Abstract

Mining is very important to South Africa, contributing 7% of GDP directly, and 15% indirectly and employing more than 450,000 people. With the world’s largest resources of gold, platinum and ferrochrome, and major coal resources, mining will continue to be important to South Africa for decades to come.

Mining is also facing significant challenges: Too many people are killed in our mines; an even larger number of people contract occupational diseases from working in mines; there is a shortage of human capital at all levels from labourers to professionals; and as costs rise, operations are threatened.

Research has a role to play in overcoming all these challenges, as illustrated by other papers at the conference. But it is perhaps in the challenge of competitiveness where the greatest impacts can be made, and where CSIR is demonstrating new techniques:

- The unpredictability of the geology is a major contributor to delays and cost overruns in mining. Tools developed at the CSIR, such as borehole radar, in-mine electrical resistance tomography and the radio imaging method, all have a role to play in lessening the surprises in mining operations.
- The management of modern open-pit mines is technologically advanced, with high levels of computerisation, communication and sensing. The same cannot be said for underground hard-rock mines. The CSIR is active in developing a new sensor, communications and decision support standard, AziSA, which promises to bring underground operations to a similar state of efficiency as that in open-pit operations.
- 22 000 tonnes of gold remain in reefs in the Witwatersrand. These are uneconomical to mine by traditional methods, because the orebody is significantly thinner than the mining width required to get people in. To access these resources, the CSIR has a long term project to develop a miniature mechanised mining system that will be able to mine narrow orebodies economically. The project will require substantial technology developments in many fields, including rock breaking, sensing, robotics, communication, transport, energy and operations research, but can potentially open up gold worth more than R4 trillion at today’s prices. It is already yielding developments in rock breaking and sensing that point the way to radical changes in thin-reef mining.
- A change in drilling technology will greatly reduce both noise and the dust that causes silicosis, while simultaneously improving energy efficiency and production rates. Pneumatic drills have been the primary tool for drilling blast holes for over 100 years. A technology survey is being followed up with experimental work in electric rock breaking. From early results, the tool promises to be fast, clean and efficient, and could replace pneumatic drills in years to come.

1. Introduction

Mining is important to the South African economy. In 2006, mining generated total mineral sales of R195.6-billion and made up 7% of GDP directly, and 18.4% taking into account indirect multipliers. The industry employed 458,600 people directly and 152,800 in associated industries and is estimated to have supported 5 to 7 million people. Mining also provided more than 32.5% of the country’s merchandise exports, and 25.2% of foreign exchange income, rising to just over 50% if beneficiated products are included. Another key benefit of mining is the provision of coal that ensures our electricity is among the cheapest in the world (Chamber of Mines, 2006).

The industry is also not likely to shrink substantially in the near future. Where some commodities, most notably gold, are in decline, others are becoming more important. As illustrated in Figure 1, South Africa is the world’s largest producer of platinum group metals, gold, chromium, ferrochrome, vanadium, manganese and vermiculite and a major supplier of many other mineral resources (Chamber of Mines, 2006).
In the long term, the country has enormous reserves of many of these minerals, which will allow mining to continue at current rates in many commodities for decades to come.

According to Godsell (2006), there are three key challenges to mining:

1. Growing production and reserves.
2. Defending profit margins.
3. Maintaining social licence to mine.

The first challenge is addressed through exploration, supported in South Africa by the Council for Geoscience, from a research point of view. The CSIR seeks to address the remaining two challenges.

As a price-taking industry, there is a very strong pressure on mining companies to control costs in order to maintain profit margins. However, improvements in competitiveness cannot come at the expense of people or the environment: there is increasing social pressure on mining companies illustrated through recent public outcries over environmental issues, for example over dune mining in Pondoland (Compton, 2008); safety in mining, particularly following the Elandsrand shaft failure in October 2007 (Olivier, 2007); and the adverse effects of mining on health epitomised by the silicosis action being defended by Anglogold Ashanti (Momberg, 2007).

In this paper, four initiatives being undertaken at the CSIR are discussed as examples of how mining competitiveness can be improved. While the initiatives discussed here do not directly affect health and safety, they cannot be isolated from the important health and safety research also undertaken within the CSIR.

