# Mechanization in stoping narrow tabular orebodies

by R.J. Kendall* and M. Gericke*

## Synopsis

As we enter the new millennium, the South African mining industry has to ensure that it becomes more competitive if it is to survive in the ever more demanding global environment.

Traditionally, mechanization in narrow stopes has been limited to the use of scraper winches, and numerous mechanization attempts have been restricted to pilot projects operated on an extremely limited scale (with varying degrees of success).

The benefits of hydropower are well documented, and Northam Platinum has shown these benefits to be achievable on a mine-wide basis. However, the equipment originally developed for hydropower systems has followed the traditional labour-intensive approach commonly used in deep level narrow stoping operations. The problems experienced with the hydropower system are discussed and the rationale for developing alternate technologies is explored.

The hydropower system has shown to be a versatile powering medium which can be harnessed for a diversity of uses. It (hydropower) enables the mining engineer to change traditional paradigms and to design an entirely new approach for optimizing the mining operation based on explosive techniques.

The system developed for Northam consists of the following:

- Purpose-built stope drill rig operated off the hydropower system with special features to ensure accurate drilling patterns throughout the length of the blast hole
- Purpose-built high rate cleaning system for rapid transfer of fractured ore to the stope orepass
- Redesigned stope layout to facilitate in-stope water control and to recover fines from the run-off water
- Purpose-built drill rig for rapid establishment of reef raises and advanced strike gullies
- Purpose-built drill rig for flat end development. On both types of development end rig, emphasis is placed on ensuring accurate drilling patterns throughout the length of the hole to maximize linear advance per blast.

The paper discusses the implementation of the Northam system on a large scale as well as current initiatives to further improve on the efficiencies of mining operations. It concludes by emphasizing that mechanized hydropowered stope technologies are in their infancy and thus offer unlimited scope in progressing beyond today's paradigms to present as yet unthought of solutions for optimizing deep level ore extraction.

## Introduction

With the general acceptance of South Africa back into the international community, it has become essential for all South African based companies to become competitive in the global arena. There are many factors which have influenced the cultural make up of deep level mines which operate within narrow tabular orebodies in South Africa, but it is widely recognized that our mines are 'high cost' producers due to the labour-intensive nature of deep level mining operations. Thus it is of fundamental importance that we focus on ways of turning the situation around so that our mines become more profitable and hence have a more secure future.

There are a number of ways in which the profitability of a mining company can be improved, each having it own merits and disadvantages. Mechanization of stoping activities can provide a means of achieving much improved efficiencies and hence improved profitability. In the stoping context, mechanization may be divided into explosive and non-explosive techniques. Most of the non-explosive methods have been confined to pilot projects and while a number of methods show much potential, none have been expanded to mine-wide use. Thus, generally speaking, mechanization in-stope has not been widely applied because of difficulties in introducing these methods on a large scale.

This paper focuses on the approach at Northam Platinum of expanding mechanization in the stopes as a means of improving efficiency and productivity by remaining with explosive mining techniques but focusing attention on the methods employed for each cycle within the deep level mining operation. This discussion will look at stope layouts, drilling and blasting, and the cleaning cycle as separate topics.

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### Initial practice at Northam

Due to the geological structure of the Platiniferous reefs in the Northam lease area, a scattered mining approach was selected with breast mining layout for the stoping panels. Typical panel length is in the region of 25 metres.

The geothermal gradient of the Bushveld Igneous Complex is higher than that encountered in the Witwatersrand basin, with the result that virgin rock temperatures at 2000 metres are approximately 65°C. The impact of mining at depth in the Bushveld Complex was unknown, and thus the mine was designed at the outset to utilize backfill as a regional support system as well as minimize back areas in order to reduce the heat load in the underground workings. Hydropower was selected as the powering system due to the primary benefit of creating a micro climate in the working area, thus vastly improving the positional efficiency of the chilled water cooling system.

Commercial hydropowered equipment was not freely available at the time of stoping operations commencing at Northam, and hence mining operations had to be adjusted to suit that equipment which had been developed through the auspices of the Chamber of Mines Research Organization. Drilling was done with hand-held drills which offered exceptionally rapid drilling rates. However, these drills are extremely powerful and weigh approximately 30 kg. This makes collaring of drill holes difficult in stopes dipping at angles in excess of 20°, and thus accuracy of the drilling pattern is not readily achieved.

Stope cleaning was done with aquajet-assisted face scrapers, and where the panel length was less than 25 metres, with aquajet only.

Runoff water from the hydropower equipment was channelled along the strike gullies into the centre raise where it ran into the stope orepasses.

