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Non-explosive mining: An untapped potential for the South African gold-mining industry

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SYNOPSIS

Few innovations in the South African gold mining industry could have a more significant impact on improving profitability than non-explosive methods of mining. The far-reaching benefits of this approach are explained and the progress made through development work funded by the industry is described. Three methods are considered: impact ripping, slotting with abrasive waterjets and diamond saws, and breaking from drilled holes with waterguns and electric pulses.

Of these methods, impact ripping is the most advanced and requires only minor refinements before production applications can be initiated. Although this method, based on current performance, is expected to yield considerably increased profits, it is predicted that it could perform several times better than at present with further development.

The other methods of rockbreaking also show potential. Waterguns and electric rockbreaking would be attractive in unfractured rock for difficult geological conditions, and for confined areas such as gullies and development ends.

Methods based on slotting could be combined with any of the other methods to enhance their effectiveness and thus yield further improvements in profitability; also, they could be used to advantage in specific applications. All the discussed methods, therefore, deserve to be developed further.

SAMEVATTING

Min nuwighede in die Suid-Afrikaanse goudmynbedryf kan 'n betekenisvoller uitwerking op verhoogde winsgewendheid hê as plofstoflose mynboumetodes. Die belangrike voordele van hierdie benadering word verduidelik, en die vordering word beskryf wat gemaak is vanweë ontwikkelingswerk wat deur die bedryf gefinansier word. Drie metodes word tans ondersoek, naamlik slagskeurdelwing, gleuwing met slytende waterstrale en diamantsae, en breking uit geboorde gate deur waterkanonne en elektriese pulse te gebruik.

Van dié drie is slagskeurdelwing die gevorderdste, en dit moet slegs effens verfyn word voordat daar begin kan word om dit vir produksiedoeleindes aan te wend. Hoewel daar op grond van huidige prestasie verwag word dat slagskeurdelwing winsgewenheid aansienlik sal verhoog, word daar voorspel dat hierdie mynboumetode baie beter as huidiglik kan presteer as dit verder ontwikkel word.

Die ander rotsbreekmetodes toon ook belowende moontlikhede. Waterkanonne en rotsbreking deur middel van elektriese pulse sal 'n goeie uitweg wees vir ongebreekte rots onder moeilike geologiese toestande en vir beperkte ruimtes soos skraperslote en ontsluitgange.

Metodes wat op gleuwing gegrond is, kan met enige van die ander metodes gekombineer word om hulle doeltreffender te maak, iets wat winsgewendheid dan verder sal opstoot; en hulle kan in bepaalde aanwendings voordelig gebruik word. Al die metodes wat bespreek is, behoort dus verder ontwikkel te word.

Introduction

To ensure the long-term survival of the South African gold mining industry, which is faced with decreasing profitability, all options which allow more profitable mining operations need to be explored. These options include improving existing or developing new processes, the latter having an inherently greater potential for far-reaching and fundamental improvements. Although new technology has been introduced in some mining activities by applying or adapting developments from elsewhere, few and less significant changes have been made in the key operations of rockbreaking and rockhandling at the stope face because of the uniquely arduous geological and environmental conditions.

The direction developments should take to improve the operations at the stope face has long been recognized[1]. It is based on the understanding that the fundamental obstacle to major improvements is the use of explosives to break the rock. Although in itself an efficient process, blasting causes major difficulties and restrictions for all the subsequent activities of mining, beginning with rockhandling in the stope face, and it enforces a cyclic and sequential operation of mining.

Blasting is in fact the major cause of lack of mechanization, poor labour productivity, and poor utilization of capital and equipment. The desirable solution is therefore the introduction of non-explosive methods of rockbreaking. These permit the presence of operators during the breaking process and the simultaneous and continuous performance of all mining functions in a manner similar to mechanized longwall coal mining.

The benefits which can be derived from this approach can be summarized as follows:

- Continuous operation—a consequence of non-explosive methods of rockbreaking—enables high face advance rates and concentrated mining. This facilitates better utilization of resources and reduced expenditure on non-stoping activities. The productive portion of shift time can be increased because congestion in shafts can be avoided and transport facilities for workers improved. Ventilation and

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cooling requirements are reduced and the absence of noxious fumes from blasting permits further reduction in the quantity of fresh air required. Cost-effective methods of continuous rockhandling in the stope face can be extended to other areas, particularly in the gullies. Increased mechanization also becomes economically attractive for materials handling and other service activities. Full-cover mechanized support can be considered for difficult ground conditions.

- Reduced dilution of ore can be achieved by the better control of the hangingwall resulting from less violent rockbreaking and mechanized methods of horizon control. Dilution is also reduced by increasing the panel length, thereby decreasing the number of strike gullies; these furthermore can be of small cross-section. The mining of waste rock from development can be reduced by better methods of rockhandling in gullies which leads to a decrease in the numbers of boxholes and an increase in the spacings of dip gullies and cross-cuts. Furthermore, in the case of narrow channel widths, waste sorting can be conducted in the stope and the waste used as backfill. Thus the grade and the reef hoisting capacity can be improved.
- Safe operating conditions can be provided for workers because they can operate from between rows of supporting props. Also, unsupported spans are less, and backfill can be installed close to the face.
- The possibility of gold losses is reduced, because far less fines are being produced. Losses of equipment are far less likely in well-supervised areas of continuous and mechanized mining. Also, damage from blasting will be eliminated, enabling the use of lighter and less costly equipment.
- Highly mechanized operations require significantly less labour for the same production. Therefore, aspirations for more highly skilled and better-paid jobs can be satisfied, the effects of the rise in labour costs can be combated, and efforts to accommodate a permanent labour force can more easily be met. At the same time, improvements in safety, the reduction of physical effort, and the improvement in the environmental conditions should be conducive to higher motivation and productivity.

