Progress in the development of mechanized stoping methods

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SYNOPSIS

Progress during the last two years in the Chamber of Mines programme for the development of mechanized stoping methods is reviewed, and advances in the basic technology are outlined. Specifically, advances in the understanding of rock fracture around stope faces, in rockbreaking techniques, in rockhandling techniques, and in engineering are described. The state of development reached with mining systems based on cutting, impacting, and blasting is also described.

SAMEVATTING

Die vordering wat daar gedurende die afgelope twee jaar met die Kamer van Mynwese se program vir die ontwikkeling van gemeganiseerde afboumetodes gemaak is, word in oënskou geneem en die vooruitgang in die basiese tegnologie in hooftrekke beskryf. Veral die vordering wat betref die begrip van rotsbreuke om afboufronte, rotsbreektegnieke, rotshanteringstegnieke en in ingenieurswese word beskryf. Die ontwikkelingstadium wat bereik is met mynboustelsels wat op sny-, slag- en skietwerk gebasseer is, word ook beskryf.

Introduction

The Chamber of Mines commenced its investigations into mechanized stoping methods for gold mines a little more than ten years ago. In 1975, after a number of technological advances and with an increased understanding of the problems, the possibility of mechanizing stoping no longer appeared so remote, and a greatly expanded programme of machine development was undertaken. The objectives of this programme, the problem areas, and the associated technology were defined, and the basic mining systems under consideration were described in a paper written shortly after the commencement of the enlarged programme[1].

The purpose of the present paper is to review the progress made in the development programme since the time of writing of the previous paper. For readers unfamiliar with the Chamber of Mines' programme, the present paper should be read in conjunction with the earlier one.

The same development programme is being adhered to. Progress has been in the form of an increased understanding of the problems involved, the solution of some of these problems, the identification of new problem areas, the achievement of advances in basic engineering technology, and the elimination of unrewarding approaches.

Rock Fracture at Stope Faces

Perhaps the most far-reaching progress is in the increased understanding of the way in which the rock around stope faces becomes fractured by stress and the way in which geological features affect the fracture pattern. Two years ago it was known only that the rock was fractured to a depth of about 0,5 m ahead of the face, and that at times the face could be solid and at other times so intensely fractured that the rock had the consistency of gravel. It is now known that the fracturing is far more extensive than this, and that it can be exploited very advantageously by some types of machine while being an insurmountable obstacle for others.

The formation of fractures around stope faces is being observed where mining experiments with mechanized rockbreaking are being conducted and where it is possible for the stress-induced fractures to be observed without the confusion caused by the effects of blasting. Observations have now been made over a wide range of circumstances, extending from shallow, unstressed conditions to very deep, highly stressed conditions.

The reef-boring experiment conducted by the Chamber of Mines was highly instructive in that it was carried out under very low stress conditions at a depth of 1300 m, and it was possible for the formation of fracturing around an opening of well-defined geometry to be observed. In this experiment, a series of overlapping holes, 550 mm in diameter, were drilled in the plane of the reef. No fracture occurred around the first few holes, but, as the span of the opening was enlarged and the stress concentrations on the rock ahead of the opening increased, a stage was reached where the stress was equivalent to the uniaxial compressive strength of the rock. At that stage, the sides of the opening became fractured, as might be expected. As the span of the opening was enlarged beyond this condition, the fracturing around the opening became more extensive. Once extensive fracturing has occurred around an opening, it is no longer meaningful for stress to be used as a measure of the incidence of rock failure because the shape of the opening cannot be defined; the energy-release rate is a more useful criterion for assessment of the extent of fracture.

In the reef-boring experiment, when the span of the opening had reached 6 m, the energy-release rate was about 0,5 MJ/ca, and the fracture zone extended a few hundred millimetres into the rock at the edge of the opening. Observations in other circumstances have revealed that, where the energy-release rate is about 10 MJ/ca, new fractures form about 2 m ahead of the face and the fractures are typically 50 to 500 mm apart. Where the energy-release rate is 30 MJ/ca, the fractures

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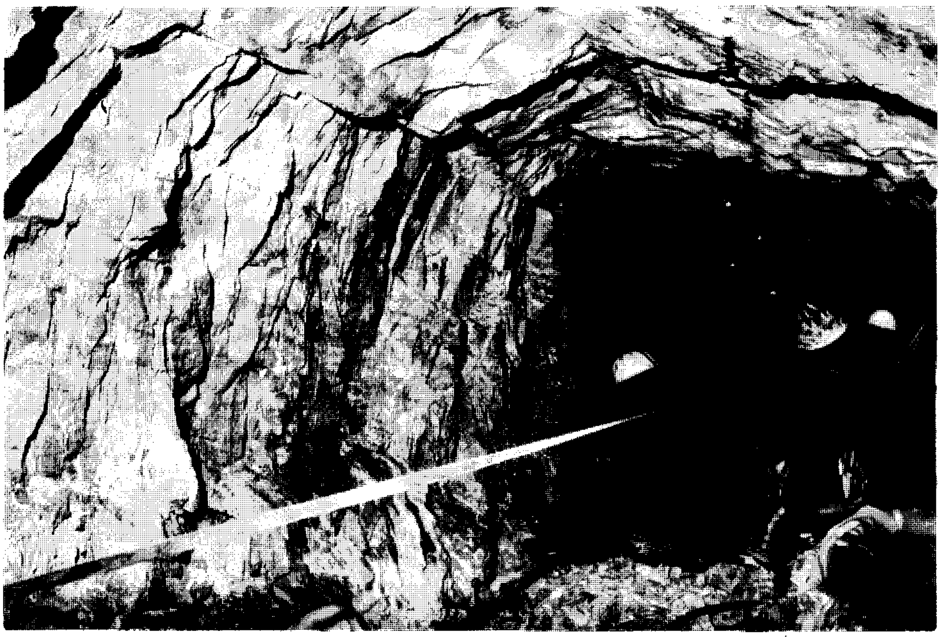

Fig. 1—Fracture in the rock ahead of a stope face. The photograph was taken from inside a heading mined into a stope face

form about 5 m ahead of the face and are typically 10 to 100 mm apart. Fig. 1 illustrates the fracture in the rock a few metres ahead of a stope face subjected to 25 MJ/ca. Where the energy-release rate was about 100 MJ/ca, it was not possible to observe more than 7 m ahead of the face, but the rock was intensely fractured for this entire length.

