

# **The Raise Boring of Large Diameter (>7.0mØ ) Vertical Shafts on a South African Colliery**

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## **SYNOPSIS**

A requirement was identified at Sasol Mining to harness the cost, safety and time advantages associated with raise-boring as a shaft sinking method with the ever increasing requirements for ventilation volume.

Previously a maximum diameter of 6.1 meters had been raise bore reamed; this allowed for a maximum air volume of a little over 560 m<sup>3</sup>/s for a single raise bored upcast shaft. Sasol Mining required upcast ventilation installations on two of its Collieries, which could each deliver in the region of 760 m<sup>3</sup>/s.

Simply put, the solution for this requirement was to either raise bore two shafts, execute a blasting operation or move the boundary for raise boring diameter to at least 7.0m.

Sasol Mining (Pty) Ltd and Rucbor (Pty) Ltd have successfully concluded the raise boring of three shafts at >7.1 meters diameter as part of a sequence of nine new shafts on Sasol Mining's Secunda Collieries.

This paper discusses the planning and execution of these three large diameter shafts, particular reference is made to the prevailing local geological conditions and to the risk mitigation methods employed to ensure that this technology,-stretching project was completed successfully.

*"Risks exists, and the successful mining engineer is the one who never accepts a solution at face value, he strives continuously to learn from the past and the present and he is always prepared to sow his knowledge into the future".*

## INTRODUCTION

This paper serves to document the generic as well as specific investigative, design, planning and control work that was undertaken during the various project phases for the establishment of three large diameter (> 7.0mØ) raise bored shafts for Sasol Mining at it's Secunda complex.

### *The Secunda complex*

Sasol Mining has operations at Sasolburg and Secunda; the Secunda operations consist of the seven fully underground mines and the Syferfontein combined strip and underground operation. The combined output from the Secunda mines is 41 million tons per annum.

Brandspruit, Bosjesspruit, Middelbult and Syferfontein Colliers supply gassification coal to the Sasol Synthetic Fuels (SSF) plant at Secunda; Twistdraai Central Mine produces both gassification and export quality coal and the Twistdraai East and West mines are dedicated export coal producers.

Infrastructure upgrade requirements for ventilation, safety and logistical reasons resulted in Sasol Mining establishing nine new vertical ventilation shafts between June 2000 and July 2001.

- Twistdraai Central Colliery: 1 off 6.1m Ø downcast (D/C), 125m deep, equipped with escape ladder.
- Middlebult Colliery: **1 off 7.1mØ upcast shaft, 85, deep**  
1 off 8.6m Ø downcast shaft equipped for man and material transport.
- Bosjesspruit Colliery: **1 off 7.1m Ø upcast haft, 176m deep**  
**1 off 7.1m Ø d/cast shaft, 176m deep**

- Syferfontein Colliery:
  - 1 off 5.1m Ø upcast shaft, 111m deep
  - 1 off 4.1m Ø downcast shaft, 105m deep
- Brandspruit Colliery
  - 1 off 4.8m Ø upcast shaft, 145m deep
  - 1 off 5.5m Ø downcast shaft, 145m deep.

Project pre-feasibility and feasibility study investigations had determined that raise-boring as a shaft sinking execution method was the preferred techno-economic solution.

Therefore these 9 shafts are raised bored and shot-crete lined with the exception of the Middlebult man and material shaft which was raise bored to 3.8m Ø, sliped to 9.2m Ø and concrete lined to final diameter (8.6m) as required for the permanent hoisting equipment.

#### *Projects and Technology Services (P & TS)*

This department, a division of Sasol Mining is based in Secunda and provides a full Project Management and Engineering Technical service to the Sasol Mining operations.

P&TS were appointed project managers for these shaft projects and accepted responsibility for all engineering, procurement and construction management functions (EPCM), as well as the statutory responsibilities.

Rucbor (Pty) Ltd, a division of RUC mining were appointed as raise boring contractors with Rucmin (Pty) Ltd executing the sliping, lining and equipping operations at the Middlebult man and material shaft.

Piek Mining (Pty) Ltd were awarded the contract to bolt, mesh and shot-crete line the remainder of the shafts.

Percusso Bor (Pty) Ltd executed the pre-mining ground stabilisation work at the Bosjesspruit shafts.

## **LARGE HOLE RAISE BORING - A TECHNOLOGY INSIGHT.**

Sasol Mining has had previous experience with raise boring in the Highveld Coal field. An understanding of the geological conditions and the effect these conditions have on a raise boring operation are a pre-requisite for successful project execution.

The raise boring technology, equipment and operational methods to be used have to be understood in order to carry out the mining design and assessment of risk.

These risk assessments must take into consideration the mechanical performance of the raise boring equipment as well as the prevailing mining and geological conditions.

The technology for the smaller diameter (up to the 6.1m Ø required at Twistdraai) raise boring operations was operationally proven and standard reaming tools were available. A diameter of 6.1m was however insufficient for the ventilation requirements at Middlebult and Bosjesspruit Colliers.

Opting for either a dual raise bored shaft system option or an alternative mining method was not cost effective and Sasol Mining requested that Rubcor investigate the potential of reaming to greater than 6.1m Ø with an objective of achieving  $\pm 7\text{m}$ .

Rubcor were successful in achieving technical solutions for their equipment requirements, and although this mechanical design still had to be operationally proven, embarked on this project with Sasol Mining. Risk mitigation in this regard is discussed later in this paper .