2. CSIR strategy for research to support mining competitiveness

In 2005, CANMET undertook a comprehensive survey of the research needs of the Canadian mining industry (Laverdure and Fecteau). This survey was used as the basis for a small survey of South African platinum producers, and showed that the needs of South African miners are largely similar to those of their Canadian counterparts.

Seventeen axes of research were identified and prioritised. Of these, the five most important to the South African industry were:

1. Orebody information.
2. Improve excavation support.
3. Improve or optimize layouts.
4. Better drill and blast technology.
5. Mechanical rock breaking.

- The first axis of research recognises that miners can be more competitive if they have a good understanding of the shape and grade of the orebody. Orebody information is therefore an enabling technology for productivity.
- The next three axes recognise that the majority of mining in platinum mines is undertaken using the hand-held drill and blast method, and seek to optimise that method as far as possible. They seek evolutionary development.
- The final axis, mechanical rock breaking, would be a revolutionary change in the way that platinum mining is undertaken.

The CSIR’s mining unit aims to meet the enabling technology, evolutionary and revolutionary needs of the industry. Research is concentrated on gold and platinum, as the orebodies and mining methods used are unique to South Africa.

3. Glass rock

The economic horizons of the two major precious metal ore deposits of South Africa, the Bushveld Complex (platinum) and the Witwatersrand Basin (gold), have much in common – these thin, tabular orebodies, or reefs as they are locally referred to, are relatively non-undulating and laterally continuous on a regional scale. Mine design is therefore fairly straightforward from a regional perspective. Where major structural alterations to the reef exist, these can be detected through the use of geological mapping or 3D surface seismic reflection.
At the local scale within individual mines, however, the continuity of the reef is often unexpectedly disrupted by geological features that are not detected prior to mining. The glass rock project is concerned with discontinuities that will cause a delay in mining within a period of a week to three months. If the rock were made of glass, it would be possible to see such discontinuities directly. As rock is not transparent at optical wavelengths, geophysical techniques are used to provide information that can assist with day-to-day operational decision-making on mines.

3.1 Typical applications of glass rock

3.1.1 Abrupt reef topography variations, rolls and terraces on the gold bearing Ventersdorp Contact Reef

The gold of the Witwatersrand Basin occurs within a series of conglomerate bands or reefs hosted within a sequence of quartzites and shales. One of the most important gold-bearing reefs, the Ventersdorp Contact Reef (VCR), occurs at the contact unconformity between the sedimentary, terraced palaeo-landscape and the overlying lavas (McCarthy, 1994).

The gold is concentrated in palaeo-river channels situated on the terraces. If accurate information about reef topography is available, mining can be planned so that higher-grade areas are accessed first. Sterilisation of gold is also reduced if supporting pillars can be placed in low-grade areas.

Abrupt changes in reef topography cause further problems for mining. If the reef elevation changes more than about 3 m, redevelopment is required, resulting in delays in production. Elevation changes, particularly the so-called ‘rolls’, are also associated with dangerous ground conditions. Advance knowledge of such features would improve mine planning and safety.

3.1.2 Potholes and iron-rich replacement pegmatoids on the platinum reefs of the Bushveld Complex

On the platinum mines of the Bushveld Complex, the continuity of the reefs is often disrupted by slump structures, locally referred to as potholes, and by iron-rich ultramafic pegmatite bodies or IRUPs (Cawthorne et al, 2006). Mine-scale potholes and IRUPs may vary in size from only a few metres to several tens of metres across and can result in local distortions or discontinuities in the reef horizon, with inevitable adverse economic implications.

Pothole occurrences are also linked to poor ground conditions, which increase support requirements and impact negatively on safety. The detailed extent and geometry of potholes and IRUPs is often very unpredictable. Unknown features lead to a loss of mineable ground or the need for unplanned and expensive development to negotiate the slumping reef.

3.2 Mining layout

Typical gold or platinum working occurs at depths from a few hundred metres to a few thousand metres below the surface. Access to the mineralisation is provided by a system of tunnels, including haulages or main travelling ways, cross-cuts, and raises that are developed from the main vertical shaft to positions within the plane of the tabular reef (Figure 2). Strike-parallel haulage tunnels are developed from the shaft along the orebody, at different levels below the orebody. A series of parallel cross-cut tunnels branch out perpendicularly from these haulages in the dip direction, and intersect the plane of the orebody. From these intersection points, raises are developed in the plane of the orebody, in the direction perpendicular to the strike (up-dip).