The benefits of non-explosive methods of rockbreaking are therefore numerous and address many of the long-term concerns of the industry.

Promising Developments

The industry and COMRO have endeavoured to identify and improve those non-explosive methods of breaking quartzitic rock which can achieve adequate rockbreaking rates at acceptable costs and which do not release unacceptable amounts of heat or pollutants into the underground environment[2]. Of all the different rockbreaking methods investigated, only three are presently thought worthy of development: impact ripping; slotting with abrasive waterjets and diamond saws combined with secondary methods of breaking; and breaking from drilled holes with waterguns and electric pulses. The development status of these methods varies from the most advanced—impact ripping, a completely integrated prototype mining system—to the most recently investigated ones in the feasibility study phase.

Impact Ripping

The most advanced method is impact ripping, in which a powerful hydraulic hammer is used to break the rock off the face. The major reason for the effectiveness of this method, and in fact a precondition for its effective operation, is the stress-fractured state of the rock.

The machine configuration is shown in Fig. 1, and the complete system and the stope layout in Fig. 2[2]. Although this system can perform all the necessary mining functions such as rockbreaking, rockhandling and the advancing of support, it is exceedingly simple. Simplicity has, from experience, been found crucial for a successful mining system. It was brought about by the ability of the machine to perform a simultaneous loading function, pushing the mined rock on to the face conveyor while the footwall is being mined.

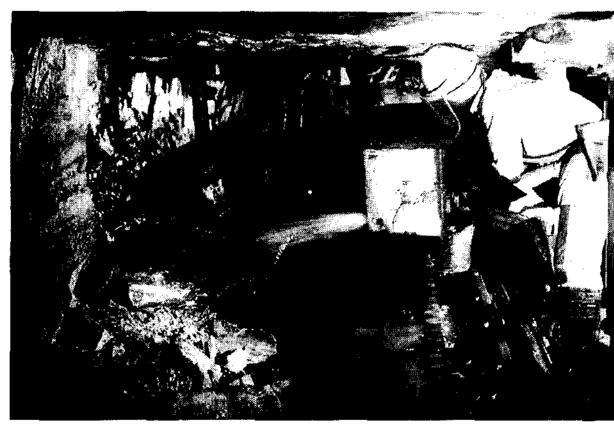

Fig. 1—Impact ripper in underground operation

Further simplification was achieved by powering the complete system with high-pressure water. Because water is a low-cost and non-polluting fluid, only a one-way distribution system is required; the return water can be discharged in the stope. This simplifies the hydraulic circuit for the face equipment and enables the powering system to be used for hydraulic props and other secondary functions, such as dust suppression and water-jetting of fines. Simultaneously, cooling can be provided if the water is refrigerated. Lastly, further simplification and cost benefits can be gained by obviating the need for underground pumping equipment by utilizing the power available from the hydrostatic pressure in the water feed line in the shaft.

Many other innovative concepts have been incorporated into the system, such as a simple articulated reciprocating face conveyor and a device at the top end of the conveyor which allows the machine to mine the otherwise unreachable top corner of the face. Operators work within the protection of densely spaced hydraulic supports, and safety is further enhanced by narrow unsupported spans and the installation of backfill as close as 2,5 m from the face.