Addressing the operational risks associated with the site specific mining conditions required detailed information on the in situ strata conditions as well as an understanding of how the relevant strata would react under reaming and exposed (rapid weathering) conditions.

## **GEOLOGICAL CONDITIONS**

*General geology*

The Karoo supergroup sediments in the Highveld Coal field are represented from the base upward by the Dwyka formation, the Pietermaritzburg formation, the Vryheid formation and partially the Volksrust formation of the Ecca Group.

The sediments range through coal, mudstones, siltstones, sandstones, grits and tillites. Doleritic dykes and sills related to the stormberg lavas extensively intrude the coalfield. (Addendum 1)

The portion of interest to the rock engineer and shaft sinking project planner at Secunda Colliers is the portion of the stratigraphy from the Number 4 Lower Coal Seam to the surface. There are a number of aspects that affect the creation of an excavation in this ground, these are:

- The wide disparity of Uniaxial compressive strengths, from 7Mpa for Coal to >250Mpa for the more competent dolerites.
- The reaction of individual rock types on oxidation, the rocks with high clay content tend to weather preferentially resulting in negative profiles on the excavation.
- The distinct jointing sets in the Dolerite with the principal directions at 90° to each other in the vertical axis and a third jointing set in the horizontal axis resulting in blocky ground.

The overburden of the Number 4 Lower Coal Seam can be classified as a sequence of upward coarsening sedimentary units each capped by a coal horizon that is typical of prograding deltaic sequences.

#### *Specific geology: Middlebult and Bosjesspruit (7.1mØ) shafts*

The disparity of the uniaxial compressive strengths was less evident at Middlebult where the shaft collar is situated stratigraphically below the Number 4 Dolerite sill (B4) and the Number 8 Dolerite sill (B8) does not intersect the shaft position. The Middlebult shaft presented a low geological/mining risk profile.

The situation at Bosjesspruit is however quite different, both the B4 and B8 sills are present at both shaft positions. (Addendum2)

The B8, although very hard by karoo sequence standards was well below the hardness of >450 Mpa UCS material frequently encountered during raise-boring operations on South Africa's platinum mines. In addition, this strata has been successfully piloted and reamed several times at Secunda.

The stratification of the B4 dolerite sill was known from earlier shaft projects to present raise boring challenges, the reasons for this area covered in the next section.

The Number 4 dolerite sill at Bosjesspruit is covered by 15 metres of semi-weathered to weathered over burden and has three major lithological units:

- The lower unit is a 10metres thick fine to medium crystalline granular dolerite with minor non-oriented feldspar laths. It is a competent unit with semi vertical jointing with a 90° angle between the two principle joint directions. The spacing between the joints was assessed to be  $\pm 1.4\text{m}$  (figure 1). There is also a horizontal jointing component, the vertical spacing here was determined to be  $\pm 1.0\text{m}$  as observed at various road cuttings in the Highveld Coal field area.
- The next lithological unit, which is approximately 12 metres thick consists of a highly serpentinized fine to medium crystalline dolerite. This unit is highly jointed horizontally, with a typical joint spacing in the order of 5 to 8 centimetres. This unit weathers exceptionally quickly (figure 2).
- The uppermost lithological unit is similar to the lowermost unit. This unit is 18 metres thick and outcrops on surface with the upper 10 metres being highly weathered. The jointing again is similar to the lowermost unit.

## EXECUTION RISK IDENTIFICATION AND MITIGATION ACTIONS.

Tabled below are the major execution risks identified and the mitigation actions undertaken.

*Increased shaft diameter (Mechanical risk*

	RISK IDENTIFIED	MITIGATION ACTION
Risk 1	Additional torque effort on drill string, and reamer stem	Acquisition of suitable drilling equipment to manage additional engineered requirements.

*Challenging geological conditions (Mining Risk)*

	RISK IDENTIFIED	MITIGATION ACTION
Risk 2	<ul style="list-style-type: none"> <li>▪ The drilling of the pilot hole by the raise-bore machine is by rotary water flush method. Passage of ±200K1/hr would result in washout of the pilot hole in the upper 10m weathered zone.</li> <li>▪ The same risk exists in the highly serpentinized middle zone of the B4 dolerite</li> </ul>	<ul style="list-style-type: none"> <li>▪ Remove the weathered material by means of drilling a 600mm ø hole on the shaft centre and back filling with mass concrete, the pilot hole is then drilled through this backfill.</li> <li>▪ Apply a bentonite drill mud additive to the flushing water, this acts to seal the sidewall of the pilot hole during drilling.</li> </ul>
Risk 3	<ul style="list-style-type: none"> <li>▪ The blocky nature of the upper and lower B4 dolerite zones could result in a “block” dropping out of the reaming face during rod change. This is because the reamer is lowered ±400mm during each rod removal. The risk of this occurring was considered to be highly probable and would entail a lowering of the reamer head each time it occurred.</li> </ul>	<ul style="list-style-type: none"> <li>▪ Install a pattern of fibreglass dowels from surface to ±2m below the base of the B4 dolerite.</li> <li>▪ Dowels spaced on a 1.2m grid to ensure coverage required for 1.4m grid vertical 90<sup>0</sup> jointing. <b>Figure 3</b></li> <li>▪ Dowels designed for a tensile strength of ±60K.n to ensure integrity to hold 1.0M thick blocks against reaming face (Safety factor 1.1).</li> </ul>
Risk 4	<ul style="list-style-type: none"> <li>▪ The extremely friable nature of the rapidly weathering middle zone as well as the weathered upper 10m of the B4 dolerite could potentially self mine before they could be supported (see also risk 5 below)</li> </ul>	<ul style="list-style-type: none"> <li>▪ A ring of re-enforced concrete spiles was constructed around the perimeter of the shaft. <b>Figure 3</b></li> </ul>
Risk 5	<ul style="list-style-type: none"> <li>▪ A “block” from the upper or lower B4 dolerite zone could key out of the sidewall. This would create a hazard during loading out and support operations.</li> </ul>	<ul style="list-style-type: none"> <li>▪ As per risk 4 above</li> </ul>
Risk 6	<ul style="list-style-type: none"> <li>▪ The extremely friable nature of the rapidly weathering middle zone as well as the weathering middle zone as well as the weathered upper 10m of the B4 dolerite could potentially self mine before they could be supported</li> </ul>	<ul style="list-style-type: none"> <li>▪ A 45mm thick shot-crete layer was applied to the upper 60m of the shaft. This was completed within 3 days of the reamer being removed and within 14 days of the B4 dolerite zone being exposed.</li> </ul>