### Problems experienced

#### Ore handling

Although a mine operating on hydropower has been shown to use less water overall than a mine with a similar heat load operating on compressed air, there are generally greater quantities of water in the stoping horizon. This is due to the waste water (and hence cooling water) from the mining equipment powered by the high pressure water being in the stope panel. Experience has shown that numerous problems occur if large volumes of water enter the orepasses. These are:

- Mud rushes which cause extensive damage to equipment as well as causing delays in the tramming of ore from the cross cuts are a regular occurrence.
- Additional loads are imposed on boxfronts due to the hydraulic head of the water in the orepass. Failures of the whole boxfront have occurred.
- Handling of the ore becomes extremely difficult, because the flow characteristic of the ore changes with a change in moisture content. These ore handling problems continue throughout the transport system, e.g. hoppers, shaft orepasses, transfer belts, shaft loading arrangements, hoisting arrangements etc.

#### Drilling accuracy

The face advance per blast was negatively influenced due to the inaccuracy of the drilling pattern. Work done to improve the face advance per blast indicated that drilling at 90° to the face yielded the best results. Although much emphasis was placed on the importance of accurate drilling, the results were dependent on the degree of proficiency as well as the level of motivation of the drilling crews.

The hydropower drills require large in-line thrust forces to drill at their best efficiency. If the included angle between the thrust leg and the drillsteel is greater than 30°, the lifting component of the thrustleg limits the amount of thrust that can be applied axially onto the drillsteel. Thus the drills are not always operated within their optimal parameters, negatively impacting on drill reliability as well as drillsteel life due to shank wear caused by excess motion between the chuck bush and the drill steel.

### Stope layout

As a result of the problems experienced with excess water in the stope orepasses, Northam has had to adapt a stoping layout to ensure that water (including the runoff water from backfilling operations) is kept well clear of the stope orepasses.

The Northam stope layouts are now as follows.

- Strike gullies feed directly into a slusher gully on each side of the centre raise. The centre raise is used as a travelling way and as a service raise for hydropower piping, electrical cables and backfill piping.
- Down-dip scrapers transfer the ore down the slusher gullies to the orepass positions.
- Up-dip scrapers pull the ore up into the orepass.

Hence the water has the following path from the face to the stope crosscut:

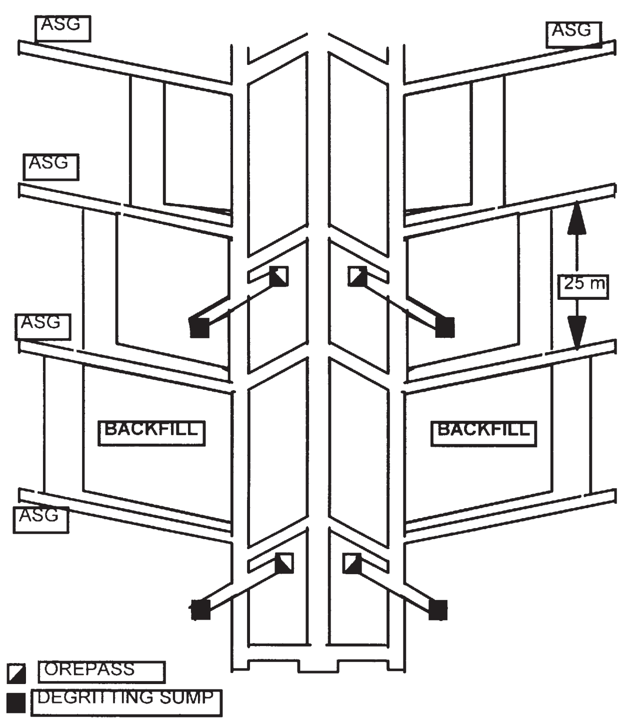


**Figure 1—Northam stope layout**

- down the face to the strike gully
- along the strike gully to the centre slusher gully
- down the slusher gully into a settler situated at the bottom of the up-dip gully which is at the lowest point of the slusher gully.
- either gravitate into a secondary settler in the crosscut or alternately piped directly into the transfer pump sump.

The advantages of the improved stope layout is as follows.

- Up-dip scraping into stope tips prevents water entering orepasses and this eliminates mud rushes.
- Separating the cleaning into 4 separate stope districts with separate dip slushers speeds up production.
- Four separate grizzlies prevents bottle-necks at tips.
- Advance strike gullies give valuable geological information and give free-breaking faces as well as allowing for an effective scraper overrun.
- The new layout provides a separate travelling way, top to bottom without any scraper ropes crossing the travelling way. Hydropower pipes and electric cables can therefore be installed in the travelling way without possible damage. Persons travelling in stope don't interfere with dip gully scraping.
- Platinum rich fines are recovered in the primary settler, and are transferred into the orepass by means of the up-dip scraper.

## Drilling and blasting

The concept of utilizing an in-stope drill rig is certainly not new, and various attempts have been made over the years to develop a user-friendly drill rig which can meet the requirements of drilling within the confines of a narrow tabular orebody. At the outset of the design of the Northam rig, it was decided to define a number of design parameters which were as a result of lessons learned from previous industry experience.

