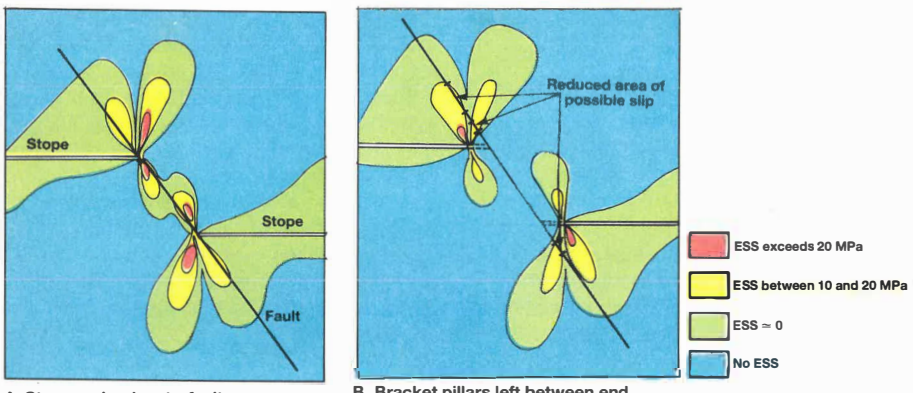
Monitoring of the performance of mining excavations and rock structures was continued during 1985. In particular, work concentrated on the performance of highly stressed pillars in mines. These are either used to protect shafts and service excavations, to support stoping excavations or to reduce energy changes resulting from extensive stoping operations.

As part of a programme to improve on the design of stabilizing pillar systems, the type and extent of deformation within and around stabilizing pillars were investigated. Results suggest that while 20 m wide stabilizing pillars (the narrowest used in the Industry) may fracture and suffer some foundation failure they can still fulfill their primary function of reducing the ERR in deep level mines. However, because of the extent of fracturing around narrow pillars local support problems are likely to be experienced. This information together with a new analytical method of estimating the magnitude and distribution of stress within and around a pillar is being used to design improved pillar layouts.



Shown are the results of a field experiment monitoring the performance of stabilizing pillars. Boreholes were drilled into the footwall and hangingwall adjacent to a 20 m wide pillar to observe, among others, movement along parting planes and bed separation. Holes were also drilled into the pillar to monitor the development of fractures in the pillar, and movement along fracture planes. As can be seen from the diagram, significant movement occurred along the parting planes several metres into the footwall and hangingwall of the stope. Fractures observed several metres into the pillar indicate a significant amount of inelastic pillar deformation.

During 1985 several field experiments were conducted to determine the nature of fracturing around tunnels. The lack of a suitable method for predicting the strength of an inhomogeneous rock mass has shown to be a major stumbling block to progress in this area. Work therefore concentrated on the development of a suitable predictive method for use in gold mine tunnels.



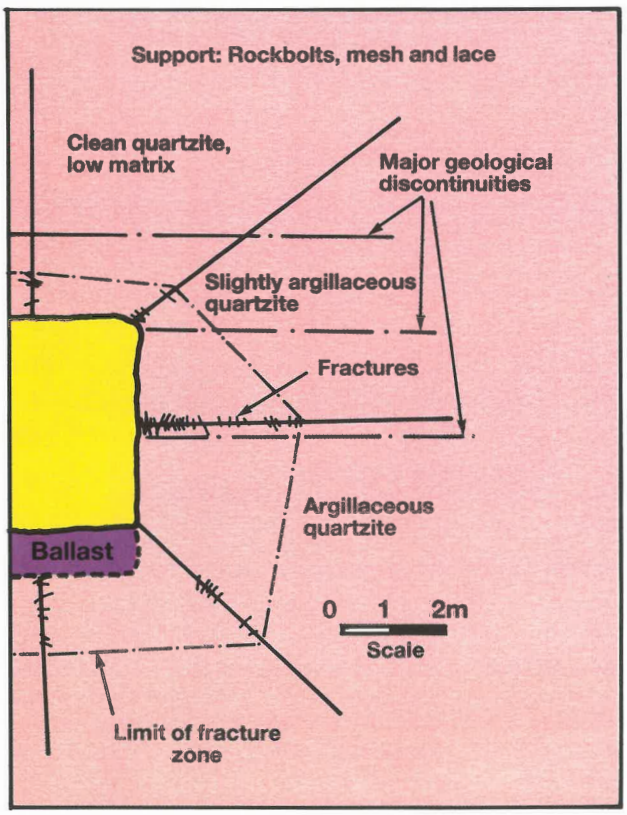
A. Stopes mined up to fault

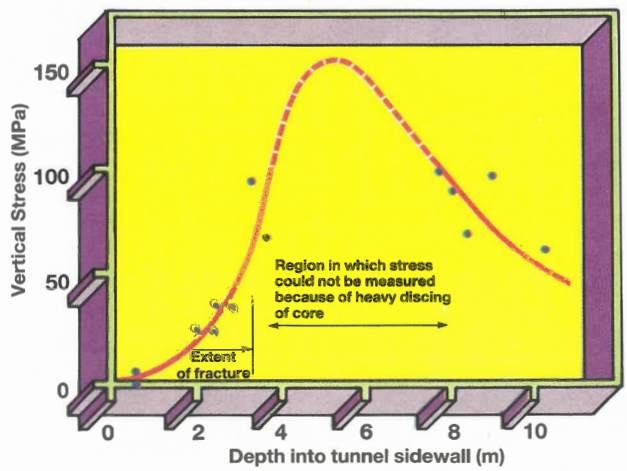
B. Bracket pillars left between end of stope and fault

Illustrated above, as a demonstration of one use of excess shear stress (ESS), are comparative plots of shear stress when mining up to a fault. The red and yellow areas are regions of ESS; where these regions intersect a fault, the shear stress could cause the fault to slip. The diagram (a) shows that if the stope were mined up to the fault the large area of ESS intersecting the fault could cause the fault to slip. However, by leaving bracket pillars between the stope and the fault, (b), only a small area of the fault would be exposed by ESS.

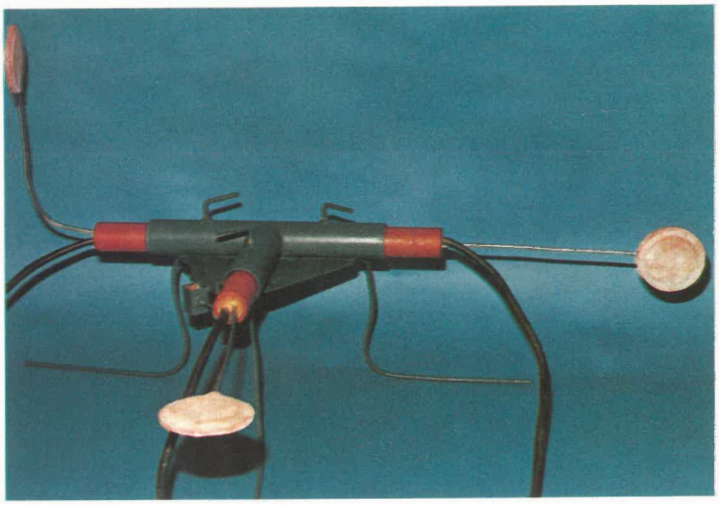
Specific design investigations

With the increasing depth of mining, the protection of shaft systems from high stresses has become an important area of research. Theoretical research conducted several years ago had highlighted the need





The top diagram, half of a tunnel monitored during the year, shows the development and extent of fracturing around the tunnel, 2 200 m below surface. It was found that the extent of the fracture zone into the sidewall was two-thirds the height of the sidewall, while that in the hangingwall was one quarter the width of the square tunnel. Stresses acting at different distances to the sidewall were also measured. Theoretical modelling of this situation using the GOLD-suite program substantiated these results (illustrated below).



Robust and corrosion resistant instrumentation was developed during the year and installed at three mine sites to monitor the performance of placed fill. The photograph is of an experimental triaxial stress meter which is designed for permanent immersion in backfill material to measure the build-up in stress as the stope advances and the fill is compressed.

to rethink the concept of protecting shafts and service excavations in their vicinity by means of traditional shaft pillars. A study of alternative methods of shaft protection has shown that the displacements and strains induced in the shaft from the early extraction of the reef around the shaft can be kept within acceptable limits by backfilling the stoped out areas with suitable fill material to reduce stope convergence.

In another study the criteria for the design of water barrier pillars between adjacent mines were re-examined. It was found that the effect of high water pressure on the flooded side of a barrier pillar can be neglected as this does not reduce the stability of the pillar. Analysis also showed that design requirements can be relaxed and consequently a revised pillar width design equation was proposed which produces an acceptable pillar size.

SUPPORT

The objective of this strategy is to devise improved and economic support systems to control the fractured rock surrounding deep excavations.

During 1985 progress was made in examining the merits of backfill as a means of regional or local support, and in identifying the load-bearing capabilities of various stope support systems. The support requirements of tunnels under rockburst conditions, and of large excavations subjected to gradual changes in stress were also assessed.

Backfill

Backfilling of the stoped out area with waste rock from underground or with processed tailings material from surface offers a number of potential benefits in deep level mining. In respect of strata control, backfilling can provide good local support to the fractured hangingwall strata and reduce the development of very high stresses in the abutments of extensively mined out areas.

The effects of backfill, as a means of local support, on rock conditions around a stope face were observed on a regular basis during the year. It was found that fill placed near the face improved the quality of the hangingwall and reduced the amount of inelastic closure. There is also some evidence that backfill can reduce the damage caused by a rockburst, particularly if the backfill is kept close to the stope face.

Theoretical studies on the effectiveness of backfill as a regional support have shown that at depths of between two and three kilometres good quality backfill ribs can provide sufficient support to enable complete extraction of the reef horizon. At greater depths backfill can supplement the regional support provided by stabilizing pillars and thus help reduce the amount of reef which must be left in the pillars.

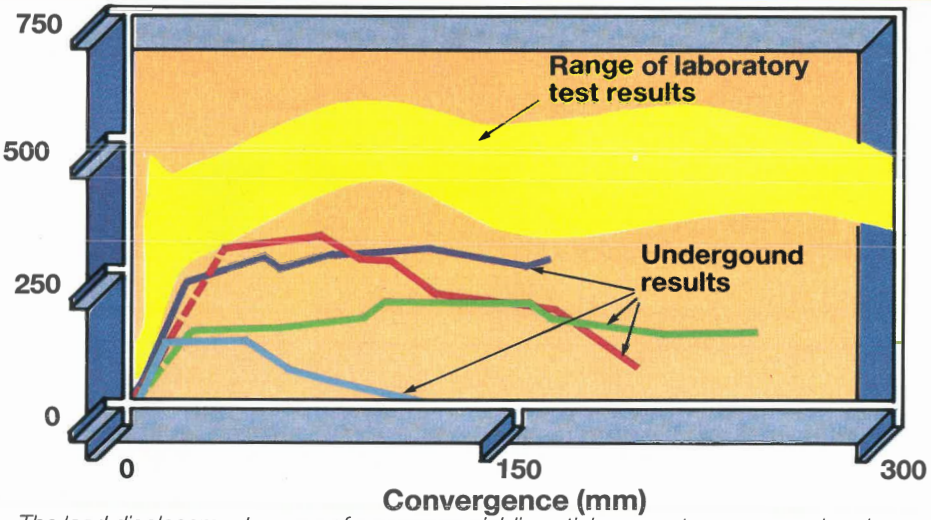
Research conducted on backfill preparation and placement is covered under the Gold Distribution and Exploitation Problem and an evaluation of the benefits accruing to environmental control by the use of backfill is given under the Underground Environmental Problem.

Stope Support

Stope support must not only support and retain the integrity of the highly fractured rock in the hangingwall, but it must also yield as the stope converges. In order to assess the load deformation characteristics of various types of stope support available commercially, in situ and laboratory investigations continued throughout the year.

Emphasis was placed on understanding the deformation characteristics of the various

types of yielding timber props. Results from extensive tests showed that depending on their construction, these supports have varying yield characteristics. However, in comparison to normal mine poles, they can support loads for longer periods while being compressed. In most instances resistance to compression reaches a maximum value soon after installation near the stope face but the load supported by the different prop designs then varies characteristically as closure occurs. An important finding of an extensive field test programme was that the load-bearing performance of timber supports underground was about half that determined by laboratory testing. The significance of this observation on the design of support systems is being investigated.



The load displacement curves of a common yielding stick support as measured underground and in the laboratory during the year are shown in the accompanying diagram. Reasons for the variations in loading characteristics include the uneven stope hangingwall, variations in the quality of the timber and its final preparation, and the quality of installation procedure.

Support of service excavations

Over the years good progress was made in the development of support methods for mine tunnels subjected to high rock stresses. However, there still exists a lack of understanding of the performance of tunnel supports under dynamic loading conditions. This is largely due to a lack of information concerning the ground motions to which tunnels are subjected by nearby seismic events. During 1985 much emphasis was placed on the development of instrumentation to obtain this information. Good progress was made and the results obtained were encouraging.

FUNDAMENTALS

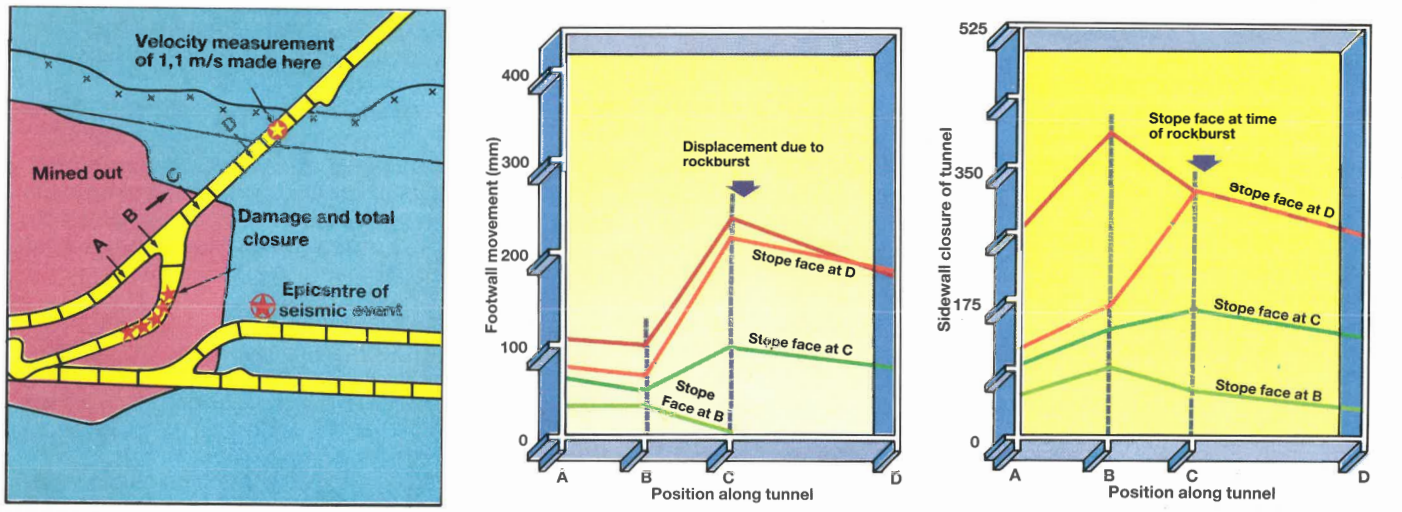
Despite the many advances which have been made in rock mechanics there is still much which is not understood about the behaviour of rock around mine excavations. Of particular importance is the way in which rock fractures and the effect that mining methods and geology have on disrupting the stable growth of fractures. A fundamental understanding of this subject is essential for the design of safer mine layouts, better supports and improved mining methods.

