ANNEXURE 7.12

“Reef Development with a Tunnel Boring Machine on a South African Platinum Mine”

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Reef development with a tunnel boring machine on a South African platinum mine

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Anglo Platinum have perceived a need to increase the rate of reef development both for new mechanised stopeing technology and on conventional new developing mines. The Research and Development Division of Anglo Platinum therefore initiated an experimental reef raise project with a tunnel boring machine (TBM) at Bafokeng Rasimone Platinum Mine (BRPM).

The scope of the trial was for the boring of a reef raise 340 metres in length on the Merensky Reef. The boring phase of the trial took place over six months and the average rate of penetration of the TBM was 0.47 metres/hour. TBM utilisation was 22%.

The TBM used in the trial was a Jarva MK6 manufactured in 1972 and its design with its back-up system was not considered to be an ideal machine for reef development. However it was the intention of the trial to prove the concept of developing with a TBM on reef. In this respect the trial was unequivocally a success. There were many problems and long delays did occur during the boring phase. Nevertheless there is every confidence that a new TBM can be designed specifically for this type of work that will achieve high rates of advance up to (say) 400 metres/month and with a more flexible steering system in order to negotiate reef changes.

It can therefore be expected that TBMs will be used in the future for reef development on South African platinum mines.

Background

The use of a tunnel boring machine (TBM) for civil engineering projects is common practice worldwide. However with a few exceptions the mining industry has failed to take advantage of this proven technology. At a newly developing mine such as Bafokeng Rasimone Platinum Mine (BRPM) there is a need to develop reef raises and reef strike drives at high rates of advance in order to build up to planned production as rapidly as possible. The Research and Development Division of Anglo Platinum therefore initiated an experimental reef raise project at BRPM. This trial project has been carried out by Bomar, a South African mining contractor, in association with Robbins Company in the USA.

In terms of a contractual agreement, a small diameter (2.1 metres) TBM was brought into this country from Robbins. It should be stated from the outset that although the design of this TBM is not considered ideal it was the intention to prove a concept. The success of the trial would then serve to motivate an ongoing TBM programme with machines specifically designed for the purpose.

Scope of trial

The scope of the project was the establishment of a reef raise between 3 Level and 2 Level at BRPM (North) Mine. The length of the raise was 340 metres. It was known that the raise would have to commence in hanging wall waste due to the presence of a pothole at the start of the raise.

Geology

The Merensky reef is being mined at BRPM and an ideal cross section of the reef raise when developed by the TBM is illustrated in Figure 1. The immediate hanging wall is pyroxenite with anorthosite and leuconorite in the footwall. Figure 2 shows the geological mapping of the complete raise.

Figure 1. Cross section of reef
Specifications
Abbreviated specifications for the trial machine are listed as follows.
- Year of manufacture 1972.
- Open type 4 gripper machine.
- Diameter 2100mm.
- Motor 175kW water cooled
- Thrust 230 tons at 200 bar.
- Number of cutting discs: 18
- Cutter size: 330mm
- RPM 9.5
- Stroke length: 600mm
- Conveyors: 450mm wide
- Power requirements: 500kVA
- Motor circuit: 380V 50Hz
- Mass TBM: 25 ton
- Mass back-up: 6 ton
- Water requirements: 12 litres/second @ 7 bar
- Dust suppression: 5 spray nozzles on cutter head
- Cutter head: open type front loading cutters

Cleaning arrangements
Machine chippings pass through the TBM by means of an internal conveyor that feeds a second conveyor which tips onto the footwall of the raise. Cleaning of the raise was carried out by scraper winch, the return sheave wheel being attached to the back of the TBM. This rock clearance system has not proved to be ideal and alternative cleaning systems will have to be considered for future work.