### *The Northam stope drill rig*

With the experience gained from numerous attempts to improve on hole accuracy, Northam conceived and then developed a purpose built stope drill rig in conjunction with Sulzer Hydromining. This has enabled hydropowered drills to efficiently produce accurate hole patterns with a dramatic resultant productivity gain. Safety and health of personnel has also improved in areas using these drill rigs due to the following innovations.

- Drillsteels are self collaring, thus there is no need to handle rotating drillsteels.
- Operator is positioned behind the rig and is thus at least two metres from the face. This position is very close to the backfill support and the hydraulic roof supports, thus minimizing the risk of injury due to falls of ground.
- A single operator is required to drill an entire 30 m panel, reducing the number of people exposed to risk.
- No physically demanding work is required from the operator, thus injury risk due to lack of concentration or fatigue is eliminated.
- Operator is not exposed to drill vibrations and long-term risk of vibration-induced tissue and joint damage is eliminated.
- Noise levels are reduced even further due to proper on-collar drilling as a result of optimized in-line thrusting on the drill.

Stope drill rigs have existed for many years, yet have not proved successful in narrow stope deep level mining. In examining the reasons why the Northam drill rig is succeeding where others have failed, the following factors should be considered.

The urgency in improving productivity is greater now than ever before. The current drill rig has quickly proven to dramatically improve productivity, and thus enjoys the active support of both senior and middle management.

Safety legislation is forcing management to reassess methods and to reconsider equipment which aids compliance to safety requirements. The drill rig has proven to be singularly successful in reducing accidents during the drilling cycle.

These rigs require no external power packs, but are supplied via the standard hydropower hose fed directly from the hydropower system. It has a limited maintenance requirement which is easily carried out by the operator. Thus no specialized skills are necessary to operate and maintain the rig.

The rig has received universal acceptance from the operators due to the fact that it reduces the physical effort to drill, improves the safety levels, and allows the operator improved earning capabilities due to production related incentives.

### *Design philosophy*

From the very beginning, a '*low cost, simple to operate and maintain high rate miner, suitable for narrow tabular ore-bodies at inclinations of typically 25° and powered entirely by hydropower*' was envisaged. In addition, the following criteria had to be met:

- Single operator of same skill level as current drill operators
- Safe to store in stope without the need to disassemble, but with no risk of blasting damage
- Operator must be able to assemble and install the rig in the stope face with one assistant
- Minimal underground maintenance, all of which must be done by the operator
- 30 m panel must be drilled out in under 3 hours
- Hole pattern must be fixed and repeatable but allow for reef undulations and variations in stope widths
- Modular construction for ease of assembly, transport and replacement of service exchange modules
- Must be safe—minimize risk of toppling or running away down the incline.

The standard Northam 'WASP' stope drill rig meets all of these requirements.

The main modules are as follows.

#### *Bogie*

This is the moving base onto which all other modules are assembled. It has 4 driven wheels which run inside the

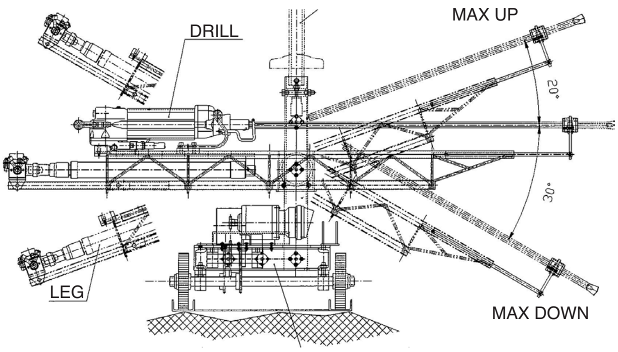


Figure 2—Schematic of the Wasp stope drill rig

channel tracks which are installed at a set parallel distance away from the stope face. The bogie is motorized with a Turgodrive to permit indexing and tramming up or down the face. A trailing safety chain interlinks with a securely fixed load chain which spans the length of the face.

*Centre post*

This centre post projects upwards from the bogie and functions as a temporary roof support and as a means of locking the rig in position for drilling. It is extended and retracted by a double-acting hydraulic cylinder.

*Boom*

This consists of a frame on which a slide which carries the drill is thrust forward and back by a 2-stage telescopic leg (alternatively, rodless cylinders or turbine-driven cable/chain drives have been used). The frame is attached to a height adjustable collar on the bogie or centre post via a cone clutch which facilitates the tilt (up or down) angle to be set in the vertical plane. An additional pivot point can be integrated into the frame attachment to facilitate setting fanning angles in the horizontal plane.

*Drills, telescopic legs, hydraulic props and Turgodrives*

These are all standard OEM products used elsewhere in hydropower applications.