Mining activities, such as drilling and blasting, are started from within these raises and the virgin block between two adjacent raises is gradually mined out in segments called panels. The spacing between raise tunnels is a function of factors such as the mining method and the dip of the orebody. A typical block width, or raise spacing,
may vary from as little as 35 m to more than 200 m.

3.3 Geophysical solutions
In order to meet the demand for tactical, short-range geophysical imaging in mines, the CSIR is developing three techniques, each at a different stage of maturity.

3.3.1 Electrical resistance tomography (ERT)
ERT exploits on-reef developments (raise lines and strike-parallel developments) surrounding a virgin block to probe for disruptive features within the block (Van Schoor, 2005, 2005b). Electrodes are attached to the sidewall at intervals along the developments. Electrical current is applied by means of a pair of electrodes, while the resulting potentials are measured between various other pairs of electrodes.

These four-electrode measurements are repeated in a systematic fashion for many different source-receiver electrode combinations. The resulting set of resistance data is then inverted using a tomographic reconstruction algorithm. The output is a two-dimensional colour-coded image of the reef plane showing spatial variations in the electrical resistivity. A disruption or distortion of the reef will manifest as a resistivity anomaly on the output image. Both known features, intersected by developments or boreholes, and unknown features can be delineated.

The ERT technique is applicable to blocks of up to 200 m x 200 m at a resolution of approximately 5 m. To date, in-mine ERT has only been tested in South African platinum mines and of the three techniques described here it is the least mature (Van Schoor, 2005). Even though the technique has shown a lot of promise, it still requires some significant research and development before it reaches the same level of maturity and acceptance that ground penetrating radar and borehole radar have achieved.

The technique is illustrated in Figure 3: three potholes were already known from intersections with mining and from drilling. ERT was able to clearly map the three occurrences, and a small fourth anomaly. ERT can be used to scan the area between two raise lines prior to any mining. Anomalies can then be investigated prior to mining, when the information can still be used to change the mining layout.

![ERT survey result from Impala mine](image)

**Figure 3.** An ERT survey result from Impala mine. Electrode positions are numbered. Electrodes 9-12 were located at the ends of short exploration tunnels branching out from the strike-parallel development.

The logistical problems associated with collecting a set of data for imaging are currently a stumbling block to the routine application of ERT in mining. Current research emphasis is on improving the logistics.

3.3.2 Ground penetrating radar (GPR)
GPR is a high frequency electromagnetic technique for imaging in the earth (Daniels, 2004). An antenna transmits pulses into the ground that are reflected from geological discontinuities. The reflections are detected and can be displayed in real-time and stored for later analysis. The typical operating frequency for in-mine GPR applications is between 250 MHz and 500 MHz, which equates to a maximum range of approximately 5 m to 10 m in typical hard rock environments, with a resolution of the order of a few centimetres.

One niche application for GPR is the probing of the immediate hangingwall to determine distances to specific interfaces, layers or partings for support design for rock engineering purposes. In Figure 4, the distance from the hangingwall, or roof, to the leader seam, the prominent horizontal reflector in the lower half of the image, is between 0.6 m and 1.2 m. From the radargram, the correct length of roofbolt to go through the leader seam can easily be determined. GPR can also identify hazardous geological features such as angled joints or faults and can thus play a key role in monitoring hangingwall integrity.
GPR is now used routinely on several platinum mines for rock engineering quality control. CSIR research efforts are being concentrated on automating the analysis of results so that unskilled staff can use GPR.

3.3.3 Borehole radar
Borehole radar is an in-borehole application of ground penetrating radar. A closely spaced radar transmitter and receiver operate along the length of an exploration borehole. The fundamental principles of data acquisition are similar to those of GPR except that a much lower operating frequency is employed, giving longer range, but lower resolution. Geological interfaces will reflect some of the transmitted radar energy back to the receiver, making it possible to determine the distance between the target and the tool at points along the profile defined by the borehole.