Laboratory studies were carried out to determine those rock properties which can influence the behaviour of the rock mass, and to examine rock movement along faults and other planes of weakness. Seismic investigations continued in an effort to clarify the interaction between mining activities, mine layouts and geological structures so as to identify the causes of seismic events and rockbursts. Knowledge of these is vital for the development of rockburst control strategies.

Behaviour of fractured hangingwall strata

Experiments were carried out in 1985 at mines to determine the amount of fractured rock which has to be supported under static and dynamic loading conditions. First results indicate that the localized geological conditions and the extent of fracturing play a vital role in this respect. To obtain detailed information about the fractured hangingwall strata, instruments were installed in the hangingwall to a height of 18 m and measurements were made to determine the height to which rock behaves inelastically. Furthermore the effects of the orientation of fractures which cause irregular shaped slabs and the importance of frictional properties between blocks of rock were analysed.

First attempts were made to analyse the behaviour of fractured hangingwall strata using a rigid block, large displacement model. The objective of this investigation was to identify the influence of bedding plane distance, spacing and orientation of fractures and distance of support from the stope face on the behaviour of fractured hangingwall beams.



Shown above is an example of results obtained from monitoring a tunnel which was overstoped. Details of the stoping configuration can be seen on the left. The centre picture shows the tunnel deformations at different face positions. The sudden increase in tunnel deformation resulting from a nearby seismic event of magnitude M_L = 2,6 with a ground velocity of 1,1 m/s is shown on the right. The tunnel, supported by mesh and lacing, remained in good condition but part of an adjacent tunnel, supported only by rockstuds, experienced severe damage.

The recently constructed 25 MN compression test rig is shown in the photograph. To obtain a measure of the strength of rock which has numerous joints, fairly large specimens need to be tested. The rig is capable of loading large rock specimens to failure so as to determine their strength.

Laboratory Testing

Equipment was prepared, and two test procedures developed to obtain information regarding the friction behaviour of rock surfaces such as in fractures and bedding planes, to provide quantitative data for the inelastic analysis of mine excavations.

During the year tests commenced on the 25 MN compression machine built for testing rock cube specimens with sides up to 300 mm in length. This has made it possible to test strength, mode of failure of the rock cubes and frictional properties of fracture surfaces.

Seismicity and rockbursts

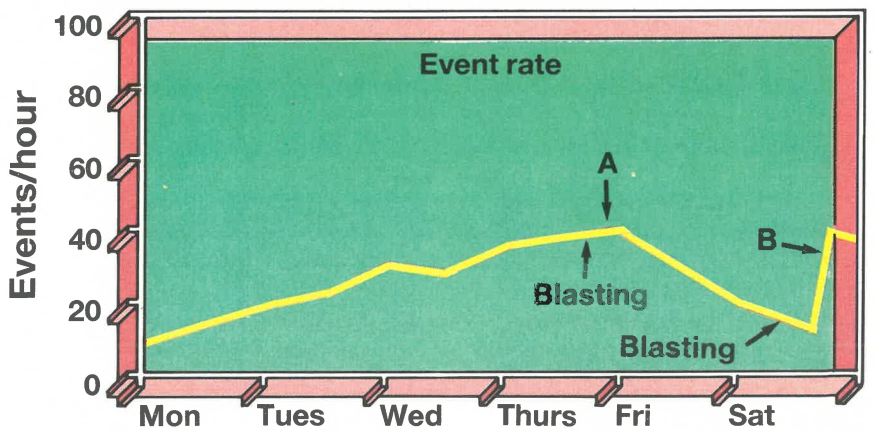
The ultimate objective of research into rockbursts is to devise methods of minimizing the occurrence of these events and of reducing their effects on underground excavations. Much progress was made in identifying the factors which lead to seismic events. However, much needs to be learnt to understand the factors which result in some seismic events causing damage to underground excavations.

An analysis of previous rockburst occurrence over a period of one year, in scattered and longwall mining situations, revealed that one in every seven to eight seismic events of magnitude above $M_L = 1,5$ results in a rockburst. It was also confirmed that the likelihood of a rockburst accompanying a seismic event increases with the magnitude of the causative event. For events with magnitude greater than $M_L = 3,0$, three out of four events cause rockbursts.

To obtain a clearer understanding of the mechanism of damage accompanying rockbursts, several rockburst sites in the Klerksdorp mining district were visited during the year and observations made of the movement of strata near the excavations adjacent to geological structures. Preliminary results indicate that damage to excavations appears to be greater where these structures intersect the excavation and where movement on the structure is greater.

The mechanisms whereby mining activity triggers seismic activity were also investigated. A study of case histories showed that certain ways of mining up to a structure are more likely to result in seismic activity than others. Back analysis using the ESS concept was carried out in conjunction with these case studies to determine at what stage in mining the structures are likely to become unstable. Results obtained to date were inconclusive and more work needs to be done in future in this area.

Monitoring of microseismic activity ahead of an advancing longwall face continued at Western Deep Levels gold mine and some success was achieved in predicting seismic events by identifying certain characteristic precursive patterns. An important factor has been the co-operation of mine management in testing the predictive capabilities of the microseismic monitoring system in a real life situation. On a daily basis section management is being informed of the seismic hazards, and on several occasions the shift was prevented from entering the stoping area. However, thus far the predicted time of occurrences was insufficiently precise. Further difficulties were in estimating the size of an impending event and whether or not it would result in stope damage. Nevertheless despite these uncertainties, management and mine worker reactions have been positive and research is continuing so that a conclusive statement as to the suitability of this approach as a management tool can be made.



The graph shows the monitoring of a build-up in microseismic activity as determined by the microseismic network, which led ultimately to a decision at (A) to prevent personnel from entering the relevant area. As can be seen from the graph at time (B) a larger seismic event did in fact occur in the area some hours later.

STOPING

Stoping represents a major proportion of the total cost of mining and it is a highly labour intensive operation. Increasing mechanization is necessary for significant improvements in labour productivity to be made, either through improving conventional mining techniques or through the development of new stoping equipment to make continuous mining possible. The problem in achieving the latter has always been the development of equipment able to withstand the harsh operating conditions underground. Recently, however, considerable progress has been made in basic engineering technology and materials which could facilitate the development of new stoping methods. It has also enabled the development of hydraulically powered machinery which could ultimately bring about the rationalization of operations through the evolution of a completely new powering system for gold mines.

Four strategies are being followed in addressing the stoping problem. The first strategy deals with improving individual constituents of the **conventional** stoping method. The second strategy is concerned with **mechanizing** in an integrated system the most critical stoping activities in **stopes mined by blasting.** The third and potentially most promising strategy is the development of **mechanized systems for stoping without blasting.** The fourth strategy addresses the question of **engineering technology** for use in the harsh stoping environment. This strategy is crucial for the success of the first three, since developments in this area make possible the technologies developed in the other areas.

IMPROVEMENT OF STOPING OPERATIONS

Improvements in the efficiency of the stoping cycle will always be dependent on attaining optimum performance of each individual activity of that cycle. Consequently, existing equipment needs continual reassessment for potential improvement or replacement by more advanced technology if the Industry is to keep abreast with the difficulties encountered in mining, particularly those associated with the depth of workings. In this regard, work in 1985 was concentrated on improving the basic activities of the stoping cycle, namely blasting, rockdrilling and rock removal. Work on support, which is another basic stoping activity, was covered under the Rock Pressure section.

Rockdrilling

Greater mining depths have presented new stoping difficulties, not the least of which is that of drilling blast holes in the extremely fractured rock prevailing at such depths. This highlighted the need for a new drilling technology capable of fast and efficient drilling in crushed rock, and led to the development of the handheld water-based emulsion rockdrill. The drill successfully completed its production trial at West Driefontein gold mine during 1984. During this trial the drill achieved penetration rates approximately twice those of conventional pneumatic drills and proved to be highly labour and energy efficient. In subsequent tunnelling trials the rockdrill proved equally successful.

Application

As a result of the successful production trial, West Driefontein gold mine continued to use the drill during 1985, and a further four mines

introduced the drill. The Research Organization maintained a close involvement with these varying applications, providing assistance in the introduction of the drills, as well as monitoring closely the performance and providing support services where necessary. In each case, the drilling rates confirmed expectations but problems with the reliability of the drill were experienced. Although the drill proved as reliable as the pneumatic drills, the higher drilling rates achieved with the hydraulic rockdrill mean that the breakdown rate is below target. These trials therefore highlighted the weaknesses of the rockdrill which are now being addressed. In addition to the few engineering problems, other teething problems included those associated with the introduction of new technology, particularly the need for strict supervision and preventative maintenance. An example of inadequate supervision with increased running costs incurred through unnecessary losses of hydraulic fluid.

Engineering

Work on the few components which were found to impede the reliability of the rockdrill commenced during 1985.

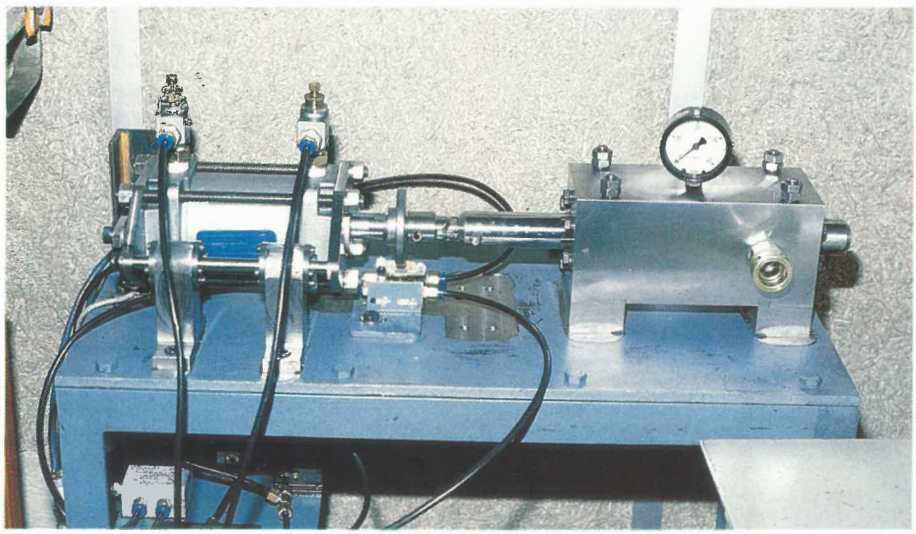
power units for drilling in tunnel development.

In addition, alternative types of pumps are being investigated to determine their ruggedness and ability to withstand operational conditions underground.

Finally, the advent of hydro-power and its application to rockdrilling has identified a need for water-to-emulsion transformers to enable emulsion rockdrills to be driven using high pressure water as a power source. Prototypes have been built and some preliminary testing was carried out during 1985.

Water Rockdrill

Work on producing a rockdrill powered directly by clear water continued during 1985 and the evaluation of pre-prototype water drills has shown that their performance is similar to that of emulsion drills. The advantages of this drill are that, since it will operate directly from hydro-power, it will eliminate the need for complex powering systems and the costs incurred with the use of emulsions. Since these drills were specially designed for use on water, corrosion and abrasion resistant materials such as stainless steels, ceramics and plastics are used in their construction and they are yielding encouraging results.



One of the many test beds required for evaluating components in the rockdrill is shown above. These test beds form part of facilities set up by the Research Organization to enable engineering refinement of those components which were identified during 1985 as influencing significantly the reliability of the system. The test bed above was designed and built specifically for investigations into piston seal friction and wear in hydraulic rockdrills powered by water-based emulsions.

As part of the continued effort to improve the reliability of the overall drilling system, further improvements were also effected during 1985 in the properties of the dilute water-based fluids used to power the drills.

Power Systems

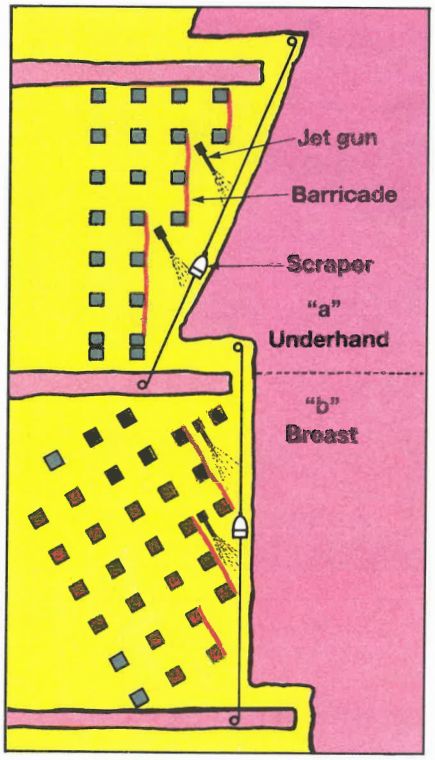
The widespread application of the rockdrill into a number of mines and mining situations including tunnelling has led to the development of differing powering systems for varying mining conditions. These systems now include centralized pump stations, used successfully during the production trial and each capable of powering several rockdrills, smaller powerpacks for use in gullies in scattered mining conditions, and

Rockhandling

Rockhandling both at the face and in the gullies is one of the major factors affecting productivity. The two approaches concentrated on during 1985 were the use of low and high powered water jets for face cleaning and the application of the continuous scraper for gully cleaning.