*Hydraulics*

These consist of standard OEM building blocks and include hoses, distribution manifolds, fuses, valves and a back-flushable filtration unit.

*Tracks*

These are standardized 1,6 (or 1,8) m long modules, interlocked using pins. Marks are provided on the tracks to assist the operator with moving the rig by the correct indexing distance.

*Traverse car and pipe rails*

The traverse rails are installed perpendicular to the tracks and permit the rig to be driven onto the traverse car which enables the rig to be moved into the back areas for storage during blasting. Alternatively a turntable can be used to turn the rig (by 90°) and drive it under its own power into the back areas for storage.

## *Transport, operation and maintenance*

*Transport*

The modular construction permits tracks, drills, telescopic legs, booms and bogie to be individually transported underground thus ensuring that bulk and weight remain manageable at all times. Once in the face, the operator reassembles the rig with an assistant but without the need for any special tools. The rig remains fully assembled unless moved to another section.

*Operation*

After the usual cleaning, making safe and installing of temporary support has been completed, the tracks are manually installed parallel to the face at a set distance away from the furthest protrusion (note that these diminish within the first three blasts as clean breaking faces, hangings and footwalls result). After installation of the load chain, the rig is retrieved from its parked position in the back areas by manually pushing it along the traverse guide rails back into the face. Next the safety chain is interlinked with the load chain. This is followed by connecting up the hydropower supply and a pre-use inspection of the rig.

The miner assumes the responsibility for marking up the face (height elevations only as marking hole positions is now superfluous) and setting the drill rig up such that the holes are drilled at the correct height and angle. He does this by driving the rig into the starting position, thrusting out the temporary roof support, adjusting booms and then proceeding with starting each drill and thrust leg in sequence. Once the holes are drilled, he retracts each drill, switches them off, lowers the prop and operates the Turgodrive motor to advance to the next position from where the process is repeated.

After completing the first round of holes and being satisfied that the pattern is correct, the operator takes over and completes the round by repeating this process, ensuring each time that the safety chain is advanced and any in-stope supports are re-established as the rig advances. At shift end, the rig is driven back onto the traverse car, disconnected and pushed back into the back areas. Tracks are also removed and stacked for storage.

*Maintenance*

Minimal maintenance is required on this rig. All modules are readily removed and the operator will replace any defective module with a service exchange unit and return the failed unit to the surface workshop for repair.

## *Experience to date*

To date, 22 stope drill rigs have been built for Northam. Typical production figures over the past 6 months show that production gains of at least double the centares per stope employee (excluding ASG crew) can be expected with total staff count dropping to two thirds!

| | $m^2$ /panel | Total labour | $m^2$ /man |
|---|---|---|---|
| Hand-held | 260 | 14 | 18 |
| Drill rig | 400 | 9 | 45 |

Maintenance costs and reliabilities of drills are improving, the current expectations being an improvement of at least 20% over hand-held drilling. Longer replacement intervals have been noted for drill steels and an ongoing workstudy programme is expected to yield more accurate figures shortly.

One of the fundamental aims of the drill rig is to improve the accuracy of the blastholes so that maximum face advance can be achieved with each blast. If each hole in a particular row of holes is parallel to the preceeding hole, the burden at the toe of the hole is very similar to the burden on the face itself.

Experience with the drill rig has yielded exceptional results in that the face advance per blast is equal to the length of the hole drilled, and there are no sockets in either the middle and bottom rows of holes. Sockets in the top row of holes appear sporadically, and the maximum length of these is 4 cm. At present, the length of hole (and subsequently the face advance) is 1,1 metres, and this is only limited by the stroke of the telescopic thrustleg (which in turn is limited by the acceptable overall length of the boom as regards distance from backfill to face). Hence there is scope for optimizing the length of hole drilled, and other methods of thrusting the drill slide forward are being investigated.

Replacing fuses and igniter cords with more precise timing methods has shown that the total number of holes required per 30 m panel can be reduced by typically 100 holes. Increasing hole spacing, size and depth can further increase productivity by yielding even more tons per blast.

Although conceived for breast mining this concept is so flexible that it can be repackaged to meet a host of different applications. The rig can be reconfigured from the Northam layout by changing:

- Boom length (drilling depth)
- Spacing and height between booms (hole pattern)
- Number of booms
- Drilling angles other than perpendicular to face.

Other variations include

- Down- or up-dip mining at dip angles of typically 20° and with drilling angle fixed at 70° and 80° to the face
- Fan drilling in adjustable increments by rotating the centrepost about its vertical axis
- Two rigs powered exclusively with compressed air of at least 5 bar have been built. This permits using more sophisticated (and heavier) air drills that achieve similar rates of penetration as water drills. This approach is only viable in mines which can generate more than the industry average of 2–3 bar pressure at the drill. The advantages inherent in using high pressure chilled water, do not of course transfer to this pneumatic rig. Nonetheless, we welcome this approach, as it permits at least the mechanization advantages of the Northam concept to be exploited.

