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The optimization of mining method and equipment

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Conventional mining is an excellent match of mining method and equipment. The result is guaranteed performance. Change in the form of different technology requires change in mining method until the best match is achieved. This paper covers the development of technology and mining method that has occurred in the last five years to arrive at the objective of successful mechanized mining in narrow reef platinum deposits of the Bushveld Complex.

Introduction

The purpose of this paper is to explore the integration of technology and stoping systems. For the last hundred years the South African narrow reef mining industry has battled to control working costs in a labour-intensive industry. It is only through the application of appropriate technology that change will occur. It is the stoping method that is at the heart of the mining system. Introduce a different technology that results in a more efficient stoping system and the mining system will look after itself.

The technology applied to stoping in narrow reef mining, over the last 100 years, can be categorized as follows:

- The introduction of pneumatic rock drills early this century. The cumbersome rig-mounted units were replaced by smaller, lighter, handheld units that were then made easier to use with the addition of an air leg (the so called Swedish method of mining). As late as the early 1970s some drilling was still being carried out without the assistance of an air leg
- Scraper winches to replace gravity and shovels to move rock, both in the face and the gullies, were first introduced in the late 1920s
- Hydraulic props installed close to the face and capable of applying force against the hangingwall as well as yielding in a controlled manner under dynamic load arrived in the 1960s. In many instances these have now been replaced by yielding elongates fitted with water hydraulic tensioning devices
- Some people argue that the introduction of tungsten carbide inserts, to improve drilling, was equally important.

The match between current technology and current stoping systems is near perfect. The objective is a blast at the planned time, and this is achieved 85% to 90% of the time. The following is an attempt to describe some aspects of this optimization. It must be born in mind that different mines introduce different variations on the same theme.

- In the gold mines most individual faces are about 30 metres in length. Drilling the face in a shift is not the issue as the number of rock drill operators on a panel can easily be changed. Support is installed concurrent with drilling and the necessary labour to complete the installation of the desired support in a drilling shift can be calculated. Face length is determined by the ability of a scraper to complete the cleaning operation in a single shift. Thus, face length is a function of the volume of rock broken in a blast and the cleaning rate of a scraper winch. Actual scraper operation will be of a far shorter duration than the shift time
- Conversely, if the cleaning method in the face is throw blasting, then the face length is usually limited to 12 to 15 metres
- Strike gully length is again dictated by the capability of the scraper winch. However, in this instance cleaning time available is the duration of the cleaning shift plus part of the drilling shift.

There have been a number of attempts to introduce different technologies into stoping, the most recent being trackless equipment. Where the stoping layout suits the technology it has been successful. However, in the history of our mining industry there have been too many instances where a technology has been installed because it is fashionable and not because there has been a clear understanding of the 'added value' that such a change will bring.

The issue is that we have to change and the introduction of change is something that none of us is good at—we would all prefer the other person to change rather than ourselves.

At the end of the day the outcome from change in the stoping systems has to be safer and more profitable mining systems. It is the contention of the authors that change is only likely to be effective if the introduction and application of appropriate technology support it.

Other industries and mechanization

It is interesting to see how other mining industries have changed in the last 50 years. The British coal mining industry is a good example. Table I gives an overview of the statistics between 1947 and 1994 (from the time that the industry was nationalized through to the time that it was privatized). Total tonnage produced in 1994 was 25% of that produced in 1947. Mechanization had increased productivity from 270 tons per year per employee in 1947 to 5 810 in 1994. Fatalities were also substantially reduced (by a factor of 60) with million tons produced per fatality rising from 0.35 to 21.5.

Table I
British coal 1947 and 1994

		1947	1994
Number of Mines		980	16
Production (million tons)	Deep mines	180	29
	Open cast	8	14
Employees		697 000	7 400
Tons per man shift		1,03	13
Fatalities		543	2

Table II
South African gold mines (Chamber Members) 1947 and 1993

	1947	1993
Production (million tons rock)	49	122
(tons gold)	332	617
Grade (grams/ton)	6,8	5,6
Gold value (R/oz)	17,3	1 176
Employees	334 696	366 248
Fatalities	482	390

Over the corresponding period the SA gold mines productivity increased from 146 tons of rock per employee per year in 1947 to 333 in 1993. Fatalities were reduced (by a factor of 3) with million tons of rock produced per fatality rising from 102 to 313 (see Table II).

The author of the paper that contained the coal mining statistics went on to say: 'These improvements have been made by the application of advanced technology. From the early stages of mechanization in the 1950s through to the rapid development of the 1970s and 1980s and onto the heavy duty mechanization in more recent years.'