New fractures form ahead of the face in response to mining of the face. No evidence of time dependency has been observed. When faces are not advanced for long periods, virtually no new fractures are formed during the periods of standing.

The fracture pattern at a specific energy-release rate is regular and systematic[2], and occurs without any significant seismic activity[3]. However, this pattern is disturbed by geological features; for example, it is fairly common to find more intense fracturing on one side of a fault than on the other. Where a geological discontinuity such as a near-vertical fault is inclined at a small angle to the face, it may interrupt the normal development of the fracture pattern and relatively solid rock could be encountered at the face. Such circumstances are associated with violent rock fracture.

Horizontal discontinuities such as parting planes also affect the fracture pattern markedly. Fractures tend to terminate at parting planes. Thus, where there are two planes within the width of the stope, it is common for the rock between partings to be intensely fractured and the rock outside the planes to be fractured to a much lesser extent than it would have been had there been no parting planes. Where two parting planes occur at a distance apart that is convenient for forming the hangingwall and footwall of a stope, the easiest mining conditions arise since the rock between the partings can be removed readily, leaving a smooth and strong hangingwall and footwall. Where two planes are too close to form a convenient hangingwall and footwall, the most difficult mining conditions arise. With mechanized rockbreaking, it is more difficult to break the rock beyond the parting planes, and severe side loads are generated against the breaking tool. With blasting, it is more difficult to define the footwall or hangingwall, and a very irregular surface results with steps and hollows, creating difficulties in cleaning broken rock off the footwall and hindering the movement of machinery. The absence of parting planes near the reef represents intermediate conditions; the positions of the hangingwall and footwall can be chosen at will, the rock would be uniformly fractured, and, while the footwall and hangingwall would be rough, they would be less likely to have steps and hollows.

Rockbreaking

The rate at which rock can be broken by any direct mechanical method is determined by the size of the fragments produced by the method and the power that can be applied. The performance of a method used to break quartzite can be estimated from the following expression[1]:

$$E = \frac{450}{a}\ \mathrm{kW.h/m^3},$$

where E is the specific energy needed to produce fragments of mean size, a, in millimetres.

In practice, the power that can be applied is limited to a few tens of kilowatts by circumstances in the stopes and by the ability of the breaking tool to transmit the power. With the limitation on power and a limitation on size of fragments that can be produced, it is extremely difficult to attain acceptable rockbreaking rates. Considerable effort has been devoted to finding ways of overcoming these limitations. Two approaches have emerged that now make it possible to achieve very much faster breaking rates. These are the application of high-pressure water jets to cutting tools, and the matching of the blow energy of impactors to the intensity of the fracturing on stope faces.

A discovery was made that, if moderately high-pressure water jets are directed at the edges of a drag bit, the forces required to drive the bit through the rock are reduced very significantly[4]. Conversely, very much deeper cuts can be made for the same applied forces. The explanation for this effect is that water penetrates the cracks by exerting pressure on the surfaces of the cracks[5].

Water jets at a pressure of 30 MPa and a flow-rate of 0,5 l/s have been applied with great success to a number of drag-bit cutting machines working underground. It has been found possible to cut about five times as deep with the water jets. Cuts of 10 to 15 mm per pass can be made in the hardest quartzites, and cuts up to 50 mm per pass have been made in more-fractured rock. Instantaneous cutting rates have been increased from between 2 and 5 ca/h to a rate of at least 7 ca/h in the hardest quartzite.

In principle, the improvement that water jets make to drag-bit cutting could also be obtained with other forms of cutter such as disc cutters. However, the full advantages may not be obtained since the geometrical configuration of disc cutting is not as amenable to the use of water jets as is the configuration of drag bits.

In the course of studying the mechanism of drag bits, it became apparent that the application of a small transverse force to an indentor made it possible for the indentor to penetrate the rock with a significantly reduced normal force[6]. This finding could be of considerable value when applied to roller cutting. It is planned to investigate the effects of transverse forces, skidding, and water jets on roller cutters by use of a new laboratory test rig that is at present under construction. It is expected that a significant improvement in the performance of roller cutters can also be obtained.

Several experiments have been carried out with impactors having blow energies in the range 500 to 2500 J. It was expected that the size of the fragments produced by the different impactors would be in proportion to the blow energy. In the experiments that were conducted in relatively unfractured rock, it was found, allowance being made for the imprecise nature of the measurements, that the breaking rates obtained were consistent with the specific energy as expressed above, and confirmed the expectation that the fragment size is in proportion to the blow energy of the impactor. For example, the swinghammer miner, which delivered blows of 500 J at the rate of 18 blows per second, broke rock subjected to an energy-release rate of less than 10 MJ/ca at a rate of about 1 ca/h. This corresponds to a mean fragment size of 50 mm. Similarly, an impact ripper delivering blows of 2500 J at a rate of 4 blows per second to rock subjected to 10 MJ/ca broke the rock at a rate of more than 5 ca/h, which corresponds to a mean fragment size of about 250 mm.

In another experiment, conducted in relatively fractured rock subjected to an energy-release rate of about 30 MJ/ca using an impactor delivering blows of 1500 J at a rate of 5 blows per second, breaking rates of 10 ca/h were obtained on average, and rates of up to 30 ca/h were obtained in those parts of the face where the rock was more intensely fractured. An impactor with this blow would produce fragments of about 150 mm in size in unfractured rock, compared with the typical spacing of fractures of 10 to 100 mm in rock subjected to an energy-release rate of 30 MJ/ca.