### *Reef raise and ASG drill rig*

Due to the fact that the stope drill rig is capable of improving face advance significantly, the emphasis will swing to the high speed development of raise connections and the pre-requisite ASGs (where ground conditions permit).

The Wasp stope drill rig has shown that good face advance per blast is a function of the correct drilling pattern and the accuracy of drilling the blast holes to this pattern. Thus, it has been a logical progression from a stope drill rig to a small end development end rig which employs the same basic philosophy i.e. to drill an accurate blast hole pattern with the minimum of operator effort and discretion in terms of hole spacing, drilling direction and depth.

The Scorpion drill rig is being developed to enable a single operator to drill the round accurately in either a raise or on a horizontal ASG. At present, the rig is intended to drill a small end in the region of 1,5 m x 2,7 m, but does allow for flexibility in terms of size of end. Due to the limited number of holes, only one drill boom is necessary for drilling all the holes to an effective depth of 2,0 m. The thrust mechanism for the drill slide is such that the hole depth can be tailored to suit any requirement, although present experience indicates that the practical limit for 25 mm hexagonal drillsteel which is thrust at approximately 200 kg is in the region of four metres before excessive flexing occurs during the hole collaring operation.

The rig consists of a 'Z' frame platform with two hydraulic cylinders to control height adjustment, a cross slide arrangement to allow horizontal adjustment of the boom, a boom assembly complete with drill slide and modular thrust mechanism, and an index slide to ensure the hole length drilled is constant irrespective of the height of the boom assembly above the base. Two separate ratchet arrangements are used to lock the 'Z' arrangement in position for each of the different heights required for each row of holes in the pattern. To ensure that the correct tunnel profile is maintained, all the perimeter holes are inclined outwards at 7°.

### *Operation*

Figure 3 shows a typical blast hole pattern for a small development end using a 'cut' pattern.

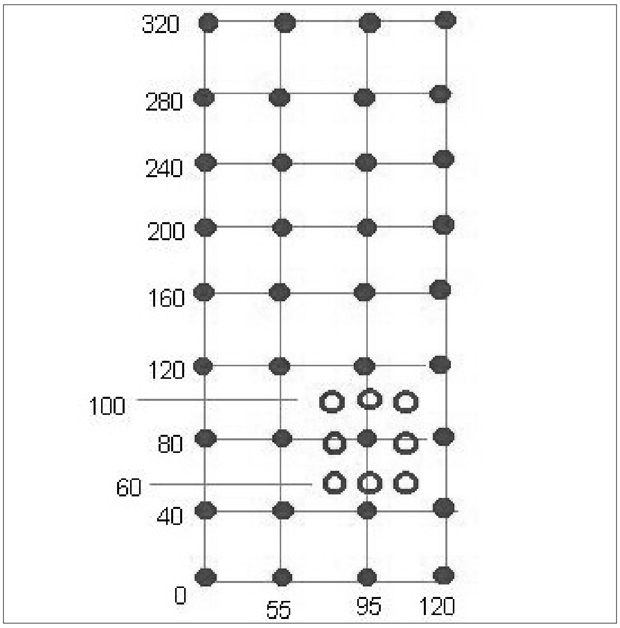


**Figure 3—Drilling pattern for small development end**

After the usual cleaning, making safe and installing of permanent roof support has been completed, the miner marks the centre line and grade line onto the tunnel in the appropriate positions. The rig is retrieved from its parked position in a cubby in the back area either by lifting it up on a driven crawl running on crawl beams mounted in the hanging, or by pulling it in with the scraper winch rope. Due to possible damage caused by any obstruction in the gully, the crawl beam and driven crawl is the safer and preferred method. Once the rig is in position, it is aligned with the centre and grade lines. This is followed by connecting up the hydropower supply and a pre-use inspection of the rig.

The miner assumes the responsibility for marking up the face (perimeter lines only as marking hole positions is now superfluous) and attaching a chain from the face to the front of the rig to prevent it moving away from the face during drilling operations. The operator moves the boom to its outer drilling position and locks the boom in place by pulling it rearward into the locking guides. He moves the index slide forward until the drill bit touches the face, then starts the drill. He engages the forward direction of the thrust turbine, and the hole will be drilled. When the drill reaches the end of the boom, he stops the forward thrust, and engages the reverse direction of the turbine. Once the drillsteel is clear of the hole, he retracts the index slide, then raises the 'Z' frame to the first notch on the ratchet. The next hole is drilled by repeating the drilling process described above. Once all the holes in that column of holes are drilled, he lowers the 'Z' frame fully, moves the boom horizontally to the next position, then drills the next column of holes. This process is repeated until all the columns have been drilled. Because the ratchet determines the height at which the 'Z' frame is locked in position, all the holes for a particular ratchet position will be at the same height i.e. a 'row' of holes will be formed. All that remains is for the 8 holes for the 'cut' to be drilled. A separate ratchet is used for setting the drill boom height for the 'cut' holes.