Ventilation Arrangements
Initially the ventilation arrangements provided for two 305mm galvanised exhaust columns fitted with dust filters extending from the cutter head of the TBM (1.5 metres from the face) into a 570mm adaptor on the underside of a 7.5kW high pressure fan mounted on a stand on the TBM back-up. From the fan a steel 570mm column (approximately 15 metres) connected into a flexible ducting system. In practice only one of the 305mm exhaust columns could be introduced as the other fouled the laser system. The system proved effective but very soon the interference of the scraper system in the limited cross section of the raise caused continuous damage to the flexible ducting. It was then decided to re-position the fan at the entrance to the raise and change the flexible ducting to galvanised steel. This also had the advantage of reducing noise levels at the

Rock engineering criteria
Some average uniaxial compressive strengths of the major lithological units are recorded as follows.
- Pyroxenite 130 MPa
- Merensky Reef 123-133 MPa
- Anorthosite 180-290 MPa
- Leucorionite 189-235 MPa

In terms of support of the raise it was determined before boring commenced that no systematic support would be installed but that spot bolting would be practised only. In fact no support was installed for the development of the raise from start to holing.

TBM
Brief details of the TBM and back-up system are given

Figure 3. Section through grippers
TBM because the high pressure fan could now be replaced with a normal 8kW fan. This in turn improved communication between the TBM operators and the scraper winch drivers.

Ventilation conditions were continuously checked with a formal weekly report submitted. Face air quantities exceeded standard requirements and temperatures were satisfactory.

Flammable Gas Detection
The presence of flammable gas (methane) is not uncommon on platinum mines. It was therefore mandatory to fit an flammable gas sensor device as close as possible to the cutter head. This device was set to trip the power on the TBM at the level of 1.2%. The exhaust fan remained on a separate electrical circuit and therefore the exhaust fan continued to operate even if the power to the TBM was cut off. The gas sensor was checked and calibrated at weekly intervals. In addition all personnel were trained for gas detection and operators carried a personal continuous methane monitor an carbon monoxide detector with them at all times.

Transport of the TBM underground
The machine arrived on site in a dis-assembled condition, the breakdown being as follows.
- Main body and grippers
- Cutter head without cutters
- Drive head assembly and dust shield
- TBM conveyor
- Back-up sled with conveyor

Transport down the main decline was restricted to components not exceeding 10 tons and of a maximum length of 5.0 metres. In all 11 machine pieces were transported into the mine for re-assembly underground. At the underground site an assembly bay was excavated and equipped with a crawl for re-assembling the TBM.

Launching arrangements
In order to launch the TBM it was necessary to design and construct a launching ramp to provide the means for the TBM to sump into the reef horizon above the elevation of the crosscut; see Figure 4.

On completion of the assembly bay the TBM components were correctly positioned for re-assembly and the first section of the ramp (nearest to the assembly bay) constructed to enable an initial platform to be established for the TBM to move onto the ramp. The ramp was then constructed from the TBM to the face and the machine was then moved up the ramp to the face utilising walking brackets designed for this purpose. Close to the face concrete was placed on both sides of the TBM to enable the grippers to push against in order to sump in.

Boring
After collaring and establishing the grippers in rock the machine was surveyed and found to be slightly below its planned position. The reef was known to be in a pothole and it was required to develop on a grade to the anticipated reef intersection.

The laser and its targets were set up and boring commenced. The TBM started boring on 13 December 2000 through to holing on 15 June 2001 during which 22 days were lost due to the Christmas and Easter breaks. There was an exceptionally long learning curve, numerous problems and delays were experienced which caused the project to overrun the original expected programme.

Problems and delays
Initially it had been expected that the boring of the raise (340 metres) would have been completed in little more than 2 months. In reality this proved to be extremely optimistic. Some of the more important problems which occurred causing major delays are highlighted and discussed below.

Steering
From the outset the original operators had difficulty (or so it was assumed) with the steering of the TBM particularly related to the climbing of the machine. This inability to cause the TBM to climb at the required inclination culminated in major delays to boring, briefly described below.

An orepass had been previously developed to a position just below the reef horizon and it was the intention to pass over the top of the orepass with the TBM and later bore through into the raise from the orepass in order to be able to clean the raise through a box in the crosscut (cleaning had up to that time been directly into hoppers at the back of the crosscut). Specific written instructions had been given to operators which would have caused the raise to pass two metres above the orepass. However in spite of repeated warnings it became inevitable that the raise would in fact intersect the orepass and this happened in late January and boring stopped as the TBM had no means of gripping the sidewall (specifically on one side). A steel structure was designed for and constructed in order to re-launch the TBM but when boring re-commenced the structure collapsed and a further decision was later taken to establish concrete walls to re-launch the TBM. Boring restarted in February after a 24 day delay.