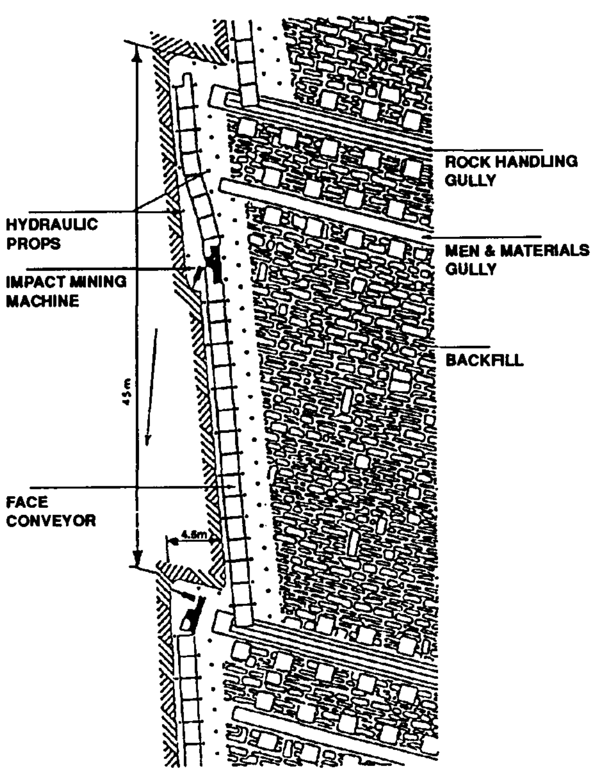

Fig. 2—Face layout for the impact mining system

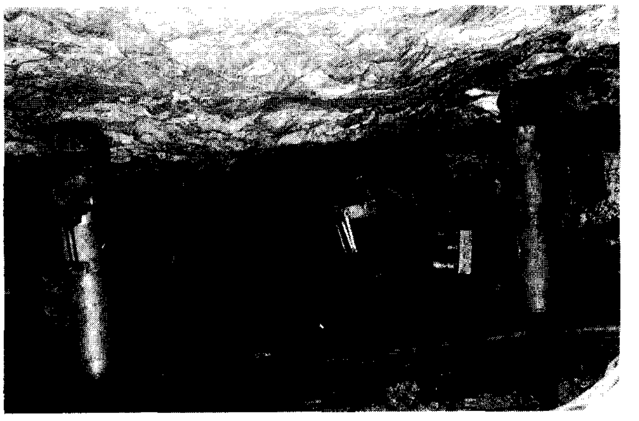

Fig. 3—Hangingwall mined by impact ripper

Impact ripping is effective in reducing dilution of ore because it can mine the hangingwall to reasonably close tolerances (Fig. 3). Overbreak occurs less frequently than in explosive mining owing to the considerably lower breaking energies of impact mining. These are approximately 4 kJ per blow of the impact hammer, compared with the 3000 kJ per shot fired for mining with explosives. Dilution can be considerably further reduced if the reef is narrower than the stoping width and if it can be visually distinguished from the waste. In this case waste can be sorted from the slow-moving face conveyor and stowed in the back area. This provides the usual benefits of backfill, with the added advantage that it costs only approximately 50 per cent of the cost of tailings backfill. This generates important economic benefits as a consequence of the higher grade of ore leaving the stope.

The results produced with the latest prototype system are a mining rate of 2,1 m^2/shift hour at a stoping width of 1,15 m and a system utilization of 43 per cent over a continuous period of eight months. Face advance rates on single-shift operations were equivalent to double-shift operations for conventional mining. The economic breakeven point has been passed for this system, and it is estimated that on current performance the profitability for a particular mine would be increased by R30 per ton milled. Impact ripping has been estimated to be applicable to 50 per cent of the known ore reserves in the industry.

In assessing the present achievements and goals for impact ripping it would be appropriate to compare them with the performance of longwall coal mining in the 1950s. Work was conducted by COMRO to assess the longer-term potential for impact mining. Improvements in rockbreaking rates were estimated based on a theory by Grantmyre and Hawkes[3] which states that

$$R \sim B^{1.5} \quad (1)$$

if R = Rockbreaking rate (area mined while impact hammer is impacting)
B = Blow energy of impact hammer.

This was modified by COMRO based on operational data gathered during underground rockbreaking using five different impact hammers with different blow energies, frequencies, and power levels:

$$R \sim B^{1,2} \cdot f^{0,7} \quad (2)$$

if f = Blow frequency of hammer.

Fig. 4 is based on the experimental data and Equation [2], and permits an extrapolation of performance abilities of impact hammers with increased blow energies and different blow frequencies. Preliminary work has shown that large improvements in hammer performance are technically feasible, which would enable significant improvements in rockbreaking rates. Detailed analyses of present results and trends has indicated that this would increase mining rates several times over presently achieved figures and would dramatically improve the profitability of the operation. However, further investment in engineering development work would be required to achieve this result.

Methods Based on Slot Cutting

The second most advanced method, which is being pursued by Technical and Development Services of Anglo American Corporation, is based on slotting the rock along the hanging and footwall prior to breaking it (Fig, 5)[4]. Although slotting is an expensive operation and complicates the mining system, it offers important potential advantages. For instance, the lowest possible dilution of ore can be achieved, because of very precise control of the hanging and footwall, which reduces the likelihood of breaking through to adjacent parting planes. It also would be suitable for resue mining, provided another slot is made

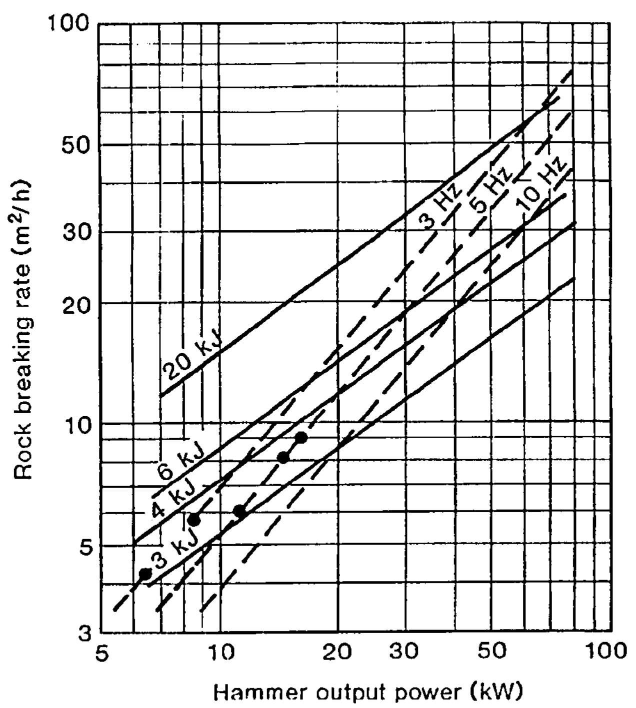

Fig. 4—Rockbreaking rates for impact ripping as a function of blow energy, blow frequency, and output power of impact hammer at a stoping width of 1,15 m and energy release rates from 15 to 60 MJ/m^2 (note experimental data points)

to separate the reef from the waste.