## **TECHNICAL SOLUTIONS TO RISK MITIGATION REQUIREMENTS.**

*Ensuring the mechanical integrity of the raise boring equipment.  
(Risk 1)*

Rucbor were successful in achieving technical solutions for their equipment requirements, these included:

- The acquisition of the upgraded drill string required for the additional torque requirements.
- The design of extension wings to be fitted to a standard 6.1m Ø reamer head base and,
- The configuration of the reaming cutters on this extended reamer head to achieve a reamed diameter of 7.1m.

The result was a reamer head, which would enable the excavation of the required 7.1mØ shafts through the strata overlying the shaft positions at the Middelbult and Bosjesspruit ventilation shafts.

*Actions prior to raise boring (Pre-mining ground stabilisation)*

### **Stabilisation of centre core for pilot hole drilling (Risk 2)**

The first requirement was to replace the upper ten metres of weathered material in the shaft centre to a diameter that would safely accommodate the 381 mm Ø pilot hole. This was achieved by drilling a 600mm ø and back filling with 30 Mpa mass concrete prior to the establishment of the raise-boring contractor.

Various drilling options are available, included the Chamber of Mines rescue drill and piling auger rigs. Due to time, safety and logistical constraints at the time of execution, a button bit reamer on a percussion drill rig was used to widen a 203mm hole, foam was added to the drill liquid to ensure adequate flushing of the drill chips with the increased annulus of the hole. (Figure 4)

The second requirement was to minimise the amount of pilot hole erosion in the middle zone of the B4 dolerite. Extending the 600mm  $\varnothing$  hole to a depth of  $\pm 50$ m was unacceptably costly; the selected solution was to apply a bentonite mud additive to the flushing water during pilot hole drilling.

### **Stabilisation of reaming face (Risk 3)**

A collapse or partial collapse of the reaming face during rod change out will result in costly delays, ensuring that the face remains intact is a prerequisite.

Standard strata control principles are used in designing the load bearing requirements of any support system employed.

The reamer face support system has the following design drivers:

- The minimum tensile failure strength of the supports (dowels) should be determined by the mass of a "block" of B4 dolerite, which potentially could key out of the reaming face.

$$\begin{aligned} \text{Mass} &= \text{Volume S.G} \\ &= 1.4\text{m} \times 1.4\text{m} \times 1.0\text{m} \times 2.7\text{m tons/m}^3 \\ &= 5.3 \text{ tons} \end{aligned}$$

- A safety factor of 1.1 was applied resulting in a tensile strength requirement of each support dowel of 58.2 Kn.
- The dowels should have shear strength as low as possible and should definitely not include any steel so as not to interfere with later raise boring operations should a hole deviate into the shaft.
- Dowel spacing should ensure coverage of the full shaft diameter taking account of the 1.4m spacing of the vertical joints in the B4 Dolerite.

A 10mm  $\varnothing$  fibre glass reinforced plastic rod with a specified tensile strength of 50Kn was sourced; three rods are used in each composite dowel. Twenty dowels are installed in each shaft

Three test dowels were made up and failure tested at CSIR Mining Tek with the following results:

Test one -	Maximum loads carried =	61.6 Kn.
Test two -	Maximum load carried =	71.3 Kn.
Test three -	Maximum load carried =	58.8 Kn.

#### **Stabilisation of shaft side walls (Risks 4,5 and 6)**

The known instability of the upper 10m weathered overburden as well as the propensity of the friable and rapidly weathering middle zone of the B4 Dolerite to self mining dictated that a means be found to effect the following:

- Structurally reinforce these regions to negate the effect of any lateral forces on the shaft sidewall/
- Arrest any over mining that may occur.

#### *Note 1*

Consideration was given to the injection of a resin based matrix into the weathered areas as well as the serpentinised dolerite zone, the idea being that a consolidated core roughly the diameter of the shaft would be created which could then be reamed. Field trials showed that a resin mixture injected through a 76mm Ø hole did not migrate sufficiently through the strata to reach the shaft perimeter and in fact took the shortest route, which was directly into the feed hole directly above the point injection.

High-pressure cement grouting technology could not be applied, as the nature of the strata is not conducive to this technology.

The solution opted for was to install a ring of reinforced "spiles" outside the perimeter of the shaft. Each spile consist of a 250mm Ø vertical hole drilled from surface to below the B4 Dolerite, a 50mm Ø steel pipe is inserted along the full length of the hole and the hole is full column cement grouted through the pipe.

