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Long hole drilling applied to narrow reef mining

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Sandvik, Tamrock

Objective

The purpose of this report is to chronicle the interaction between Anglo Platinum and Sandvik Tamrock during the development and application of Long Hole drilling as a viable, practical method of narrow reef mining. Appendix I identifies the people from Anglo Platinum and Sandvik Tamrock who participated in the project.

Experiments in long hole drilling and blasting were conducted in a number of mines during the late 1950s and early 1960s. Some of the advantages envisaged were:

- The face would require no daily examination
- No barring down or immediate face support required
- No sockets to clean
- Only a few well drilled holes rather than large numbers of short blast holes
- Avoidance of poorly-marked holes, inaccurate drilling and improper charging
- Better supervision and better face advance.

Holes 50 mm in diameter were drilled parallel to the stope face by pneumatic rock drills from advance strike gullies. Holes were charged with amon gelignite cartridges. All holes were traced with detonating cord to ensure propagation of the explosive along the entire hole length. Rock was blasted onto a rolling scatter pile.

A number of reasons have been cited for the failure of this mining method. The two most important were:

- problems in controlling hole deviation which was exacerbated by the fractured ground
- difficulty of charging up holes in fractured ground, due to relative movement of rocks along fracture surfaces over the hole length.

The idea of drilling a few long holes parallel to the face rather than a large number of short blast holes perpendicular to the face was an attractive option to mechanize narrow reef mining.

This particular project started in 1998.

Initial trial

The Union Section of Anglo Platinum purchased a Solo H 606 RA long hole drilling rig from Sandvik Tamrock in 1997. In order to evaluate long hole drilling as a basis for face mechanization. The Solo series of drill rig was selected because it combines high drilling performance and good drilling accuracy with high versatility with a compact size.

The mining method proposed by a consultant to Anglo Platinum was based on the current trackless mining method practised by Union Section. The trackless mining method is better described as a trackless development and transport method. Reef strike drives were installed approximately 40 metres apart on dip using trackless equipment. Reef was mined using hand-held pneumatic rock drills and scraper winches and the excavation was supported by sticks and crush pillars at the top of the panel. Rock scraped from the panel was loaded by Lad Haul Dumps (LHDs), trammed to an inclined haulage, and loaded into trucks for transport to the surface.

It was intended that the Solo would drill from the bottom advance strike drive to the top advance strike drive. Blasted rock would still have to be scraped from the panel. It is also difficult to understand how well the support would have survived.

In the initial motivation it was stated that drilling accuracy was of the utmost importance. Previous work by Sandvik Tamrock had shown that, in other parts of the world, 20 metre long holes could be drilled with a deviation not exceeding 100 mm provided that:

- holes were collared with low thrust pressure
- operating percussion pressure was kept low—often not exceeding 10 MPa
- drilling was to be with tubes, not rods.

In early 1998 initial trials with the Solo H 606 RA were inconclusive; attempts were made to drill 40 metre long holes from one advance strike drive to another. Difficulty was experienced in measuring hole straightness and accuracy, there was no survey of the holes, and no blasting was done to expose hole barrels.

A long hole mining system was then defined, with a corresponding face mining system, which led to the design of a test programme for the Solo drilling rig.

Earlier experience at Telfer

The proposed face mining system was based on a mining method that is practised at Telfer Gold Mine in Western Australia. Telfer has a series of domed reefs that dip at angles of less than 20° to more than 40°. The ore bodies are all thin, with widths from 0.6 metres to 0.8 metres. Figure 1 shows the face layout. Experience at Telfer indicated the following:

- The spacing and size of the dip pillars should be based on the rock mechanics of Union Section
- The length of the face is determined by the ability to correctly position the blast holes. Positioning of blast holes is a function of hole straightness and hole direction. Blast holes in Telfer were drilled 64 mm diameter with retrac bits from Sandvik. Extension steel was T38 by 1.8 metre lengths. A guide rod was fitted immediately behind the bit. To achieve greater accuracy' operators drill at relatively low percussion and thrust pressures. Results show that very good accuracy is achieved in 20 metre stopes and only fair accuracy in longer stopes. In 34 metre long stopes 10–15% of the holes are not sufficiently accurately positioned and have to be re-drilled. All blast holes are