Furthermore, slotting reduces the energy requirements for subsequent rockbreaking, and the smooth hanging and footwall could simplify methods of rockhandling and the use of forward support. These advantages could far outweigh the costs of slotting. Suitable methods for breaking out the slotted rock could either be through impact ripping or alternatively by using water or electrical pulses in drilled holes, as explained in the following section.

Most effort has so far gone into identifying and developing suitable methods of producing slots at acceptable rates and acceptable depths of cut[5]. Slotting rates of 1,4 m^2/h have been achieved for abrasive waterjet cutting[5], and greater than 4 m^2/h for circular diamond sawing[5]. Development efforts are now being concentrated on producing a prototype mining system.

Rockbreaking from Drilled Holes

Methods based on breaking from drilled holes have the advantage of direct inducement of tensile failure inside the rock mass, resulting in low specific energy requirements. This makes non-explosive methods of rockbreaking practical in hard unfractured rock.

High pressure water pulses. One method of breaking from drilled holes, which is in the feasibility study stage, is based on generating an ultra-high pressure water pulse in a drilled hole to substitute gas pressure pulses generated from explosives. The energy for the water pulse is stored externally in a watergun and released into the hole via a partially inserted nozzle. An experimental gun is shown in Fig. 6. It is a simple device, consisting only of an ultra-high pressure accumulator, a nozzle and a release valve[6].

The benefits of using a water pressure pulse are that it is non-toxic and can control the dust problem better than any other method. This is because virtually no fines are generated since the rock around the hole is not crushed and any potential dust is wetted at source. Also, very little flyrock is generated on account of the limited elastic storage capacity of compressed water. Although the lower energy of waterguns in relation to explosives may require the drilling of more holes, it will have the beneficial effect of reduced overbreak and reduced dilution of ore.

The essential requirements for effective water pulses were first determined from work on permeability enhancement of oil wells. One of the key requirements for multiple fracturing and the creation of high driving pressures for crack growth is a short pressure rise time[7]. This can be explained as follows: slow pressurization from hydrostatic devices results in a single fracture when the tensile strength of the weakest part of the rock is exceeded. This destresses the rock, and loss of fluid reduces the pressure so that no further fractures are generated and the rock fragment is typically not dislodged. If, however, pressurization rates are high, then the pressure and the stress around the hole can still rise and initiate further fractures before the stress relaxation wave from the first fracture arrives.

Because of the limited speed of fracture growth and the inertia effect of the rock, pressures many times above the tensile strength of rock can be generated, which is important for driving fractures for suitable distances. The range of operating conditions for various pressure pulse shapes and driving media is shown schematically in Fig. 7[7].

COMRO has conducted extensive feasibility studies in a norite quarry to determine the rockbreaking ability of a propellant-driven gun of approximately 75 kJ energy output. A typical result is shown in Fig. 8, in which a 200 mm