Handheld Water Jets

Low powered handheld water jets have been used in the mining industry for many years for face rockhandling, either on their own where the dip is relatively steep, or in conjunction with a scraper. Problems with the application of handheld water jets are mainly associated with the pumping systems which have experienced poor reliability in the harsh stoping environment. However, the introduction of hydro-power into a stope at Kloof gold mine has eliminated the need for pumps, and has led to a re-evaluation of the techniques and equipment necessary for water jet cleaning of stope faces.



Examples of the various stope layouts being investigated in tests at Kloof gold mine to assess the effect of stope layout on the cleaning rate of handheld water jets used in conjunction with scrapers. These jets are powered directly by hydro-power. Results from the breast panel layout (below) show cleaning rates (including all delays) of 27 to 28 tons of rock moved per hour.

High Powered Water Jets

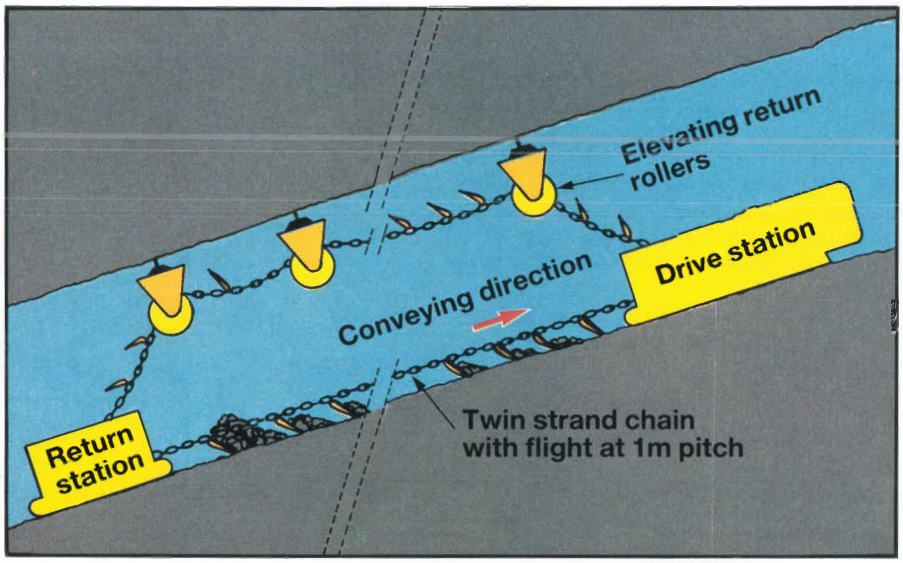
The maximum force which a man can control with a handheld water jet is 350 N, giving these jets an effective operating range of less than 5 m. A method of improving the rockhandling capability is to use more powerful, mounted water jets which have reaction forces of up to 1000 N and which can be effective at operating distances in excess of 15 m. The higher water flow rates required for these jets are readily available using hydro-power. The greater rockhandling capability and effective operating range of these units should reduce appreciably the time taken to remove the blasted rock from the stope faces. In addition, the quantity of water used is small in comparison with conventional methods. Initial results from an underground trial at Kloof gold mine, where the water jet is being used at various angles of dip, are promising.

Continuous Scraper

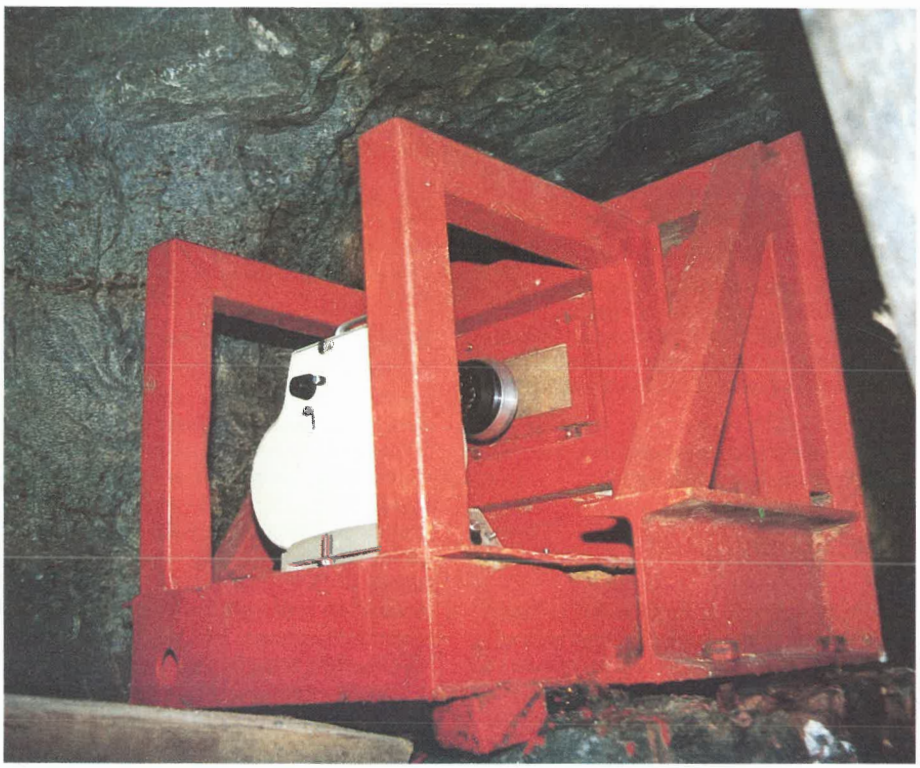
In the past many different devices to improve gully rockhandling have been evaluated but the most promising device is a continuous scraper which has been adapted from chain conveyors used in coal mining. In preliminary testing in gold mines, the continuous scraper has demonstrated the potential to significantly increase conveying rates and to have the capacity to handle ore over long distances, the latter enabling cross-cut spacings and box-hole spacings to be increased.

The scraper successfully completed its first underground performance trial during 1985 at West Driefontein gold mine where it was shown to be capable of moving over 100 t/h of rock over distances of more than 150 m. In addition, indications are that it can successfully withstand the harsh stoping environment although only approximately 5 000 tons of broken rock were conveyed in this trial. Despite the scraper having a tandem drive with two 30 kW units, it was operated by only one 30 kW unit for a significant portion of the trial. Tests at West Rand Consolidated gold mine have also indicated that when used to move rock up-dip the scraper can handle more than 90 t/h of rock at 20 ° inclination, and over 60 t/h at 30 °, over distances of 150 m.

Further trials of the scraper have commenced. At Western Holdings gold mine, the scraper is installed in a 25° winze where its performance in conveying up-dip is being evaluated and the wear lives of its components are being determined. At Hartebeestfontein gold mine, a continuous scraper, powered by a hydraulic unit in place of an electrical unit, has been installed to establish the performance of this type of cleaning device over a range of conveying speeds.



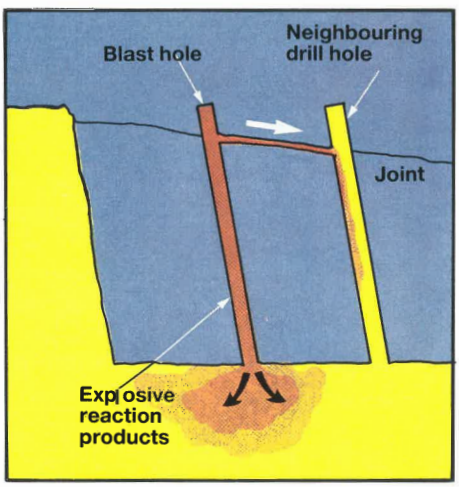
Schematic of the continuous scraper. The continuous scraper consists of a pair of chains connected by flights at intervals of approximately 1 m. The top or return part of the unit is suspended from rollers attached to the hangingwall while conveying is carried out by the flights running on the gully footwall.



The method of high speed photography of stope blasting was finalized and is proving to be a useful diagnostic tool as it provides a visual description of rock disintegration from the time of explosive initiation through to final rock movement. The method uses two cameras capable of filming at rates of more than 1 000 frames per second to provide a visual record of the rock breaking process.

Blasting

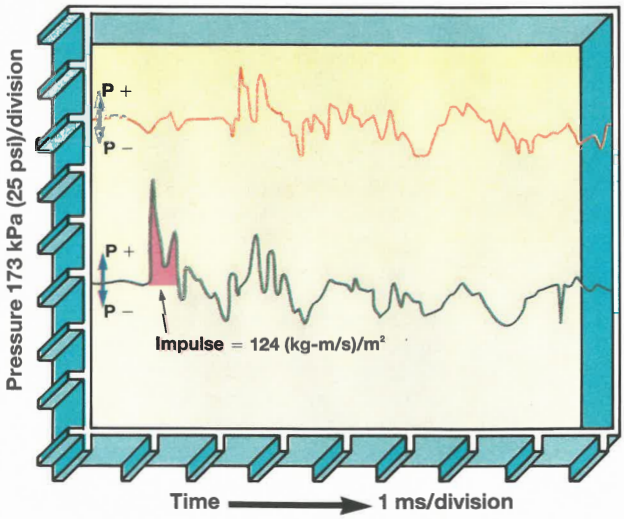
Investigations into the fundamental physical process involved in stope blasting continued at a near-surface test site at West Rand Consolidated gold mine. The overall objective of this work is to develop a firm understanding of the explosive rockbreaking process in stoping so that blasts may be designed to achieve desired end results.



An important observation made from the use of high speed photography was that structural fractures act as conduits for gases to travel from the exploding hole across to adjacent holes. Such gas pressurization of loaded but unfired holes can desensitize the explosive prior to initiation and cause ejection of the charge from the hole. This is particularly serious for deep level mining where numerous mining induced stress fractures are present.

In addition a model of the fragmentation of the rock during blasting, and a methodology for blast layout have been developed. These form the basis for a rational design of stope blasting and take into consideration explosive type, charge configuration as well as the burden geometry as defined by the stoping width, drilling pattern and hole diameter.

Work at a blasting test gallery at Stilfontein gold mine continued with emphasis on monitoring and testing blasting accessories.



Measurements of air-shock taken at close proximity to blastholes have shown that although high pressures result, the time duration is too short for damage to be caused to blast barricades. The impulse from the leading air shock pulse is equivalent in terms of momentum to one per cent of the kinetic energy of rock heaved from an average stoping blasthole. The impact of the rock can be considered to be solely responsible for damage to barricades during blasting.

MECHANIZATION OF STOPING SYSTEMS

Any viable mechanized stoping system must be a successful integration of the appropriate techniques for rockbreaking, rockhandling, temporary and permanent roof support, moving equipment to and from the face, and, if necessary, manipulation of blast barricades and the installation of backfill. In addition, the system must be easily operated and maintained to ensure an acceptable labour productivity and must be cost-effective in terms of a mine's profitability. Currently, mechanized systems are being developed and evaluated both for stopes mined with blasting, and for stopes mined without blasting.

Engineering input is particularly essential to the design of successful mechanized systems since the equipment will be required to operate in the harsh conditions underground. In this regard, engineering covers not only the equipment itself, but also water treatment processes and the development of materials able to withstand the abrasive and corrosive conditions underground. The development of water treatment processes is particularly important given the current progress of hydro-power and thus the potential for the wider use of water as a powering medium.

Mechanization of stopes mined with blasting

Clearing the broken rock from the face is the most time consuming and restrictive operation in the blasting cycle. Consequently, the development of mechanized face conveyors is considered to be the area most requiring improvement in stopes mined by blasting. Earlier it had been established that the reciprocating flight conveyor had the most potential for forming the basis of a mechanized mining system using explosives.

Experience from previous trials has shown that the greatest difficulty in the design of a mechanized stoping system is the interaction of the various components of the system. Specifically, solutions were required to the question of how to load the rock onto the conveyor, the method of drilling and type of drill to be used, the mode of operation and type of drive station of the conveyor, and the erection of blast barricades without interfering with the support system. During 1985, a complete system was constructed which takes account of these aspects. The system incorporates a new reciprocating flight conveyor, the rear profile of which has been redesigned to enable a larger volume of blasted rock to land on the conveyor so as to minimize the amount of loading required.

The lower profile also enables a fully mechanized drilling system using 5 kW water-based emulsion rockdrills to be mounted onto the conveyor. Blast barricades form an integral part of the conveyor and are rotated to a vertical position prior to blasting.

In addition, greater operational flexibility is offered since each 20 m section is operated by a drive station. The fact that the conveyor drive, the manipulation of the barricade and the advancing of the conveyor can all be adapted to water powering is another advantage when considering current research into the use of hydro-power as a powering medium.

Comprehensive surface testing of the conveyor, together with the associated drilling equipment, was successfully concluded prior to underground testing, and the method of operation of the mining system was re-evaluated in terms of the new design. The system can be operated in two different modes. In the one, the cycle of operations, which consists of cleaning, drilling and blasting the face, is completed in one shift and should result in good labour productivity with a high rate of face advance, while the other, a two-shift operation, offers high labour productivity with a good rate of face advance.

The integrated mechanized mining system for stopes mined with blasting undergoing surface trials at West Rand Consolidated gold mine.

Mechanization of Stopes Mined without Blasting

Mining without the use of explosives offers many potential benefits because the rockbreaking and rockhandling activities are not constrained by the cyclic nature of the blasting process. Non-explosive mining can be continuous, allowing for high rates of face advance and staggered shifts to alleviate underground travelling and shaft congestion. Waste rock can be sorted at the face and used as an effective backfill, thereby reducing the amount of rock to be hoisted. The improved strata and environmental control resulting from backfill permits mining at greater depths, and working conditions can be greatly improved. An important engineering advantage is that since the various components of the integrated mechanized mining system do not have to withstand blast forces, the equipment does not need to be as robust. However, it must be reliable and simple to operate and maintain.

Rockbreaking Methods

Impact ripping, that is subjecting the rock face to heavy blows by means of a hydraulically operated hammer, has been established in previous research to be the most promising means of non-explosive mining as it exploits the natural fracturing which occurs around the stopes in deep level mines.

A re-evaluation during 1985 of the various options available for mining without the use of explosives confirmed the view that impact ripping is presently the only feasible method which has the potential to yield a technical and economic solution. The main concern with impact ripping is the problem posed by the occurrence of hard patches in the face and this is receiving attention.