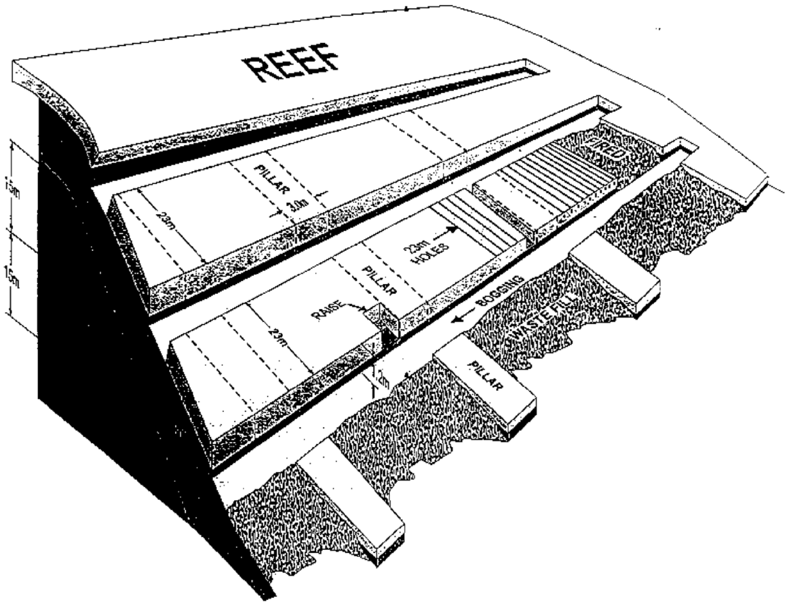

Figure 1. Telfer mining layout

drilled as up holes. Attempts have been made to increase face lengths by drilling up and down holes' but this resulted in too many bridges and increased the difficulty of getting the ore out of the stope. *A very important lesson from Telfer was that as all holes break through, operators are able to check the drilling accuracy regularly, and make the necessary adjustments.*

- Face advance is dictated by the time taken to drill the holes, the burden between the holes and the number of holes blasted at any one time. At Telfer, where there are excellent footwall and hangingwall contacts, holes are drilled centrally in the orebody with a burden of 0.9 metres in the 20 metre long stopes. In the 34 metre long stopes the burden was reduced to 0.75 metres. A single operator drills 120–150 metres in a 12-hour shift. Blasting is in rings of five holes. All long holes are double primed and loaded with ANFO, leaving an uncharged collar of between one and 1.5 metres
- A process of rapid raising is essential to realize the benefits of increased rates of face advance. Development of the raise could be by hand or drop raising
- Face cleaning at Telfer, where the dip is less than 32º, is by means of a scraper mounted in a frame that sits in the bucket of an LHD. When the dip exceeds 32º the stope is water-bombed using the LHD bucket full of water.

Vision for long hole stoping system

In November 1998 it was agreed that the vision for a Long Hole Stoping System should encompass the following objectives:

- a totally mechanized system
- a necessity for change in the existing mining layout
- all hand held drilling on the face to be eliminated
- no support should be required in the long hole drilled area
- in effect the stope should be man-free
- the final mining system should be more profitable to the company than the existing mining methods.

It was also argued that some elements of the proposed final system should be trialed. The purpose of the trials would be to determine the parameters on which the final design of the system was to be based. A trial that focused on the following was initiated:

- drilling accuracy
- drilling performance or drilling rate
- throw of the blasted rock
- effect of the blast on the hangingwall
- blast design for the most efficient breaking of the full channel width.

Trial UG2 at Union Section

A site for trial drilling was selected at Union Section. The site was at an intersection between one of the advance strike drives and a decline roadway, giving a triangular-shaped section of reef. This position was selected because it would be possible to drill varying lengths of holes from the ASD to the roadway. Experience from Telfer had clearly dictated the methodology of drilling into an opening as the most effective way of determining hole straightness. Drilling results are shown in Tables I and II.

All the drilling was carried out by an operator trained by the Tamrock Drill Master for the previous abortive experiment. He was supported by an experienced Tamrock technician/operator, with additional advice provided by the Tamrock Drill Master. Holes at the first site were drilled with 64 mm Retrac bits and T38 male/female rods. In the second stage of the drilling, trial T38 Guide Tubes were fitted immediately behind the Retrac bit.