The CSIR's Aardwolf BR40 system (Vogt, 2002) operates at a centre frequency of 40 MHz, which implies a maximum range of up to 50 m in hard rock environments, with a resolution of 1 m. The major advantage that borehole radar has over GPR is that the borehole can be targeted to image specific horizons even well ahead of mining, where discontinuities are expected.

In Figure 5, a borehole radargram is illustrated. The radargram was acquired from a borehole drilled below the VCR on a gold mine. The borehole is roughly parallel to the VCR, at a distance of 10 m to 20 m from it. The coordinates of the VCR as imaged in the radargram are transferred to the mine planning software where they can be used to improve the quality of the orebody map.

Du Pisani (2007) calculated the economic benefits of using borehole radar in platinum mining. In one case study involving mapping the topography of the Merensky reef, her calculations reveal that it costs 23× more to define a reef intersection point by drilling than by using borehole radar.

Borehole radar has become widely used by platinum mines in the Bushveld Complex. Research efforts are concentrating on developing higher frequency and directional tools.

4. AziSA
As discussed above, gold and platinum mining in South Africa is typically undertaken on thin seams having low to moderate dip and huge lateral extent. The relatively poor grades dictate a high requirement for capital, but the extent of the orebodies provides a very long life of mine in which to recover that capital.

Mining practice is dominated by hand operated drill and blast methods, although the industry is slowly moving towards mechanisation. Hand operated drill and blast is cyclic, as mines must be vacated during blasting with resulting loss of production. The underground environment contains hazards to both health and safety, leading to accident levels that are higher than international norms and to occupational health problems including noise induced hearing loss and silicosis.

Part of the solution to improved competitiveness is better management. If operations can be managed more effectively, costs can be controlled and health and safety can be improved, leading in the long term to the return of the social licence to mine. The primary obstacle to better management at present is the absence of real-time objective information on which to base decisions.

AziSA is a philosophy, a standard, and a reference implementation for a technology that can make widespread real-time sensing a reality in South African underground operations.

4.1 Philosophy
In 1989, Ackoff described the concept of the Data-Information-Knowledge-Wisdom hierarchy (Ackoff, 1989), which underlies the architecture of the sensor-network discussed here. The hierarchy describes how measurements can become the basis for decisions (Figure 6).

- Data are at the lowest level in the hierarchy.
- Ackoff and others (Ackoff, 1989; Bellinger et
al, 2007) define data as simply symbols, or measurements. However, measurements only have value with descriptive information as to when and where they were made. A temperature reading of 29° C is meaningless. If it is the temperature today in Springbok, it becomes an item of data.

Information is formed by data in relationships. The data acquires meaning through its relationships with other data. If other information is available for Springbok, such as wind speed and direction, and for other towns in the Northern Cape, the data becomes information.

Knowledge is the appropriate collection of information. It is formed through the process of understanding patterns. Using information from all the towns in the western half of the country, and our experience that some weather patterns move from west to east, suggests that tomorrow will be warm in the eastern half of the country.

At the top of the hierarchy is wisdom, or evaluated understanding. While the first three categories relate to the past, it is wisdom that deals with the future. From the knowledge that the weather will be fine in Johannesburg tomorrow, a wise person can make an informed decision about action to take in the future, such as whether to hold a braai or not.

In the context of a measurement system, data are raw measurements, stamped with time and date. Information is created by gathering data in a relational database, allowing connections to be identified. The process of generating knowledge out of information is still a frontier for computer science research because it is difficult for computer systems to reason about patterns. Finally, wisdom remains the domain of the human: even when knowledge can be deduced automatically from information and knowledge, decisions about the future are still made by humans.

In the context of decision support for mining, a similar hierarchy can be constructed. For example, ventilation is provided underground primarily to create a healthy working environment, but also to protect the safety of workers by eliminating the build-up of explosive gases such as methane.

To determine the state of the underground environment, many sensors can be used. The data from sensors can be combined into information, in this case either for safety or for environmental control.

At the knowledge level, advice can be given on the solutions to both environmental and safety problems. In both cases, the knowledge is encapsulated as ventilation advice. At the top level of the hierarchy the wisdom of the decision maker informs decisions on actions to take, as a result of knowledge provided by the system.