Integrated Stoping System

Research has, for the past three years, concentrated on evaluating the most efficient method of using the hammer to break and to load the broken rock onto a conveyor. These studies have shown that many of the manipulations which were possible with previous machines were not required, and has resulted in the design of a very simple mining machine.

The new prototype impact mining system commenced underground trials at Doornfontein gold mine during 1985. Unfortunately it was not possible to operate the system for sustained periods due to difficulties with the hammers; nevertheless it appears that all other sub-systems are working satisfactorily and that many of the previously identified shortcomings have been overcome.

The new prototype impact mining system installed underground at Doornfontein gold mine. It consists of an impact ripping machine which is mounted on a reciprocating flight conveyor and which mines while moving in a down-dip direction. The rock is broken out and loaded onto the conveyor by the hammer manipulation. The machine is currently powered by an emulsion powerpack attached to the back of the machine frame. However, it is envisaged that in future the machine will be powered by water, ideally from a hydro-power system.

Development of the hammer

Engineering work on the design of high energy hammers for operation on both emulsions and water has resulted in the development of shorter, simpler and more powerful hammers.

In view of the good progress made with the use of hydro-power in deep gold mines, work concentrated on the development of water powered hammers. It has been shown that hammers designed initially to operate on emulsion can be run on water without major design changes other than the selection of corrosion resistant materials for the manufacture of the internal components. However, the lack of lubricating additives puts an additional constraint on the choice of materials suitable for manufacturing seals and bearings. A test bed has been constructed which simulates conditions found in a water powered hammer and about 100 hours of seal and bearing testing have been completed to date.

The high speed seal and bearing test unit simulates the sliding velocities and frequencies found in a water powered impact hammer. The unit can be run on clear water and is used to examine the wear characteristics and design features of various bearing and seal materials.

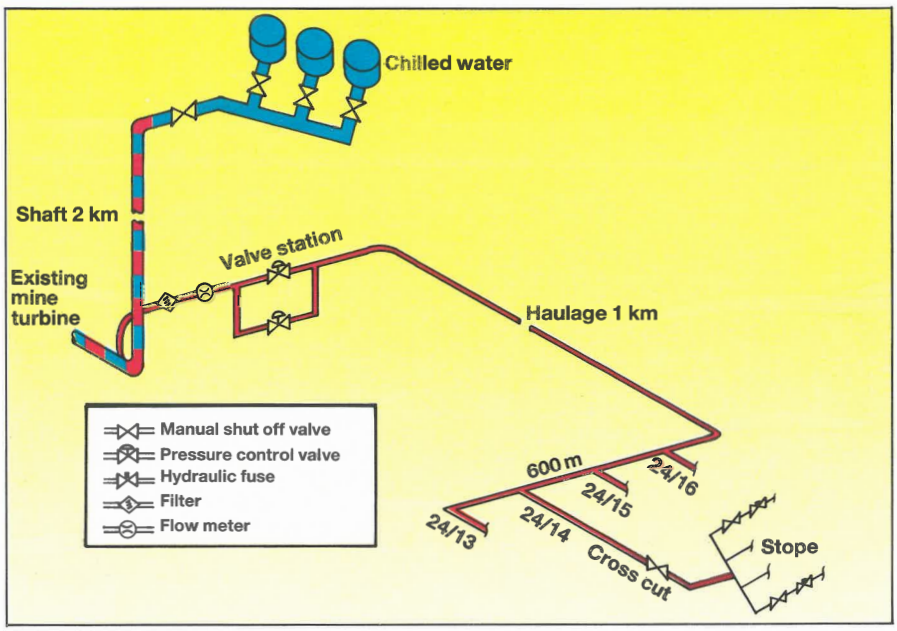
ENGINEERING

Experience in the development of stoping machinery has shown water to be a desirable form of powering in this equipment. Consequently, work in this area is directed towards providing water power, developing components to operate with water, ensuring the availability of water of a suitable quality, and developing materials to operate in the corrosive and abrasive conditions underground.

Powering

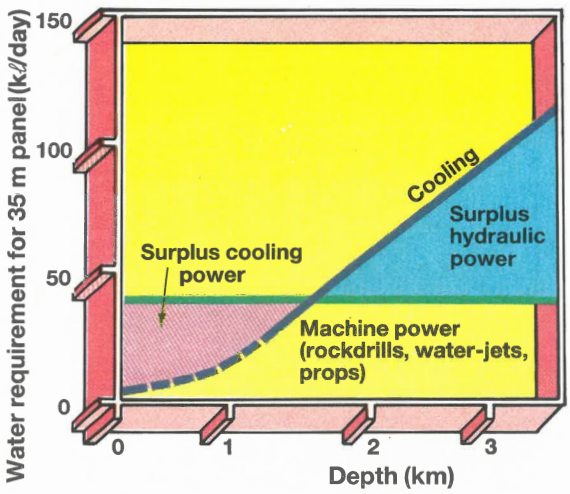
Conventional practice requires the use of water to suppress dust and to cool deep level mines, and the utilization of this water in future for driving mechanized stoping equipment has the potential to revolutionize powering in deep mines. Such a system, known as hydro-power, exploits the difference in elevation between the surface and underground workings to generate a sufficiently high pressure to power equipment. This water has the potential to provide both hydraulic power and cooling to the working areas, thus satisfying both needs with one energy distribution system. Such a system offers simplicity, compatibility with the mine's infrastructure and the potential for significant savings in energy costs. In addition, it is feasible with existing technology although the development of control valves better suited to the mine environment would be a definite advantage.

An evaluation of the required flow rates of chilled water needed to cool the mine workings has shown that the quantities are more than adequate for powering stoping machinery within these workings. It has been demonstrated already that hydro-power can provide a means of powering basic equipment such as water jets, rockdrills, props, and other miscellaneous equipment such as watering down devices and blast hole cleaners. An important implication of this approach is that it is no longer necessary to provide compressed air to the workings. Surplus amounts of hydraulic power available in deep mines introduces the possibility of powering additional equipment with high pressure water, thus reducing the dependence on electric power in stopes. The Research Organization is currently adapting various types of equipment for this purpose, an example being a scraper winch powered by a Pelton turbine. Laboratory testing of the turbine and initial testing of the full winch assembly at West Rand Consolidated gold mine were completed during 1985 and the winch has now been installed into the pilot hydro-power system at Kloof gold mine.



Schematic diagram of the pilot hydro-power system at Kloof gold mine. The system utilizes the hydrostatic head in an existing 2 000 m shaft column and distributes water at a pressure of 17 MPa to two production stopes, the longest distance over which the water is distributed being some 1 700 m from the shaft. The pipeline is fully instrumented for the monitoring of its performance, and provision has been made for the evaluation of various pressure regulating and line-break protection valves. Initially, the emphasis was on operating water jets and props from hydro-power, but towards the end of 1985 additional types of equipment started to be introduced.

The graph shows the typical water requirements for cooling and machine powering for one working panel 35 m long. It can be seen that at depths greater than 1 500 m a surplus amount of hydraulic power is available. This is because the heat generated in deep mines comes from newly exposed rock, and since the rock temperatures increase with depth, the heat problem, and hence the requirement for chilled water, also becomes greater. On the other hand the flow requirements of water powered machines for stoping (that is water jets, rockdrills and props) are essentially independent of depth.



Considerable attention is being given to installation and maintenance procedures for high pressure pipelines. Experience gained from the pilot hydro-power system at Kloof gold mine has indicated that highly specialized skills are not required, but the need for a comprehensive Code of Practice has been highlighted. Such a document is currently being compiled.

A study carried out in 1984 into the full-scale operation of hydro-power had confirmed that the control systems and hardware essential to maintain safety and control were available, although not necessarily in an ideal form. Work continued in 1985 to adapt various of these components to make them less complex and more suitable for use in gold mines. All control valves had to be operated by high pressure water actuators to eliminate the dependence on separate pneumatic and electrical power sources. A number of prototype safety shutdown and pressure regulating valves conforming to these requirements, but representative of a variety of basic design approaches, were developed, and evaluation is in progress. Work has progressed on some of the valves to the stage that production versions should be available.

An additional requirement for the successful operation of hydro-power is the availability of small directional control valves to control the various functions of water powered machines at the working face. Some valves are available, but have yet to be proved for reliable operation on high pressure water. Further facilities for accelerated testing of these valves were established during 1985 by the Research Organization.

In addition, the effect of water quality on the lives of valves needs to be assessed and the results of the laboratory testing of the valves should assist in determining the degree to which water quality must be controlled.

Water Treatment

Large quantities of service water are used in conventional mining practice, and with the trend towards mining at greater depths there is an increasing dependence on water as a coolant in stopes. However, the quality

of this water needs to be improved if hydropower is to be introduced successfully. Research continued during 1985 into identifying the reasons for the deterioration in mine water quality, on testing methods of preventing this deterioration, on investigating water treatment processes and on developing effective water management procedures.

It was established that the type of explosive used during blasting has a significant effect on the quality of the water leaving the stope. It was found that not only did the explosive affect the amount of nitrate left in the broken rock, and thus the amount of nitrate transferred to the water used for washing down this rock, but that they also affected the rate of sulphate formation by oxidation of the pyrite in the rock.

Bacterial catalysed oxidation of pyritic ores has previously been established as another of the major causes of contamination of mine service water. Investigations into the use of an anionic surfactant to reduce this bacterial oxidation continued during 1985 with arrangements being made for adding a surfactant to the water supply of a total shaft system.

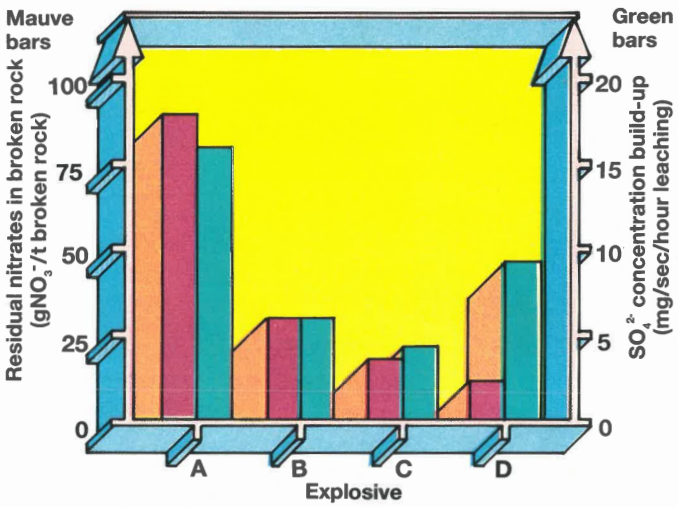
Many mine waters have high concentrations of calcium sulphate which lead to scaling and make the application of conventional water treatment systems impractical. Small scale pilot plant studies (0,05ℓ/s) on a novel process known as seeded reverse osmosis (SRO) have shown it to be capable of producing water of an acceptable quality while operating at high recovery efficiencies on these waters. A larger pilot-plant (0,5 ℓ/s) has been installed at the ERPM gold mine to establish design details and costs for full-scale SRO plants.

Conventional desalination processes are only applicable to mine waters which are non-scaling, such as mine waters containing high concentrations of sodium chloride and low concentrations of calcium sulphate. To treat these waters preparations have been made to evaluate electrodialysis reversal and tubular reverse osmosis pilot plants at Beatrix gold mine.

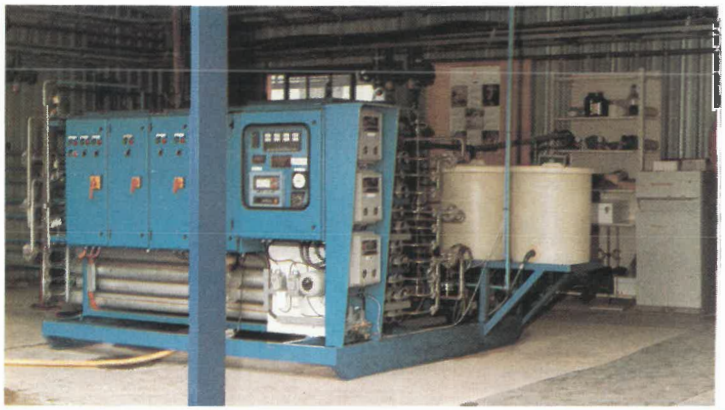
An alternative method of removing dissolved solids is freeze desalination which has the potential of combining ice making and desalination in one plant. Investigations into various direct contact freeze desalination processes continued and resulted in the selection of a pilot plant for evaluation of typical mine waters.

In addition to dissolved solids, mine waters become contaminated by suspended quartzite particles which are abrasive and cause severe wear within hydraulic equipment. Studies into the removal of suspended solids from mine water on a bulk scale by sand filtration have continued with the evaluation of a continuous backwash upflow sand filter. These investigations have shown that the treatment of mine water directly by sand filtration is limited by occasional high concentrations of suspended solids in these waters. An alternative method, cross-flow microfiltration, has been investigated using a small scale unit (0,02 ℓ/s). The process has been able to produce a consistently high quality water having a suspended solids content lower than that of municipal water.

As part of the water management programme undertaken in 1984 to investigate the treatment and use of water on the mines, a computer model for simulating water systems is being developed as a water management tool. During 1985 this model was refined by modelling more accurately the areas in the mine where the contamination of the water occurs.



Histogram showing marked differences in the effects of four different explosives on the amount of nitrates in the broken rock after blasting, and on the rate of sulphate build-up in the water leaving the stope due to oxidation of pyrite in the broken rock. These findings were established during tests at Durban Roodepoort Deep gold mine.



The 0,5 ℓ/s seeded reverse osmosis pilot plant installed at ERPM gold mine. This unit treats mine water containing about 3 000 mg/ℓ of dissolved solids, delivering a product water which has less than 500 mg/ℓ of dissolved solids while operating at 95% product water recovery.