Further problems with the TBM not climbing at the required inclination (it was necessary to develop generally at +14°) continued, with the real possibility that the raise could intersect an existing travelling way. However after intense discussions between the surveyor, the operators and a Robbins technician (who was brought to the site and stayed until holing) the TBM climbed at 17° and cleaned the travelling way. Notwithstanding, the travelling way had been extensively supported by pre-stressed elagates.

Scraping and Services
From the beginning there had been (and they continued for much of the boring phase) problems with the scraper fouling the ventilation flexible ducting and even the steel service columns. Delays caused by damage to services because of the scraper winch cleaning system were significant thereby demanding a re-consideration of the cleaning system for future TBM work.

Figure 4. Launch chamber including ramp
Mechanical failures and maintenance

There were major delays during the project associated with mechanical and electrical failures on the TBM. Some of these were as follows:

- The main thrust cylinder developed a leak and continued to give problems (with severe oil loss) despite repeated attempts to effect repairs. It was only finally resolved after the arrival of the Robbins' technician.
- During May the main drive motor failed and major modification had to be carried out to the replacement motor causing several days' shutdown.
- Excess time was spent with repairs to the conveyors exacerbated by the lack of equipment to carry out repairs.
- Repair of bucket lips was a major delay.
- Replacing cutters was slow and arduous marginally improved by the installation of a monorope system to transfer cutters through the machine to the face.

Towards the end of the project, at the suggestion of the Robbins' technician, it was agreed to change to day shift maintenance and two boring shifts only on afternoon and night shifts. This undoubtedly caused a marked improvement in performance. Previously boring was planned for all shifts with Saturday maintenance only.

Intersections of flammable gas

Methane was intersected on three occasions during the last 40 metres of boring and on each occurrence the TBM was shut down automatically by the flammable gas sensing device. After the last intersection (2.4% CH4 in the general atmosphere) specific instructions were issued in order to effect a safe holing.

- Boring to stop at 1.4% CH4 in the general atmosphere until the ventilation system had cleared the gas.
- Ventilation technicians were to be present throughout the boring shift until holing.
- Face air quantity to be not less than 0.4m3/second/ m2 of face.
- TBM operators issued with flammable gas warning caplamps.
- Continuous methane monitoring instrument (ICAM) installed on the intake side of the fan.
- All TBM operators were re-trained in flammable gas detection.

Performance

Although the boring phase of the project lasted almost exactly 6 months, only 5 months actual boring took place (22 days or approximately 1 month was lost in holiday breaks).

Penetration

The average instantaneous rate of penetration (ROP) was 0.47 metres/hour during boring. Such an ROP was considered low for TBM boring on the reef horizon. However progress was slow due to large sections of the raise being off reef (potholes) and problems with steering. Average penetration rates achieved in the various rock types are shown below.

<table>
<thead>
<tr>
<th>Rock Type</th>
<th>Metres/Hour</th>
</tr>
</thead>
<tbody>
<tr>
<td>Anorthosite</td>
<td>0.35 - 0.40</td>
</tr>
<tr>
<td>Norite</td>
<td>0.60</td>
</tr>
<tr>
<td>Mereynsky Reef</td>
<td>0.90 - 1.10</td>
</tr>
</tbody>
</table>

A further constraint to penetration was the low power of the TBM and an inefficient cleaning system impeding advance.

Efficiencies/Statistics

Some of the more significant statistics related to performance were as follows:

- Best advance in a day: 13.8 metres (27/05/2001)
- Best advance in a week: 47.6 metres (21-28 May 2001)
- Best advance in a month: 104.7 metres (June 2001)
- Best ROP in a shift: 1.33 metres/hour

It can be seen from the above that the best performances were in the latter stages of the boring phase (May/June).

Cutter Life

Cutter life, a major parameter in terms of TBM costs, proved to be better than expected. Life was 12.21 m3 rock/ring. Centre cutters had a low life initially until carbide cutters were introduced.

Availabilities/Delays

The table below shows a breakdown of the hours for the boring phase.