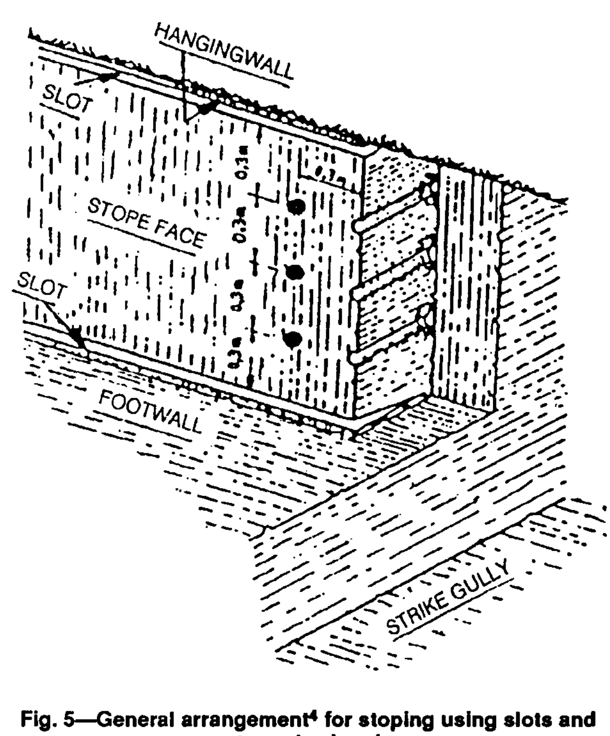

Fig. 5—General arrangement[4] for stoping using slots and water pulse breaker

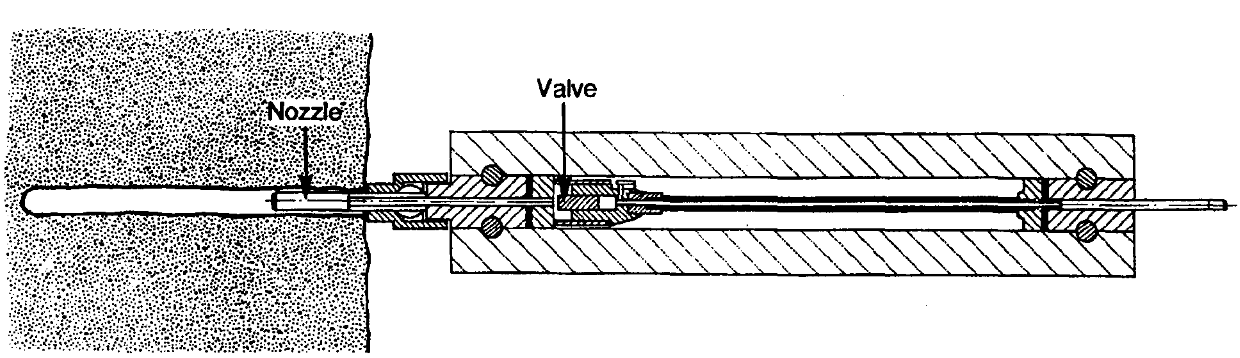

Fig. 6—'Hydrex' accumulator-driven water gun inserted into drilled hole

burden in confined unfractured rock was broken. Subsequently, efforts were concentrated on increasing the transfer efficiency of energy into the hole. Pressure pulse measurements in an instrumented test cell indicated the useful effect of introducing the pulse from the top of the hole. The reflection of the pressure wave in the water at the bottom of the hole resulted in a doubling of the pressure at the toe of the hole and thereby assisted in the breaking of the rock surrounding the most confined part of the hole (Fig. 9).

The experience gained with these investigations was incorporated into the design of an accumulator driven gun of 300 kJ energy, which was supplied by the leading manufacturer in this field (see Fig. 6). This experimental gun has been successfully operated in a test cell at pressures up to 400 MPa and is ready for tests in rock.

The envisaged mining systems based on high pressure

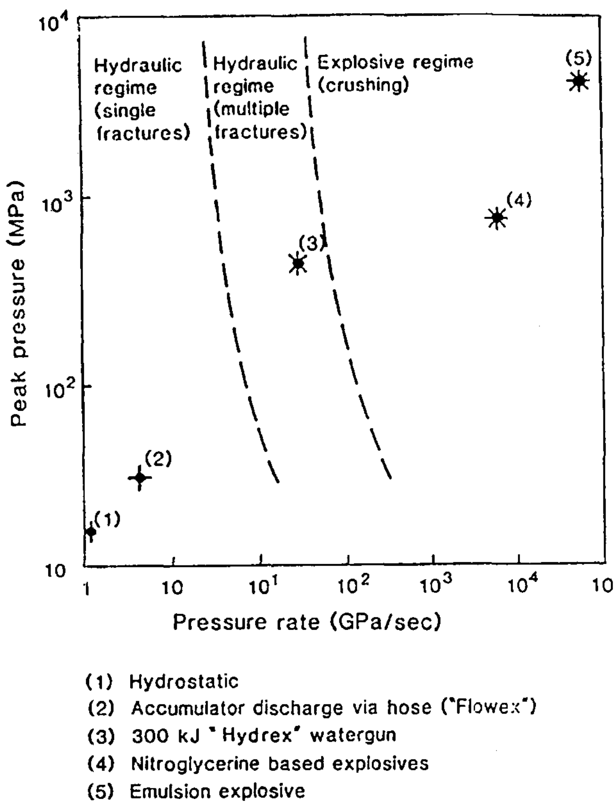

Fig. 7—Fracture regimes for different pressure pulse shapes (based on ref. 7)

water pulses would incorporate a mobile carriage combining a drill rig with a watergun. Rockhandling could be handled with waterjet-assisted scraping as the simplest and most flexible approach for the more difficult conditions of mining. Obviously combinations with face conveyors and slotting would also be feasible. Other possible applications for waterguns include the development of gullies and haulages.

Electric rockbreaking. Electric rockbreaking would permit applications similar to the watergun concept. It is based on the discharge of electric energy between two electrodes inserted into drilled holes. The principal feasibility of this concept has been proved on South African quartzitic rock samples, as shown in Figs. 10 and 11. The mechanisms involved are still poorly understood, but they occur in two sequential steps. In a sufficiently high electric field a dielectric, such as rock, breaks down through the creation of a conductive gaseous path in the so-called 'treeing process'. Stored energy is then discharged in a return streamer which creates very high forces from the expansion of solid plasma[8].

This process appears to be highly energy efficient, judging from the results shown in Figs. 10 and 11 which were achieved with 5 kJ of energy. Some understanding of how operating parameters influence rockbreaking has been gained, as shown in Fig. 12[9]. The area below the lower curve represents conditions for which no electrical breakdown occurs. The area between the two curves covers conditions at which electrical breakdown and rock disintegration occur—the latter with increasing probability as conditions approach those reflected by the upper curve. Above the upper curve rock disintegration is always assured.

Progress has also been made in the design of pulse generators with very short current rise time and large energy storage. This recently developed technology enables the storage of adequate amounts of energy in packages which can be accommodated in the stoping environment. The next step in the feasibility study would be to have a generator built for underground experimentation.