Materials

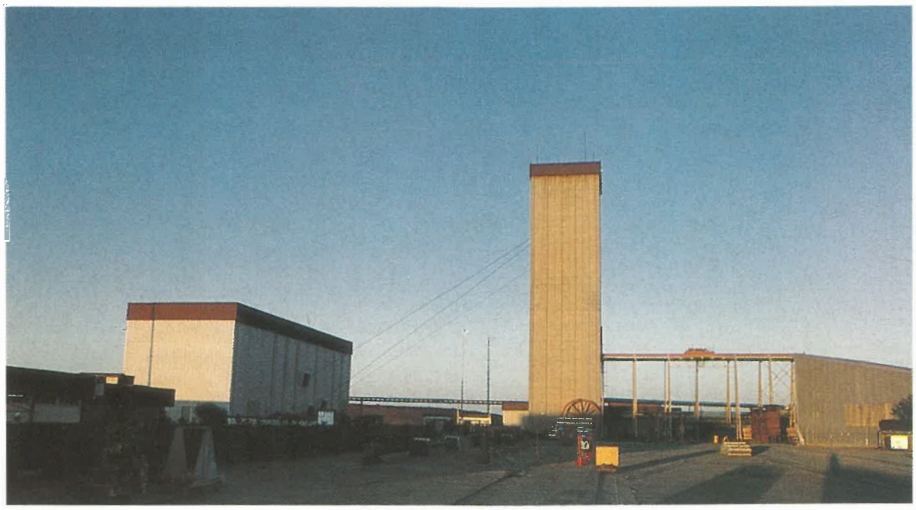
The gold mining environment is highly corrosive owing to the release of blasting fumes and the pyrite content of the rock. These factors combined with the high temperature and humidity and the abrasive nature of the rock result in an environment that is extremely deleterious to stoping machinery. It is therefore necessary to develop suitable materials for the construction of mineworthy stoping equipment. Proprietry abrasion resistant steels corrode at much the same rate as mild steel and the soft corrosion products are removed easily by contact with abrasive rock allowing fresh corrosion of the exposed metal surfaces. On the other hand, stainless steels do not possess the necessary mechanical properties to make them suitable for use as general engineering materials in stopes.

Research into alloy development has resulted in the production, on a laboratory scale, of four new steels with differing alloy compositions, but all being economical, corrosion resistant engineering steels having the suitable combinations of strength, toughness, corrosion and wear resistance. An additional requirement of these steels was that they should be amenable to conventional fabrication methods such as forging, machining, cutting and welding.

During 1985 several steel manufacturers, both in South Africa and overseas, were approached to assist in commercializing the four development alloys. A programme of work was initiated to produce first 500 kg and subsequently 15 t melts of the four selected alloys for evaluation. Favourable results have been obtained for castability, weldability and hot workability of material from the 500 kg cast. Furthermore, although the mechanical properties obtained in the rolled product of the 500 kg material were below specification for two of the alloys, the results obtained were sufficiently encouraging to merit scaling up to 15 t casts for all four alloys.

Ceramics and polymers are being investigated intensively for water lubricated sliding components within hydraulic machinery. During 1985, various components were manufactured from these materials and are showing considerable promise in water-powered machines such as rockdrills.

SPECIAL RESEARCH



While the research programme is concentrated on the five crucial areas confronting the gold mining industry, special research is undertaken when the need arises. Two areas, namely, research into current metallurgical practices, and investigations into the engineering factors which affect the safety and performance of mine shafts are being addressed.

METALLURGY

The programme of research into the improvement and optimization of gold and uranium extraction practices in South Africa is administered mainly through contract projects with the Council for Mineral Technology. Research during 1985 covered a number of areas with emphasis being placed on gold recovery.

For example, investigations into carbon-in-pulp processes continued, with further work on the development of a carbon concentration meter.

An important spin-off from this investigation was the development of a broken screen detector which enables prompt corrective action to be taken to prevent gold-loaded carbon from short-circuiting the system thereby lowering the recovery efficiency. Design specifications have been prepared and negotiations are underway with commercial firms for the manufacture of these detectors.

Gold recovery is to a large extent dependent on the fineness of grind and better ways are being sought for the continuous on-line determination of this parameter. Plant tests have shown some promising results in the development of an improved ultrasonic measurement technique.

As a result of the volatile nature of the sulphuric acid market, the development of a process for the recovery of gold from pyrite from elemental sulphur has been undertaken. A number of methods have been investigated, two of which have shown the potential for gold recoveries in the order of 95%.

The combined recovery of gold and uranium could materially reduce recovery costs of both commodities. The use of a lixiviant which could dissolve both gold and uranium and which has the added potential advantage of being recycled, has been investigated. Under optimum conditions on a laboratory scale the efficiency of leaching both metals is comparable to that currently achieved on a Witwatersrand ore using conventional practices.

MINE SHAFTS

Engineering problems relating to shafts and hoisting affect all deep level mining operations. They include winder brakes, the dynamics of shaft steelwork and conveyances, and practices concerning the selection of winder ropes. Investigations into these areas continued during 1985.

Winder Brakes

The safe performance of winder brakes under emergency stopping conditions is largely dependent on the selection of a brake lining material which can accommodate the vast amount of heat generated during braking. Investigations into the frictional behaviour of a variety of brake linings continued during 1985 and a method for predicting temperatures during braking has been established. In addition, the effect of temperature rise on the friction coefficient of various lining materials has been identified.

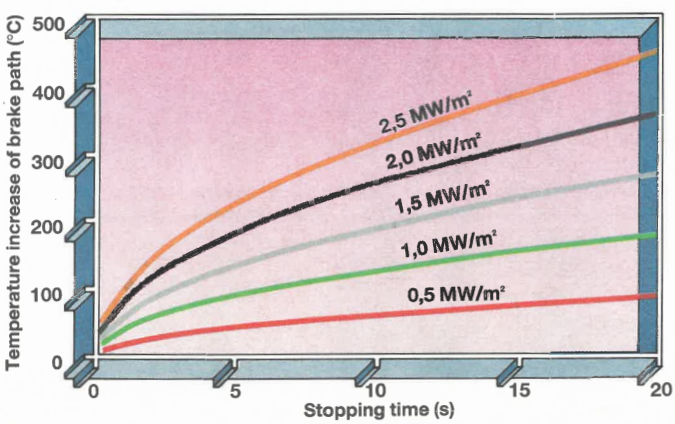
Shaft Steelwork and Conveyances

Adverse dynamic phenomena during hoisting result in reduced performance and high maintenance of mine shafts. Investigations on fully instrumented steelwork and skips were continued during 1985 to gain a detailed understanding of the dynamic loading on steelwork and conveyances. A mechanism, known as slamming, has been identified as a contributory factor in severely loading skips and steelwork. During slamming, the skip lurches sharply from side to side as the result of a guide misalignment and/or a difference in flexibility between the buntons and the guides.

An integral part of the shaft steelwork project has been an assessment of the flexibility of skips and its effect on the forces induced in the system. As part of that work, a test was conducted on a fixed body skip to find its modes of vibration, and it was established that the lowest mode consists primarily of torsion. Further analysis showed that the slamming forces between the skip and the guides are insensitive to this mode of vibration. Other modes were identified, however, that could contribute to skip fatigue cracking. It was also verified that bridle flexibility is important for rotating body skips.

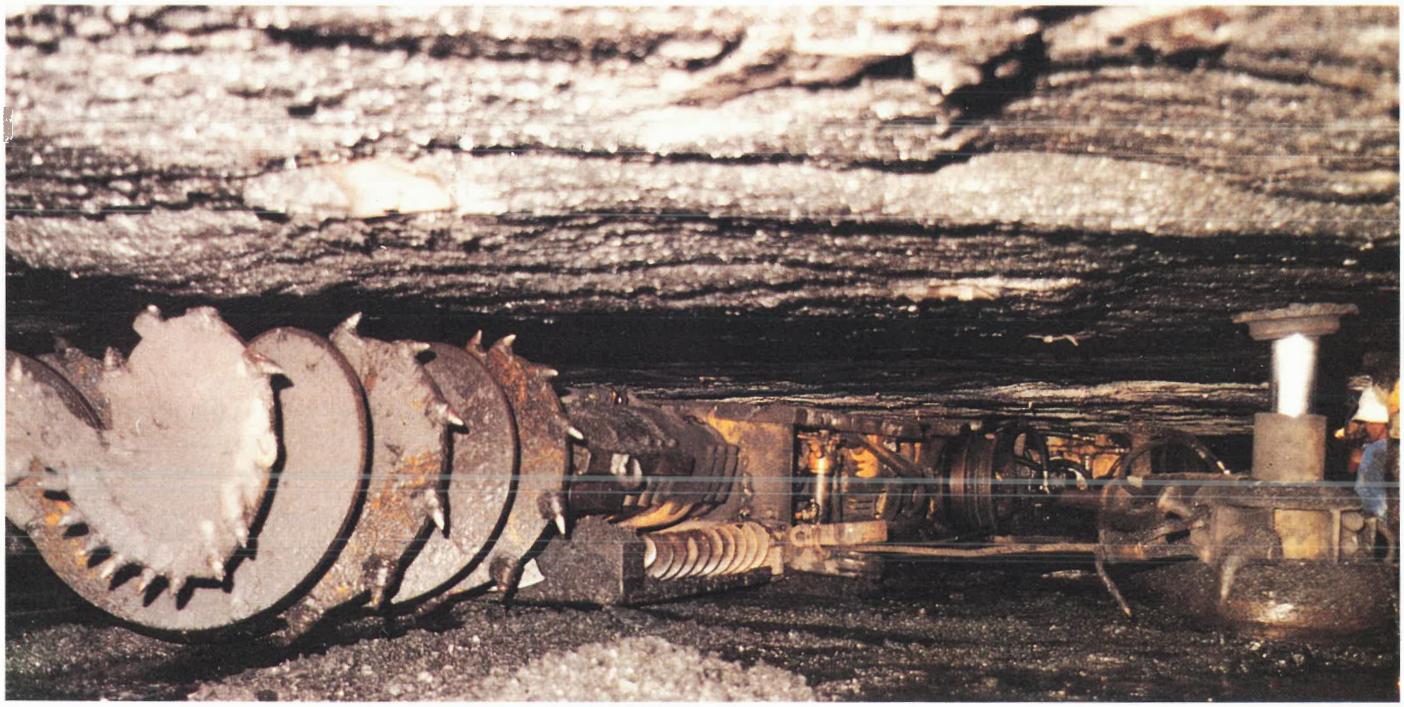
WINDER ROPES

The evaluation of statutory factors of safety applied in the selection of winder ropes continued with exhaustive examination and testing of two complete lengths of discarded ropes, measurements of dynamic rope loads at three shafts and the completion of a report on factors of safety used in other countries.



As shown, the temperature reached by the brake path is governed by the rate of heat generation, the area of the brake path and the stopping time. This chart can be used in conjunction with the friction coefficient/temperature properties of the brake lining material to assess the likelihood of brake fade under emergency stopping conditions.

Work sponsored by Coal Producers



Compared to the research for gold mining, the Research Organization's coal mining research effort is smaller in scale and focuses on those aspects which are specific to the South African coal mining industry.

The programme of work is designed around three specific areas – Environment, Mining and Strata Control. Investigations within the **environment problem** relate mainly to safety and health, while work on the **mining problem** is concerned with the efficiency of mining equipment and systems. Aspects covered by the **strata control problem** include safety, as in the control of ground movements due to underground workings, and efficiency, which is defined as the better utilization of coal reserves.

ENVIRONMENT

The increased use of mechanized coal cutting machines, the greater mining depths and a wider application of total extraction methods have emphasized the problems associated with airborne dust, emission of methane and spontaneous combustion.

Self Rescuers

The loss of life in colliery disasters over the last few years has highlighted the need for greater protection of underground workers. As a result, the South African mining industry is preparing itself for the introduction of legislation making the wearing of self rescuers in coal mines at all times mandatory.

Specifications for self-contained self rescuers have been established and the testing of four prototype models by the Research Organization is in progress.

The models are being tested both underground and in the laboratory with regard to their robustness, acceptance by the user and the duration over which oxygen is provided. In addition, information on the ease of distributing units to the workers, the maintenance needed, and training required by the wearers is being collected.

Dust

The potential hazards of airborne coal dust include poor visibility at the face, unpleasant working conditions and the potential for

A 30 ℓ/min belt-worn self rescuer designed specifically for local conditions (left). As most of the models are newly developed, the products are being thoroughly tested by the Research Organization in anticipation of their full scale introduction into South African collieries.

The units are both tested underground continuously for six months and in the laboratory to evaluate their user acceptance and robustness as well as their life support capabilities. Rescue Training Services tests, in which a man wearing a self rescuer follows a strenuous obstacle course, are also conducted to determine whether the unit interferes with the wearer's mobility, and what, if any, hazards are associated with the wearing of the unit (right).

converting methane ignitions into coal dust explosions. In addition, respirable coal dust, the finer particles of airborne dust, is the cause of pneumoconiosis, a crippling lung disease.

Research in this area is consequently aimed at developing more effective means of dust suppression on coal cutting machines, either by adapting existing systems or by developing new ones. Work continued on evaluating the effectiveness of various combinations of ventilation networks in continuous miner sections and dust suppression systems on the continuous miner. In particular, the water powered scrubber and the venturi spray system were found to reduce dust significantly when used in conjunction with an effective exhaust ventilation system.

Poor maintenance of dust suppression systems was, however, identified as one of the major difficulties in maintaining effective dust control in continuous miner sections. As a result, a programme was initiated in 1985 to make mine personnel more aware of the importance of regular maintenance and also heighten operator awareness of common maintenance problems associated with these systems. For this purpose a video explaining the operation of the various systems, pointing out the problems which may occur and advocating a regular maintenance programme was produced and will be distributed shortly to collieries.

An essential aspect of controlling dust in coal mines is effective monitoring of mine personnel's exposure to respirable coal dust. The coal mining industry is preparing to introduce the personal gravimetric sampler, an instrument designed to measure over a full shift how much respirable coal dust a worker is exposed to.

Trials of 12 personal gravimetric samplers drawn from four different suppliers were completed this year. It was found that all instruments performed satisfactorily during 85 percent of the shifts in the underground trial. However, two models performed significantly better than the remainder and were considered suitable for use in local collieries.

The four personal gravimetric samplers evaluated. During the trial, the performance of the personal gravimetric samplers was monitored over 550 shifts with regard to reliability, robustness, worker acceptance, servicing and repairs. The samplers were also tested in the laboratory following the underground trials, where their performance in a dust chamber was measured against international standards.

Water Networks

Effective dust suppression requires an underground water supply which is adequate in terms of both water pressure and water quality. Work commenced at two mines in assessing the effectiveness of their present reticulation networks with the overall objective of establishing better water reticulation circuits. In addition the feasibility of re-using mine drainage water is being examined to reduce a mine's consumption of fresh water. A computer simulation program known as WATERNET is being used in this research.