Selection of appropriate technology

In a recent paper, Stacey quotes Bieniawski's definition of engineering design as being:

'Engineering design is the process of devising a system, component or process to meet desired needs. It is a decision-making process (often iterative), in which the basic sciences of mathematics and engineering are applied, to convert resources optimally to meet a stated objective. Among the fundamental elements of the design process are the establishment of objectives and criteria, synthesis, analysis, construction, testing and evaluation. In addition, sociological, economic, aesthetic, legal and ethical considerations need to be included in the design process.'

Stacey goes on to discuss the application of basic design principles to rock engineering. He is critical of how successfully the mining industry is in applying engineering design principles to rock engineering.

The author has been involved in the development of stoping systems for a number of mines. The process usually involves mine employees and suppliers of technology. It is important that the team includes people who have the ability to think broadly and who, preferably, have had experience in the development of novel stoping systems. The basic requirement of any new stoping system is safe production, that is, safer and more profitable mining. It is achieved by ensuring that competent people carry out safe working practices on fit-for-purpose equipment. Like risk assessment, the process used for the development of these systems requires proactive and participatory behaviour from the team. However, the fundamental process is one of engineering design and the process is iterative.

- *Define the untouchables*—These are factors that are inviolate and cannot be contravened. They are almost always safety related and in the various debates have included the following:
  - No employees to work under unsupported hanging
  - The spacing between pillars not to exceed ? metres
  - The ground must be destressed before mining

  These factors are defined at the beginning of the session and each suggestion or stoping system proposal is tested to ensure that it conforms or does not violate the untouchables
- *Proposed stoping layout*—To the best knowledge of the team, the proposed layout must be practical. (If use is to be made of long hole drilling, then what is a practical limit for straight holes?) The equipment must not be expected to perform outside its normal operating parameters. The major issue is will the equipment be able to operate practically in the defined environment; and how the layout will cope with variations in geology, grade and rock structure. At all times the various proposals are tested to ensure that they do not contravene the untouchables. At this stage a preliminary suite of equipment is identified
- *Equipment selection*—The appropriate equipment is now selected. The focus is not on a particular manufacturer but rather on the functional specification for the equipment and how it impacts on the proposed stoping layout. The equipment is now fitted into the stope excavations, i.e. the stope excavations are sized to accommodate the equipment
- *Definition of mining district*—Based on the expected performance of the individual pieces of equipment, an equipment fleet is identified. Every effort is made to optimize the production from the fleet. Rock handling capability is matched to rock breaking rate. Support is integrated into the mining cycle. It is at this stage that the stoping system and technology requirements are defined

- *Costing*—The capital and operating costs of the equipment are now determined based on experience and historical data from similar environments. Dilution and manning levels are often major issues at this stage. These cost and performance figures are compared to conventional mining costs. The new system has got to be more cost effective than the old system.

Implementation of new technology

It is recognized that the implementation and application of new technology in the mining industry is a difficult process and has often been unsuccessful. However, it is also important that we are able to learn from our previous experiences to ensure that the installation of new technology is more successful in future. It is well known that safe production can only be achieved with a combination of the right equipment, trained people, and appropriate operating procedures. The purpose of any technology implementation plan or technology transfer process is to ensure that these objectives are achieved. At a workshop attended by senior people in the mining industry it was determined that the most important issues that govern the successful transfer of technology were as follows:

- Recognizing needs
  - People at all levels in an organization must see the benefits of the technology for themselves
  - The need addressed by the innovation may have to be described differently to the various levels in the mine or organization
  - Mine staff should be involved in the need definition process at an early stage to ensure that real needs are recognized and appropriately described
- Mining people
  - People in the mining industry rely heavily on word-of-mouth to gauge the effectiveness or otherwise of equipment trials
  - The training of people in the application of new technology requires a professional approach
  - People must be educated in the concepts on which the new technology is based
  - Unanticipated consequences during the introduction of new technologies can lead to failure of the technology transfer process
  - Technology suppliers should under promise and over deliver.
- Champions
  - Champions are essential at all levels in the mining hierarchy; they must be identified early and adequately supported by their superiors and the staff involved in the technology transfer
  - Championship is a managed process, and champions should be created at all the stages of the transfer process. The 'flame of championship' must be spread
  - Good champions are innovative, successful and leaders with credibility and integrity
  - Champions are more objective than passionate about the technology they are promoting; they put success of the technology above personal ambition.
- Appropriateness of the technology
  - A new technology must be appropriate to the skills of mine production and maintenance staff, and it must be sufficiently robust to withstand the underground environment
  - It must address real and current needs
  - Sophisticated technology must be 'invisible' to the end user
- Management of the technology transfer process
  - The introduction of new technology, although a complex social process, can and must be carefully planned and managed
  - Technology transfer plans must be compiled early and reviewed regularly, to ensure that the need and the solution remain relevant
  - It is easier to transfer incremental change than it is to transfer technologies that result in significant changes in work practices
  - The technology transfer process must be managed to minimize the risk to all concerned.