Clearly, where the blow of a hammer is such that the dimensions of the fragments it would produce in unfractured rock are greater than the spacing between the stress-induced fractures at a stope face, then the fractures greatly assist the breaking process, and breaking rates will be obtained that are very much higher than that determined from the expression for specific energy. Conversely, if the spacing between fractures is greater than the fragment size that would be produced by the hammer in unfractured rock, there will be little advantage and the rock would be broken up as though it were unfractured.

Most mining is carried out in rock subjected to energy-release rates of more than 10 MJ/ca, which would have fractures spaced typically from 50 to 500 mm apart. Thus, the use of impactors delivering blows of about 5000 J, which would produce fragments of about 500 mm in solid rock, makes it feasible that extremely high rockbreaking rates can be achieved throughout the mining industry. Mining experiments will be carried out during 1978 with hammers having blow energies as high as 8000 J.

Rockhandling

The development of rockhandling techniques for stoping in gold mines has been mainly through the adaptation of known rockhandling principles.

For the purposes of moving broken rock out of a stope panel, three devices have been selected for further consideration: scrapers, reciprocating-flight conveyors, and shaker conveyors. There does not seem to be any merit in the use of load–haul–dump devices in narrow stoping since scrapers would be superior in most respects. Work on armoured-chain conveyors[1, 7] has been discontinued because they have been superseded by reciprocating-flight conveyors. Vibratory conveyors have not received further attention because the only advantage they have over shaker conveyors is their silent operation. Belt conveyors cannot find application unless there are major advances in loading and support techniques.

Scrapers have received little attention except in experiments with rockbreaking machines. However, with the realization that reciprocating-flight conveyors are the only alternative to scrapers for stoping with blasting, it is intended to devote more effort to the improvement of scrapers. Most effort has been concentrated on the reciprocating-flight conveyor. Conveyors of this type have been tested in stopes mined with blasting and with rockbreaking machinery, and very encouraging results have been obtained. A hydraulically powered shaker conveyor has been tested in a stope panel with satisfactory results.

The three devices under consideration have distinctly different characteristics that determine their areas of application. The only characteristics that they have in common are that their conveying rates improve with steepness of dip and that their performances deteriorate as their lengths increase.

Scrapers

Scrapers are used extensively in the industry, and their features are well understood. Their good features are that they are reliable, they are relatively inexpensive, and their cost of operation is relatively low. They are insensitive to rock properties and are particularly good with small rock fragments. Starting under load is easy in that it can be arranged that the scoop and ropes are not buried under the rock pile. Scrapers are very flexible in terms of irregularities in the reef.

A disadvantage of scrapers is that they have low rockhandling capabilities — about 10 t/h when used in a panel. The capability falls off drastically as the length is increased. The length is normally limited to 40 m, and, on some mines seeking very rapid rates of face advance, the panel length has been limited to 20 m. This feature is particularly disadvantageous when scrapers are used with machines that break rock continuously, since the rockhandling rate is not constant along the face. Other adverse features of scrapers when used with rockbreaking machines are that the scoop cannot approach close enough to the breaking tool to clear rock from the tool, and that the scoop cannot pass the machine. Face scrapers have no bunkerage; they are dangerous, and no other operations can be carried on in the path of the scoop, precluding waste sorting in the stope.

Reciprocating-flight conveyor

The good features of reciprocating-flight conveyors are their extremely low height, good bunkerage capacity, and great rockhandling capacity (about 100 t/h). They are extremely rugged and can be used in blasting stopes, or with mechanized rockbreaking, where heavy machines can be mounted on them. They are very safe, and other operations can be carried on in the stope provided these do not interfere with the flow of rock. They are reasonably insensitive to rock properties, but small fragments increase wear and are not conveyed as effectively as are large fragments. Articulation is reasonably good since the conveyors are made up of sections 1,5 m long with a fair degree of angular movement at the joints. It is possible to have conveyors 40 m long, but they cannot be much longer than this unless the rock to be conveyed is free of small fragments.

The disadvantages of reciprocating-flight conveyors are high cost, vulnerability to corrosion and wear, and large mass. Their high cost is likely to restrict them to applications where high rates of face advance can be obtained. The wear life of the conveyors is a major concern, and much of the development has been directed at improving their resistance to wear and corrosion. It has been possible to arrange wear-resistant replaceable surfaces in most of the wear-prone parts. However, the cost of operation almost certainly will be significantly higher than that of scrapers. The large mass makes it necessary to advance the conveyors under power, but this is not a serious disadvantage since the advancing system also makes it possible to load the conveyor by forcing it into the rock pile. Starting under a heavy load of blasted rock with a high proportion of fine fragments can be difficult.

Shaker conveyors

The good features of shaker conveyors are their low cost, reliability, excellent wear life, and an operating cost that could be less than that of scrapers. They are safe and are very convenient for waste sorting. They are insensitive to rock properties, although clay minerals in the rock can cause starting difficulties if the conveyors are left standing full of rock for long periods. Depending on the conveying rate required, they can be made of a light construction so that they can be moved or extended easily. The conveying rate is in the range 20 to 50 t/h, with moderate bunkerage capacity. Articulation is moderately good but depends on the length of the conveyor. It is possible to have conveyors 100 m long, but they have to be made up of long sections with little angular movement between sections to minimize the lost motion along the length of the conveyor.

A serious disadvantage of shaker conveyors is that a loader is required to get rock into them. Other disadvantages are that they are noisy and not sufficiently rugged to withstand blasting.

Loaders

The inability to lift rock in a stope or to move it a few metres back from the face has been recognized as a major obstacle in the development of more effective rockhandling systems. It is the absence of effective loading devices that restricts rockhandling systems to scrapers and reciprocating-flight conveyors. The only loader that has been made to work moderately well is a plough attached to an armoured face conveyor. This type of loader is extremely rugged and is capable of loading well in excess of 50 t/h. Its main disadvantages are that it requires an extremely rugged guide rail, such as the frame of an armoured face conveyor, and that it moves the rock only a short distance from the face.

More attention will have to be given to the development of loading devices. A technique considered worthy of investigation is flushing with high-pressure water jets.