Methane

In addition to ineffective dust control, poor ventilation practices can lead to excessive methane concentrations. Laboratory work contracted to the University of the Witwatersrand has commenced to determine the methane absorption characteristics of South African coal seams. Such work is fundamental to understanding how much methane is released during mining and will assist in the design of improved face ventilation methods and layouts to assist in methane control.

MINING

The growth of coal mining in the past few years has seen a parallel increase in the equipment used and in the diversification of extraction methods. Because of the high capital cost of modern coal mining equipment it is important to be able to quantify the expected performance of a mining system under given conditions. Work in this problem area is, as a result, aimed at collecting and analysing the necessary information on types of equipment, mining methods and coal strata characteristics.

SELECTION

The research is currently aimed at evolving procedures for selecting mining methods and equipment using economic and technical criteria.

Computer Simulation of Production

A new suite of computer programs was developed specifically for South African conditions to simulate various methods of extraction. Known as COMSIM, the programs simulate production from continuous miner sections and are highly user friendly. In addition, an enhanced version of the FACESIM program, which was developed purely for simulating production from bord and pillar mechanized sections, has been produced. Additions include facilities to increase the user friendliness of the program and, to improve its versatility, an easy arrangement for multiple simulations.

A mathematical model for predicting the performance of a continuous miner section was also developed to assist in diagnosing section bottlenecks and problem areas.

Continuous Miner Monitoring

The collection of data on the monthly performance of continuous miners from various collieries continued and there are now seven years of information on file. Analysis of this information so far has shown that the overall performance of continuous miners is very low in comparison with their designed production rates.

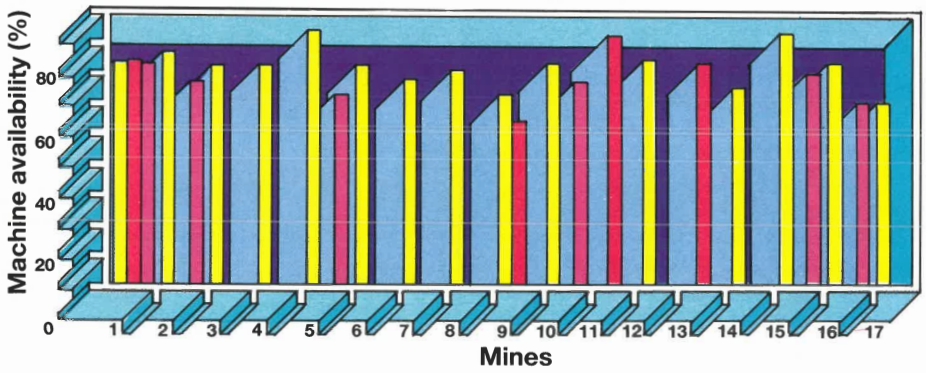
The use of this information, together with the mathematical model and the sumpmeter, an instrument developed for measuring the speed at which a continuous miner cuts into the coal during sumping, has meant that the cutting rates of continuous miners are now being more accurately quantified. Information from these three sources is being used to evaluate machine and section performance at various coal mines.

COAL CUTTING

Data from field and laboratory investigations have been collected to improve the performance of coal cutting machinery. A method of predicting the performance of a machine and its ability to cut a seam given certain physical and chemical parameters is also under investigation.

Laboratory Cutting Investigations

While research overseas has concentrated on roadheading machines working in medium strength strata, the emphasis here

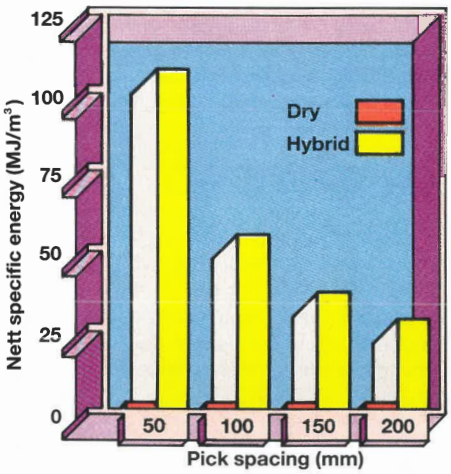


An analysis of the data on file concerning the performance of continuous miners has highlighted the considerable variation in machine availability and downtime between the various collieries and different machines. Each colour represents a different machine manufacturer.

is to optimize machine operating variables to deal with the hard South African coal and the sandstone roof and floor conditions which frequently occur.

High Pressure Water Pre-Slotting

The use of high pressure water slotting to reduce the forces on a pick when cutting has been investigated. It was found that compared to normal cutting, the forces acting on a cutting pick were greatly reduced by cutting between relieving slots. However, a considerable increase in energy is required for the whole system because of the energy required by the water jets. Furthermore, it was found that the depth of the relieving slot is very much dependent on the speed at which it is being cut. At cutting speeds in excess of 3 000 mm/s it was found that the depth of slot cut by a water jet at a pressure of 220 MPa was 2 mm deep, while at slow cutting speeds of 225 mm/s, 50 mm deep slots could be cut. This speed dependency of the depth of slot cut by the water jet limits the practical application of the otherwise attractive hybrid coal cutting system.



Graph showing the considerable difference in overall power requirements of a conventional 'dry' cutting system where no jet cut slots are made and the 'hybrid' system where intervening jet cut slots are made in the coal face prior to cutting with picks.

Water Jet Assisted Cutting

Investigations into the benefits from directing water jets at the coal during cutting continued using water pressures up to 200 MPa. This was thought necessary as at the water pressures so far tested of 35 MPa, a reduction in cutting forces only occurs at cutting speeds of below 500 mm/s, which is well below normal cutting speeds of around 3 000 mm/s.

A rotary cutting rig is being used which is a full scale simulation of underground cutting machines. Originally designed as a 30 kW cutting facility, the rig has been modified to allow for a power availability at the pick of 40 kW. In addition to water jet assisted cutting, the rig is being used in laboratory investigations into pick wear, frictional ignitions and for collecting input data for a computer model predicting the performance of continuous miners. This model will be used to investigate design concepts for continuous miners operating in local conditions.

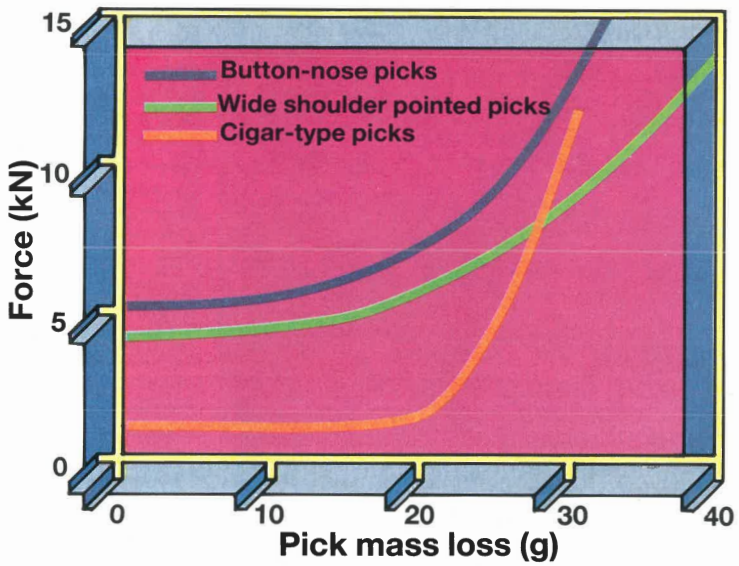
Pick Geometry and Wear

Extensive underground tests to investigate pick wear particularly with regard to determining the progression from new to completely worn were continued at three collieries. The information gathered is being used to draw up wear profiles and contours for correlation with production figures and results from laboratory investigations.

The difference between a blunt and a sharp pick can be clearly seen. During the underground tests investigating pick wear, particular attention is being given to identifying the characteristics of the pick and its location on the cutting drum. Each pick's loss of mass is measured and the wear is graded visually in terms of change in geometry. A geological assessment of the coal seam at each location and a collection of samples for size analysis are also being made.

Laboratory investigations comparing the force requirements of three differently shaped picks confirmed that picks with wider tip angles and shoulders require larger forces during cutting. Of the three shapes used, the cigar shape, wide-shoulder pointed picks and the button nose picks, the latter two were found to require higher forces because of the wider angle of the pick tip and shoulder.

The cigar shaped picks were therefore found to be more suitable for cutting in medium strength strata. In strong seams however the tungsten carbide insert of the cigar shaped picks was found to fail badly. These findings will have to be considered in the design of new picks.



Graph showing the variation in forces required for differently shaped picks at different conditions of wear. It is evident that although the shape of the pick does affect the forces required during cutting, the wear on the pick does not have any significant effect until severe wear is evident.

STRATA CONTROL

The demand for increased coal production in recent years has led to mines being established in and planned for regions more remote from the existing coal producing areas. Since coal seams in these areas tend to be deeper than those previously mined, good strata control and the maximum extraction of reserves have assumed increasing importance. The programme of work is consequently largely directed at collecting information which will lead to a better understanding both of ground movements around total extraction panels as well as of the stength of coal pillars.

MINE DESIGN

Increased extraction of coal reserves in an economic and safe manner is of paramount importance to the coal mining industry. As a result, the Research Organization is concentrating on improving design procedures through monitoring ground movements and support systems in and around total extraction panels.

Longwall Mining

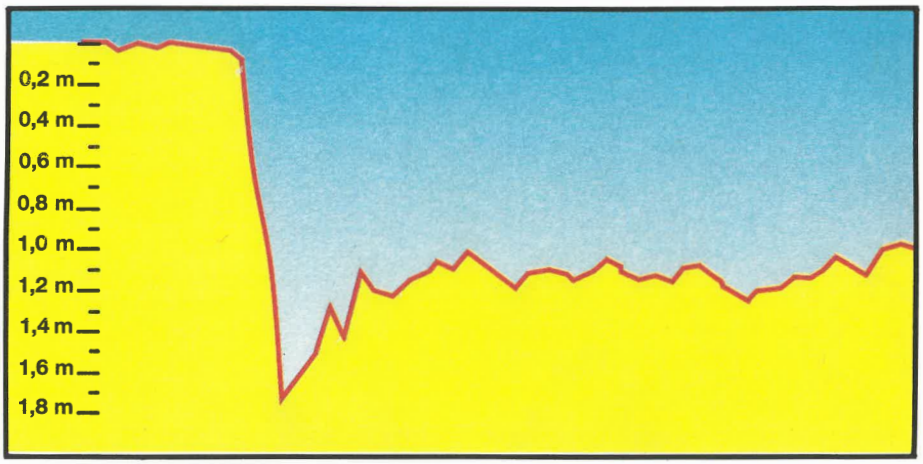
As part of an on-going programme to improve the overall efficiency of longwall operations, investigations were conducted to determine how strata behave above a shallow longwall extraction panel and how the surface is affected by total seam extraction. Information from such investigations is fundamental to assist with the design of future similar panels with regard to support requirements.

A shallow longwall panel of 2,0 m extraction height, at a depth of 55 m below surface, was studied during 1985. Research concentrated on both the yield zones around the panel and the face support characteristics. The latter were determined by monitoring variations in the loads, caused by overhang of dolerite sills, on the hydraulically operated face supports.

A new radial survey method as well as a novel photographic method were used to monitor the vertical displacement of the surface above the longwall panel. Hourly subsidence profiles obtained using the latter method showed that subsidence occurs very close behind the longwall face.

Protection of Surface Structures

A significant proportion of South Africa's



Graph of surface subsidence above a shallow longwall panel showing vertical movements along the centre line of the panel. A noticeable feature is that initial subsidence, which takes place at the initial goaf break, is of the magnitude of 1,75 m. Thereafter it averages at around 1,1 m.

Compressive damage (top) proved to be the worst form of damage to the tarred road as a result of undermining by a total extraction panel. As a preventative measure, stress relieved slots were cut across the tarred road (middle) and after undermining, were repaired with infill and tar surfacing (bottom).

coal reserves cannot be mined because of existing regulations to protect surface structures. This affects the overall extraction of reserves and limits the application of total extraction methods.

As a result, the Research Organization is investigating the effect of surface subsidence on surface structures above total extraction panels. With regard to tarred roads, it has previously been found that undermining causes two forms of damage, namely, cracks across the width of the road and subsequent compressive damage resulting in peaking of the bituminous layer and crumbling of the sub-base.

Research this year concentrated on assessing the effectiveness of preventative measures in reducing subsidence damage to tarred roads. Two strips of tarred road were undermined and slots on average 200 mm wide and 300 mm deep were cut across the width of the road to prevent compressive damage. These slots, known as stress relieved slots, proved highly successful by eliminating the compression 'humps' and reducing the cost of repairing the road.

Another means of minimizing surface damage investigated was reducing the width of the pillars left between adjacent longwall panels. It had been established that a marked hump in the road formed above the area where a large barrier pillar had been left between two longwall panels. Research during 1985 showed that reducing the width of this pillar from an average of 20 to 30 m wide to 5 m wide resulted not only in a much smaller hump and reduced surface movement, but also in increased extraction of the coal reserves.

Multi-Seam Mining

Bord and pillar extraction is commonly used in South African coal mines when mining thick seams on two horizons or two seams lying adjacent to each other. This method of extraction inhibits the maximum extraction of the coal reserves, and thus the life of the mine, as pillars are left underground.

As a result, investigations have commenced at the Springfield coal mine into the use of total extraction methods for multi-seam mining. During the study, the performance of the parting between the two seams will be investigated, as will be the performance of the support of the lower seam or parting and the stresses on the pillars.

The effect of goaf consolidation on the degree of surface subsidence when using total extraction methods for multi-seam mining is also being assessed. This is being achieved by determining how the load builds up in the goaf and whether it returns to, or close to, the original load.

PILLAR DESIGN

The general trend towards deeper coal mine workings has increased the importance of pillar design, both as a means of support and in relation to percentage extraction. Research into these aspects is being conducted.

Design of Coal Pillars

The existing pillar design formula for coal pillars has been in use since 1967 and although it has performed very satisfactorily, it does not take into account certain important influences, namely the regional differences in coal strength, the method of mining and the effect of large width to height ratios.

In particular, all cases used in deriving the existing formula were mined by the drill and blast method and therefore the effects of blast damage to the sides of the pillars were indirectly incorporated. Consequently, a pillar designed using the present formula, and mined by a continuous miner, is effectively larger than a similarly sized pillar formed by drilling and blasting.