Case study—mechanization in the Bushveld Complex

Room and pillar mining in chrome

Due to the competitive and cyclical nature of chromitite ore production, the need to find improved and cheaper mining methods was recognized in the early eighties. Chrome producers had to deal with massive retrenchments that were a prominent and unattractive feature of the industry. As a result, the first 'room and pillar' mining projects were started at the Millsell operation of Rand Mines and the Waterkloof operation of Samancor in 1985. The orebody that lent itself to this type of operation was the LG6 and LG6A chromitite seams of the Bushveld Complex in the Rustenburg area.

Mining methods employed in the area are room and pillar or variations thereof. Panels are generally 10 to 14-metres wide with pillars varying in width between four and six metres, depending on depth below surface. Typical extraction ratios of 73% are being achieved.

For the first fifteen years mechanization was limited to cleaning and ore transport operations. Initially the mines used a variety of load haul dump machines (LHD) designed for small tunnel cleaning (Eimco and Schopff). The LHDs used during this initial period proved to be ineffective due to their size, lack of power to handle the heavy chrome ore, and their instability when tramming on strike, in areas where the inclination of the reef was in excess of 10°. Manufacturers reacted to the need of the mines and Toro 150s and later the Toro 190 and GHH Aardvark loaders, specifically designed for the conditions prevailing on these mines, ensured more efficient and safer cleaning operations.

Access to the orebody on these mines is generally by means of declines developed on reef, equipped with conveyors for ore transport and chair lifts for the transport of men. A system of strike conveyors is installed and advanced with the mining faces for the transport of ore to the main conveyor. All mining takes place on the reef horizon and waste rock mining is kept to the absolute minimum.

The mines had a working system: hand held drilling, LHD cleaning and transport to conveyors, and roof bolts installed by hand, plus an on reef mining layout that minimized waste mining.

Mine management, however, realized as far back as 1991 that the room and pillar mines required a suitable drill rig to take the process to its logical conclusion. To this end, various manufacturers were approached to design and build a suitable drill rig for the unique conditions prevailing on these mines. In the period 1991 to 1999 experiments were conducted with a Stomec rig as well as a twin boom Furukawa drill rig equipped with pneumatic drills. In the latter half of the Nineties the effect of HIV/aids resulted in an increased urgency in finding a suitable drilling solution. During 1999 Tamrock, after working closely with the management of some of the mines, introduced a low profile drill rig (Tamrock's Axera LP). The machine was intentionally designed as an electro-hydraulic drill rig capable of operating in heights of 1.5 metres and capable of tramming in dips of 18°.

The Axera LP was used to drill three metre rounds compared with the 1.5 metre rounds achieved with hand-held pneumatic drilling. This longer round created more rock on the floor after a single blast. A single, smaller LHD was no longer capable of completing the cleaning of an end in the available shift time. This led to the introduction of 5–6 ton LHDs.

The typical width of the LG6 and 6A is about 1.7 metres and the mines now had a mechanized mining method consisting of a face drill, drilling three-metre rounds, a loader that could cope with this quantity of rock and transport it to an in-stope belt conveying system. The quality of the hangingwall was excellent and the pillar layout only required occasional roof bolts; these were installed by hand.

Room and pillar mining in UG2 platinum reef

What had worked very well in the LG6 and 6A was now transposed to the UG2. However, the two different reefs are not the same, nor are the mining imperatives.

- The LG6 footwall contact breaks easily and forms an excellent footwall for the trackless equipment; the UG2 is bottom loaded with platinum group metals and the normal drilling instruction is to break the footwall contact plus 100 mm
- The footwall for LG6 does not require very accurate drilling as the ground naturally breaks to the contact; in the UG2 footwall drilling accuracy is essential to recover all the PGMs and to create a good footwall
- Thus the trackless equipment had to work on a much rougher footwall in the UG2; drilling longer rounds and the creation of a 'factory roof' footwall exacerbated the roughness of the footwall
- In mining the LG6 and 6A, most of the drilling is in the chromitite and the waste middling is cracked out; the waste is then sorted underground and discarded. In areas where trackless mining was applied to the UG2, the reef was separated from the leader seam by a relatively narrow waste middling—making it cost effective to mine both seams at a design width of about 1.8 metres
- In the LG6A roofbolting was an incidental issue; in the UG2 the presence of the leader and a number of chromitite stringers in the hanging made it essential to introduce a systematic roofbolting strategy.

It was at this stage that the manufacturers produced a roofbolting rig specifically designed for drilling in a 1.8 metres stope height. Because of the limited height and the required length of roofbolts, drilling was a two-pass process. The coupling on the drill steel dictated that the minimum hole diameter was about 35 mm. This hole size was fine for end anchored bolts but caused problems when resin anchored bolts were used, mainly inadequate mixing of the resin and thus incomplete curing.