Barricades

Barricades are a vital part of rockhandling systems for stopes mined with blasting. The main concerns with barricades are the human effort required to erect the screen, and a suitable material for the screen. Materials that have proved successful for the screen are rubber matting made from old vehicle tyres, and thin steelplates made from steel with a very high yield strength. Arrangements for decreasing the human effort involved in the erection of barricades will be discussed in the section dealing with mining systems for blasting.

Rockhandling in gullies

Scrapers are the most effective means of moving rock in gullies, their main disadvantage being that they are dangerous and obstruct access while they are in operation. Shaker conveyors are being developed for use in gullies where interruptions to the rock flowing from a stope with continuous rockbreaking machines would be unacceptable. A conveyor more than 100 m long is at present working moderately well underground. The development is still at an early stage, and many details at the ends of the conveyor still have to be resolved.

Support

Temporary support

In mechanized stopes, the installation of temporary support close to the face is a severe hindrance to the passage of machines. Therefore, it is essential that the mining system should be arranged in such a way that a line of rapid-yielding hydraulic props can be installed behind the machinery but as close to the face as possible.

With rockbreaking machines there is no difficulty in maintaining hydraulic props within 1,8 m of the face, and it is feasible that, with certain configurations of machine, they could be much closer than this. For a face advance of 0,6 m per pass of a machine, the unsupported span immediately behind the machine would be 2,4 m. Experience has shown that additional temporary support ahead of the prop line is required infrequently.

In the mechanization of stopes mined with blasting, the distance to the front line of support is a crucial consideration in determining the advance per blast. For a nominal advance per blast of 0,7 m, the nearest distance a line of hydraulic props could be installed is 2,1 m, giving an unsupported span of 2,8 m after the blast. For an advance of 1 m, the nearest distance is 2,5 m before the blast and 3,5 m after the blast. There are many circumstances under which the latter prop-free front would be considered unacceptably dangerous and that would restrict the mining system to shorter advances per blast.

In the design of mining systems, hydraulic props are frequently used for purposes other than hangingwall support, such as staking pusher rams and supporting barricades. Experience underground has shown that combining the support with other functions leads to numerous operational difficulties where the hangingwall is a bit weak or where the footwall is unduly rough. Mining systems that separate the support function from other functions are preferred.

Permanent support

It is a fundamental principle that permanent support should be installed as close to the face as possible. In mechanized mining with blasting, there is difficulty in installing timber packs close to the front line of hydraulic support because the packs interfere with the barricade supports and the advancing equipment, and because it is difficult to build the packs in the restricted space. The possibility exists that this difficulty could be avoided by the use of pipe-stick props as permanent support.

With mechanized rockbreaking, it is possible to install permanent support reasonably close to the face. Where the reef is sufficiently narrow for waste sorting to be carried out, it is possible to pack the waste within 3 to 4 m from the face. Large areas have been fully waste-packed in various mining experiments, and the pack has proved to be an excellent form of permanent support.

Waste packing has a beneficial effect on the fracturing of the rock at the face. In the early stages of mining, when the mined-out span is small, the waste pack has no effect on the energy release rate at the face so that the fracture that is necessary to facilitate mechanical rockbreaking is not prevented. When mining progresses to a stage where the waste pack comes under full pressure, the energy-release rate is prevented from increasing so that the intensity of fracturing around the stope does not become excessive. There is another effect on the fracturing of the rock at the face that is thought to be caused by the waste packs, although the mechanism of this is not fully understood; the face tends to be more intensely fractured than it would have been had it been mined without the waste pack, and this is possibly caused by the waste pack preventing fractured rock in the hangingwall and footwall from being squeezed into the excavation.

Engineering

Machines in gold-mine stopes are subjected to extremely harsh environmental conditions and very severe space constraints. It has been necessary to devote very considerable effort to the development of basic engineering techniques that would enable mineworthy machines to be built. The developments have been concerned with electric and hydraulic power systems, the movement of machines, and machine life and maintenance.

Electric power

It has been necessary to develop an electric-power system that permits frequent disconnection of machines, provides an independent supply to each machine, allows control devices to be incorporated, and is safe for workers in wet stopes. The system consists of a compact rail-mounted 200 kV.A transformer that supplies stope gully boxes by means of plug-in cables. There is a gully box for each machine, and the supply to the machine is by means of plug-in trailing cables. Each gully box contains earth-leakage protection and control circuits. Special features of the system are that all the electrical equipment can be disconnected or reconnected and defective equipment replaced by unskilled workers. If a fault develops on a machine, only the supply to the faulty machine will be interrupted. The system is safe for personnel by virtue of the earth-leakage protection, and by virtue of a control circuit that disconnects the supply if a circuit is opened. It is less likely than conventional mine power supplies to cause fires. Any number of control devices, such as temperature and level controls, can be incorporated readily. It has also been used successfully with remote control by radio.

The plug-in electric-power system has been developed to the extent where it is sufficiently reliable to be used in production.

Hydraulic power

Water-based hydraulic-power systems are being developed for economy, safety, and the avoidance of pollution in the workings. Very good progress has been made in the development of equipment for use with 5 per cent soluble oil-in-water emulsion. In collaboration with manufacturers, variable-delivery pumps have been developed that have good lives and efficiencies when operating at a pressure of 15 MPa. Valves in a variety of forms have been developed by some manufacturers. Several have been tested with good results, and it is expected that, within a short period, such valves will be readily available commercially.

A variety of impacting devices operating with 5 per cent oil-in-water emulsion has been developed and tested with encouraging results. Low-power rockdrills for hand drilling, high-power rockdrills for rig mounting, and high-blow-energy impactors have been tested. Progress has been achieved by attention to seal friction in the small devices, the selection of materials including plastic bearings, the surface treatment of materials, and careful geometrical design to avoid cavitation, which is more prevalent in the large devices.

A serious problem in the use of oil-in-water emulsion in mines is the maintenance of a stable emulsion on account of the poor quality of mine water. There are many grades of soluble oil, but a survey of mine waters has indicated that the high concentration of calcium and magnesium salts is such that, on many mines, a stable emulsion can not be formed with any of the grades. However, from laboratory tests it would appear that filtration to remove the suspended solids and softening to remove some of the harmful dissolved salts would make virtually any mine water amenable to the formation of stable emulsions.