Although the small end rig is available as a proof of concept only, a large rig built along similar principles has been in use on the horizontal haulages for a number of months. Face advance per blast has been equal to the length of hole drilled, with a marked improvement in haulage profile as well as ground conditions due to markedly less blast-induced damage to the surrounding rock.

### *Anfo loader*

One of the main disadvantages of hydropower to date has been the inability to charge the blast holes with 'Anfo' type explosives which are commonly used in the platinum mining industry because of both cost efficiency and effectiveness in the platiniferous reefs.

To date, the only effective and rapid means of charging the Anfex into the hole at the correct density is by means of a loader which uses compressed air as the transport medium. However, since a hydropowered mine does not have any compressed air supply in-stope, an alternative arrangement must be found. The solution has been to develop an Anfo loader unit which has its own built-in compressor driven by the hydropower supply. This compressor is extremely compact, and easily fits onto the commercially available Anfo loader.

## Cleaning

The efficiency of the whole mining operation is very strongly influenced by the cleaning of the broken ore after the blast has taken place. Hence, even though the drilling cycle can be improved upon by means of the drill rig, the face advance per month may not improve much if the cleaning is not completed timeously. Northam has focused on the method employed to move the broken ore from the stope face into the stope orepass.

### *Ekscalibur stope cleaning system*

#### *Design requirements*

The system must be able to replace the face scraper and must be capable of moving the ore from the panel into the strike gully at a rate faster than the water jet assisted face scraper method. The system must be easy to operate and must utilize the hydropower system as its primary power source to ensure that adequate cooling is provided for the operator on the stope face.

#### *Description of Ekscalibur*

The Ekscalibur is in effect a very powerful jetting gun which is mounted to a fixed support. It consumes approximately three times the amount of water used by a standard jetting gun, and due to improved hydraulic design, the impact force of the water jet on the rock is approximately five times that of the standard jetting gun. It has been designed to fit the standard hydropower reticulation and all the parameters are consistent with the excess flow safety devices already in use at Northam.

The general features of Ekscalibur are as follows.

The nozzle size is designed to limit the flowrate to a value below the closing flow of a number three fuse, i.e. less than 9 litres per second. (Note that nozzle size can be varied to suit the hydropower system pressure or the power pack system pressure and flow capacity.)

Ekscalibur is supplied via a NW25 supply hose fitted to a No 3 Combi valve. These are the standard items of equipment for the supply of hydropower to the drilling manifold, and are thus already available in the stopes at Northam.

Although the pressure drop across the hose becomes significantly high at these flowrates, the impact force on a

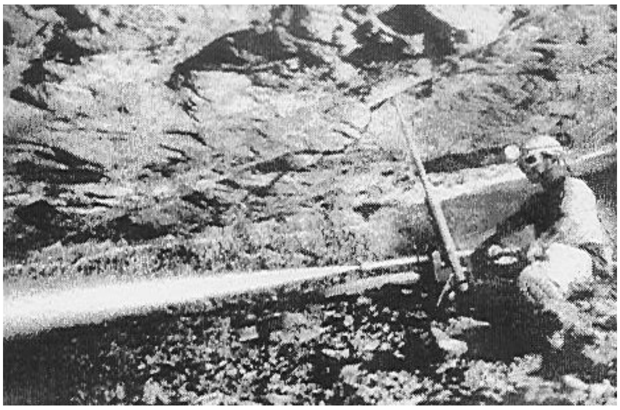

**Figure 4—Ekscalibur cleaning system**

200 mm diameter target positioned 6 metres from the nozzle is approximately 700 N.A standard jetting gun tested on the same rig gives an impact force of approximately 120 N at 5 metres from the target.

The Ekscalibur can be supported in three distinct and different ways.

- Mounted to a camlock prop by means of a pivoting clamp. The prop is installed *after* the blast by the Ekscalibur operator—normally during night shift.
- Mounted to a hydraulic blast-on prop by means of a second type of pivoting clamp. The hydraulic prop is installed *before* the blast by the dayshift crew.
- As a self-contained unit with its own hydraulic prop and pivoting assembly. This is the preferred arrangement because of ease of operation (refer to Figure 4).

### *Operating characteristics of Ekscalibur*

The Ekscalibur is extremely easy to operate and has been well accepted by all the operators who have used it. A significant safety advantage over conventional water jetting systems is that the operator does not have to resist any reaction forces and is thus not exposed to fatigue factors. Hence the cleaning operation can be carried out continuously.