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Total available hours</td>
<td>3,208</td>
</tr>
<tr>
<td>Total delays hours</td>
<td>2,452</td>
</tr>
<tr>
<td>Boring time hours</td>
<td>716</td>
</tr>
<tr>
<td>Machine availability:</td>
<td></td>
</tr>
<tr>
<td>(cognisance of breakdowns only)</td>
<td>82.3%</td>
</tr>
<tr>
<td>TBM boring utilisation</td>
<td>22.3%</td>
</tr>
<tr>
<td>Delays</td>
<td>77.7%</td>
</tr>
</tbody>
</table>

The breakdown delays are shown below with a pie chart shown in Figure 5.

<table>
<thead>
<tr>
<th></th>
<th>Delays in Hours</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maintenance</td>
<td>159</td>
</tr>
<tr>
<td>Breakdowns</td>
<td>362</td>
</tr>
<tr>
<td>Cutter changes</td>
<td>344</td>
</tr>
<tr>
<td>Cleaning</td>
<td>296</td>
</tr>
<tr>
<td>Utility services</td>
<td>295</td>
</tr>
<tr>
<td>Blasting</td>
<td>65</td>
</tr>
<tr>
<td>Ventilation</td>
<td>165</td>
</tr>
<tr>
<td>Survey</td>
<td>117</td>
</tr>
<tr>
<td>Flammable gas</td>
<td>52</td>
</tr>
<tr>
<td>Box hole and travelling way</td>
<td>437</td>
</tr>
<tr>
<td><strong>TOTAL</strong></td>
<td>2492</td>
</tr>
</tbody>
</table>

Lessons gained

Notwithstanding the extended length of this trial, it can be unequivocally stated that this project was successful in that the main objective of proving the concept of TBM"
development was achieved. Further the use of a TBM for the development of raises and strike drives on the reef horizon will build up available face more rapidly for production. This is of great importance specifically to newly developing mines and at certain existing mines where reserves are critically low. However learning from the lessons of this project and in order to improve the performance of future TBM development cognisance must be taken of the following.

On reef mining
As can be seen from the penetration rates achieved in the different rock types increased performance will follow from more on reef mining. The best results will therefore be achieved where the reef is least disrupted specifically by pothole activity.

Rock clearance
It is necessary to design for an alternative method of cleaning: scraper winch cleaning will never be able to achieve optimum advance rates for TBM’s. The most obvious option is conveyors but this aspect does require full investigation.

Services
The method of installation of services also requires some further interrogation. The use of scraper cleaning precluded any work at all while boring was taking place notwithstanding that in small diameter raises any work on services is likely to be restricted.

Operation, supervision and management
This project started off without adequate hands-on supervision and management. Performance was seen to improve almost immediately that a site manager and specifically a TBM technician/advisor had commenced work on the project. It then became evident that delays associated with logistics were markedly reduced and TBM maintenance being handled by the site manager and TBM technician respectively.

Shift organisation
The splitting of the 24 hour period into one shift (day) for maintenance (including services installation, survey work etc.) and two shifts for boring proved to be very successful. It is also to be realised that the selection of TBM operators is a key to high performance.

Incentives
It is important to agree to significant monetary incentives from the outset. Late in the project a substantial bonus was offered to all the crew and this had a marked effect on morale and attitude. Immediately following this incentive being given the best performances were achieved.

Ventilation
Although ventilation considerations proved to be more than satisfactory throughout the project the installation of ventilation columns in confined spaces needs to be addressed. In addition the immediate ventilation arrangements (including the scrubber arrangement) at the TBM needs to be purpose designed for a small excavation.

Logistics
Finally as a general comment considerable pre-planning must be carried out for future TBM projects on mines. The use of a TBM in an underground mine means that TBM operations interface with normal mining development and TBM management must accept this and plan ahead for the supply and transport to the TBM area for consumables, equipment, stores etc. Almost all TBM tunnels world wide are civil projects which stand alone and are therefore totally independent; it is not so in a developing mine and this should be realised by TBM management from the beginning.