Progress has been made in the use of mine water without any soluble oil for the powering of machines. A rockcutting machine that uses filtered mine water treated with a corrosion inhibitor is currently in operation underground.

Moving of machines

The improved rock-breaking ability shown by mining machines and the desire to achieve faster mining rates led to experiments with machines mounted on guide rails along stope faces. These have been so successful in controlling the movement and easing the passage of machines that they had been adopted for all the mining systems being developed.

Haulage chains have been used effectively for moving many machines along faces, but they interfere with other operations in the stope. Ram haulages and walking arrangements have been tested with a view to avoiding this problem. The ram haulages have been most successful and have completely avoided interference between different operations.

Moving forward of the guide rail is still problematic, mainly because the pusher rams are easily damaged.

Machine life and maintenance

Corrosion, abrasion, and lack of robustness are the main causes of the deterioration of stope machines in service.

External corrosion of steel fabrications can be controlled adequately with sacrificial coatings such as electrodeposited cadmium and electric-arc sprayed aluminium. Small items in storage underground, such as bolts, can be protected with zinc phosphate coatings. Where surface coatings are inadequate, such as on hydraulic props subjected to blasting, the use of stainless steel has been successful.

Internal corrosion in hydraulic cylinders can be controlled by the use of stable emulsions, or of flame-sprayed or wrought stainless steel.

Where abrasion is coupled with corrosion, such as in areas associated with the moving chain of a reciprocating-flight conveyor, rapid wear occurs. The corrosion products formed are abraded away, exposing fresh material, which again corrodes. Some success has been achieved with the use of low-alloy, roller-quenched, and tempered steels. It is felt, however, that eventual success will be achieved with the use of hard-facing alloys and high chromium–molybdenum castings, methods that are currently being tested.

Robustness has been achieved through the recognition of those machine configurations that are vulnerable to damage and through the use of high-strength steels. Machines have been subjected to rockfalls and rockbursts without any significant damage, and equipment can be designed to withstand blasting.

There is now little fear that a long machine life cannot be obtained. A rockcutting machine at Doornfontein that has been in operation for five years is still in good condition.

Progress has also been made in the design of machines so that they can be repaired by unskilled workers through the use of modules, and simple fixing and connecting methods, and in the training of machine operators to replace faulty modules. Operators of rockcutting machines at Doornfontein have kept their machines in working order for long periods without the need of skilled assistance.

Mining Systems under Development

Rockbreaking by cutting

These approaches have as their primary object the removal of as little rock as possible from the stope. They are meant for deep, narrow reefs, where they could lead to increased profits and improved working conditions. They do not lend themselves to rapid rates of mining and high labour productivities. The two approaches being followed are cutting of the rock from the stope face with sorting and packing of the waste rock in the stope, and boring of the reef out at a much narrower width than the stoping widths used in conventional mining.

Rockcutting

The total area mined in rockcutting experiments is now 55 000 ca. The development effort during the last few years has been directed at the achievement of a mining rate of at least 5 ca per shift and a labour productivity equivalent to that attained in conventional mining. Although for rockcutting to be economically viable it is not necessary to achieve these performance figures, a rate of mining slower, and a labour productivity lower, than those in conventional mining would make rockcutting unattractive.

Several features have been built into rockcutting systems, all of which have proved very successful. These are high-pressure water jets, which make it possible to cut the hardest quartzites at acceptable rates; mounting of the cutter on a guide rail, which permits faster moving; an inverted machine configuration, which avoids the obstruction caused by rock falling off the face during cutting; a ram haulage, which eliminates the interference between different operations caused by the haulage chain; a machine configuration that eliminates the need to drill finishing holes at the end of the slot; and techniques for cutting against the hangingwall, which decrease the effort involved in face preparation. With these improvements, two different mining systems were built with the emphasis on the investigation of rockhandling problems and the improvement of labour productivity.

In the first system, a rockcutter was mounted on a guide rail positioned close to the face. A line of hydraulic props was positioned behind the guide rail with a shaker conveyor behind the props. A secondary breaking device was mounted on the guide rail behind the rockcutter, and this, in turn, was followed by a loading plate and cross-feed conveyor that discharged broken rock into the shaker conveyor. Sorting was done from the shaker conveyor, which discharged the ore into a small car in the gully. In this system, the secondary breaking and rockhandling equipment were simply not able to keep up with the cutter. So that the performance of the cutter itself could be assessed, additional labour had to be introduced to supplement the secondary breaking and loading. It was then possible to achieve a mining rate of 6,0 ca per shift when averaged over a few months. On occasions, more than 12 ca were cut in a shift.

In the second system, a rockcutter was mounted on a reciprocating-flight conveyor, which served as a guide rail. The conveyor was placed close to the face, and it was visualized that most of the broken rock would fall directly onto the conveyor. A line of props was placed behind the conveyor, and sorting was done directly from the conveyor. At the end of the panel, the face conveyor discharged ore into a cross conveyor, which in turn discharged the ore into a car in the gully. Secondary breaking was done with pneumatic picks. In this system, the rockhandling arrangements were not able to keep up with the cutting machine. The rock from the face did not fall onto the conveyor as had been visualized and had to be lashed onto it. Rock on the conveyor above the cutter did not pass under the cutter readily, and a second discharge had to be added to the conveyor to permit rock on the upper part of the face to be conveyed while the cutter was working on the lower part of the face. Finally, there were severe difficulties at the discharge end of the conveyor.

Work studies to investigate the labour requirements of the system revealed that the work content was within the limits for an acceptable labour productivity; however, the incompatibility of rockbreaking and rockhandling equipment caused much enforced idle time so that the actual labour productivity was somewhat less than the target.

The main obstacle in the finalization of a mining system based on rockcutting seems to be the development of a device that will move broken rock from the face into a conveyor along the face.