A total of 51 "spiles" are installed around each shaft at 500mm spacing between centres, the net effect is a ring of 250mm Ø reinforced concrete piles spaced 250mm apart and to a depth of

60m around each shaft, accuracy of drilling verticality was closely monitored.

The integrity of this solution was verified by testing a design proposal by means of numerical modelling, this work was carried out by CSIR Mining Tek and entailed the use of proprietary software programs. The design proposal modelled included a double ring of spiles as was proposed from previous experience.

What the modelling showed was that a single ring of spiles was sufficient; this resulted in a considerable cost saving from estimates during the design phase.

### **Continuous operation in B4 Dolerite (Risk 6)**

Observation of the serpentine B4 zone of the geological core (figure 2) indicated that severe weathering of this zone would occur within two weeks of exposure to air. This meant that the serpentine in-fill between dolerite joints would disappear and that the 5 to 8 centimetre joint spacing in this zone would result in rapidly unravelling strata.

Planning was in place to apply a layer of shotcrete to this zone as soon as possible after access could be obtained to seal the area from the atmosphere and therefore halt the weathering process.

The expected advance of the raise borer was  $\pm 5\text{m/day}$  through the B4 Dolerite, as this zone is 40-50m below surface it would take at least 8 days from initial exposure of this zone to completion of the reaming operation. Reaming operations therefore had to be continuous once the B4 Dolerite had been intersected, for this reason cutter and reamer maintenance was done prior to the B4 being reached.

### **Immediate removal of reamer and raise bore equipment (Risk 6)**

For the same reasons as noted above, removal of the reamer and raise boring equipment from the shaft should take place within 24hrs of holing. Once the reamer had holed to surface this was achieved by using a 550-ton crane to first lift the 85t raise bore machine and then the 105-ton reamer head. (Figures 5a. & 5b.)

### **Rapid sealing of B4 dolerite (Risk 6)**

Now that the shaft was clear of raise boring equipment a layer of shot-Crete was applied to the shaft sidewall. The requirements were as follows:

- Apply a 45mm thick seal (flash-coat) to the shaft sidewall from the collar to a depth of 60m.
- Ensure that the shot-Crete would attain a final strength of 35Mpa and sufficient early strength that would allow safe access of workmen below newly applied shot create.
- Complete this flash-coat within 72 hrs of the reamer being removed from the shaft.

As the schedule requirements precluded any scientific testing of shot crete for logistical reasons, trials were conducted with various mixes of cement and accelerators, a best option selected and a standard operating procedure drawn up to ensure the correct and safe execution of this operation.

The shot-crete was a dry mix applied manually from a bosun's chair. Mix and water were supplied via suspended hoses from surface.

Figure 6 is a birds eye view of the Bosjesspruit upcast shaft prior to the installation of the support stage and temporary access system.

### **B8 DOLERITE ANOMALY**

The B8 dolerite has never been the cause of any failure or non-conformance at previous shaft sinking operations at Secunda. Although the material, at 250-350 Mpa is hard by Karoo sequence standards, the net result of this hardness in a raise boring operation is usually limited to a slower advance rate and increased cutter wear.

The B8 dolerite was present as expected at both the upcast and downcast shafts at Bosjesspruit Colliery; at the upcast shaft, which was raise bored first, this dolerite was encountered where expected

and managed as planned.

At the downcast shaft, the Dolerite was expected to be  $\pm 12\text{m}$  thick as per a core hole drilled 5m from the shaft perimeter, instead this intrusion was wedge shaped (Addendum 3) with a thickness varying between 7.46m and 12.40m over the 7.1m diameter of the shaft. This anomalous situation of hard (250 Mpa) and soft (55Mpa) material on the same reaming elevating resulted in the reamer head being pulled off level and the reamer stem failing causing the reamer to drop to shaft bottom.

The loading standard operating procedure enforced ensured that no persons or equipment were at risk when this happened. The net result was a delay of six weeks on the project schedule and considerable repair costs.

This risk has been mitigated in future shafts by drilling core samples from four positions around the shaft, a practice that is now standard procedure.

## CONCLUSION

- The cost, safety and schedule advantages of raise boring as a shaft sinking method vertical ventilation shafts are without question for the conditions prevailing at Secunda Colliers.
- The technical feasibility of the 7.1m diameter reaming operation has been proven, lessons learnt with the unique conditions experienced at the Bosjesspruit downcast shaft have been well documented and the required additional mitigation actions for future shaft projects already instituted.
- The project manager, when approaching such work where new development and significant risks are encountered must ensure that technically competent contractors, with a professional attitude are appointed as partners in the project development.
- A greater appreciation is also held for the need to manage out, where possible, as many assumptions and geological interpretations based on assumption as practically possible.

It is a strongly held belief that having detailed information on the prevailing geological and mining conditions, and being able to successfully synthesise this knowledge with the operation to be undertaken is a requirement for successful project planning and implementation. The more complete the technical input information, the greater the success of the risk mitigation actions and the lower the risk of non-conformance.

The degree to which the shaft sinking project manager is prepared to invest in the acquisition of geo-technical and geological information has to be evaluated with reference to the following factors.

- What previous experience in similar geological conditions have been suitably documented
- How consistent and uniform are the geological structures in the area? i.e. to what degree can assumptions be made on specific conditions?
- Has all the technology and equipment to be employed been operationally proven?

Ultimately though, mining remains as always, a science for the pragmatic.