4.2 The AziSA standard
AziSA is a specification for an open measurement and control network architecture that can form the basis of systems that apply the data-information-knowledge-wisdom hierarchy in underground platinum and gold mines. AziSA itself is an open standard, which references other open standards, including IEEE 1451 (NIST, 2008), Zigbee (Zigbee Alliance, 2008) and CORBA (OMG Group, 2008).

4.2.1 Physical and logical architecture
The physical architecture of a typical deep level gold or platinum mine resembles an upside-down tree (Figure 2): it consists of a single shaft, branching underground into a network of haulages and crosscuts, similar to the branches of a tree, with working places at the end of the haulages, analogous to the leaves on a tree.

The physical architecture suggests a logical architecture that forms the basis of the AziSA specification (Figure 7), discussed in more detail in Stewart et al (2008). At the root of the tree is the class 1, the network controller and data warehouse. There is a single class 1 in an AziSA network. The class 1 communicates with a number of class 2s. Typically, there will be a class 2 in each working place that has AziSA sensors in-
stalled. The sensors themselves communicate with class 2s, and with each other, and are further classified as class 3s and 4s.

The class hierarchy is defined by decision-making power:

- Class 4 devices are only capable of making measurements, and of passing these back to the class 2s and to the class 1.
- Class 3 devices can take measurements, but can also make decisions based on their own information. A methane sensor can initiate a local alarm if it senses methane above a given threshold.
- A class 2 device aggregates data from all the class 3s and 4s in its local network. It can then use data from multiple sensors to make decisions, but only from sensors in its own local network. If a methane sensor signals a rising methane level, and an air flow meter signals a low airflow rate, the situation is serious because the lack of airflow indicates that methane is being allowed to build up. The class 2 might then raise an alarm over a wide area.
- Class 1 devices have access to all the data in the network. Their primary task is to collect and store data. Applications that access the data on the class 1 can then undertake analyses in order to provide diagnostic information. If a class 2 has raised a methane alarm, an analysis programme using class 1 data might query nearby networks to determine the extent of a ventilation failure. It can then issue a warning with advice on corrective action.

4.2.2 The AziSA specification

The AziSA specification describes the hierarchy discussed above; a set of messages that must be understood by all compliant devices; and a data storage format that allows for generalised storage of data, even from sensors that have not yet been invented. To comply with the standard, this basic set of characteristics has to be implemented.

Sensors need to be able to describe themselves. Sensor metadata is implemented through the IEEE 1451 Transducer Electronic Data Sheet or TEDS specification (NIST, 2008).

AziSA also contains profiles. These are standard ways of implementing specific features in an AziSA compliant network. At present, two profiles exist: AziSA Zigbee and AziSA TCP/IP. AziSA networks do not have to use the profiles, unless they use the specific technologies.

4.2.3 AziSA Zigbee profile

A sensor and communications network for ubiquitous sensing in underground mines has to fulfil a number of requirements:

- It has to be cheap. Sensors need to be low cost to be widely deployed.
- Sensors have to be maintenance free. In many cases, the working places where sensors might be deployed rapidly become back areas where no access is available.
- Deployment has to be quick and painless. A major cost in any sensor deployment is the cost of wiring in the sensor.

For low cost, and low power wireless communications, Zigbee was chosen as the wireless sensor network protocol. Zigbee is an emerging standard for very low power, low data rate, wireless mesh networking (Kinney, 2003). For applications such as energy management and home automation it is expected to become as ubiquitous as the well known Bluetooth wireless standard. Components to implement Zigbee communications links are targeted at a quarter of the price of Bluetooth components. In a typical AziSA network, all communication between class 2s, 3s and 4s would be via AziSA Zigbee.

4.2.4 AziSA TCP/IP profile

In the AziSA standard, the communications links between the various class 2s and the class 1 are not specified. The simplest hardware and trans-
port layer to implement in practice is probably Ethernet, TCP/IP. If TCP/IP is used as the transport medium, the AziSA TCP/IP profile defines the method of communication.

The profile is implemented using CORBA: the Common Object Request Broker Architecture is a standard defined by the Object Management Group (OMG group 2008).

4.3 Implementation

The AziSA project, as undertaken by the CSIR, delivers a standard and a reference implementation. The reference implementation described here is an example of a physical AziSA system that has been constructed and is operational.