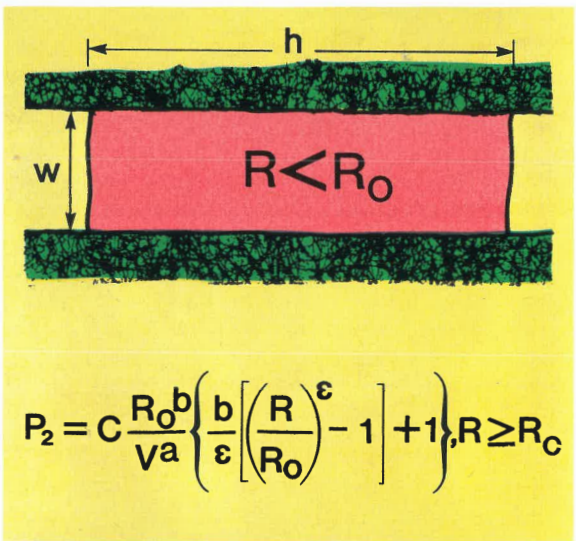
Since the blast damage zone has been found to be between 0,25 and 0,3 m deep, it can be assumed that pillars formed by the continuous miner are overdesigned by this amount. These results have shown that somewhat smaller pillars can be used in continuous miner sections, thus increasing the percentage extraction of coal reserves by between 3 and 4,75 per cent.

However, it has been established that these benefits are limited to depths less than 150 m, since stress induced fractures form in the sides of pillars mined beyond this depth.

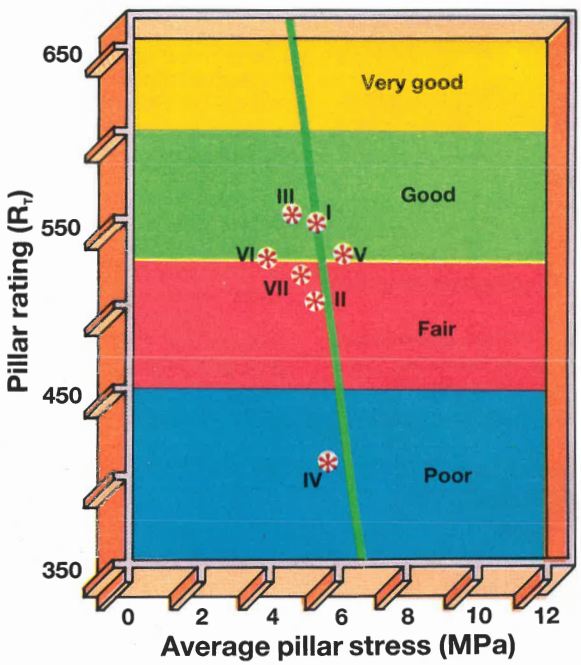
The effects of large width to height ratios on the strength of pillars is another aspect being researched since the existing pillar formula was derived from case-histories in relatively shallow mines.

The original pillar design formula has been extended for the design of pillars with width to height ratios in excess of about four. The extended formula is known as the squat pillar formula and is of considerable interest for the design of pillars in deeper collieries. Field trials are in progress to monitor the performance of pillars designed to the squat pillar formula.

The present pillar design formula neglects any variation in coal strength from place to place or seam to seam. As a result, an investigation was conducted to evaluate the in situ strength of different seams using the visual method or pillar rating system. This method includes a classification of the condition of underground pillars, followed by a rating process which rates the conditions according to the relative importance of different parameters. A total of 114 situations were assessed covering seven seams and further observations are continuing.



The squat pillar formula is based on the existing formula used by the Industry but includes two additional parameters: the critical width-to-height ratio, R_O, which is assumed to be greater than 5; and the rate of strength increase, ε, which is assumed to be 2,5.



Graph showing the pillar rating for seven coal seams. It is evident that all but one of the seams are grouped in a narrow band and fall in the range of fair to good pillar condition.

Research Organization Services

The Research Organization offers to Chamber members a range of specialist and consultative services on a contractual basis to support the implementation of developments arising from research. A review of some of the services performed during 1985 for Chamber members is given below.

Human Area

A number of manpower planning exercises were carried out on behalf of mining Groups to determine recruitment requirements as well as training quotas for technicians and artisans to establish required training levels. In addition, in-depth studies into the propensity of employees in certain essential skilled occupations to leave the Industry were carried out to ascertain alterations that could be made to employees' packages to retain such staff.

A survey was conducted at the request of one mining Group to assess employee opinion about labour relations on one mine, and several executive presentations were made on the findings. Assistance was also provided in practically applying the use of printed media in communications with employees as a means of resolving labour tension in one mining region.

A series of seminars on conflict resolution and communication strategies was held in the various mining regions to assist in preparation for the 1985 wage review. Procedures were introduced to the Industry for use by individual mines in the in-house monitoring of employee responses towards employment conditions.

Routine quality control inspections and supervision of the Classification Test Battery (CTB) at 37 aptitude test centres continued.

The Research Organization also trained 35 mine personnel in the administration and scoring of the Practical Mathematics and Technical Comprehension (MACO) test battery.

Assistance was also given in the design and implementation of improved selection procedures for Winding Engine Drivers, and assistance was given to one mining Group in the revision of its employee performance evaluation exercise.

Health and Safety

The tenth survey of dust conditions on gold mines, conducted over two years, was initiated during 1985 and results are made available to mine managers as they come to hand.

The variety of services offered by the Industrial Hygiene Branch (IHB) on a contractual basis to assist members of the Chamber in air pollution monitoring of acid mist, lime, manganese, siliceous dust and uranium continued during the year. Gas analysis was added during 1985. Typical requests are for the determination of air quality indices and dust scrubbing efficiencies in reduction works and smelthouses. A consultative service is also offered to mines on the effective operation of dust extraction and ventilation systems.

Environmental conditions at Nufcor, the Rand Refinery and all uranium plants on gold mines were monitored at regular intervals. IHB continued to monitor uranium plant workers for uranium contamination; over 6 000 analyses were performed during 1985 and results are reviewed periodically. In a similar service the lead content in both blood and urine of over 400 samples was also analysed.

The calibration and repair of instruments used by environmental control departments of mines continued. Konimeter practice and microscope techniques were checked routinely to maintain a high standard.

Annual returns on ventilation, noise and illumination in gold mines were collected and summarized.

Instruction was provided by IHB for supervisors in acclimatization procedures and six training courses and four refresher courses were held during the year. Four visits were paid to each of the 32 gold mines with acclimatization centres in order to monitor acclimatization procedures; the importance of this service in maintaining standards is vital to the more than 423 500 men who passed through acclimatization chambers during 1985. Assistance was given to a number of mines in introducing procedures for microclimate acclimatization.

In addition, circumstances surrounding the incidence of heat stroke continued to be investigated and the information used to compile improved recommendations for its reduction. In collaboration with mine medical officers, heat tolerance was assessed in ex-heat stroke victims and in those men suspected of displaying a very low level of heat tolerance.

Six hearing and vision assessment training courses were held during the year and were attended by 91 candidates; 47 test centres were visited to ensure the maintenance of recommended standards. Nine mines were assisted in planning and equipping new test centres.

Environmental Engineering

Performance tests on new types of heat exchangers were carried out at the Heat Exchanger Test Centre at the request of mines. Routine testing of pipe insulation was carried out in situ.

Rock Mechanics and Strata Control

Consultative services in the field of rock mechanics and strata control were provided to mines. These included the introduction to users in the industry of newly developed computer programs such as MINSIM-D which can be used to analyse mine layout problems in multiple or faulted reefs. Advice was given to mines in the area of mine support.

Rock and Support Testing

The Testing Section of the Engineering Materials Branch has, for research purposes, a wide range of facilities for evaluating the physical properties of rock and backfill material, and for assessing the performance of support elements currently being used in the mining industry. The Research Organization assists mines with specialized tests in this area. Details of machines available, and their capabilities, are given in the table below.

ROCK AND SUPPORT TESTING

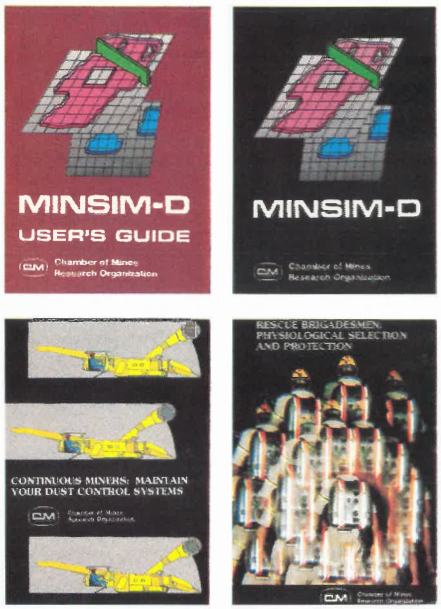
Existing Test Machines	Type of Test Performed
2 MN Stiff Compression Testing Machine	Uniaxial, Brazilian, Point Load Rock Tests. Triaxial tests up to 250 MPa confinement.
1,25 MN Compression Testing Machine	Uniaxial, Brazilian, Point Load Rock Tests. Concrete/Grout Strength Tests. Physical Model Testing.
4 MN Extension Testing Machine	Triaxial Extension tests up to 1 000 MPa confinement.
Friction Testing Machine	Dry and wet rock friction tests.
2 MN Backfill Testing Machine	Routine and fundamental tests to evaluate properties and performance of backfill
2 MN Servo-controlled Terratek Testing Machine	Variable rate load/displacement tests on mine props, elongate supports and anchors.
New Testing Machines	
25 MN Compression Testing Machine	Large scale uniaxial and triaxial tests on rock samples. Characterization of spalling and discing in rock. Determination of frictional properties of discontinuities in rock. Routine and fundamental tests of backfill material.
3 × 0,9 MN Elongate Support Tester 2 MN Elongate Support Tester	Variable loading rate tests to evaluate elongate support performance

Communications

A good communication system is essential if the results of research are to be disseminated in an efficient and meaningful way. As a result, the communication channels recently adopted to facilitate maximum awareness by the Industry of the current research programme and its achievements were consolidated during 1985.

Brochures

The publication of literature designed to promote the practical application of research findings or new technology was expanded. Three well illustrated, to-the-point brochures were produced on physiological protection and selection of rescue brigadesmen, dust suppression in continuous miner sections and the MINSIM-D stress analysis program. The latter accompanied a comprehensive User's Guide. These publications are available on request.



In the brochures the prime features of a new technology and its applications are highlighted. Brochures are often prepared as an overview at seminars or as the introduction to a package of documentation (eg. manuals, reports) or visual material (eg. videos) in which full details of the innovation are communicated.

R & D News

R & D News continued to provide a valuable means of highlighting and communicating significant research results and progress to the Industry. Towards the end of 1985 its format was extended to include inserts on topics which require more in-depth treatment than news items receive in R & D News. The first such insert to be produced dealt with the system of colour coding fuses which was developed recently by the Research Organization in conjunction with AECI. In addition, the circulation of R & D News was increased to 4 500 copies distributed in quarterly issues to Groups and mines, members of various professional, mining-related societies, as well as to a wide range of other organizations. It is also available on request.

Annual Report

The Annual Report is designed to give a comprehensive review of the Organization's activities and the extent of progress on the research programme during the year. The presentation of the Annual Report was modified during the year. More emphasis is now being given to the graphics and captions to enhance reader awareness of work undertaken. The report is distributed both locally and overseas, and is available on request.

Videos

An innovation during 1985 was the production of videos both to provide a visual record of research results, and as an educational medium when specific topics need to be highlighted. A 10-minute video on the importance of maintaining the dust control systems in continuous miner sections in collieries was produced in English and Afrikaans for distribution to the collieries.

Seminars

All problem areas were covered in the seminars held during 1985 and this method of communication continued to provide a valuable forum for discussion and exchange of ideas. To further disseminate the discussions and conclusions reached during these seminars, report backs were produced and circulated to Groups.

CoMIC

CoMIC, a current awareness bulletin comprising abstracts of mining-related articles, maintained its popularity. To provide this service, the Research Organization scans journals and magazines not normally available to mining personnel, preparing abstracts from articles with a bias towards mining and related technologies. During 1985 more than 1 000 abstracts were prepared receiving over 8 000 requests. CoMIC is produced monthly and is distributed to members of the Chamber of Mines.

Visits

As part of its policy to enable people connected with the Research Organization to have a greater understanding of the work actually done by the Organization, a number of visits to and tours of the laboratories and branches are arranged. In 1985 more than 20 visits were organized for various groups including overseas delegates and university students.

Research Reports

Approximately 30 research reports, which are detailed records of the work conducted on specific research, were distributed during 1985. These reports are for the exclusive use of the members of the Chamber of Mines.

Articles and Papers

Over 75 articles and papers written by Research Organization staff were published in professional journals, periodicals and conference proceedings in 1985. They are not distributed on a formal basis but are listed in R & D News and are available on request. Those published during 1985 are listed on page 36.

Library

Since the aim of the library is to serve the information needs of the Research Organization and therefore indirectly the mining industry, material relating to all areas of the Organization is collected, stored and disseminated.

Currently the library holdings total 29 918 publications incorporating books, pamphlets and microfiche, and a monthly list of all new accessions is sent to all mining house libraries.

A subject index which contains comprehensive details of all research reports, brochures and papers written by Research Organization staff is updated annually and sent to the mining houses.

A thesaurus consisting of 4 000 keywords relating to the South African mining industry is also compiled by the library and is available for use by the Industry. The thesaurus serves as a subject guide to the catalogue of Research Organization publications, as well as to the subject index.

The inter-library loan service continued to be used extensively. In 1985, 2 395 inter-library loan requests were sent to other libraries, and the Research Organization library supplied 1 093 inter-library loans.

The demand for computerized literature searches – which produce specific references in a matter of minutes – also increased during the past year. The recent acquisition of the Post Office's SAPONET tele-communications facility means that the cost of on-line searching has been drastically reduced. The references drawn from these searches are included on the library's monthly accessions list and copies are available on request.

RESEARCH ORGANIZATION STRUCTURE

The Research Organization of the Chamber of Mines comprises the Research Adviser's office, six laboratories and six branches. A brief summary of their activities is given below. During 1985 the total staff establishment was 653 posts.

Overall direction of the research programme is maintained by the Research Adviser and two Assistant Research Advisers.