The initial focus of the trial was to determine hole accuracy. Accuracy is a combination of hole direction and hole straightness. The sites selected enabled the operators to check where the hole exited into the Roadway, thus determining direction. Hole straightness was checked using a small torch attached to a flexible plastic rod. Typically the light is lost when the torch is between 100–15 metres into the hole. This suggests that at this depth of hole the deviation of the hole is less than one hole diameter. Some of the holes were blasted so that the hole barrel could be

Table I
Initial drilling trial

Date	No.	Length	Time	Pressures (MPa)			Dip	Comments
		(m)	(min)	Percu'n	Rotation	Thrust	(Deg)	
10/11	1	6		9	2,5	3,5	18	OK
	2	8		10	2,5	3,5	18	OK
	3	9		9	3,5	3,5	18	OK
	4	10		9	3,5	3,0	18	OK
	5	11		9	2,5	3,5	19	OK
11/11	21	12	38	9	2,5	3,5	19	
	25	14,5	45	9	2,5	4,5	19,5	
	26	15	35	9	2,5	4,5	21	Laser straight
12/11	32	16,5	38	9	2,5	3,5	21	
	27	16	32	9	2,5	3,5	21	Deflection 300mm
	28	17	34,5	9	2,5	3,5	21	Deflection 250mm
13/11	29	17	34	9	2,5	3,5	21	
	23(a)	16,5	37	9	2,5	3,2	21	
	24(a)	20	49	9	2,5	3,5	21	On the mark
	24(c)	16	33	9	2,5	3,5	21	On the mark
	24(d)	16	33	9	2,5	3,5	21	Deflected 500mm

Table II
Drilling in Roadway 3 north to decline 3B

Date	No.	Length	Time	Pressures (MPa)			Dip	Comments
		(m)	(min)	Percu'n	Rotation	Thrust	(Deg)	
17/11	1	39		9	4-5,5	3,5-4	21	Not straight
18/11	2	21,5		7,5	5	4	21	
	3	22,5	70	7,5	2,5-6	3,8-4	23	
19/11	4	30	70	7,5	3-5	4	21	Deflected up 400mm
	5	21		7,5	5	3,5-4,5	21	Deflected up 1m
20/11	6	39		9	5	4-5,5	21	Straight for 13m
	7	30		9	3-4	3,5-4	21	Into footwall
23/11	8	22,5	39	9	2,5-4	3,5	21	Good hole
	9	30		9	2,5-4	3,5	21	Light for 17m
	10	39		9	2,5-4,5	3,5	21	Not holed, in hanging
24/11	11	30	44	9	2,5-4,5	3,5	21	
	12	30	44	9	2,5-4,5	3,5	21	15m barrel
25/11	13	30		9	3-4,5	3,5	21	30m straight in triplets
	14	40,5	36	9	2,5-5	3,5	21	Holed OK
	15(c)	15		9	2,5-4,5	3,5	21	On line
	16	7,5		9	3	3,5	21	Short hole
17/12	17	22,5		9	4,5	3,5	21	
	18	6						Rod stuck
22/12	19	19,5		9	4	3,5	21	
28/12	20	13,5						Lost guide tube + rod
6/1	21	15	35	9	4,5	3,5	21	Good hole
7/1	22	15	40	9	4,5	3,5	21	Good hole
Blasted holes to check straightness								

inspected. On the advice of AEL the holes were charged with 38 mm Magnum cartridges taped end to end to a piece of cordtex.

Evidence from observation of the blasted holes suggests that the ideal position for drilling the top hole in the stope would be between the two waste bands that make up the triplets of the UG2 reef at Union Section. The ideal position for the footwall hole would be along the footwall contact, particularly as there is a grade kick on the footwall contact of the UG2. Hole number 26 was started 100 mm above the footwall parting and exited 15 metres later, 200 mm into the footwall. The hole was absolutely straight. This demonstrated that with this suite of long hole drilling equipment it was possible to drill from soft (30MPa) material into much harder material with no hole deviation.

Wing bit type drill bits were tried to see if they would stay in the softer material, and deflect when in contact with the harder material. The bits burnt out within two metres and no further work was carried out.