Sensors: The reference application uses available sensors as far as possible, connected to Zigbee wireless networking. A closure meter, a crack counter and a Geiger counter have already been implemented. Development is continuing on an infrared sensor, a methane sensor, a basic environmental sensor and an electronic sounding device.

Location sensing: As all data has to be tagged with location, a system of locating mobile sensors has been developed (Ferreira, 2008). The system uses ultrasonic beacons to trilaterate the position of sensors. Beacons will be located at survey pegs.

Wireless network: The wireless network is being implemented using the AziSA Zigbee profile. Zigbee development has been undertaken using an Ember Zigbee chipset, due to the ready availability of development tools.

The aggregator, or class 2: In the reference implementation, the aggregator obtains power from the power supplied to the stope for the scraper winch. It communicates with the class 1 along the power cable using a power line carrier modem. Local communication with the wireless sensor network in the working place uses a Zigbee radio. The class 2 is implemented using a small computer called a Gumstix that runs a version of Linux (Gumstix, 2008).

Communications underground: In the reference implementation, the class 2 communicates directly to a power line carrier (PLC) modem. Another PLC modem is placed at the other end of the power line, where the signal can be transferred to the mine-wide communication network. TCP/IP is the transport medium.

The class 1, or database: The class 1 on surface collects data from across the network. It also controls the network, and can issue alarms back into the network, for transmission to people in the working places. The class 1 is a standard high reliability server class computer. The primary novel feature of the database running on the class 1 is its ability to accept unknown new sensor types automatically. A new type of sensor can be installed underground in a wireless sensor network, and the class 1 will start to acquire and store data from that sensor without prior programming to support the sensor.

Converting information to knowledge and wisdom: In the AziSA architecture, the final step of mining the data stored on the class 1 is left to clients of the class 1. How this is done is not specified by the standard. Once the AziSA infrastructure is designed and in place, adding additional sensors, or additional communications methods or additional networks is expected to be relatively easy. Each application of a sensor network is likely to require substantial investment in design to capture the processes currently undertaken by people to synthesise data into knowledge. AziSA, though, frees the designer from concerns over the hardware required to get the data.

4.4 Case studies

4.4.1 A rock belt monitoring system

The first application of AziSA principles and components of an AziSA system was to a system for monitoring ore and waste belts on a gold mine. On this particular mine, gold ore is associated with uranium, and therefore with modest levels of radioactivity, while waste is not radioactive. Geiger counters are mounted above each belt, monitoring the rock that comes past on its way to the plant or to the waste tip.

The mine also has a system of radio-frequency tags that are scattered in the stope faces before blasting. After blasting, they join the recently blasted rock as it travels through the mine transport system. As the tags pass the Geiger counters, their identification can be determined, pinpointing the location where ore or waste is coming from.

The system does not provide the highest levels of the D-I-K-W hierarchy, but does show how sensing can improve mine management: problems in ore-waste allocation can be quickly identified, traced to source and corrected.

4.4.2 A rockfall early warning system

The Mine Health and Safety Council gazetted a project in 2006 to research and develop a system to provide mines with an early warning of rock-
falls. The CSIR was awarded the project, and is using AziSA as the infrastructure to undertake the monitoring (Brink, 2007).

In this application, the parameters to be monitored are still to be determined. There is no known unequivocal precursor to a rockfall, so a major component of the work is to monitor a number of potential precursors on a large number of mines, in the hope of statistically linking a particular precursor to a rockfall under specific circumstances. As the project has developed, it has migrated from detecting precursors to quantifying the risk of a rockfall in a particular working place.

An AziSA compliant sensor network is being deployed at a number of mines. Zigbee closure meters have been installed, together with a class 2, PLC communications and a class 1. At the time of writing, the system was being commissioned.

5. The Nederburg Miner

So called because it was conceived to be the size of a bottle of wine, the Nederburg Miner is a new approach to the development of a mechanised mining system for very narrow stopes. The technology is targeted to be small, low cost and locally made. It is designed to extract narrow reefs that are currently uneconomic because the current minimum stoping width has to accommodate the people operating the mining system.

The small size represents a change in philosophy: rather than miniaturising conventional machines for narrow stopes, this system will be conceived and developed from the ground up for its intended purpose. This implies that operation must be truly remote - there is no place for an operator.

