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DRILLING EXPLORATION BOREHOLES BEYOND 4000M IN SOUTH AFRICA

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INTRODUCTION

South Africa has a mineral endowment that is unequalled in value and diversity by any similar region in the world. The geological setting of these mineral deposits, and the associated mining methods, are often unique; as are the exploration and drilling methods used to prospect existing and potential orebodies. These deposits placed South Africa along the top ten producers in 23 out of 26 mineral commodities in 1987. (Figure 1).

For many years the mining industry has been South Africa's largest earner of foreign exchange. Gold sales between 1980 and 1990 have averaged some 4570 of total annual export earnings. Average gold grades have steadily decreased from 14g/tonne in 1970 to 5g/tonne in 1988. Gold accounted for 33%, or US$7,750 million, of foreign exchange earnings in 1988.

Gold mining commenced close to Johannesburg in 1886 when surface outcrops of the pebbly, oxidized "banket" reef were first mined. The surface mining was limited to very shallow depths and adits and vertical shafts were then sunk to intersect the reef underground. When the surface and shallow deposits were exhausted, deeper shafts were developed giving rise to the largest and deepest gold mining industry in the world. In 1977 a shaft complex at the Western Deep Levels Mine was completed to a depth of 3777m.

The establishment of a deep level mine costs an average of US$4 billion, involves a high degree of risk and considerable leadtimes between investment and initial dividends. Exploratory boreholes to define the geological structure and grade distribution reduce the risk and allow confidence levels to be placed upon investment decisions.

GEOLOGY Of THE GOLDFIELDS

South Africa's gold is contained within tabular conglomerate beds between 0.1 and 10m thick. The metal is incorporated with the molecular lattice of iron pyrite (FeS_2); it is extremely uncommon for gold to be found as a native element. The conglomerates are separated by sequences of quartzite, many hundreds of metres thick, and have a wide lateral extent with strike lengths covering tens and even hundreds of kilometres. The reefs were formed some 3500 million years ago when sediments containing gold

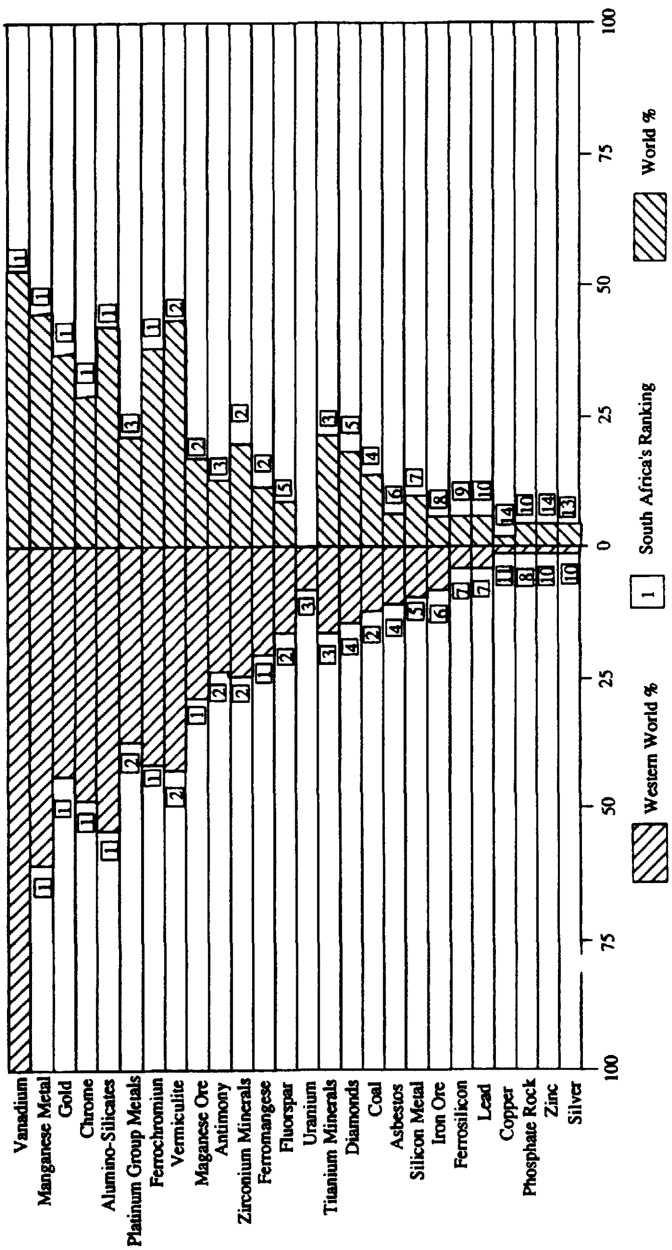

Figure 1. Role of South Africa in World Mineral Supply: Production 1987.