If the support prop comes loose during operation due to a poor installation, the flow to the Ekscalibur is shut off immediately the prop starts moving. The operator is not exposed to danger of injury at all.

The Ekscalibur can move rocks up to 400 mm in diameter, and hence the operator only has to manually break exceptionally large rocks which would have to be broken anyway in order to fit through the grizzly at the stope orepass.

The Ekscalibur can replace the face scraper at Northam (average dip 23°). During time studies in various stope panels at Northam, the cleaning time was less than $4^1/_2$ hours for a 30 metre panel of 1,5 m stoping width.

The Ekscalibur 'bars' the hanging and face very effectively because of the high impact forces which are generated. Safety is further improved because the operator is at least three metres from the position where the rock is being 'barred' down.

### *Method of operation*

The ore is moved down the stope face to the strike gully by the Ekscalibur in a series of batches. The first 5 metres of face is cleaned by positioning the unit 5 metres above the strike gully. The ore is blasted down-dip into the path of the scraper by the Ekscalibur. Once this area down-dip of the Ekscalibur is completely clean, the unit is moved a minimum of 8 metres up-dip, and this second batch is blasted down-dip towards the gully.

Once the area in front of the Ekscalibur is cleaned to the limit of reach of the high power water jet, the unit must be moved down-dip again to ensure that all the ore is completely transferred into the strike gully. The Ekscalibur is then moved up-dip again and the process is repeated.

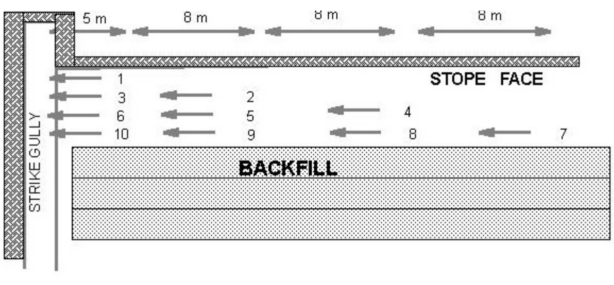


**Figure 5—Ekscalibur cleaning sequence**

### *Automated scraper winches*

As discussed previously, the new stoping layouts at Northam incorporate a short up-dip scrape to remove the ore from the water. If the winches for the strike gully, slusher gully and up-dip gully are placed in the close vicinity of each other, one operator can supervise all three if they are automated. In the case of the slusher and the up-dip gullies, the scraping cycle is point-to-point and thus is easily automated. The strike gully could either be handled on a point-to-point basis, or could be used to stack the ore in the gully during initial cleaning, then retrieve the ore and transfer it to the slusher once the panel has been cleaned.

Two different methods are being investigated by Northam. They are:

- Electrical thrustor brakes controlled by a simple PLC
- Mechanical device operating water hydraulic cylinders on the clutch brake bands.

Both methods require some modifications to the standard scraper winch. These are:

- Move the drums apart by fitting a new shaft
- Replace the clutch handles with either hydropowered or electrical devices.
- Fit distance sensing equipment and cams
- Either link to a PLC as an integral part of the starter for the electrical option, or link to hydraulic pilot circuit to operate the hydropower cylinders.

The main advantage of the electrical option is that the PLC can be programmed to give the following functions:

- Sweep cleans gully from beginning to end continuously
- Stacks piles from the tipping point backwards
- Cleans the gully in steps of increasing length
- Timed start any of the above at a preset time after the blast.

#### *Advantages of automated operation*

- One operator can supervise more than one winch
- Earlier start of scraper operation
- Efficient scraping methods
- Increased clutch band life
- Improved operator working conditions.

The main disadvantage is that the PLC requires specialist knowledge and electronics have not proven to be particularly reliable in stoping conditions. For this reason, Northam is pursuing the hydropowered option using a mechanical device to give the signal to change direction. At this point in time, the winch will still be driven by an electrical motor, although a fully hydropowered automated winch is possible.

It must be stated, however, that while the principle of automated scraper winch operations remain part of the strategy, neither option pursued to date has proved to be a reliable and cost-effective solution.

### *Hydropowered rock breaker*

Although the Ekscalibur develops a very high impact force to move the broken ore down-dip, it cannot move large flat slabs of rock as found during barring operations. If these large rocks (which due to their flat shape are not inclined to roll down-dip) are not removed, they form a barrier to the smooth flow of the broken ore down the stope face. The traditional method of breaking large rocks in the face is to use a 14 lb (6 kg) hammer. This is not very effective because the hammer cannot be swung fully due to the height restriction of the stope. Thus, this becomes a physically demanding and time-consuming exercise. Often, these rocks are dragged into the scraper path and they end up choking the grizzly over the orepass.

An experimental hand-held rockbreaker is presently being developed to be operated off the hydropower system.