*"Risk exists, and the successful mining engineer is the one who never accepts a solution at face value, he strives continuously to learn from the past and the present and he is always prepared to sow his knowledge into the future".*

## REFERENCES

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The raise boring of large diameter (>7.0m ø) vertical shafts on a South African Colliery, Presentation to SACMA, G. Trivett, August 2000.

Sasol Mining, Projects - Geotechnical aspects of the sinking of shafts in the Highveld Coalfield, J. Sparrow, Sasol Mining, March 2001.

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*For their continued trust and encouragement:*

Messrs. Jannie Van Der Westhuizen, Frik Grobbelaar, Jackie Versluis, Nico Van Eck, Gary Leibbrandt and Johan Van Zyl of Sasol Mining.

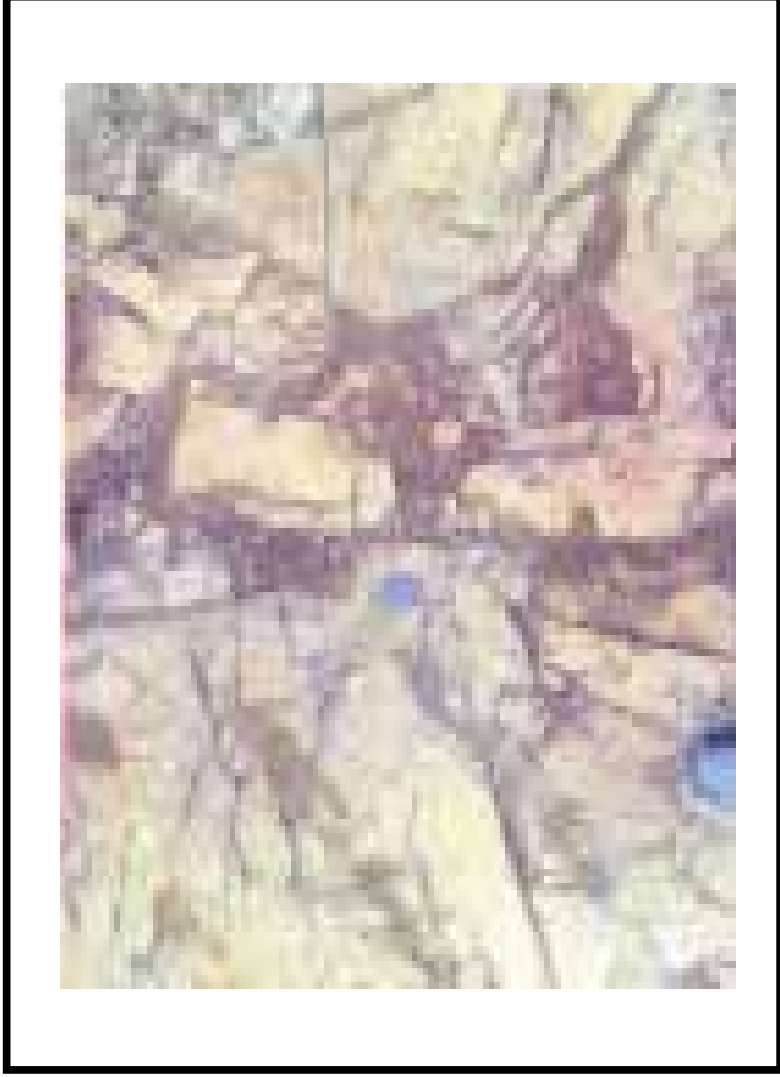
*For their technology inputs:*

To Koos De beer and Barney Bester for their past experiences in raise boring at Secunda, Dawid Postma and Brian Vorster for their rock engineering contributions and to John Sparrow for his geological insights.

*For their partnership roles:*

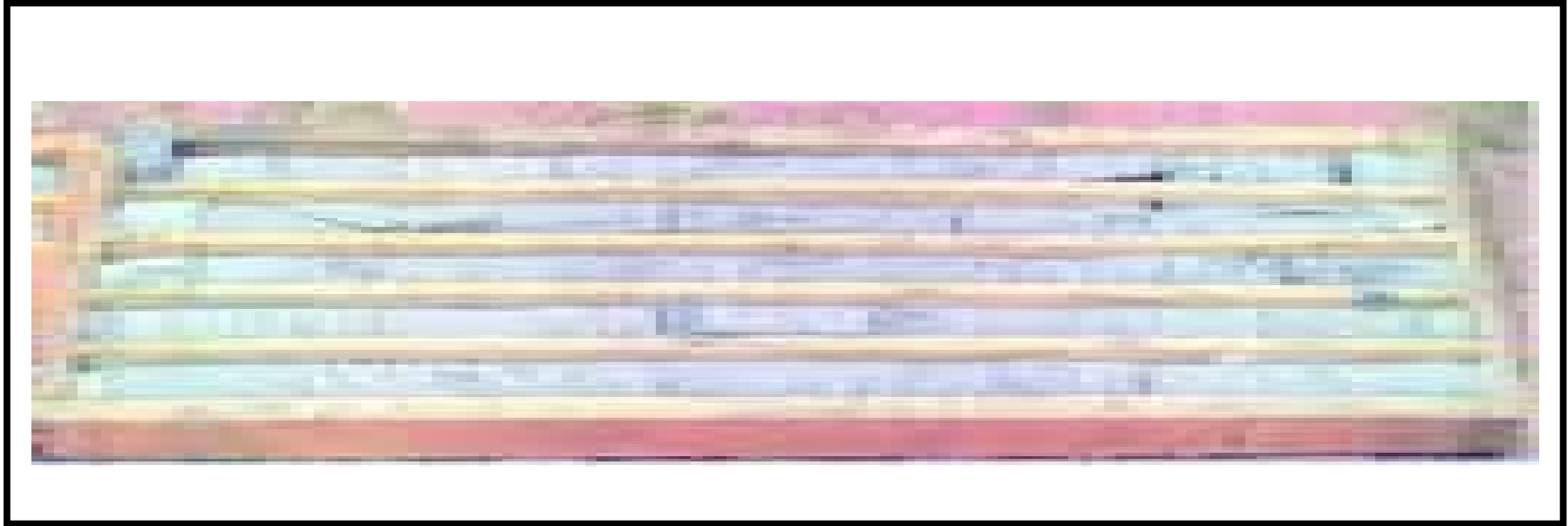
Coen Roos, Managing Director, Rucbor (Pty) Ltd  
Ivan Walker, Managing Director, Piek Mining (Pty) Ltd  
Pieter Pretorius, Managing Director, Percusso Bor (Pty) Ltd  
Kalli Le Roux and Roelf Du Preez