were deposited into the Witwatersrand Basin which extended over a large part of present day central South Africa.

The gold bearing conglomerates and barren quartzites of the Witwatersrand System are typically overlain by lava, dolomite and other sedimentary sequences such as sandstones, shales and volcanics. None of this overburden carries gold values and each causes different drilling problems. Subsequent folding, faulting and volcanic episodes resulting in dykes and sills, have substantially altered the original depositional attitude. Upthrown blocks or horst structures are mining exploration targets as the reef zones have been brought closer to the surface. Figure 2 shows a typical stratigraphic column and mine layout.

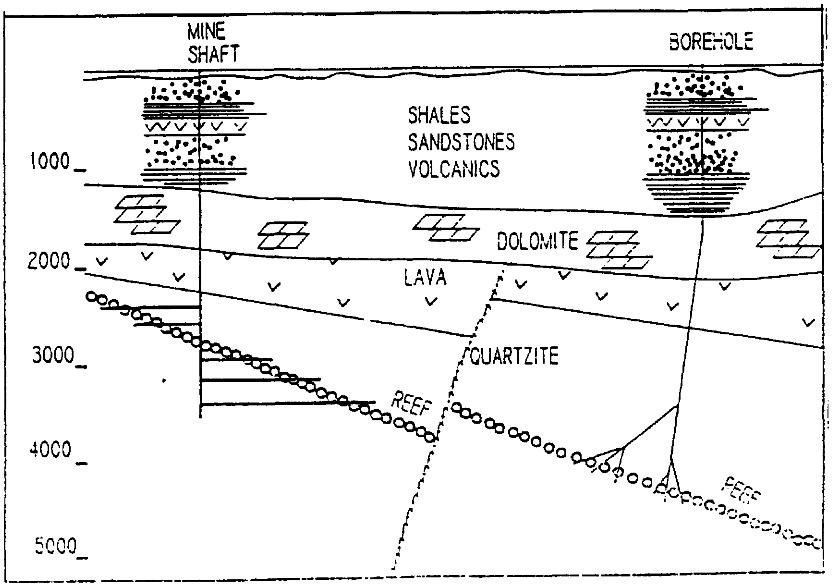

Figure 2. Typical mine Layout.

Gold mines have been established round the edge of this basin forming a Golden Arc which stretches for some 450 kms.

BOREHOLE PLAN

Each borehole is engineered prior to drilling. Topography, lithology, stratigraphy, depth and deviation constraints effect the choice of equipment, borehole sizes, casing points and inhole tools necessary to confidently complete the project. The need for deflections to gain additional reef intersections and the required separation of these from the motherhole can have a major effect upon overall costs and completion times.

Figure 3 shows a typical borehole plan with lithology, casing depths, borehole sizes and completion times.