The function of the six laboratories is to formulate and to execute the research in a specific problem area. The branches provide expertise to support the work performed by the laboratories and execute research and development where the relevant technology is lacking.

RESEARCH ADVISER'S OFFICE

Research Adviser: Prof M D G Salamon
Assistant Research Adviser: Prof N C Joughin
Assistant Research Adviser: Dr H Wagner
Technical Manager: Mr D H P Jackson
Personnel Manager: Mrs M G Vergottini
Number of professional posts: 7
Total number of posts: 11

ADMINISTRATION AND PROFESSIONAL SERVICES BRANCH (APB)

Manager: Dr T Groenewald
Number of professional posts: 12
Number of technical posts: 1
Total number of posts: 114

The Administration and Professional Services Branch provides the Research Organization with a variety of administrative services which include accounting and budget control, building maintenance, alterations and security, communications, and word processing. Promotional services are provided in the preparation of the annual report, newsletters, technical promotional brochures and visual aids, and research reports and papers are edited. A technical library is maintained and a current awareness bulletin is distributed regularly to the mining industry.

COAL MINING LABORATORY (CML)

Director: Mr D R Hardman
Number of professional posts: 25
Number of technical posts: 4
Total number of posts: 30

The Coal Mining Laboratory conducts research into mining, strata control and environmental problems in coal mines. Mining methods and equipment are adapted to suit the special geological, economic and labour conditions which characterize the South African coal mining industry. Strata control principles are developed, together with methods to assist in the planning of mine layouts. Work is in progress to minimize environmental problems such as high dust and methane concentrations and spontaneous combustion.

ENGINEERING MATERIALS BRANCH (MAB)

Acting Manager: Dr J D Greig
Number of professional posts: 22
Number of technical posts: 16
Total number of posts: 47

The Engineering Materials Branch is involved in applying materials engineering technology to solve engineering problems which arise during the development of new mining methods and associated equipment. Research into improving the quality of mine water in bulk quantities is carried out and methods for reducing the aggressiveness of the stoping environment towards engineering materials are investigated. Work is in progress to develop cost-effective alloys to replace conventional materials currently in use in South African gold mining applications.

ENGINEERING SERVICES BRANCH (SEB)

Manager: Mr J P M Hojem
Number of professional posts: 9
Number of technical posts: 41
Total number of posts: 88

The Engineering Services Branch acts in a supporting role to the Research Organization by providing an engineering service which covers design, manufacture, inspection and repairs of equipment as well as assistance in conducting experiments.

ENGINEERING SYSTEMS BRANCH (SYB)

Manager: Dr D G Wymer
Number of professional posts: 23
Number of technical posts: 15
Total number of posts: 47

The function of the Engineering Systems Branch is to provide laboratories with supportive research and development in the fields of mechanical, hydraulic, electrical and electronic engineering. Much of the effort of the branch is directed towards overcoming the engineering problems related to stope mechanization.

ENVIRONMENTAL ENGINEERING LABORATORY (EEL)

Director: Mr T J Sheer
Number of professional posts: 23
Number of technical posts: 5
Total number of posts: 31

The main objectives of the Environmental Engineering Laboratory are to devise methods for reducing the heat flow into the underground environment and to develop improved methods of dust suppression, pollutant control, refrigeration and ventilation.

GOLD EXPLOITATION LABORATORY (GEL)

Director: Dr J M Stewart
Number of professional posts: 22
Number of technical posts: 17
Total number of posts: 46

The Gold Exploitation Laboratory is involved in studying methods for predicting gold distribution and for improving reef valuation. Techniques which enable a lower grade of ore to be mined are being examined. Backfill is being developed as a method for improving stoping conditions and hence gold extraction.

HUMAN RESOURCES LABORATORY (HRL)

Acting Director: Mr D MacArthur
Number of professional posts: 27
Number of technical posts: 11
Total number of posts: 42

The Human Resources Laboratory is mainly concerned with two activities, namely assisting Industry with procedures for effectively managing industrial relations issues, and the development of appropriate industrial communications. The former assesses the suitability of present industrial relations systems and employment practices in order to develop appropriate guidelines and procedures to accommodate anticipated future developments. The latter continually assesses the attitudes and behaviour of men on mines so as to formulate proposals

for improving employer-employee communications, and the resolution of conflict.

INDUSTRIAL HYGIENE BRANCH (IHB)

Manager: Dr A J Kielblock
Number of professional posts: 24
Number of technical posts: 12
Total number of posts: 58

The Industrial Hygiene Branch is concerned with air pollution and its measurement, control and effects on the worker. Research on work stress includes monitoring the effects on workers of environmental factors such as heat and cold, noise, vibration and barometric oscillations. Much effort is given to the improvement of acclimatization procedures and to examining the nutritional status of recruits to the Industry. The Branch also assists in assessing hazards and in devising methods to safeguard workers. Research and services are provided to outside organizations on a contractual basis.

MINING BRANCH (MIB)

Manager: Mr E R Tupholme
Assistant Manager: Mr C J van den Bergh
Number of professional posts: 32
Number of technical posts: 19
Total number of posts: 73

The Mining Branch is responsible for conducting trials and financial evaluations of new mining methods and associated equipment. The human engineering aspects of mechanized mining are also investigated.

ROCK MECHANICS LABORATORY (RML)

Director: Dr A R Atkins
Assistant Director: Dr N C Gay
Number of professional posts: 27
Number of technical posts: 8
Total number of posts: 40

The Rock Mechanics Laboratory is engaged in designing mine layouts with the aim of minimizing the effects of rock pressure. Improved support systems are being developed to control the fractured rock around deep excavations. Work is taking place underground and in the laboratory to develop new approaches in the design of mine layouts and support systems.

STOPING TECHNOLOGY LABORATORY (STL)

Director: Mr R G B Pickering
Number of professional posts: 22
Number of technical posts: 4
Total number of posts: 26

The main objective of the Stoping Technology Laboratory is to develop, for gold mines, new stoping methods and machinery to improve productivity, profitability and working conditions. The three approaches being adopted are the improvement of conventional stoping techniques, the development of mechanized systems for mining with blasting and the development of such systems for mining without explosives.

OFFICIALS

RESEARCH ADVISORY COMMITTEE

M D G Salamon
Research Adviser
Chamber of Mines of South Africa
(Chairman)

N C Joughin, H Wagner
Assistant Research Advisers
Chamber of Mines of South Africa

J A Waddams, E Schmid
Anglo American Corporation of South Africa Limited

A L Coetzee, J J Geldenhuys
Anglovaal Limited

G S Lee, P N Harris
General Mining Union Corporation, Limited

O Davel, B Moore
Gold Fields of South Africa, Limited

H Scott-Russell, R C Bertram
Johannesburg Consolidated Investment Company, Limited

M A Watson, G T G Emere
Rand Mines (Mining & Services) Limited

COLLIERIES RESEARCH ADVISORY COMMITTEE

H Wagner
Assistant Research Adviser
Chamber of Mines of South Africa
(Chairman)

M D G Salamon
Research Adviser
Chamber of Mines of South Africa

N C Joughin
Assistant Research Adviser
Chamber of Mines of South Africa

C H Wiggett
Anglo American Corporation of South Africa, Limited

D J van Niekerk
General Mining Union Corporation, Limited

K P Schleicher
Gold Fields of South Africa, Limited

R Morris
Johannesburg Consolidated Investment Company, Limited

F K Purcell
Rand Mines (Mining & Services) Limited

C O Esterhuysen
Iscor Limited

B A Brislin
Kangra Holdings (Pty) Limited

B J Love
Lonrho South Africa, Limited

R Hemp
Rand Mines (Mining & Services) Limited
representing Sub-Committee of Group Environmental Engineers

RESEARCH REPORTS

Research reports are produced on behalf of, and for, the members of the Chamber of Mines. They are detailed records of work conducted on specific research and as they often contain confidential information such as comparative evaluations of manufacturer's equipment they are not available to the general public. Research reports can only be obtained by written request to the Research Adviser.

PUBLICATIONS

GOLD

GENERAL

The pigeon-hole syndrome: some thoughts on university education in engineering design.
TJ SHEER
Brief No. 1 (1985), p. 50-51

The role of automation in the mining of tabular deposits at depth.
MDG SALAMON
Symposium on Automation for Mineral Resource Development,
Brisbane, Queensland, 9-11 July 1985, ed. A.W. Norrie and D.R. Turner, p. 7-11.

ENVIRONMENTAL PROBLEM

The insulation of mine airways.
P BOTTOMLEY.
Gencor Group Environmental Symposium, Rustenburg, 2 May 1985, 26p.

The reduction in heat flow due to the insulation

of rock surfaces in mine airways.
P BOTTOMLEY.
2nd Mine Ventilation Symposium, Reno, Nevada 23-25 Sept. 1985, p. 457-464.

Energy recovery turbines for use with underground air coolers.
R. RAMSDEN.
2nd Mine Ventilation Symposium, Reno, Nevada, 23-25 Sept. 1985, 10p.

Desalination of mine water.
RDC SHONE and RC HARRIES.
Symposium on Mine Water Systems, Sun City, 6-8 March 1985, 18p.

Contribution to the paper: 'Air temperature increases in airways', by R. Hemp, January and February 1985.
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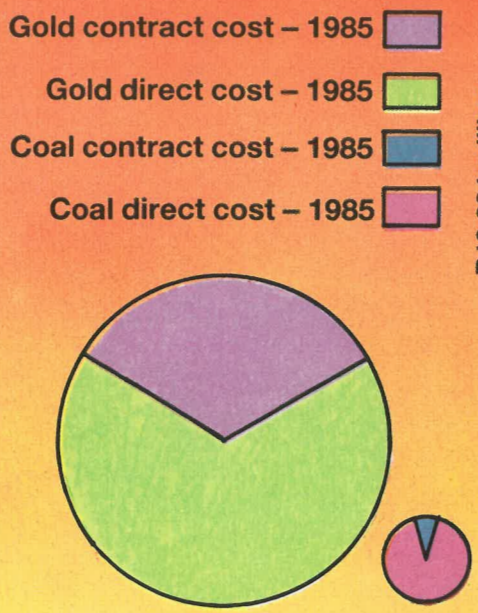
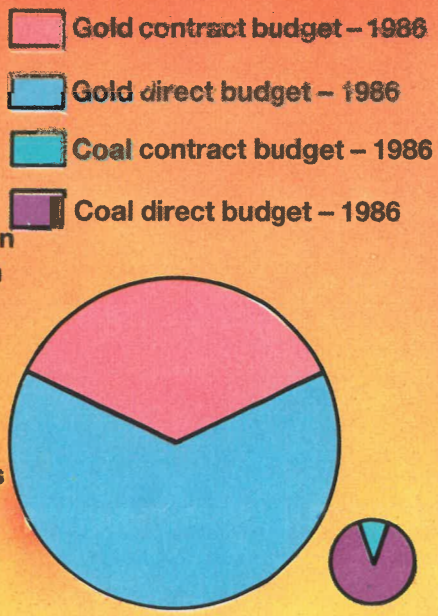
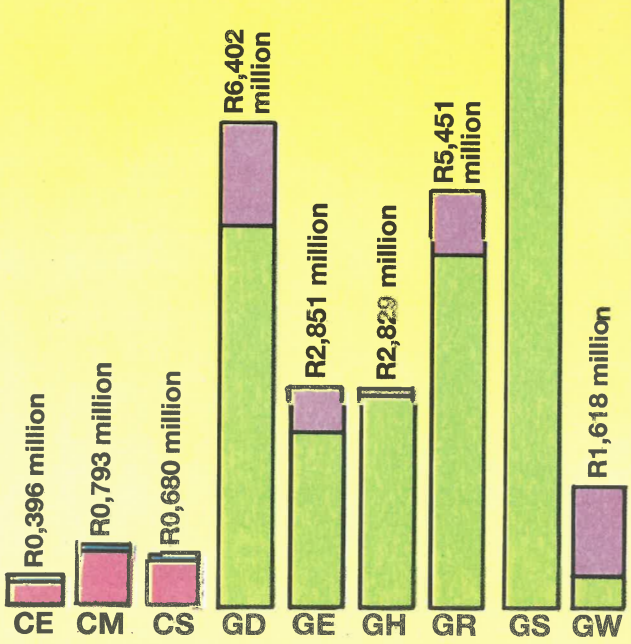


Key:
Coal
CE – Environment
CM – Mining
CS – Strata control
Gold
GD – Gold Distribution and exploitation
GE – Underground environment
GH – Human
GR – Rock pressure
GS – Stoping
GW – Special projects

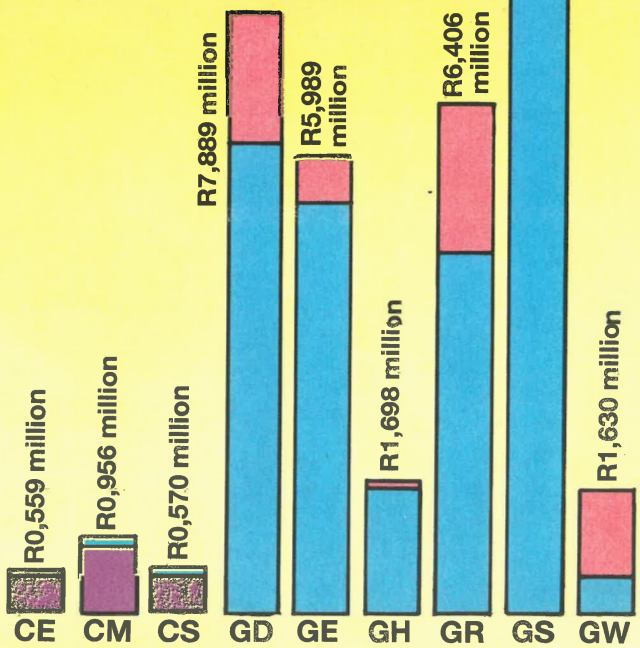


Gold direct costs	R24,878 million
Gold contract costs	R13,657 million
Total gold costs	R38,535 million
Coal direct costs	R 1,756 million
Coal contract costs	R ,113 million
Total coal budget	R 1,869 million
TOTAL	R40,404 million

Gold direct budget	R28,807 million
Gold contract budget	R15,810 million
Total gold budget	R44,617 million
Coal direct budget	R 1,865 million
Coal contract budget	R ,220 million
Total coal budget	R 2,085 million
TOTAL	R46,702 million



Research and development actual costs 1985



Research and development budget 1986

Financial Analysis