Conclusion

The conclusion drawn from this stage of the investigation was that it was possible to virtually guarantee a straight hole of 15 metres in length, and the probability of a 20 metre long straight hole was very good.

In the early stages of the drilling trial, penetration rates for the 64 mm blast hole were 0.43 metres per minute. However, this was increased to 0.75 metres per minute towards the end of the trial, with no sacrifice in hole straightness. This indicated the need for skilled operators.

Blasting trials in the 1.6 metre high stope had indicated a three row drilling pattern with the centre row staggered, and a spacing of one metre between holes in any one row. Blasting using cordtex and Magnum cartridges was very successful, leaving full barrels along the stope. With limited blasting it was difficult evaluate rock throw.

To some extent the equipment used in the existing excavations compromised the trial. The ASDs were 4 metres wide, too wide to adequately brace the drill feed. Accurate drilling requires a rigidly fixed and secured drill feed to ensure that drilling direction is maintained. The Solo drill rig is designed for drilling fans of holes in massive stopes. The position of the feed carousel means that it is not possible to drill closer than 600 mm to the hanging.

The trial had demonstrated the potential; it was now necessary to review the mining method and the preferred equipment fleet to establish a practical, narrow reef, long hole mining system.

Townlands business area—Boschfontein

There were some questions about the suitability of the mining method developed at Union Section and its applicability to the UG2. Concern was expressed about the large unsupported spans, the incidence of chromitite stringers in the hanging, and also the rolling of the reef. A decision was made to move the trial to the Merensky Reef at the Boschfontein Shaft in the Townlands Business Area. A simplifying factor was that the dip at Boschfontein was only 9° compared with the 18° at Union. This would enable trackless operation on true dip rather than apparent dip, as at Union.

Boschfontein was originally started up as a narrow reef trackless operation, but had since converted to conventional mining methods. However, numerous pillars were still available to be mined on the upper levels, and in close proximity to the decline shaft. It was considered that the long hole stoping method could be used to mine these pillars. Successful implementation of the mining method could lead to an extension of its role at Boschfontein or Townlands 2.

General stope layout

The layout developed at Union Section was now applied to Boschfontein.

Figure 2 shows the general layout adopted for Boschfontein. The mining method can be likened to Room and Pillar mining, where the rooms are relatively small. The pillars are then robbed. Excavation sizes for the rooms have to accommodate the mechanized mining equipment. However, the pillars are to be robbed as narrowly as the channel width of the orebody. A more detailed design is shown in Figure 3.

Drilling drives are 2.8 metres wide by 1.6 metres high to accommodate the Tamrock Solo LP 126 LC10. Details of the machine are shown in the Appendix. The width of 2.8 metres is to suit the long hole drilling feed equipped with 1.2 metres extension steel. The height is to suit the 1.3 metre height of this drilling rig.

Panel length or required length of long hole drilling is 15 metres. Experience in the UG2 at Union had demonstrated that holes of 15 metres in length were virtually always dead straight. It was also considered prudent to have a reasonably short panel to accommodate reef rolls and undulations. The drilling rig was designed to drill to the right and the left, in this way minimizing the required number of set-ups for the machine and maximizing the time spent drilling.

The holing raise was smaller in cross-section and was developed by long hole drilling from the advance strike drive and drop raising.

Rock engineering considerations

It was planned to mine the long hole stope panel at a minimum mining width of 650 mm. This makes it impractical to have operators in the stope. Roofbolts were installed in the drilling raise, the holing raise and in the advance strike drive. See Figure 4.

The sequence of mining blocks was scheduled to ensure that mined-out stope spans did not become excessive. Falls of ground in the panel had to be monitored closely in order to implement layout changes should the need arise.

Blasting

African Explosives Limited were present during the initial charging and blasting operations. The holes were charged with Magnum cartridge explosives (36.5 mm in diameter and 560 mm long) attached to detonating cord.