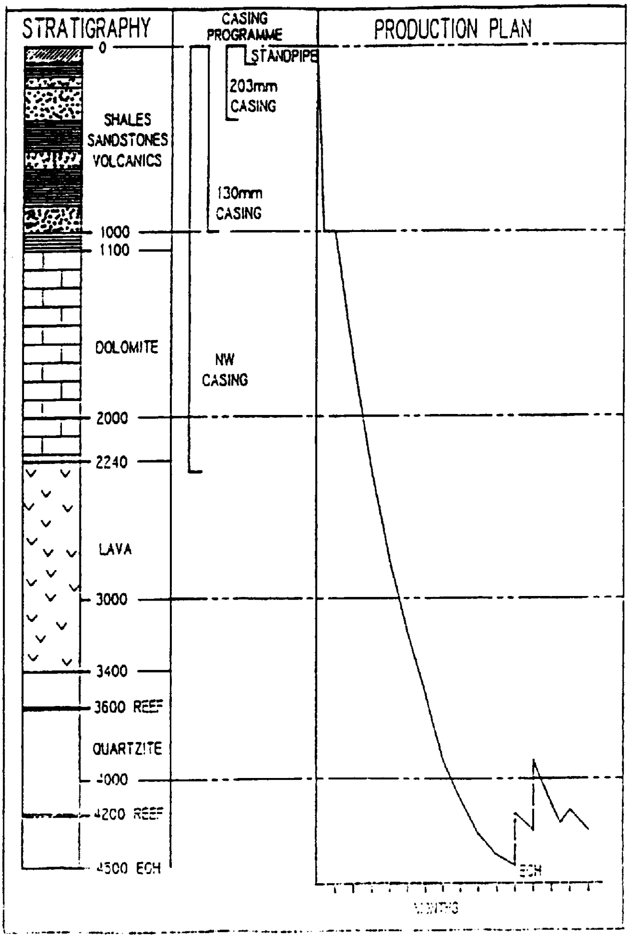

Figure 3. Typical Borehole Plan.

DRILLING PROCEDURES

The following notes are included to explain typical parameters and methods used for successful project completion.

Establishment

The majority of the Witwatersrand gold fields are situated in undulating countryside with cool dry winters and warm wet summers. Sites are generally located so that excavation or backfilling is rarely necessary to accommodate the rig. Water for drilling and the crew's consumption is drawn from wells drilled on the site. These have to provide sufficient water for drilling as circulation losses are common and must be protected from contamination by drilling fluids.

Excavations for rig foundations, fluid pits and drainage; access roads, fencing and electrical installations for the site are undertaken by sub-contractors to the drilling company's specifications.

Drilling Methods

Borehole diameters and casing programmes vary with stratigraphy, anticipated inhole conditions and locality. Typically pilot boreholes will be drilled using percussion rigs to penetrate the weathered zone and barren overburden. Percussion drilling is cheaper and quicker than diamond drilling. The disadvantages of percussion are that the costs to the contractor rapidly escalate when water bearing fissures are intersected. Yields of over 40,000 l/hr are not uncommon. Percussion boreholes tend to deviate more than diamond drilled boreholes; reducing penetration rates to control deviation soon becomes unattractive as daily revenue decreases. In such cases the percussion method is replaced by diamond drilling.

Percussion drilling begins in 380 or 330mm to establish the standpipe into solid rock. Drilling continues in 250mm diameter to +/- 400m and a 203mm ID welded casing is inserted to isolate the borehole from near surface, unstable formations. The borehole diameter is then reduced to 200mm and drilling continues to +/- 800m where the diameter is further reduced to 165mm until the target depth. No casing is inserted at 800m because the larger upper borehole section reduces the pressure loss associated with a small annulus and enables more power to be generated by the hammer for a given volume of air. On completion of the borehole a casing string is grouted into the borehole using a non-return valve above the bottom casing joint and a wiper plug.

Methane gas is occasionally associated with carbonaceous shales in the upper overburden . Diverters with bluey lines are placed on top of the standpipe to isolate the rig and crew from any potential blow out. Foaming additives are used to aid borehole cleaning when required.

The deepest recorded pilot borehole in South Africa was drilled by the author's company to a depth of 1448m in 21 drilling days.

Diamond drilling commences 96mm diameter using a heavy duty rodstring called CUD96. The CUD 96 has a internally upset cold drawn midbody onto which tooljoints are inertia welded. This construction allows strengths of the midbody, weld and tooljoint to be matched to give a balanced rod. (Specifications are given in the appendix). The tooljoints are induction hardened to a depth of 1.5mm to resist inhole wear and thread electroless nickel plated to prevent galling.

CUD96 rods are rated to a depth of 4100m with a 2:1 safety factor, at this depth the string weight in air is 65600kgs. The core produced is 47.6mm or equivalent to NQ. Standard Longyear 6m NQ innertubes are used in the CUD96 corebarrel.