Summary and Conclusions

It has been shown that non-explosive methods of rockbreaking can make a major contribution to more profitable mining because they eliminate the serious constraints imposed by blasting. Considerable progress has been made

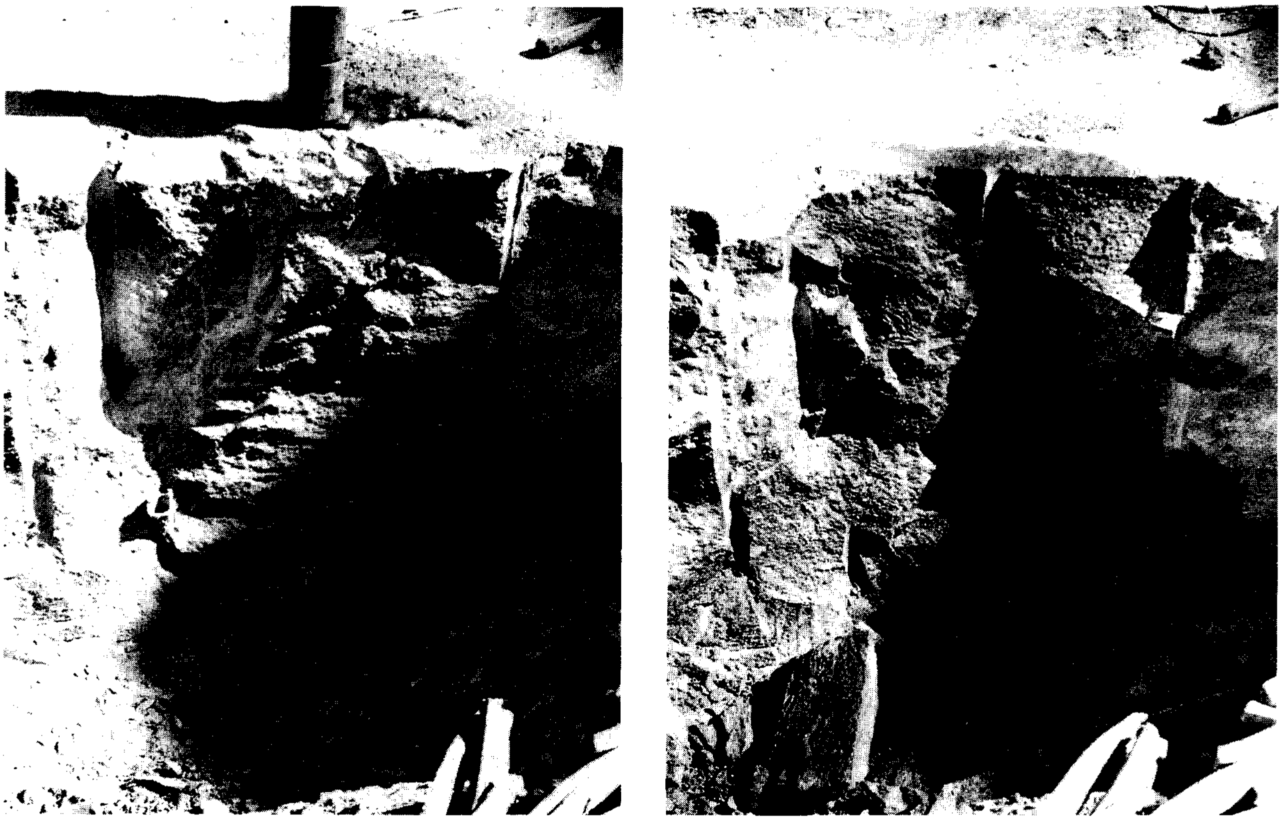

Fig. 8—Effect of 75 kJ propellant-driven watergun in solid norite

in the identification and development of suitable methods. Impact ripping, the most fully developed method, requires only minor refinements to reach the stage of production application; it has been estimated to be applicable to 50 per cent of known ore reserves. Significant profitability improvements are predicted from the application of impact mining. Furthermore, its longer-term improvement potential has been shown to be considerable.