Two questions remain to be answered:
1. Is there an economic justification for the concept?
2. What is the CSIR going to do differently from COMRO (the predecessor of the mining competency in CSIR Natural Resources and the Environment), which the former did not consider in its mechanisation activities in the mid-1970s?

5.1 The economics

A resource is the quantity of a mineral in the ground. For example, the total gold resource in the Witwatersrand, past and present, is variously estimated at 150 000 tonnes. A reserve is the quantity of gold that can be expected to be removed from the ground. A reserve discounts gold resources lost for any reason, for example because the grade is too low, or because gold bearing rock has to be left in situ to support the excavation.

The reserve, therefore, is a function of the mining method. For example, in a coal mine a room and pillar method is often employed, where the rooms are mined out and the pillars are left behind to support the roof. The maximum extraction in room and pillar is about 70%. By contrast, a longwall coal mine will remove all the coal in an area, allowing the roof to collapse behind the mining face. Given the same resource, longwalling will yield a higher reserve.

The question for the Nederburg Miner is the size of the reserve. A study was commissioned from Shango Solutions, a geological consulting company, to answer that question. Shango were directed to consider a mining machine that could extract reefs of less than 50 cm in areas where conventional mining is sub-economic at mining heights of greater than 80 cm.

Using the Middelvlei reef as an example as presented in Figure 8, it can be seen that any mining system capable of economically mining reefs at a stoping width of less than 0.5 m significantly increases the reserves from any existing resource.

![Figure 8. Additional reserves in a single block of the Middelvlei reef (Schweitzer, 2006).](image)
Miner system be capable of economically mining lower grades, then a commensurately larger increase in reserves would be achievable as demonstrated in Figure 9.

At a gold price of $800 per ounce and a Rand to Dollar exchange rate of 7.5, the additional reserves are equivalent to R4.6 trillion. To put this into perspective, the total of all the gold removed from the Witwatersrand to date is estimated at 40 000 tonnes, and current mining is extracting about 350 tonnes per year. In other words, the Nederburg Miner can create a new gold reserve comparable to the Witwatersrand itself.

5.2 A different approach

From 1974, COMRO undertook a ten-year initiative to introduce mechanisation to the gold mines of the Witwatersrand (Pogue, 2006). It failed to introduce a new system - what will be different this time around?

The CSIR has revisited the review that COMRO undertook of its mechanisation programme in 1987. Two significant changes have taken place in the past twenty years:

1. New technologies have been developed, or technology development has matured.
2. Geophysical techniques are able to delineate the orebody and guide a machine, in a manner that was not feasible in 1987.

For example, the stope coring method was evaluated by COMRO and is also under consideration for the Nederburg Miner. A boring machine drills a series of parallel holes in the reef plane, removing rock. Stope coring was evaluated in 1975 by COMRO, but it was assumed that because the boring machine was not readily steerable, the holes would have to be straight. Because the reef is not planar, the bored hole then had to have a large diameter to ensure that it would remove the entire reef that is available (Jager, 1975).

In contrast, recently developed small diameter steerable down-hole water-powered drills allow a much smaller diameter hole to be cut and can be steered to remain within the reef. By doing so, the size of the hole is far closer to the thickness of the target, meaning that less waste rock is mined. New technology and guidance tools make viable a technique that was written off in 1975.

Research to date (Harper, 2008) has reviewed COMRO findings and confirmed that the major enabler required for a successful machine is the rock breaking technology. A number of new and previously applied technologies have been reviewed, including:

- Wire rope cutting
- Controlled foam injection (CFI)
- Micro-wave drilling
- Electric rock breaking
- Rock breaking in tension (a laboratory feasibility study to verify the generation of subsurface tensile stresses via the interaction of stress waves produced by the impact of a disc shaped impactor).

Conventional explosive technology has also been considered, as part of a mechanised system.

Probably the most mature technology is CFI. After a blast hole is drilled, an injector is inserted into the hole and collared at its bottom. A high pressure foam is then injected into the hole, breaking the rock out in tension (Young, 1999). Unlike water, foam can store considerable elastic energy, and the foam can be designed to prevent dissipation in cracks, allowing all the energy in the foam to be used to break the rock.

The most promising revolutionary technology is electric rock breaking. It is not as mature as CFI, but if it can be made to work, it has huge flexibility and would be easy to incorporate into a mining machine.