The CUD96 system is used to drill through the dolomitic section of each borehole. The dolomite is highly fractured and is particularly susceptible to circulation losses and water makes. The continual flow of drilling fluids against the dolomite remove any fissure fill or joint cement resulting in spoiling and caving as drilling progresses.

After drilling the dolomite the borehole is cased with NW casing; if the dolomite is not cased caving will interfere with future drilling operations especially when wedges have to be lowered for deviation control or deflection drilling.

A 76mm diameter borehole is drilled from the NW casing point to the end of the borehole. CUD76 rods are used, these are also an internally upset and friction welded rod which enable a standard 36.5mm or BQ core to be produced. This section of the borehole may also be completed using a combination string of the heavy duty CUD76 in the upper portion of the borehole with CHD76, a lighter composite rod, below. (See appendix for specifications). The lava and quartzite are often extremely homogeneous with little fracturing enabling 12m corebarrels to be used.

Surface Plant

Surface plant configurations and ratings vary between contractors, the majority of rigs are mechanically or hydrostatically driven, an integral hoist provides lifting capacity, rotation is transmitted through a quill bushing and feed rates are controlled by two hydraulic cylinders with a stroke of +/- lm. A much smaller population of top drive or rotary table type rigs have also been used for deephole exploration. A hydrostatic drive is preferable as this greatly reduces the shock loading placed on the drillstring. Auxiliary drawworks may be used, with a more powerful hoist, to aid pulling and lowering of the rodstring.

Wireline winches capable of reaching 5000m are generally designed for a 10mm diameter non spin rope. Lighter smaller diameter ropes have been used but have proved to be less economic and more prone to failure.

Derrick designs and ratings vary greatly, The four square L.C. Moore type angle iron construction is the most common; these are slow to erect and increase establishment times. A variety of jack knife derricks and masts that are quicker to erect are used but generally have a lower rating than the four square type. 18m stands made from three six metre rods are most common but this may be increased to 30m. Increasing the stand length reduces trip times but the rods, especially the smaller diameters, are very flexible when stacked in the derrick and are often hung on slings from the crown. Making and breaking such long stands is difficult because of sway and thread galling can result. Other ancillary equipment includes mud mixers, generators and a positive displacement pump for the drilling fluids. (Specifications are given in the appendix) .

Crewing

Typical complements are two 5 man crews each consisting of a driller, top hand and three floormen working a 12 hour shift five days per week. The crews alternate shifts under the control of an onsite chargehand who is on 24 hour call. Working hours are controlled by government legislation. Each borehole is considered to be an individual mine and is subject to the Mines and Works Act and the control of the Government Mining Engineer. The Act prohibits any mining on certain public holidays and Sundays, if a 7 day week operation is required exemptions may be obtained. However, this requires four crews two of which work a twelve hour shift for seven days and are then rested for seven days.

Directional Constraints and Control

These vary between project and client, and are also dependent upon the anticipated geology and target intersection parameters. For example, a borehole may be restricted to a cone centred on the borehole collar which has a base at the final true vertical depth with a diameter not exceeding one tenth of the true vertical depth. Borehole deviation can be controlled to an extent by bit selection, drilling practices and the use of stabilizers. Other more active methods are conventional steel wedges, with the ever present risk of leaving steel in the borehole; the less effective Clappison type retractable wedge and the more costly downhole motors with some form of online steering system.

Magnetic survey tools are used to monitor borehole inclination and azimuth at regular intervals which are governed by the deviation tendencies of the project area. Single shot instruments are used for check surveys as drilling progresses and multishot instruments are run on specified bit changes to give a more detailed analysis of the borehole drift. Some clients may specify gyroscopic surveys for greater accuracy on completion of the borehole.

Borehole deviation increases torque and the cost of drilling fluids required for lubrication; reduces equipment life and necessitates additional drilling to intersect a given target. Allowing a borehole to drift with the natural ground forces into a target may be preferable and more cost efficient than using episodes of directional drilling to control the deviation. This can only be undertaken when the ground forces within an area have been experienced and assessed.

The doglegs caused by borehole deviation must be carefully monitored and kept within 3° per 30m of borehole wherever possible. This is particularly important in the upper portion of a borehole as the cyclic stress reversals caused by severe doglegs can rapidly cause rod failure and premature casing wear as the string weight below the dogleg increases.