Acknowledgement also to all the colleagues on the project teams and on the mines for their professionalism and dedication.



**Figure 1:**  
900 Vertical jointing of B4 Dolerite

- Note camera lens cover for indication of scale



**Figure 2:**  
Serpentinised zone in B4 Dolerite

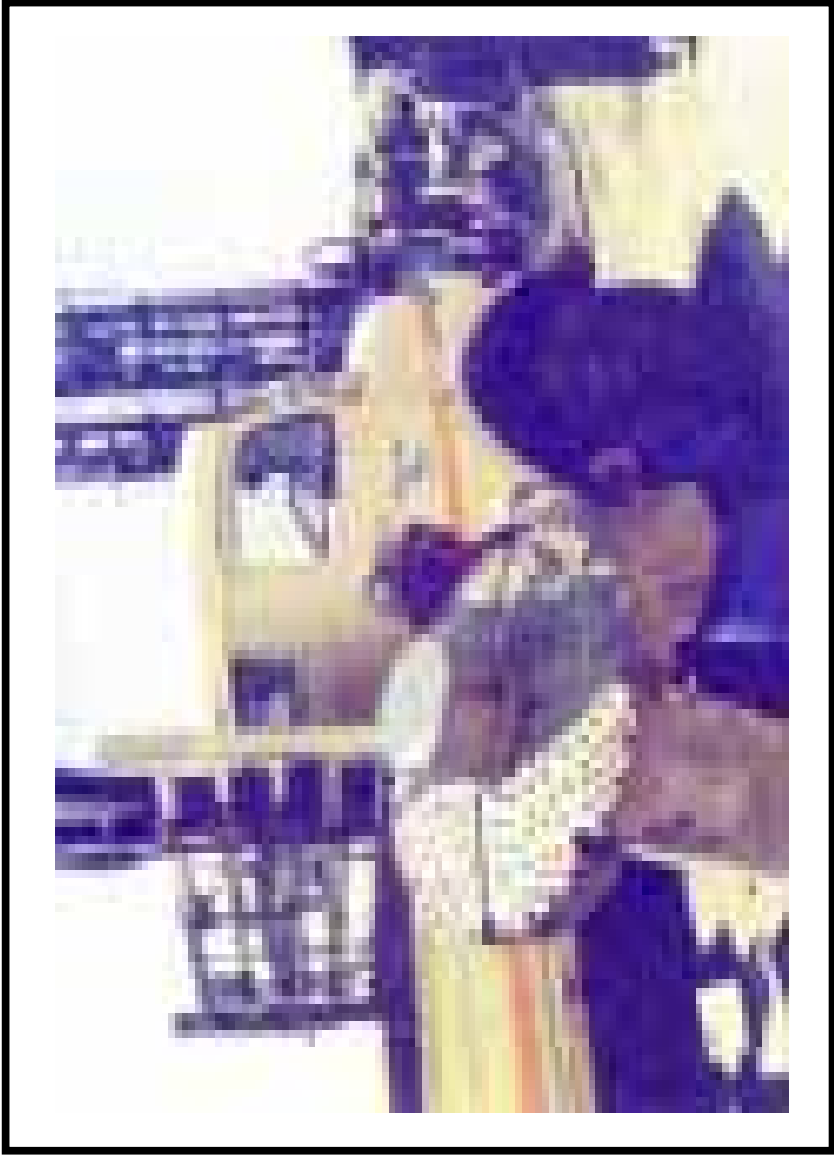
- All the lighter, serpentine bands in this core disappeared within two weeks of exposure to air resulting in a total unravelling of this 12m thick zone
- Notice also the vertical fracturing present