Provided technologies such as controlled foam injection rock-breaking, in combination with electric rock-breaking and steerable long-hole drilling with radar guidance can be developed through to a production level, then an integrated, continuous, non-explosive, non-entry mining system is feasible. Such a system could then be further de-
veloped to a fully mechanised and automated system.

However, such an undertaking is of the same order of magnitude as the mechanisation and water hydraulic technology programmes of COMRO in the 1970s and 1980s about which Pogue (2006) asserts “Despite valid criticisms of COMRO itself, without a similar stakeholder in the sector’s system of innovation, it is virtually certain that no equipment supplier would ever undertake the development of a systemic alternative technology”.

There is no doubt the potential rewards of a successful Nederburg Miner system are substantial, offering access to gold reserves comparable to the Witwatersrand itself and a mining system that can be fully mechanised and automated while providing increased levels of operator health and safety. However, developing a Nederburg Miner system through to production requires a massive act of will on the part of the mining industry, the supply industry, researchers, labour and government.

6. Electric discharge drilling

Electric rock breaking was identified as an exciting technology within the Nederburg Miner project, but almost immediately was recognised as having a more immediate application: drilling.

The South African mining industry drills a lot of holes every day: up to one million blast holes, for example. The dominant drilling technology is pneumatic percussive. The drills are robust, flexible and offer reasonable production rates. Unfortunately, the drills are also extremely inefficient, very noisy, and lead to a lot of dust, which causes silicosis if it comes from quartz-bearing rock. An ideal rock drill would offer the same or better production rates, high efficiency, low noise and low dust.

Previous work on non-percussive electric drilling had focused on the plasma drilling process developed by Tetra Corporation of Albuquerque, New Mexico, and referred to within South Africa as the Plasma Hole-Maker. However, more recently, Tetra have developed a significantly different approach to that of the Plasma Hole-Maker, known as electric discharge drilling (EDD).

In EDD, a central electrode discharges a high voltage pulse to a ring ground electrode (Figure 10). The discharge occurs within the rock, breaking segments of the rock from the solid under tension. Experiments show that the technique is comparable in efficiency to the theoretical limit (Harper, 2008), and has a lower specific energy of rock breaking than percussion drilling because the chips it produces are larger than those produced by percussion tools.

Figure 10. General arrangement of electric discharge drilling.

Ilgner (2006) has shown that South African rocks can be broken using electrical discharges (Figure 11). Electric rock breaking looks promising, but has been around since the 1960s. The main technology that might enable the breakthrough required for a production machine is the emergence of low cost power electronics.

Figure 11. Breakdown strength of economically important South African rock types.

EDD is quiet. There is noise while collaring but once the hole starts to develop, the noise is trapped at the bottom of the hole. The dust produced is also safer, as the majority of particles created are greater than 1 mm in diameter. If EDD can be developed to the point where it is...
feasible for drilling blast holes, it will revolutionise conventional drill and blast operations.

7. Conclusion

Technology can enable mining in South Africa to remain competitive and to remain an important contributor to the economy:

- In-mine application of geophysics can remove the surprises associated with mining, lowering costs and improving safety.
- Real time management systems can benefit from the introduction of the AziSA standard, leading to widespread application of real time sensing, and hence to better decision-making.
- A revolution in mining can enable access to an enormous gold reserve in the Witwatersrand Basin. However, the project to develop the technology will require commitment and deep pockets.
- A new drilling technology can be developed that improves efficiency and removes two significant health stressors: exposure to noise and exposure to silica dust.

This paper shows that mining cannot be regarded as a mature industry with regards to technology. In particular, deep gold and platinum mines need research and development if they are to meet the demands of the 21st century.

8. References


9. Endnote

We thank the funding bodies that made the projects described here possible, particularly the DST through the CSIR’s Parliamentary Grant, and the Coaltech and PlatMine collaborative research consortiums; and the many mines that have worked with the CSIR to develop the techniques presented here.

Contribution of the authors:
DV Primary author
VZB AziSA philosophy
SD AziSA standard design and class 2
GF AziSA location technology
JH AziSA standard design and class 3&4
GH Nederburg Miner
RS AziSA standard design and class 1
MVS ERT and GPR