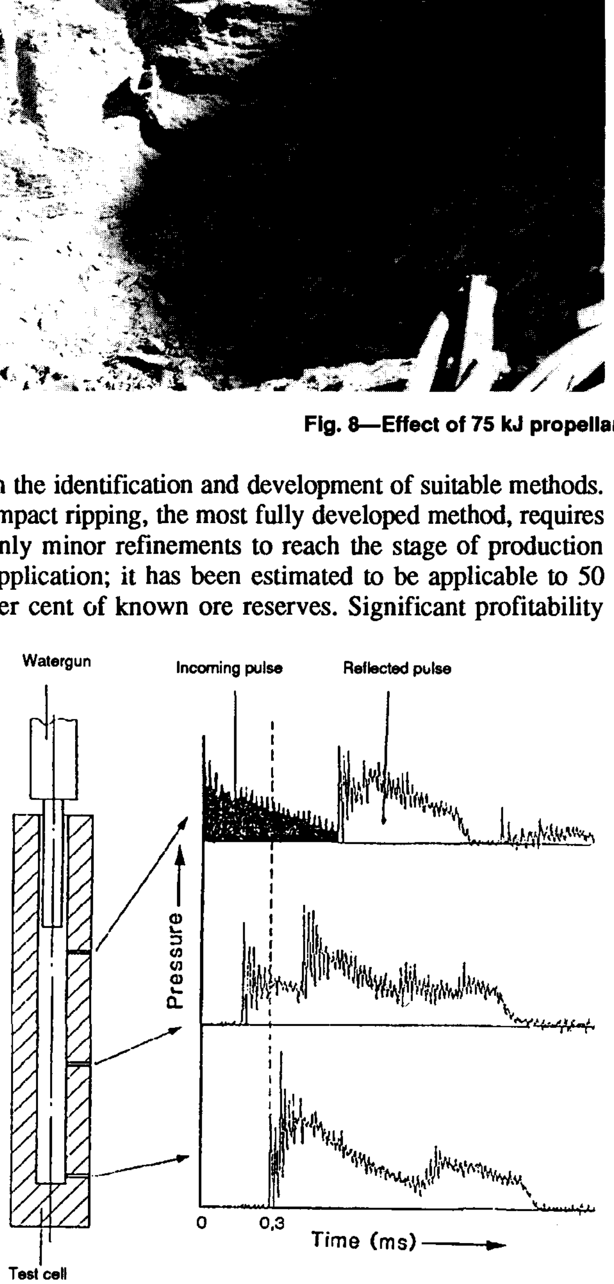

Fig. 9—Pressure pulse generated from propellant-driven gun in water-filled test cell

The other described methods show promising potential and could complement impact ripping in a number of applications. Suitable applications for watergun and electric rockbreaking could be in difficult geological conditions which would favour lighter and more mobile equipment, in confined areas such as gullies and development ends, or in any area that is insufficiently prefractured for effective impact ripping. Slot cutting could be combined with any of the other methods to enhance their effectiveness and profitability; it could be particularly advantageous in reefs with a narrow channel width and those with poor hanging conditions.

Therefore the described methods of non-explosive rockbreaking would cater for most requirements in the South African gold mining industry and, because they all have advantages for specific applications, they all deserve further development.

The progress made hitherto has only been possible because of funding by the gold mining industry and because the work was conducted in South Africa. This has ensured that efforts were clearly focused on the specific and demanding needs of the industry. It is important for the long-term future of the industry to continue on this path of developing totally new solutions for methods of stoping since only they can ensure major cost reductions and improvements in profitability.