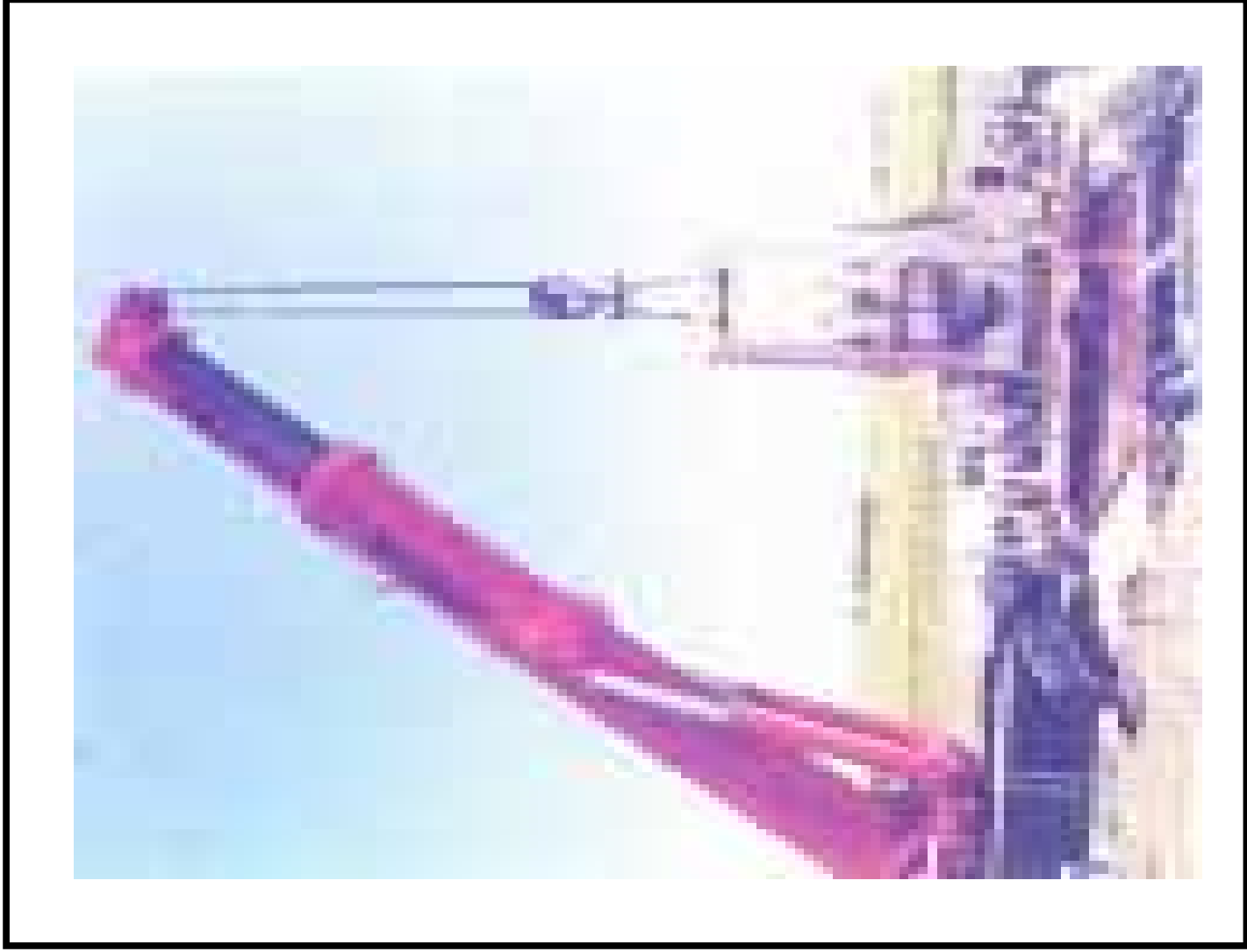
**Figure 3:**

Shaft collar ready for Raise bore machine

- Note dowels and spiles completed prior to raise boring



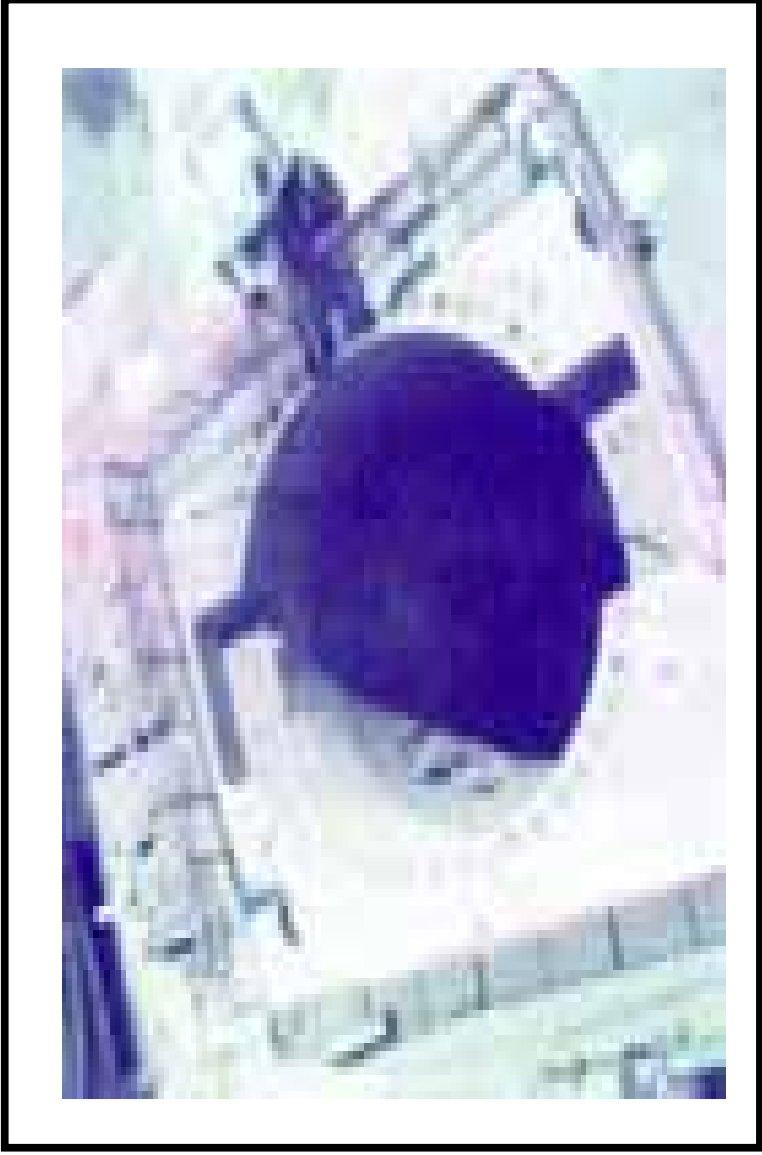
**Figure 4:**  
600mm Ø percussion drill reamer for centre core removal