Reefboring

The reefboring experiment using modified raiseboring equipment, which was commenced by Gold Fields of S.A. Limited, was continued by the Chamber of Mines. The main concerns with this approach were the stability of the fractured rock around the opening and the cutter life. To investigate the stability of the fractured rock, a series of 550 mm diameter overlapping holes was drilled in rock subjected to a low stress field. It was found that three overlapping holes could be drilled without difficulty, but, once the opening was large enough for the stress to cause failure in the rock at the sides of the opening, severe difficulties were encountered. At the stage when the tenth hole was drilled, the pilot hole was so distorted that it provided no stabilization for the reaming head. In addition, large pieces of fractured rock became dislodged, which either jammed the reaming head or had to be drilled at a very slow rate. It is clear that conventional raiseborer technology cannot be applied to the boring of the reef, particularly where the rock is more heavily stressed.

In the course of investigations into roller-cutters, it became apparent that no major developments were being made in roller-cutter technology. It was decided to discontinue underground experimentation and to continue the work by seeking a technological advance in cutters through laboratory experimentation.

Rockbreaking by impacting

Rapid rates of mining combined with good labour productivity can be obtained with rockbreaking by impacting. In addition, with narrow reefs, it is possible to sort and pack waste in the stope. Two approaches have been investigated: the swing-hammer miner and impact rippers. A little more than 1000 ca have been mined with these devices.

Swing-hammer miner

The mining system consists of a swing-hammer miner mounted on a reciprocating-flight conveyor positioned very close to the face, with a line of props immediately behind the conveyor. It was anticipated that the swing-hammer miner would break rock at the rate of 2 ca/h and deposit it directly onto the conveyor in a single process.

In the sense that the machine actually broke rock at rates approaching those predicted and that it loaded the rock onto the conveyor most effectively, it was remarkably successful. However, there are a number of features inherent in the machine that make it unattractive.

First, the angle of attack of the hammers is poor. When the hammers encounter a hard patch of rock that does not break readily, inclined fracture surfaces are formed. The configuration of the machine is such that the angle of attack becomes worse in relation to the inclined surfaces. Thus, the ability of the hammers to break deteriorates just when the rock is most difficult to break. Second, the poor angle of attack leads to a very poor bit life, an order of magnitude less than that which could be acceptable. Third, the machine is inherently mechanically complex and unreliable. Fourth, it is not possible to increase the blow energy very much without causing inordinate mechanical problems. Since it is possible to generate much higher blows more reliably and with more favourable angles of attack using impact rippers, it has been decided not to pursue the use of the swing-hammer miner and to concentrate on impact rippers.

Impact rippers

Mining systems for impact rippers are still very undeveloped. There are two major unresolved issues. The first is that there may be considerable difficulty in breaking beyond parting planes where the rock is intensely fractured on one side and relatively solid on the other. To contend with such conditions, it may be necessary to manipulate the hammer so that it can attack the rock at an appropriate angle. However, manipulation of the hammer is undesirable because it makes the machine more complicated and because the time available for hammering is reduced. The extent to which manipulation will be necessary depends on the effectiveness and the dimensions of the impactor. It is expected that, with short, very high blow-energy impactors, manipulation may not be necessary.

The second major issue concerns the method of attacking the face. By traversing the impactor parallel to the face and advancing the machine in the direction that the impactor is being traversed, it is possible to get the highest rockbreaking rates. This would require a rockhandling system with a very high surge capacity to ensure that, as the machine advances, it is not obstructed by the broken rock. This method of attack would produce large fragments that could be difficult to handle.

By attacking the face transversely and retreating along the face away from the broken rock, more manipulation would be required and a lower breaking rate would be achieved, but fragments of a more convenient size would be produced. Since the machine moves away from the broken rock, a rockhandling system of smaller capacity would suffice. The rockhandling systems being developed in association with rockcutting machines could be used with this method of attack.

To resolve these issues, a number of machines will be tested, each having different combinations of the features in question. One machine, which is being tested underground, has a highly manipulable impactor with seven different movements (Fig. 2). The articulation of the manipulator is such that the machine can dig gullies behind the reciprocating-flight coneyor on which it is mounted. The machine was designed to retreat from the broken rock and to test the feasibility of loading broken rock onto the conveyor by sweeping it with the impactor. While this machine has achieved an instantaneous breaking rate better than the 4 ca/h predicted, numerous mechanical difficulties have arisen that have prevented the attainment of acceptable mining rates.

Rockbreaking by blasting

The primary object of mechanization with blasting is the improvement of labour productivity. The achievement of improved productivity is inevitably coupled with faster mining rates. Most of the basic operations in conventional mining are either slow or labour-intensive. Although an improvement in any one operation would be a useful contribution, a major improvement requires improvement in all the basic operations, particularly those concerned with support, barricades, drilling, and rockhandling.

Reference rail

The underlying concept in the mechanization of these operations is the introduction of a continuous articulated reference rail parallel to the face, the various items of equipment associated with each operation being attached to the rail. The rail makes possible the application of more force or power in each operation and facilitates the movement and control of equipment. The reference rail could be integral with the equipment, such as would be the case if a reciprocating-flight conveyor were used.