Conclusions
This project has been a success notwithstanding the deficiencies of a TBM manufactured in 1972 and that reef development by a TBM has never been carried out before in South Africa. Nevertheless it is now necessary to design a TBM specifically for this type of work that will optimise performance at (say) 400 metres/month and that will have a more flexible steering system in order to negotiate reef changes. It is believed that this can be done and therefore there is no reason why significant development cannot be carried out in the future with TBM’s on narrow reef platinum mines.
ANNEXURE 7.13


K.A.Rhodes/P.Horrell: December 2001
SUMMARY REPORT ON THE USE OF A TUNNEL BORING MACHINE

FOR REEF DEVELOPMENT AT

BAFOKENG RASIMONE PLATINUM MINE

K.A.RHODES/P.HORRELL
DECEMBER 2001
SUMMARY REPORT ON THE USE OF A TUNNEL BORING MACHINE FOR REEF DEVELOPMENT AT BAFOKENG RASIMONE PLATINUM MINE

BACKGROUND
During November 2000 a tunnel boring machine (TBM) was dis-assembled on surface at Bafokeng Rasimone Mine and transported underground for re-assembly prior to its use for the development of a reef raise.

A full description of the project, which was completed on 15 June 2001 after a boring period of six months, has been documented in a paper presented to the 6th International Symposium on Mine Mechanisation and Automation at the Sandton Convention Centre during September 2001. This paper was prepared by the project consultant and technical advisor Ken Rhodes, of KAR Mining Consultant cc and Peter Horrell, of Horrell and Associates and was presented by Martin Stander, Business Area Manager for BRPM North Mine.

The above mentioned paper described the TBM and the launching preparations; the actual boring operations; problems and delays encountered; and also some of the lessons gained from the project. The intention of this summary and closure report is to focus only on those aspects of the project which should not be repeated in any future TBM project and further to emphasise those matters which should demand more attention for the managers of such a project.

However for completion, this report contains the project statistics (Annexure 1), TBM specifications (Annexure 2) and details some project costs not previously recorded.

COSTS
The costs of development of the reef raise (340 metres) are coarsely set out below.

<table>
<thead>
<tr>
<th>Cost in R000's</th>
</tr>
</thead>
<tbody>
<tr>
<td>Upfront payment to contractor</td>
</tr>
</tbody>
</table>
Boring: 340 metres @ R7596/metre  2583
Sundry Costs (weekend work etc)  271
On mine costs (stores)  202
On mine costs (labour)  249
Total  4305

Note that this total cost does not include additional costs made by the client Anglo Platinum to the contractor as ex-gratia payments outside of the contractual agreement.

Cost/metre is therefore estimated in terms of the above as R12 662/metre or assumed at R13 000/metre.

Actual cutter costs, always perceived as a major cost item and provided for in the boring cost of R7596/metre paid to the contractor, can be seen below.

<table>
<thead>
<tr>
<th>Cutter Type</th>
<th>Cost (R)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Centre cutters</td>
<td>601,20</td>
</tr>
<tr>
<td>Gauge cutters</td>
<td>372,07</td>
</tr>
<tr>
<td>Face cutters</td>
<td>767,57</td>
</tr>
<tr>
<td>Total</td>
<td>1740,85</td>
</tr>
</tbody>
</table>

**LESSONS**

The TBM project at BRPM must be seen to have been an overall success; nevertheless there are lessons to be learned. The matters set out below represent those aspects of the project that the project managers would not want to do again.