**Figure 5a:**  
Single lift (85 tons) of Wirth Raise bore machine from shaft  
within 6 hrs of holing



**Figure 5b:**  
Single lift (106 tons) of 7.1mø raise bore reamer from shaft within 12 hrs of holing.

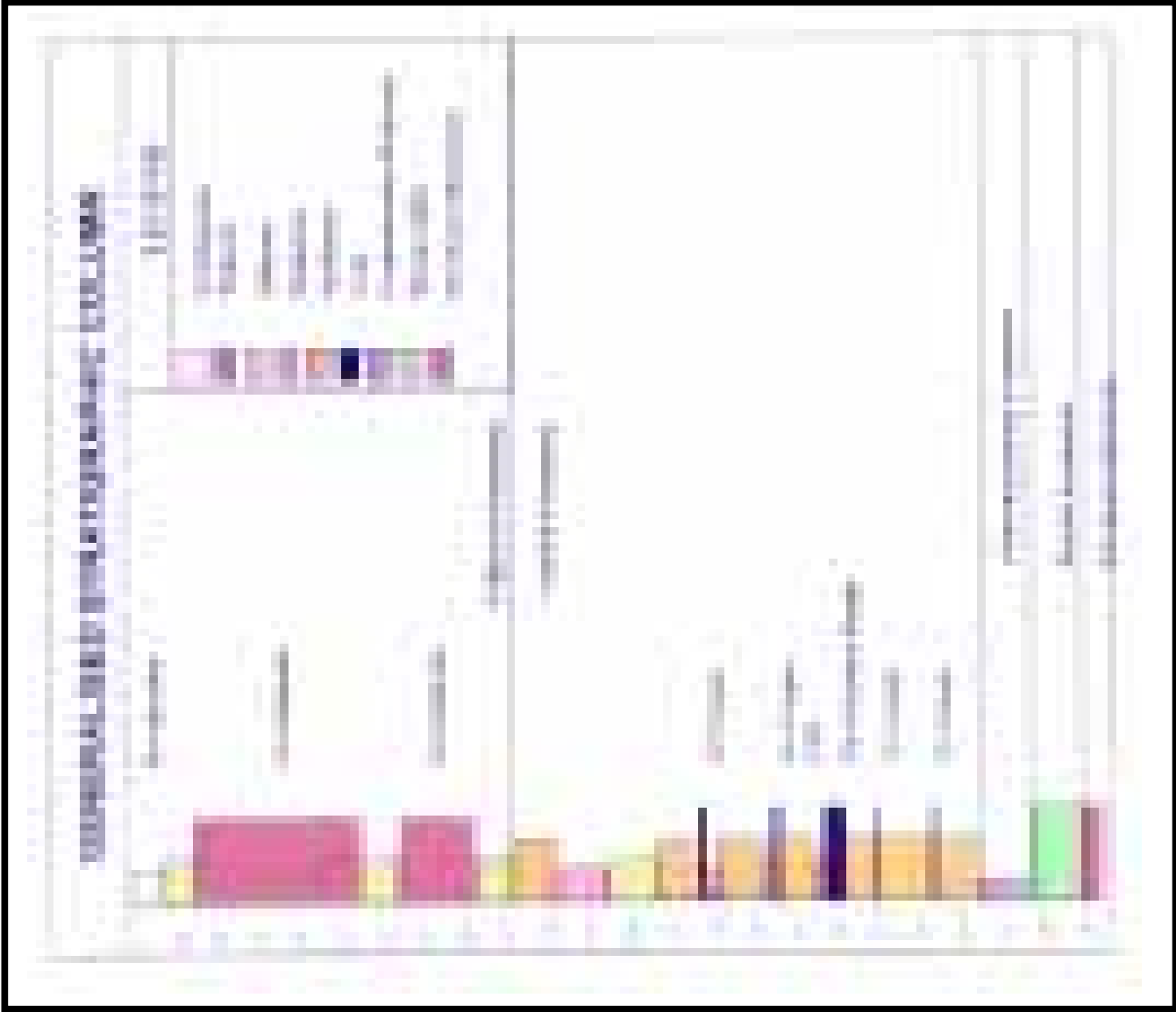


**Figure 6:**

Birds-eye view of 7.1mø raise bored shaft after removal of raise bore equipment

- Spiles around shaft
- Tendency of B4 Dolerite to self mine but arrested by spile (top left of shaft)

Addendum 1



**Addendum 2**

The image shows a large, extremely blurry table with multiple columns and rows. The content is illegible due to low resolution. The table appears to have a header row and several data rows. The bottom row contains colored cells in shades of green, blue, orange, and purple.

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**BOSJESSPRUIT - CHARL CILLIERS DOWNCAST SHAFT**