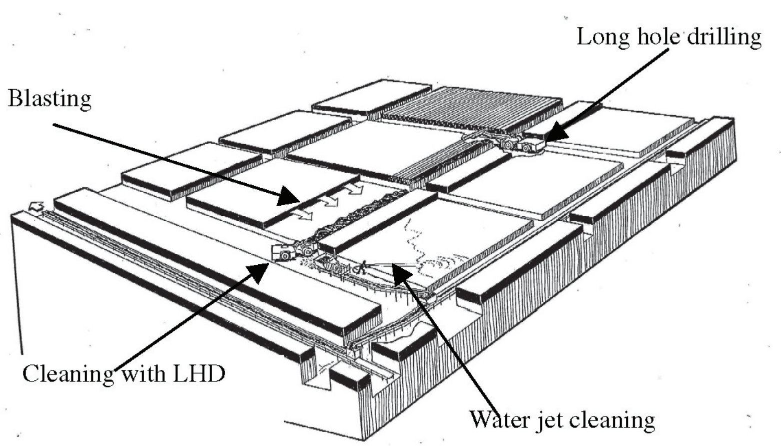

Figure 2. General stope layout at Boschfontein

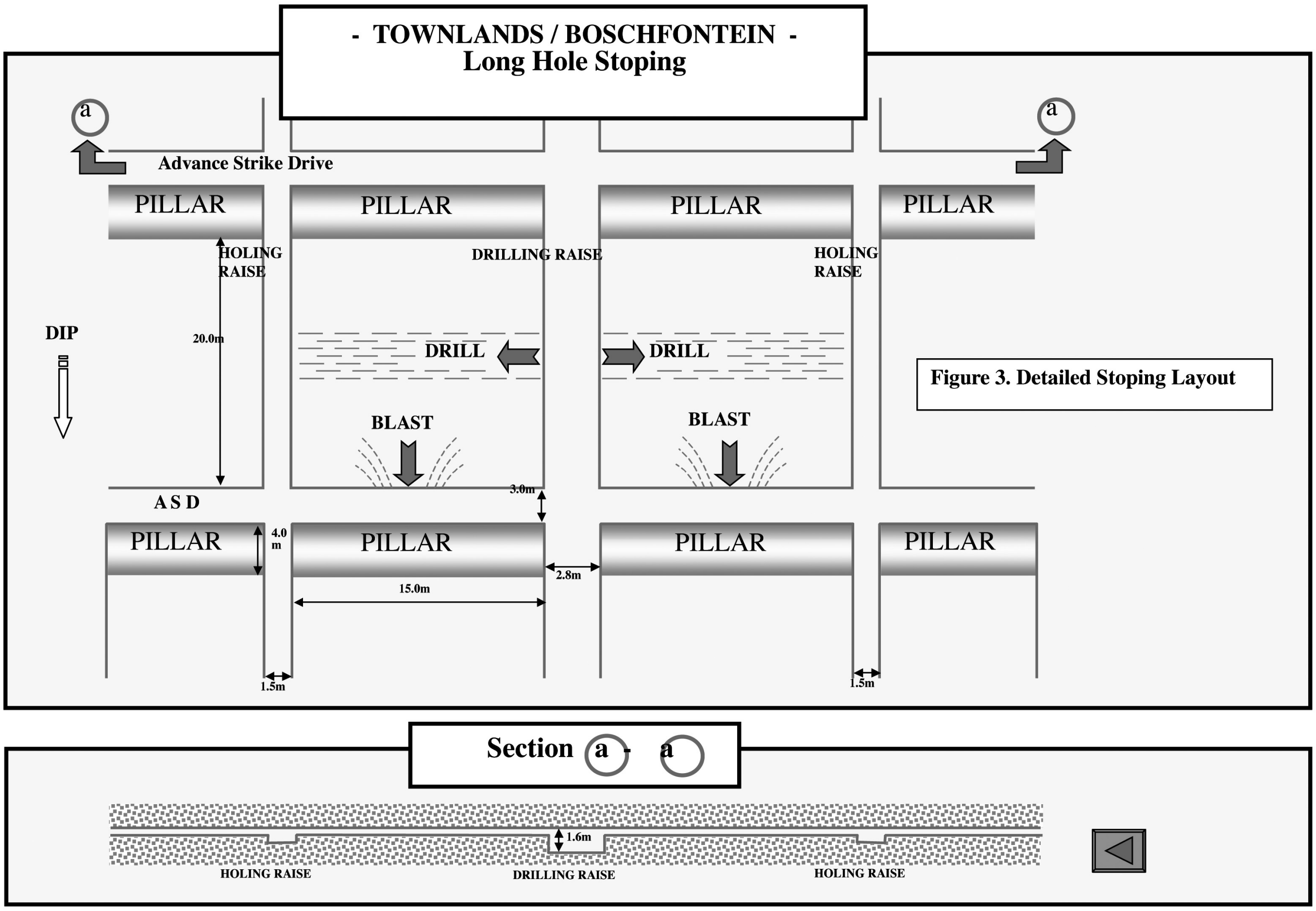

Figure 3

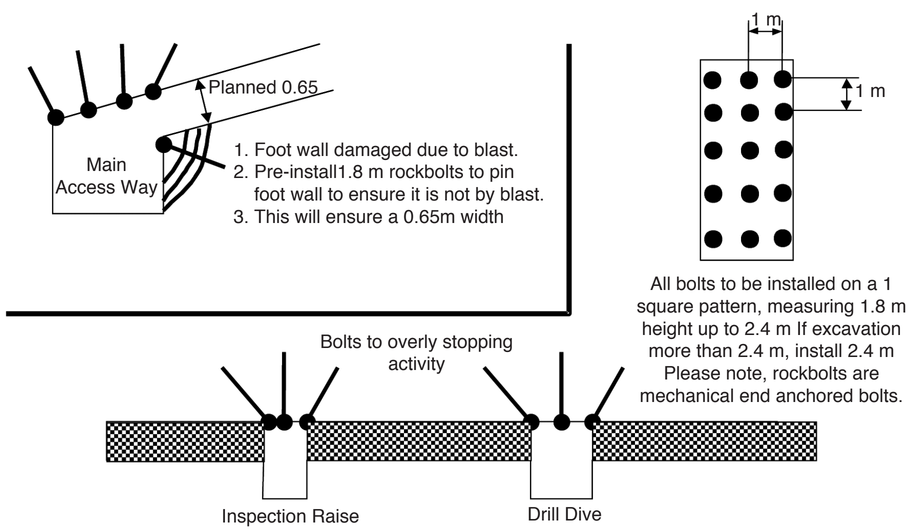

Figure 4. Support installation in access ways

Theoretical cycle of operations and equipment

The development of the 'rooms' or initial access structure would be carried out using Tamrock Axera LP face drill rigs and the EJC 115 LP 5.5 ton loader. Figure 5 shows the face drilling rig and Figure 6 the LHD. The pictures were taken underground at one of the narrow reef hard rock mines in the Bushveld Igneous Complex.

When designing a mining system it is important to size the fleet correctly. For example in a similar exercise it was assumed that a fleet to deliver 26 000 tons of reef a month would consist of three face drill rigs, two LHDs, one long hole drilling rig and one explosives utility vehicle. It is probable that in that exercise it would have been appropriate to include a roof bolter. Information on capacity

Figure 5. Tamrock Axera LP face drill rig operating in underground BIC mine

Figure 6. EJC 115 LP Load Haul Dump operating underground in BIC mine

and equipment capability should be available from most equipment manufacturers. It is an important requirement of the project team that they should optimize the match between equipment selection and fleet with mining method.

Assuming that the stope grid is developed ahead of the stoping, the cycle of operations of long hole drilling and blasting can be described as follows.

- *Long hole drilling* is seen as a continuous operation allowing blocks to be pre-drilled and blasting to take place as and when required. Hole length was restricted to 15 metres from the drilling raise to the holing raise; hole length restriction was in part due to undulating reef conditions, and in part to the known straightness of 15 metre holes. Hole diameter was 51 mm, this being the smallest hole that would accommodate rod and coupling of a sufficient size to suit the X2 drifter. Figure 7 shows the long hole drilling rig on the surface. Details are available in the Appendix.
- *Blasting* was carried out with detonating cord used in conjunction with a train of cartridge emulsion explosives. The mine planned to use pumpable emulsion explosives and electronic detonators at some stage during the trial, to make charging up easier. However, the balance between explosive and required rock breaking is very important, and the author is concerned that 51 mm holes full of emulsion may be excessive and result in damage to the hanging.
- *Cleaning* will rely mainly on throw blasting, but with final cleaning with stope water jets. Blasted rock thrown into the advance strike gully will be removed by the LHD. The final clearance is planned to be by conveyor belt or footwall haulage.
- *Support* will not be used in the narrow stope area. Roof bolts will support the advance strike gullies, drilling raises and holing raises.