The principle of operation is to provide a single, very high energy blow to the rock. At present, the design blow energy is being tuned to the requirements of the rock type, and once this is finalized, the overall packaging of the concept will take place. The design objective is for a unit which is portable and can be carried to each new position with relative ease, but still remain safe for the operator notwithstanding the recoil usually associated with impact devices

### Development end drill rig

While the emphasis of this paper is focused on mechanization within the stope horizon, it is important to note that development of haulages to access additional reef raises becomes of greater importance as a result of increased face advance on the stope panels. This results in a shorter life span of a particular raise connection, and hence the replacement raise must be available at an earlier date than if conventional stoping practices are followed.

Commercially available drill rigs are generally electro-hydraulically driven and are highly sophisticated, but suffer the drawbacks of extremely high capital cost, high running costs and require high levels of skills for both operation and maintenance. Due to the full flexibility of the boom adjustment, the spacing and direction of the blast holes is at the operator's discretion.

In order to facilitate rapid flat end development, Northam and HPE have jointly developed a hydropower-driven drill rig, which is based on the principle of removing operator discretion for hole spacing and direction. It may thus be visualised as a large hole director!

The basic approach is to mount two drill booms onto a scissors type platform with unequal arms, so that the angle of the top deck changes as the scissors are opened. Thus if the base is inclined downwards, the bottom holes are also inclined downwards so that the end of the hole is on the footwall elevation. With the scissors fully extended, the top row of holes is inclined upwards so that the end of the hole is on the correct hangingwall elevation. A ratchet mechanism is fitted to the scissors so that there is a locking position for the height of each row of holes.

A cross slide arrangement is fitted onto the top deck so that the booms can be adjusted horizontally, and there is a locking position for each column of holes. Thus the two booms are locked in a given position, and the scissors fully collapsed to drill two holes in the bottom row. The scissors are raised to the first ratchet position (adjusted according to the required burden at the end of the hole), and two holes are drilled vertically above the first two holes. The scissors are raised to the second ratchet position, and again two holes are drilled. This process is repeated until all the holes in both columns are drilled. The scissors are collapsed, the booms are moved horizontally (adjusted according to the required burden at the end of the hole), and the next two columns are drilled by following the same procedure.

From the above description, it should be evident that the direction and grade of the development end is controlled by the initial setting up of the rig, because all the holes in the drill pattern are dictated by the layout of the rig. The rig is not intended to drill the roof support holes, and a separate (but very elementary) rig is employed to drill these holes.

At present, the first prototype which drills two-metre holes has been in use for six months, and the first pre-production rig which drills three-metre holes has been in use two months. The 64 holes each 3 m long for the Northam pattern are drilled with one operator in approximately 4 hours. The broken rock is loaded by means of a hydropowered loader in approximately 5 hours. Results have shown that the development end advances by the length of hole drilled, and that sockets are non-existent. Both sidewall and hangingwall conditions are dramatically improved because of the accurate blasthole pattern. Both rigs are used on a single shift basis and a blast per day is consistently being achieved. Work studies have indicated that on a multiblast basis, two 3 m rounds per day are possible, but this has yet to be tried.

### Conclusions

Water hydraulic mining at Northam is a success story. The water powered mechanization approach currently being implemented has demonstrated that a single stope machine operator can now drill 200 holes per shift with less effort, in a healthier environment and in far greater safety than ever before.

The cleaning of the panel after blasting can be completed by one man operating an Ekscalibur on the face. Further technical advances in terms of automating scraper winches and breaking large rocks with a hand-held device will allow even greater efficiencies to be achieved.

Current achievements have shown that a blast per day can be obtained with a total crew of nine people, thus allowing in-stope efficiencies of up to 70 $m^2$ per man to become feasable. Any further improvements to the system will potentially improve this number even more.

Development of access haulages and reef raises can also be improved by accurately drilling the blast hole pattern to give maximum advance per blast with the minimum of drill operators. These rigs are of a simple construction and thus are relatively cheap and easy to maintain.

The integrated mining system currently being introduced allows far greater face advances with the resultant benefits of less operating faces required to achieve the desired tonnages. This has a major impact on all aspects of deep level mining in that less working places need supporting services. This allows far greater optimization of these services.

Thus, Hydropower technology has the potential to revolutionize narrow tabular stoping at depth.

Hydropower is user-friendly, delivers in stope spot cooling, addresses most of the current safety and health issues and makes mechanized mining possible. It provides an extremely versatile and efficient power source for operating mining equipment, and because it is a new technology, has the potential to be developed further to allow greater efficiencies than were ever dreamed of as being possible in narrow tabular reef mining at depth.

## Acknowledgements

The authors wish to express their thanks to the management team of Northam Platinum Ltd for their support and encouragement in the preparation of this paper.

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