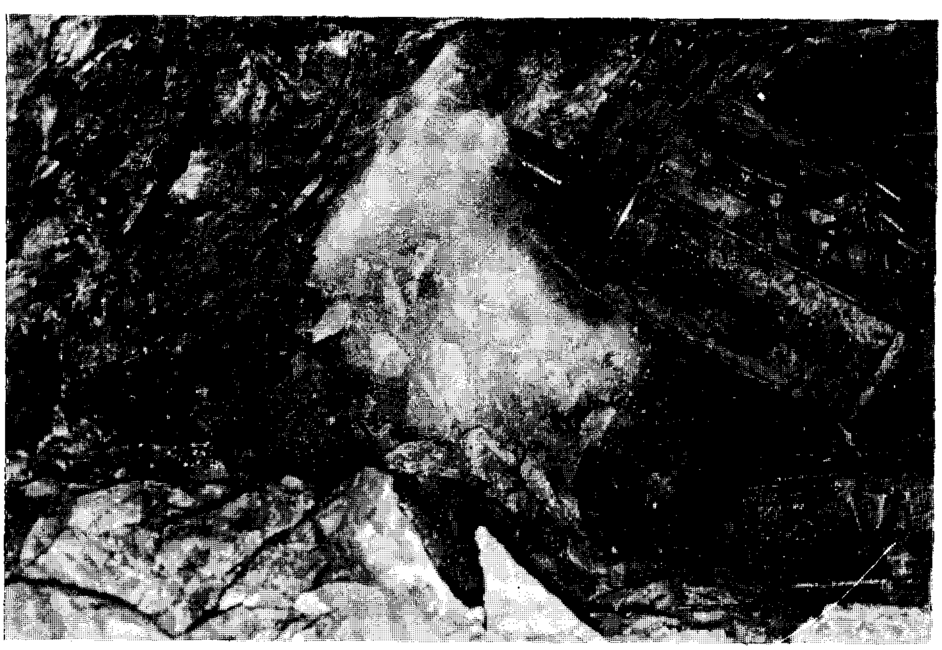

Fig. 2—An impact ripper in operation underground on a stope face subjected to an energy release of 10 MJ/ca. The dust-suppression sprays were turned off to permit photography

The control and steering of the reference rail are of great importance. There is a tendency for reference rails to slip down-dip. The slipping has to be prevented without hindering the advance of the reference rail. A technique that has been used successfully for control of the slipping consists of a long rope having one end attached to the rail and the other to an anchor station at the up-dip end of the panel. As the rail is advanced, it is forced to follow a slightly curved path, which corrects the slippage. Steering of the rail can be accomplished partially by arranging the attitude of the face slightly overhand and at right angles to the gullies. However, it is not always convenient for a face to be at this attitude, and there are always circumstances that make it necessary for the rail to be moved along the face so that a repositioning device is required.

Support

The advance of the reference rail is carried out by means of pusher rams that have to be staked at one end. The pusher rams have been troublesome devices mainly because of their vulnerability to damage. Experiments have been carried out with simple chocks attached to the pusher rams, the chocks being equipped with hydraulic props arranged in such a way that they form the front line of support. This arrangement provides a means for advancing the hydraulic props mechanically. The chocks have been moderately successful and have provided a measure of protection for the pusher rams. The main difficulty has been the control of the chocks during their advance over rough inclined footwalls and their re-alignment against the reference rail. The use of techniques developed for steep-seam coal mining can overcome this difficulty fairly readily.

Barricades

Two approaches to the mechanization of barricade erection are under investigation. In the approach using thin, high-strength steel plates, the barricade plates are attached to lifting arms, which are, in turn, attached to chocks. The raising and lowering of the barricades are done by a hydraulic cylinder attached to the lifting arm. In the other approach, rubber matting is attached to a rope arranged above the reference rail. Hydraulically powered lifting arms attached to the reference rail at 3 m intervals lift the rope against the hangingwall, the rope being pulled taut to form a light seal against the hangingwall. An advantage of this type of barricade is that it is independent of the roof support.

Drilling

The reference rail facilitates the mounting of drills on carriages, which permits the use of much more powerful drills than could be used in conventional stoping. Very high-powered drills cannot be manhandled and have to be mounted on fully manipulable drilling jumbos. Drilling jumbos with 5 kW rockdrills are being tested underground at present (Fig. 3). The main problem has been the removal of the jumbo from the reference rail for storage away from the blast. The jumbos are stored in a special parking carriage located behind the reference rail, and the transfer of the jumbo from the parking carriage to the reference rail is very time consuming. A new approach under consideration is to extend the reference rail into the south side of the adjoining panel and to park the jumbos on the extension of the reference rail behind a protective screen.

Alternatively, lower-powered drills could be mounted on simple rigs similar to those being developed by the mines. Simple rigs could be dismantled and the components manhandled for storage. The disadvantage of this approach is that the improvement in productivity would not be as great as with high-powered drills.

Hand drilling with a reference rail is most unattractive because the span between the front line of support and

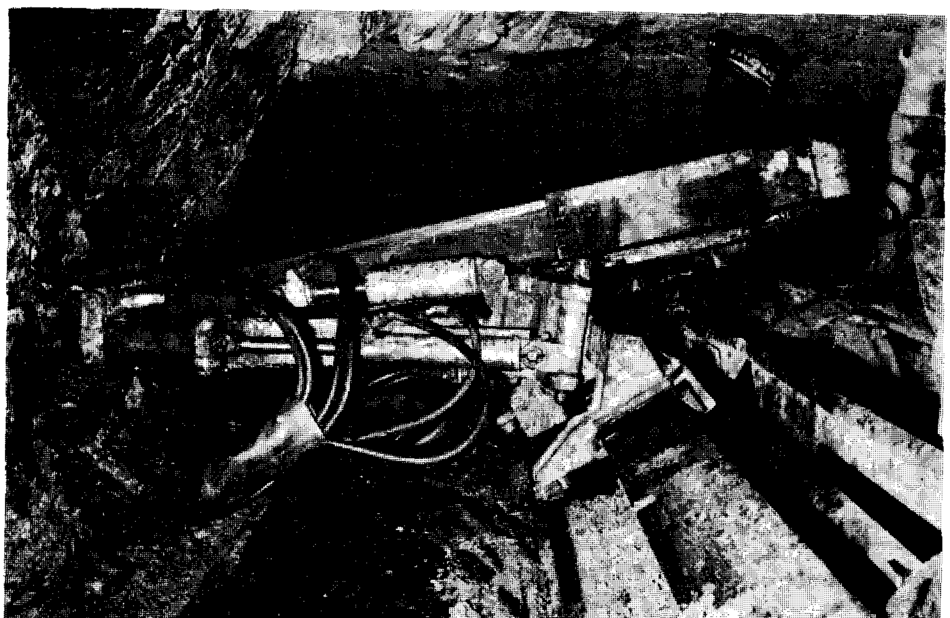

Fig. 3—A high-powered hydraulic drilling jumbo mounted on a reciprocating-flight conveyor

the face would have to be increased to accommodate the operator, and because it is important that good drilling accuracy should be achieved so that there is a smooth footwall to ease the passage of equipment.