Trial production targets

In setting up the trial the following production targets were laid down.

- Safety was the highest priority, and the system was planned as a man-free panel environment. Panel cleaning was done by throw blasting and the production crew consisted of five men
- Shaft head costs were expected to be 15% lower than for conventional mining. Though panel mining with long hole drilling is more capital intensive, cost savings would accure because no panel support and no footwall development are required
- Dilution is the other major cost/revenue driver. It was important to keep the access ways to the planned dimensions to prevent excess waste being trammed with the reef
- Panel width was planned at 650 mm, while the stoping grade was to be 6 g/t

Figure 7. Long hole drilling rig on the surface

Table III
Comparison between planned and actual performance

	Planned	Actual
Drilled metres per shift (metres)	125	105
Drill hole deflection (mm/m)	75mm/15m	45mm/15m
Hole burden (cm)	50	45
Drilled equivalent centares per shift	62,5	47
Number of holes blasted together	4	6
Face advance per blast (metres)	2	2,5
Throw blasting	Achieved	
Water jet cleaning	Achieved	
Shaft head cost reduction per ton mined	15%	10,9%
Stoping width (cm)	65	45
Revenue increase per ton mined	15%	25%

- The system would produce 15% more revenue per ton than conventional mining can
- Hole drilling accuracy was set at 0,5% deflection. The hole must be positioned to within +/- 75 mm of desired position after drilling a 15 metre hole
- The drilling rate was set at 125 metres per single shift. This was based on a long hole drilling performance target of 5 000 metres per month, drilling two shifts per day
- The pProduction rate was to be 60 centares per shift or 2 500 centares per month, and was based on a staggered drilling pattern with one metre between two holes in the same row
- Face advance per blast was to be maximized with a target of two metres per blast.

Trial results

Drilling accuracy was well within the desired 0.5% specified, though drilling rate was slower than anticipated. In the early stages of the trial it was demonstrated that drilling straight holes was the easy part of achieving the necessary hole accuracy. The difficulty was in ensuring that the drill feed was pointed in the correct direction. An angle indicator was mounted on the drill feed, giving a vertical angle read-out of 0.01% of slope. Setting the heading was more complex and involved setting the drill feed relative to survey lines. Actual hole drilling time was about 25 minutes. The set-up time of 20 minutes per hole restricted shift drilling performance per shift. Even with care taken, it was not uncommon for holes to be rejected, as they were not correctly positioned.

The following pictures give a better appreciation of the equipment and the results achieved.

Advantages of this mining method

In the words of the mine management. ‘It allows for increased safety and low health risk as well as an improved working environment. Physical work is reduced and it is easier to motivate the work force. Another advantage is the improvement in grade due to control of dilution, as only the channel width of the orebody is mined. This reduces ore transport costs and improves cost efficiency per ounce.’

Disadvantages of the long hole drilling mining method

The mine management at Boschfontein had the following comments to make. ‘Due to the lack of support in the mined-out areas, careful production planning and rock engineering design is required. Where horizontal fractures exist in the immediate hangingwall, such as the triplets above the UG2 chromitite at Rustenburg Section, critical spans will need to be reduced—this will impact on development replacement rates and therefore cost per ounce.

‘A high-competence workforce with multi-skilled mining and engineering personnel is required. It is probably this issue that is the most challenging—ensuring the operators have the relevant skills is a training issue, ensuring all levels of the mine management have the necessary understanding of the new process as a paradigm shift. This is not considered to be a fundamental problem and adequate training can be provided for operators and mine management.’