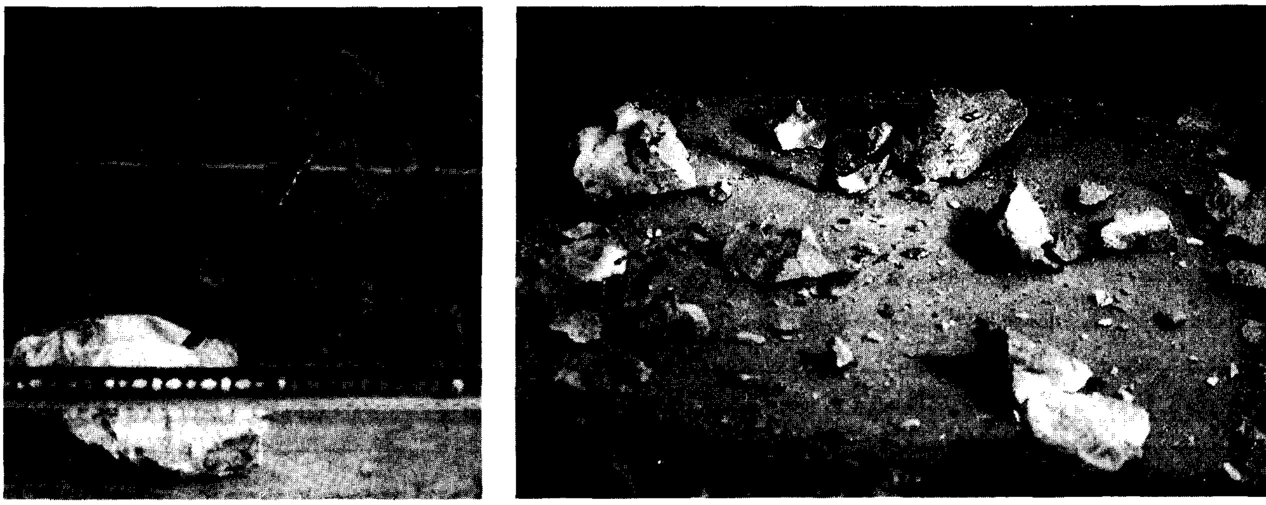

Fig. 10—Electric breaking test at 5 kJ on a 30 kg rock from Carbon Leader reef

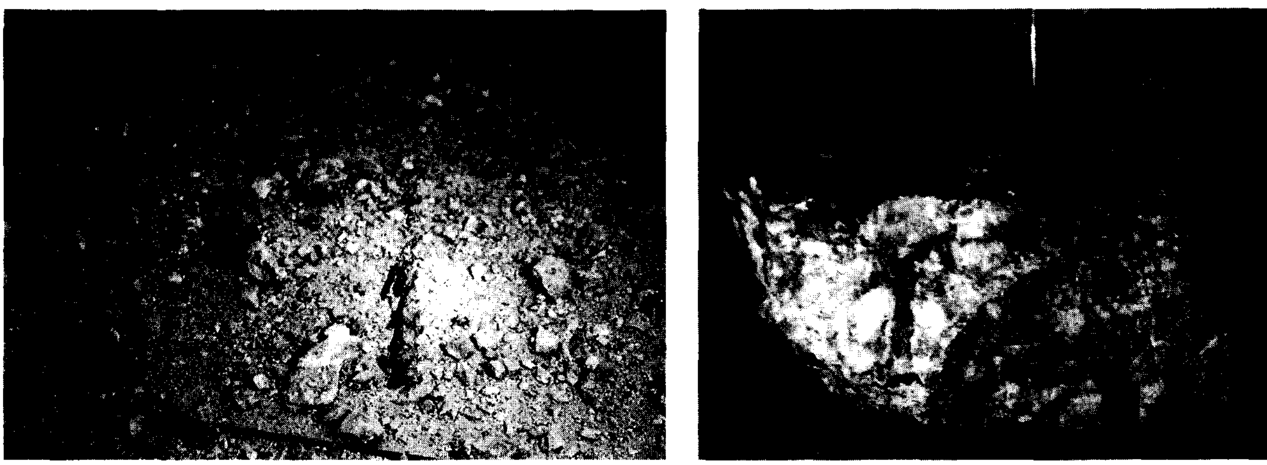

Fig.11—Electric rockbreaking test at 5 kg on a 35 kJ sample of Main reef

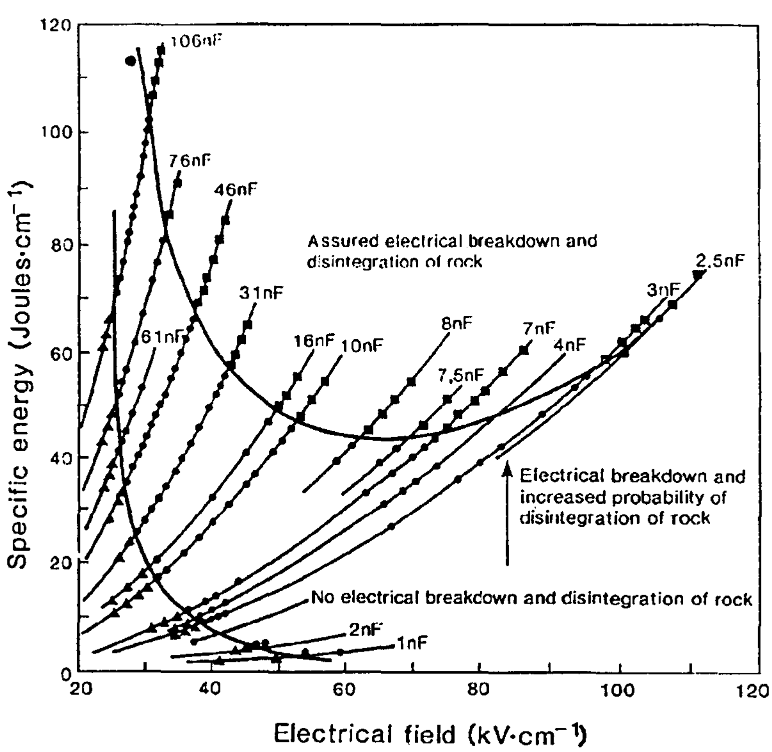

Fig. 12—Specific energy of electric breakdown and electrical disintegration (rockbreaking) of granite samples as a function of the electric field[9]

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Gold forum

Randol Gold Forum—Vancouver '92 will focus on the integration of mining, metallurgical, and environmental innovations for survival in demanding times. This Conference and Exhibition will present significant new technological advances and ways of improving productivity. It will be the 14th international conference organized by Randol International Ltd.

In addition to the technical programme, the trade exhibition will highlight metallurgical and environmental management products and services.

Papers are invited on the extraction and recovery of gold, silver, and platinum-group metals that reduce costs, improve productivity, and/or facilitate environmental management.

The main focus will be on improving productivity in gold plants. However, papers are invited also on resource trends and innovative emerging mining technologies that will have an impact on the selection of metallurgical processes and environmental management. For example, new blasting technology can make a much finer run-of-mine product. Can this be used to advantage in conjunction with hydraulic hoisting and, if so, what impact will this have on SAG milling applications? Will open-circuit WaterFlush (Nordberg) crushing make it advantageous to produce ball-mill feed directly, replacing SAG and rod mills in a primary milling mode? Can WaterFlush wet crushing be installed underground, and can the product be hydro-hoisted to the surface as direct feed for the ball mills?

In-pit crushing and conveying systems can reduce open-pit mining costs. In South Africa a technique of undercut and fill has been successfully developed for underground mining of deposits in 'poor ground'. Can this technique be used for the new deep gold deposits being found in Nevada? Can mill tailings be used as backfill and, if so, can sulphidic waste material be safely disposed of in this backfill, thereby avoiding possible future acid mine-drainage problems?

Whole-ore roasting avoids downstream viscosity problems and oxidizes sulphides, avoiding future AMD generation. Acidic pre-oxidation processes integrate well with bromine leaching. Bromination of black sands can economically replace amalgamation, avoiding environmental concerns.

Some heap-leaching operations yield much better recoveries than indicated by lab tests. Such fundamental questions as to whether to heap leach, dump leach, or mill an ore can make a huge difference to the DCFROI of a project. This determination requires not only a systems approach, but also an experience factor. Several operations have installed mills when heap leaching would have yielded a better DCFROI. These are just some of the questions that need to be raised.

The Forum is to be held in Vancouver (Canada) from 25th to 27th March, 1992.

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