Reef Deflection

Gold concentrations within a reef may vary greatly over a few centimetres. To ensure a borehole provides a representative sample, three to six intersections may be taken from each reef. This is accomplished by placing steel wedges in the borehole +/- 30 meters above the reef and drilling sidetracks to re-intersect the reef.

Longer deflections may be achieved by positioning a wedge or series of wedges 300m above the reef to gain greater separation from the motherhole. The majority of such drilling is done at depth and is a trade-off between the higher confidence levels achieved from the additional assays and the increased project cost. Deflection drilling may account for 30~ of the total drilling costs.

To provide larger diameter core samples thin walled corebarrels may be used to drill the reef cut. This precludes the use of the wireline system and necessitates the complete rodstring being withdrawn after each corebarrel is filled, which again increases deflection costs.

Drilling Fluids

Following the introduction of wireline for deep gold exploration it soon became apparent that the traditional drilling mediums of grease and water were not suitable. Water based, low solids drilling fluids were developed from the oil-field mud systems and these are used on the majority of wireline rigs. A filming amine type lubricant is used to coat the rods, casing and sidewall to reduce torque and enable better energy transfer to the bit. The amine also "west" and lubricates the diamonds thereby increasing bit life and provides corrosion protection for the rodstring. Long chain polyacrylamide viscosifiers enhance the carrying capacity of the fluid and dampen vibration. The shearing characteristics of the viscosifier enables efficient heat transfer and cleaning of the bit. Other additives are used to control pH, bacterial growth and to counter specific problems such as lost circulation, caving and swelling clays.

A 4000m 76mm diameter borehole contains over 18000 litres of drilling fluid. This is augmented by a 30000 litre surface system which contains settling sumps to allow cuttings to fall out of the fluid and pits which provide for storage, mixing and conditioning of the drilling fluid.

Fluid costs may on average represent 5% of a contractor's total drilling cost. This can increase rapidly if high torque, poor formations or lost circulation zones are encountered. The prevention of environmental contamination and the disposal of spent fluids have increased project costs and make efficient management of the systems an integral part of the drilling operations.

Completion

Geophysical logs are run prior to deflection drilling to obtain maximum information from the borehole. The type of logs vary but generally include dip meter, gamma, neutron, VSP and resistivity. On completion cement plugs are inserted below the dolomite to prevent any possible water ingress should subsequent mining operations intersect the borehole. Casings are recovered here possible and inspected and graded for future use. Site clearance is effected to leave the drill site in the closest possible condition to when establishment commenced.

Drilling Costs and Risks

The costs of drilling deep exploration boreholes varies greatly depending upon the ability to percuss deep pilot-boreholes; the anticipated lithology and related borehole sizes, the final depth and deflection requirements. From the example given in figure 2, the following costing has been estimated as a current industry average:

Establishment of rigs, site, accommodation and water well	R 48,000
Drilling costs for the percussion and diamond drilled sections of the motherhole	R 3,368,000
Casing costs, this assumes the diamond drill casing is recovered intact and can be reused	R 114,000
Services including water supply, surveying, stratimetric surveys and grouting	R 82,000
Wedging costs for deflections	R 212,000
Drilling costs for deflections	R 632,000
Total	R 4,456,000

The great majority of boreholes are drilled entirely at the contractor's risk. If a drilling company lost a borehole just above the reef zone it could contractually be requested to redrill the borehole at no cost to the client. Fortunately such cases are extremely rare as the total borehole is rarely lost and a compromise may be reached with the client. In addition to the borehole cost a contractor would have some R1,200,000 of surface plant and a R700,000 rod string on site to undertake the work. No insurance at acceptable premiums is available to cover the borehole or the rodstring. This places the contractor in a very high risk operation.

EQUIPMENT DEVELOPMENTS

The need for deeper boreholes in South Africa has led to the development of equipment particularly suited to the problems encountered, some of these are given below.