Figure 8. Long hole drilling operating in drilling raise

Figure 9. Long hole drill carrier

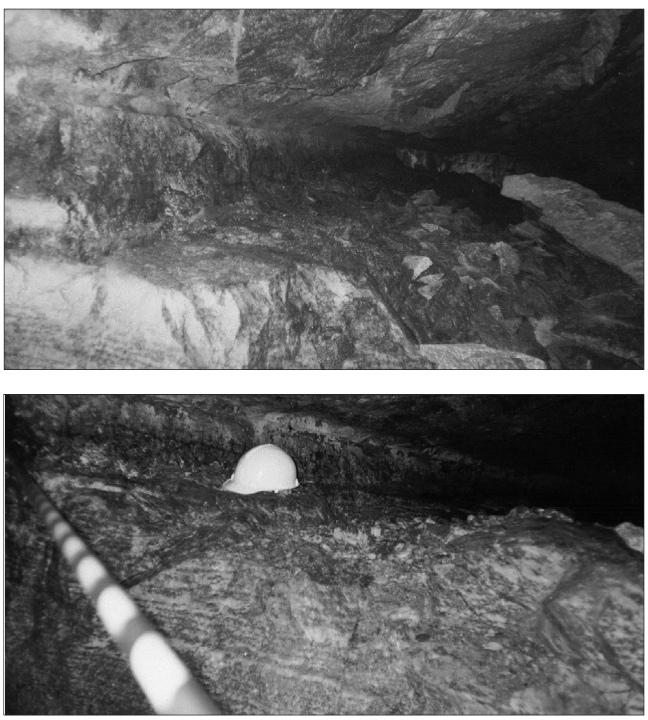

Figure 10. Blasted stopes showing hole accuracy and narrow stope

Figure 11. Mined stope after water jet cleaning

Conclusion and comment

Again it is appropriate to quote the mine. 'The results have exceeded our expectations. We have demonstrated that narrow, tabular orebodies can be mechanized and perhaps more important, that it is possible to create a man free/support free stoping environment. It has significant potential in terms of gaining both scale and learning curve efficiency. We are currently establishing a fully integrated mechanized section to take advantage of the significant potential outlined in this document.'

One of the questions commenly asked is whether it is possible to increase the output of the long hole drilling rig. The answer is an emphatic yes. It's all to do with hole straightness and direction. The drifter has been down tuned—at De Beers they are drilling 350 metres per shift, of 64 mm hole diameter, with the same drifter. At this trial R32 rods were used because the T32 rods were not then adequately developed. R32 rods have uncoupling problems. For hole direction, Sandvik Tamrock are finalising the development of a hole director that will provide vertical angle and heading to accuracy of better than 0.5 of a degree. It should be possible to achieve at least the same as the Australians of 6 000 metres per month or 150 metres per shift (10 holes).

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Appendix I

List of people from Anglo Platinum and Sandvik Tamrock who participated and contributed to the successful development of Long Hole Drilling as the basis for a new method of mining.

Anglo Platinum

Peter van Dorssen	Business Area Manager
Clem Sweet	Business Area Manager
Petre Valicek	Logistics Manager
Kobus Theron	Logistics Co-ordinator
Andre O. Neumeyer	Operations Manager
P.J. Venter	Chief Safety Officer
Alan Field	R & D
Garth Harrison	Manager R & D—Amplats Mining Technology
Jack Sealie	R & D Project Manager—Union Section
Keith Noble	Consultant: Rock Mechanics
Louis Bronkhorst	Assistant Chief Rock Mechanics Officer
Hennie Maree	Planning Officer
R. Vermaak	Senior Surveyor
M. Olivier	Mine Overseer
Neels Kotze	Ore Resource Manager
Josef Jakes	
Ettiene Malherbe	

Sandvik Tamrock

Jim Tolley	Managing Director
Nico Rossouw	Service
Basil Maddocks	Account Manager
Deon de Kock	Service Manager
Christo Buys	Technician
Rod Pickering	Manager—Strategic Projects
Jean-Claude Cambon	Drill Master—Secoma
Braam Vister	Technician
Johan Uys	Risk Assessment

JIC

D Joubert	
J L Becker	
Chris van den Heever	Project Leader
Johan Steyn	

Other

Ken Rhodes	Mining Consultant to Anglo Platinum
Hendrik Jansen Van Rensburg	AECI Explosives Ltd
Claude Cunningham	Consulting Mining Engineer—AEL
P.W. Joubert	Business Area Manager—Platinum—AEL
Colin Wilson	AEL
Gary York	Snowden Mining Consultants
Roger Johnson	Snowden Mining Consultants