Pneumatic drills are not favoured for very intensive mining. The peak demand on the compressed-air supply system will be accentuated, and their torque characteristics are unsuited to drilling in fractured rock at the thrust necessary to achieve fast drilling rates. Progress has been made in the development of water-based hydraulic rockdrills for stoping. Low-powered drills suitable for hand drilling or mounting on light rigs are being tested at present. These drills have improved torque characteristics and a mass of 20 kg. High-powered drills will be tested underground during 1978.

Rockhandling

It is perfectly feasible to use scrapers with the concept of a reference rail, and a system that will use a scraper is under construction. It consists of a heavy reference rail to which is attached chocks incorporating hydraulic props, a barricade with rubber matting, and a suspension rope and rig drilling with pneumatic drills. It is primarily intended to develop the self-advancing support and barricade features.

Systems using reciprocating-flight conveyors have received considerable attention. In an underground trial with the first prototype conveyor, a manually erected steel barricade, simple pusher rams, and hand drilling, a rate of face advance of 13,5 m per month was achieved on single-shift mining with a labour productivity of 27 ca per worker per month.

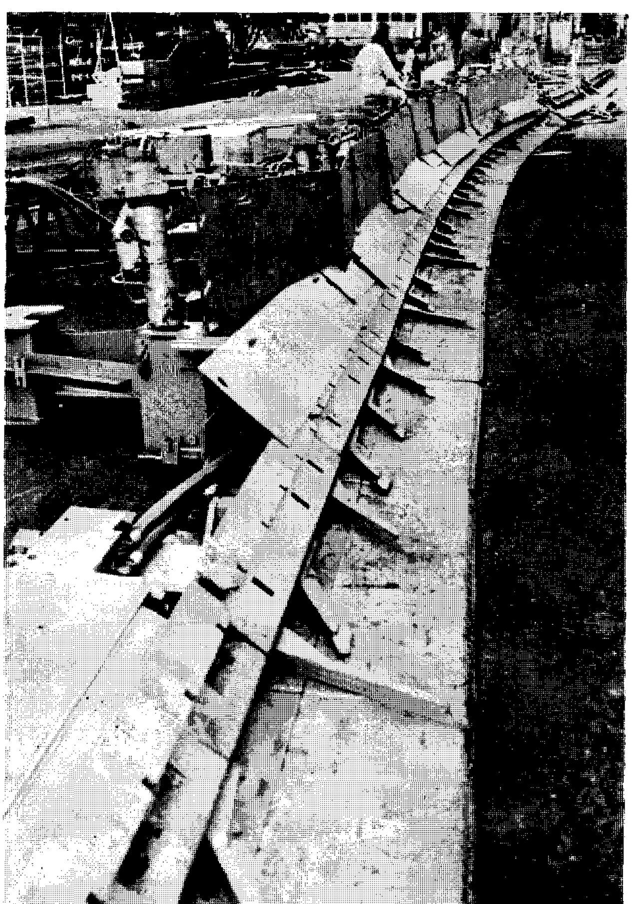

Fig. 4—A reciprocating-flight conveyor with barricade and chocks being assembled on surface

Another experiment using a reciprocating-flight conveyor is in progress, and has chocks and hydraulically operated drilling jumbos. The chocks, powered barricades, and drilling jumbos are all first prototypes, and numerous difficulties, which are normally associated with first prototypes, have been encountered. Consequently, it has not yet been possible to achieve a good performance with the full combination of equipment. However, work studies indicate that, with this combination of equipment, the potential exists for obtaining a productivity of more than 40 ca per worker per month. Fig. 4 shows the conveyor with its chocks and barricade prior to being tested underground. The barricade and chocks were subsequently modified.

Summary

(1) Knowledge of the nature and extent of fracture in the rock around stope faces has increased greatly. Fracture in the rock is of fundamental importance to the development of rockbreaking techniques, being highly advantageous to some techniques and detrimental to others. The possibility exists that impacting devices could achieve extremely high breaking rates provided that the blow of the hammer is sufficient to break through the thickest slabs of rock formed by the fractures.

(2) An important discovery was made that, if water jets are directed at the edges of an indentor, the forces required to penetrate rock are reduced substantially. This discovery has been applied very successfully in drag-bit rockcutting machines, and the possibility exists that it could be advantageous to other forms of cutter.

(3) Effort in the development of rockhandling equipment has been concentrated on reciprocating-flight conveyors, and good progress has been made. Scrapers and shaker conveyors also have a place in mechanized mining systems, and more effort needs to be devoted to their development. There is an urgent need to develop a device for moving rock from the face into a conveyor.

(4) No serious difficulties are encountered with support for mechanized rockbreaking, but with blasting the support is of great importance in determining the advance per blast.

(5) Good progress has been made in the development of engineering techniques, notably in the development of water-based hydraulic systems and in techniques for the avoidance of corrosion and abrasion. A plug-in electric system has been developed to the stage where it can be used in production.

(6) Mining systems based on rockcutting have been developed to an advanced stage. The concept of cutting, sorting, and waste packing has been proved under a wide range of circumstances. The rockcutting machines themselves have achieved the desired mining rate, but the rockhandling equipment has been unable to keep up with the rockcutters. A

rockhandling device for moving broken rock from the face into a conveyor is needed to overcome this problem.

(7) Mining systems based on impact breakers have potential for fast mining, for good labour productivity, and for sorting and waste packing. They are still in an early stage of development and there are several basic unresolved issues.

(8) Mechanized mining systems with blasting are intended to yield good labour productivity and fast mining. The concept being developed comprises a reference rail that permits the application of more power to the moving of supports, the erection of barricades, drilling, and rockhandling. Self-advancing chocks, powered barricades, and high-powered drilling jumbos are being evaluated underground in association with a reciprocating-flight conveyor.

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