Window Wedges

In some exploration programmes the main target reef may be underlain at depth by secondary reefs which are also to be sampled by the borehole. To expedite the exploration programme and facilitate the siting of future boreholes once a primary reef is intersected, a window wedge may be inserted to allow numerous cuts of the reef for assay purposes. Different methods are available but the function of the wedges is to allow sidetracks out of an existing borehole. The wedge is then recovered allowing drilling to continue in the motherhole with no permanent steel insertions.

Shear Shells

A "burn in" at 4000m will weld a very expensive rodstring to the bottom of the borehole, resulting in a lengthy fishing operation. As boreholes go deeper nearly all the pressure loss of the circulating system occurs in the small annulus between the rod and the borehole sidewall thereby making any detection of a cracked pipe by measuring pump pressures impossible. To overcome the possibility of burn ins, rods regularly undergo crack detection and wall thickness tests. As an additional safety measure the thread between the bit and shell has been designed to transmit the necessary torque for drilling and has sufficient tensile strength to break core but will fail when excessively loaded, leaving only the bit at the bottom of the borehole and the rodstring free.

Positive Landing Indicator

The positive landing indicator was developed between BES and the Boart Research Centre to show the driller when the wireline innertube landed in the corebarrel Because of high pressure losses in the rod/hole annulus, it is extremely difficult to detect any pressure change as the innertube lands. The positive landing indicator is a simple device built into a standard Longyear head assembly. When the innertube lands the water way through the latch body is temporarily blocked until a pressure increase of some 2MPa opens the indicator and normal flow is resumed. A pressure gauge with a lazy pointer needle records the pressure peak on surface to prevent the driller "missing the landing". Drillers are overly generous with innertube descent times to prevent a missrun, the simple indicator is saving up to 15 days on a 4000m borehole.

ALU 76 Drill Rods

BES designed a 76mm Alu rod string that is capable of reaching a depth of 6000m with a 2:1 safety factor. This produces a BQ core-and enables exploration to ultradeep depths or the use of lower rated surface equipment. The rod consists of an aluminium midbody into which steel tooljoint ends are screwed and glued. The aluminium is not suitable for drilling in compression and sufficient steel collars must be used at the bottom of the borehole to apply bit weight. Similar aluminium rods were used to complete the deepest recorded borehole in South Africa to 5520m.

Modified Oil-field Drill Rigs

Modified oil-field rigs which combine tricone drilling to rapidly penetrate the overlying strata and coring techniques to provide reef samples have been successfully used in South Africa.

The technique enables substantially quicker drilling rates, greater flexibility for directional drilling or multiple reef intersections at depth using downhole motors and increased confidence levels for project completion in the shortest possible time. Oil rig operations are more expensive than conventional rigs and the additional costs must be measured against the benefits of assessing mineral options faster and ultimately decreasing the time required to develop a mine. The rigs can also be used to drill large diameter mine service boreholes and to undertake complex directional drilling to assess a block of ground from one surface location.

CONCLUSION

South Africa will always require deep exploration boreholes to evaluate potential new mines. Seismic, and other geophysical surveys, provide useful tools for the exploration geologist but cannot replace a physical core sample. The contractor and supply companies must concentrate on techniques and equipment that will provide quicker drilling and reduced risk.

Gold price fluctuations and the effect upon revenue received by the mining finance houses who fund exploration projects does cause changes in the level of drilling activity. However, deep exploration drilling for gold is an integral part of South Africa's mining industry and will continue to be so.

REFERENCES

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H. Wagner,Technology and a Developing South Africa, Mining Survey No. 2, 1990.

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APPENDIX

Drill Rod Specifications

	CUD96	CUD76	CHD76	ALU76
Borehole Diameter (mm)	96.0	76.0	76.0	76.0
Core Size (mm)	47.6	36.5	43.5	36.5
Rod O.D. (mm)	89.0	69.9	69.9	69.9
Rod I.D. (mm)	75.0	57.2	60.3	50.8
Tooljoint I.D. (mm)	50.3	46.2	55.0	46.2
Depth Rating (m)	4100	4200	3200	6000
Wight (Kg/m)	16.0	11.2	8.4	6.4

IES 3000 Rig Specifications

Cross-head Capacity	100,000 Kg
Hoist Capacity (single line pull)	5,200 Kg
Rotational Speed	80-800 rpm
Feedrate	0-0.06m/sec
Weight	14,200 Kg