- No structured steel launching arrangements would be used to start the TBM; the machine must start on reef.
- Rock clearance behind the TBM by means of a scraper winch proved unacceptable; significant damage and related delays occurred particularly as the raise length increased. Further, cleaning by scraper will never meet the optimum advance requirements for a TBM.
• Before the start of any new project the TBM must be completely refurbished and inspected before its departure from the supplier; this was not done in this case.
• The TBM for this project did not come provided with laser equipment, a dust scrubber arrangement, or methane monitoring devices installed to cut out at a pre-determined level.
• The responsibility for steering the TBM did not appear to be understood or accepted by the contractor; this is the responsibility of the appointed contractor but was not seen to be in this case.
• The contractor has to accept full responsibility for the total operation of the TBM; this was not done.
• A detailed Schedule of Responsibilities (SOR) was not drawn up and agreed upon by both the client and the contractor before the start of the project. During the early part of this project an SOR was prepared by the project managers but agreement by the contractor only came after a protracted period. Clearly such agreements must be in place from the outset.
• The appointed contractor did not have any experience with TBMs and relied solely on the supplier (in this case Robbins).
• The project commenced without any hands-on management by the contractor.
• There was no input from the contractor related to shift arrangements and for holiday breaks or leave for key personnel.
• Inadequate training of local personnel and familiarisation training for expatriate workers was not carried out.
• There were no detailed job descriptions for contract personnel.
• There was no cutter shop, no spare cutters on site when operations commenced, and no adequate secure lock-up tool car available underground.
• No inclinometer was fitted to the TBM when it was critical in terms of the climbing requirements of the TBM.
• No adequate lighting.
• No suitable hand rail or other means to assist people to move around.
• No means of transport for cutters or any other equipment up the raise; everything was manhandled.
• Finally the project succeeded in spite of the choice of TBM. The machine was old (1972) and not refurbished for use in a development raise.

CONCLUDING COMMENTS
Taking cognisance of the above lessons, and also those changes made during the project which contributed to its success, then the following pre-planning requirements are considered as necessary for any future project with a TBM.

• The TBM must be specifically selected (if an existing machine and refurbished) or a new machine should be designed for; in all cases a clear understanding of the duties of the TBM is to be taken cognisance of before acceptance of the TBM and then only following frequent inspections by a competent specialist representing the client have taken place.

• Any final design or refurbishment must provide for a flexible steering system (specifically where reef drives are contemplated).

• The mucking system behind the TBM must be able to match the performance of the TBM measured as the maximum expected instantaneous rate of penetration. A scraper method would not be acceptable and for updip and down dip boring a conveyor would probably be the best choice although vacuum systems can be investigated. In flat development, rail systems should be considered particularly if rail haulage is planned for as the permanent means of transporting rock. Whatever system is finally selected it is most important to ensure that the mucking method does not interfere with the ongoing installation of services in the excavation.

• Before any agreement to commence TBM operations a Schedule of Responsibilities is to be drawn up by the client and agreed to by the preferred contractor. This schedule must clearly state where the responsibility lies between client and contractor; battery limits must be clearly defined.

• It is essential to have a site manager who is responsible for the logistics of the operation (which can be complex on a developing underground mine) and a TBM technical advisor who controls technical aspects associated with boring and specifically for the maintenance function.
• Shift arrangements and shift changeover is vital to success; it was found at the BRPM Project that by splitting the 24 hour period into one 8 hour day shift for maintenance followed by two 8 hour boring shifts, overall boring performance improved significantly.

• A streamlined transport system in the development end is essential. Transport of any equipment or consumables but particularly cutters proved difficult in the reef raise at BRPM.

• The selection of crew personnel is important. In addition to the site manager and TBM technician, expatriate TBM operators will have to be recruited as there is very limited experience of these operators locally; however these expatriates must be familiarised with local requirements. Notwithstanding the need for expatriates, it is important to recruit the remaining crew locally: artisans, personnel for services equipping, logistics etc with some multi skilling necessary as crews must be small.

• Adequate TBM spares and tools (the ability to repair quickly any TBM internal conveyor belt breakage comes to mind as an example with the BRPM experience) and to be able to store them securely in close proximity to the site.

• Ventilation arrangements must be purposely designed for any TBM development but will be critical in a small excavation as at BRPM.

• A most important factor which should be an early priority for this type of operation is the establishment of a significant monetary incentive for all the crew from the outset; this was proven at BRPM when, late in the project, a substantial bonus was offered to the crew to complete the raise before a specified target date and this proved to have a marked effect on moral and attitude and this was reflected in the best performances being achieved.