- Initial efforts with in-stope waste sorting met with limited success due mainly to the especially high grade on the contact between the reef and waste. Subsequently all face material was trammed as reef at a corresponding lower grade
- The issue of grade in UG2 mining became more of an issue, as not only does mining at a higher stope width reduce grade but the percentage recovery of PGMs in the subsequent beneficiation process is also reduced. Mining a wider stope width with mechanized equipment reduces cost per ton of production. However, the lower stope grade and the lower percentage PGM recovery also reduces the revenue per ton mined. If mining width is not controlled, then the profitability of the operation suffers
- In an effort to sweeten the grade, the T-cut method of mining was introduced.

T-cut modified room and pillar mining for UG2

This method of mining is an adaptation of room and pillar mining and was introduced to improve the grade when mining narrow UG2. The rooms are smaller, typically about four metres wide and 1.8 metres high, to accommodate low profile equipment. The reef is carried in the upper part of the room; the reef on either side of the room is mined closer to channel width, hence T-cut. The physical limitations of drill feeds and drifters restricted the sides of the T to about two-metres, giving a finished width of eight metres.

This necessitated the development of a different drill rig as the LP equipment used for driving the original room with three-metre rounds could not be accommodated in the four-metre wide room.

Hybrid mining for UG2

The next development was to increase the shoulder on the side of the T and mine the reef using conventional hand-held equipment. This mining method has become known as hybrid-mining. All excavations are on reef, the orebody is opened up using low profile trackless equipment, stoping is by conventional pneumatic, hand-held drilling, and rock handling with scrapers or throw blasting. The trackless excavations are supported with roofbolts and the face with elongates and/or roofbolts.

The trackless excavations for hybrid mining result in some dilution and a reduction in head grade.

Full circle

It is interesting to note that one platinum mine has been mining UG2 with a hybrid mining layout since 1984. How we love to re-invent the wheel. From a low profile trackless mining perspective, hybrid mining is certainly a mining method that works, and has been shown to work for twenty years.

Xtra low profile mining in UG2 and Merensky Reef

The next step in the equipment development programme was to use mechanized equipment that would fit into a stoping width of 1.1 metres. The initial trials were carried out with battery-powered coal scoops about 750 mm high, face drilling was with conventional pneumatic hand-held equipment and roof bolting with small pneumatic powered roofbolters. The mining layout was room and pillar.

- The latest fleet of equipment for room and pillar mining consists of XLP face drilling with a two-boom electro-hydraulic drill rig, roofbolting with an electro-hydraulic roof bolter and face cleaning with a diesel powered LHD. All three pieces of equipment are no more than 850 mm high. The most suitable layout for this equipment is still being developed

- A mixture of XLP and LP equipment is being used for 'breast mining'. The layout is similar to hybrid mining with the stope face being mined using XLP equipment rather than hand-held pneumatic drilling. At the shallower dips much of the rock is blasted into the gully and the balance of the rock in the face is then cleaned using a bulldozer.

Rock cutting

In conjunction with all the equipment and mining method developments using explosives to break the rock, there are four rock cutting machines operating in the Bushveld Complex. One has mined in excess of 1 500 square metres.

Conclusion

Mechanized mining is safer and more productive than conventional handheld mining. However, mechanized mining requires that we change the way that we do things. Change is not easy for any of us. The design of new stoping systems and new mining layouts is best achieved using an engineering approach. The implementation of new technology in new stoping systems must be managed and the appropriate champions developed.

Underground mechanization for mining the reefs of the Bushveld Complex was initiated in the mid-1980s. The chrome mines had a complete suite of equipment to match their mining methods by 2000. The platinum mines have used a mix of mechanized and conventional mining for twenty years. Five years ago they started using the chrome mine approach before reverting to what had been proven twenty years ago. The most recent developments have led to XLP machines that make it possible to mechanize and mine an orebody at a stoping width less than 1.2 metres.

Given these technology developments and the lessons learned, we have to ask the questions: Could we have done it all faster and more cost effectively if we had applied engineering design principals? Could we have managed the development process more effectively? Could we have implemented the technologies and mining methods more efficiently? How?

References

STACEY, T.R. The link between the design process in rock engineering and the code of practice to combat rock fall and rock burst accidents. *The Journal of the South African Institute of Mining and Metallurgy*. vol. 104 no. 1 January/February 2004.

LUBBE, O.S., ANNANDALE, G., and VAN WYK, J.W. Room and pillar mining in chrome and platinum mines. *6th International Symposium on Mine Mechanization and Automation*, South African Institute of Mining and Metallurgy, 2001.