• As a final comment, there is a need for intensive detailed pre-planning for any future TBM project specifically on an operating mine. In such cases the TBM project must interface with normal mining operations and therefore logistics planning must rate as a priority because of the possibility of long delays in getting consumables and equipment to the TBM due to an interference factor. The operation of a TBM in an underground mine is not the same as other normal TBM projects which in almost all cases are civil projects which are
totally independent, as in road tunnels or other civil construction tunnels where an interference factor with other mining operations cannot exist.
ANNEXURE 1

PROJECT STATISTICS
**BRPM REEF RAISE STATISTICS**

**Raise Details**
Level 3 to Level 2
2,10 metres diameter, 339,3 metres long

**Geology**
Norite, Anorthosite and Merensky Reef

**Milestones**
Machine arrived on mine: 21 October 2000
Launch chamber complete: 14 November 2000
Machine re-assembly started (underground): 17 November 2000
Machine assembly complete: 02 December 2000
Launch concrete complete: 05 December 2000
Brow support complete: 12 December 2000
Boring started: 13 December 2000
Boring complete: 15 June 2001

**Statistics**
Best day – 13,8 metres advance: 27 May 2001
Best week – 47,6 metres 21-28 May 2001
Best month – 104,7 metres: June 2001
Best ROP in a shift – 1,33 metres/hour: 23 May 2001 (night shift)
Average instantaneous ROP: 0,47 metres per hour

**Major Delays**
- Steering
- Scraper operations slow and damage to services; delays significant after 280 metres advance.
- Steel ventilation pipes required due to continued damage by scraper.
- Installation of utilities.
- Conveyor belt on TBM.
- Cutter changing.
ANNEXURE 2

TBM SPECIFICATIONS
**SPECIFICATIONS OF JARVA ROBBINS MK 6 TBM**

<table>
<thead>
<tr>
<th>Specification</th>
<th>Details</th>
</tr>
</thead>
<tbody>
<tr>
<td>Machine Bore Diameter</td>
<td>2,083mm (6’10&quot;) – nominal 2.1 metres</td>
</tr>
<tr>
<td>Main Bearing</td>
<td>high capacity tapered roller type</td>
</tr>
<tr>
<td>Cutter Diameter</td>
<td>318mm</td>
</tr>
<tr>
<td>Cutter Load (maximum)</td>
<td>11 tons</td>
</tr>
<tr>
<td>Number of Cutting Discs</td>
<td>18 discs</td>
</tr>
<tr>
<td>Cutterhead Drive</td>
<td>1 x 175 kW water cooled motor</td>
</tr>
<tr>
<td>Cutterhead Torque</td>
<td>176 kN</td>
</tr>
<tr>
<td>Speed</td>
<td>9.5 RPM</td>
</tr>
<tr>
<td>Thrust Capacity @ 200 bar</td>
<td>230 tons</td>
</tr>
<tr>
<td>Thrust Stroke</td>
<td>600mm</td>
</tr>
<tr>
<td>Conveyor</td>
<td>450mm</td>
</tr>
<tr>
<td>Hydraulic System: System Rating</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Working continuous</td>
</tr>
<tr>
<td></td>
<td>210 bar</td>
</tr>
<tr>
<td></td>
<td>190 bar</td>
</tr>
<tr>
<td>Electrical System: Motor Circuit</td>
<td></td>
</tr>
<tr>
<td></td>
<td>380, 3 PH, 50 Hz</td>
</tr>
<tr>
<td></td>
<td>120 V, 50 Hz</td>
</tr>
<tr>
<td>Transformer</td>
<td>500 kVA</td>
</tr>
<tr>
<td>Machine Weight</td>
<td>Approximately 25 tons</td>
</tr>
<tr>
<td>Back-up Trailer weight</td>
<td>Approximately 6 tons</td>
</tr>
<tr>
<td>Water Requirements</td>
<td>720 litres/hour @ 6.9 bar</td>
</tr>
<tr>
<td>Dust Suppression</td>
<td>Water sprays at cutterhead</td>
</tr>
<tr>
<td>Dirt Removal Machine</td>
<td>Front and rear conveyors</td>
</tr>
<tr>
<td>Dirt Removal behind TBM</td>
<td>Scraper winch</td>
</tr>
</tbody>
</table>
ANNEXURE 7.14

“Design of In Stope Pillars in Cut and Fill Mining for a Gold Mine in Ethiopia”

K.A.Rhodes, T.Rangasamy

MassMin 2008, 5th International Conference and Exhibition in Mass Mining, Lulea, Sweden: June 2008