Hard rock cutting and the development of a continuous mining machine for narrow platinum reefs

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Introduction

The hard rock gold and platinum mines in South Africa have seen little development in the technology of mining. Holes are still drilled in the rock—though the latest water hydraulic rockdrills will complete that task in two minutes compared with the eight hours for hand drilling. Charging up is with far safer explosives and with available initiation systems it is no longer necessary to run up the face lighting each fuse. Movement of rock in the stope is predominately by means of scraper buckets and scraper winches—these were first introduced in the 1920s. Support is still mainly rock, either *in situ* pillars or backfill, or alternatively wood. Just as the mining process has changed very little it is hardly surprising that the productivity of mining is also relatively unchanged.

Major efforts have been made to mechanize the mining process. However, most of the narrow reef mines where 'trackless mechanized mining' was introduced in the early 1980s have reverted to conventional mining. In the wider reefs mechanized mining is the option of choice, unfortunately most of the gold and platinum mines have very narrow reefs that are not suitable to 'off the shelf' equipment. The move to introduce room-and-pillar mining into the narrow UG2 reefs is at the expense of mining more waste with the reef, fortunately it appears that appropriate waste and reef separation processes are available. Room-and-pillar mining followed by long hole drilling and blasting of a narrow slot of reef out of the pillars currently appears to offer the best of both worlds—maximum reef recovery with minimum waste dilution.

All these mining methods are still dependent on blasting to break the rock. The cyclic nature of mining by blasting places severe constraints on the rate of face advance that can be achieved and consequently the utilization of the invested capital. For narrow reef hard rock mining to break out of these constraints and to really make progress in the 21st century it is necessary to follow the lead of the soft rock mining industry and change the technology of mining. In the underground coal mining industry, coal cutting has been proven to be the most cost effective solution, in narrow reef hard rock mining the future must be based on the development of non-explosive methods of rockbreaking that in turn are integrated into continuous mining systems.

Non-explosive so that the mining operation can be conducted on a continuous basis, with no delays for the removal of blasting fumes. Continuous mining also maximizes the return on the capital invested in developing the mine. Rock cutting will define the stope width and that in turn will be designed to minimize waste dilution; it will also minimize damage to the hanging and create a safer environment. Mechanization makes it possible to automate the mining process and further improve safety by positioning the operators in a safer environment.

This paper defines the work to evaluate cutting processes carried out by Sandvik Tamrock Voest Alpine. The evaluation was in the UG2 and the pyroxenite and norite typical of the Merensky Platinum Reefs. A novel form of mining machine is proposed that will utilize existing technology. Finally the paper describes the interaction between Sandvik Tamrock Voest Alpine and Lonmin Platinum and the initiation of an agreement to develop and trial a prototype hard rock narrow reef mining machine.

Background

Voest Alpine Bergtechnik is an Austrian company based in Zeltweg in Austria. They have had extensive experience in rock cutting and for many years they have designed and manufactured road headers and tunnel boring machines. During the late 1990s they, together with Sandvik Tamrock, were major players in the development of the Icutroc process. This development made it possible for pick cutting machines to operate cost effectively in substantially harder ground.

Initial trials

Towards the end of 1998 developments in the platinum industry were pointing the direction for massive change in the narrow reef mining processes. A number of mechanized mining methods were being evaluated, together with one non-explosive based mining system. Voest Alpine had already applied the Icutroc cutting process in the Stillwater Paladium Mine in Montana with mixed results. However, the UG2 was regarded as an easier target and it was decided that the most appropriate start was to carry out pick cutting tests, in Austria, on a sample block of UG2 reef.

The reef was sourced from the Anglo Platinum Mine, Union Section, it had a low uniaxial compressive strength of 26 MPa; the sample also contained waste bands of pyroxenite with a UCS of 110 MPa. However, the Cherchar Abrasivity Index for the chromite ore was 5,4. This is an indication of

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the extreme abrasivity of the UG2 reef, on a par with high quality quartzite.

The cutting tests were conducted with a variety of carbide cutting tools and at various speeds and depths of cut. The surprising result from the trials was the very low pick life, with the best available picks being severely damaged after only four passes over the UG2 reef. Figure 1 shows the rock sample tested and Figure 2 the condition of the picks after the tests. It is believed that the high wear rates were not a function of the hardness of the UG2 but rather the hardness and abrasivity of the chromite crystals that make up the structure of the UG2.

Phase II testing

If pick cutting could not provide the answer it was decided that the practicality of disc cutting should be reviewed. Voest Alpine have participated in various trials of activated cutting, using the Becham process, and have closely evaluated the oscillating disc cutter currently undergoing trials in Australia. The benefit to be achieved from activating or oscillating disc cutting was considered to be questionable and the technological hurdles to develop effective bearings and seals substantial. It was decided that the most cost-effective option for reef cutting would be conventional disc cutting technology.

Figure 1—Sample of UG2 Reef with pyroxenite waste bands

A second rock sample was sent to Austria. This was a pyroxenite/norite rock with an UCS of up to 140 MPa, typical of the rock comprising the Merenksy Reef. The samples were cast into a concrete block having dimensions of 4 m × 3 m × 3 m.

Three 300 mm diameter disc cutters were mounted on an ABM 105 roadheader. The configuration of the discs and the cutting action generated a slot 800 mm high and 240 mm deep in the side of the test block. The test machine was extensively instrumented. Analysis of the test results clearly showed that the disc cutting closest to the free face consumed the lowest power, generated the lowest force and created the largest rock particles. Figure 3 shows the typical rock particle size produced by the outermost disc cutter that was cutting next to the free face.

Theory of disc cutting

Mechanical rock failure is a complex process influenced by nearly all rock physical and geological properties. The dominant mode of failure is still a subject of research. One aspect shared by all the theories is the existence of a zone of highly crushed rock material beneath the cutter tip prior to chipping. As the cutter penetrates the rock, a pressure bulb or crushed zone is formed due to the extremely high stresses generated in the rock under the tip of the cutter. The pressure in the crushed zone causes tensile cracks to initiate and propagate into the rock mass. If the stresses developed in the crushed zone are sufficiently high, one or more cracks extend

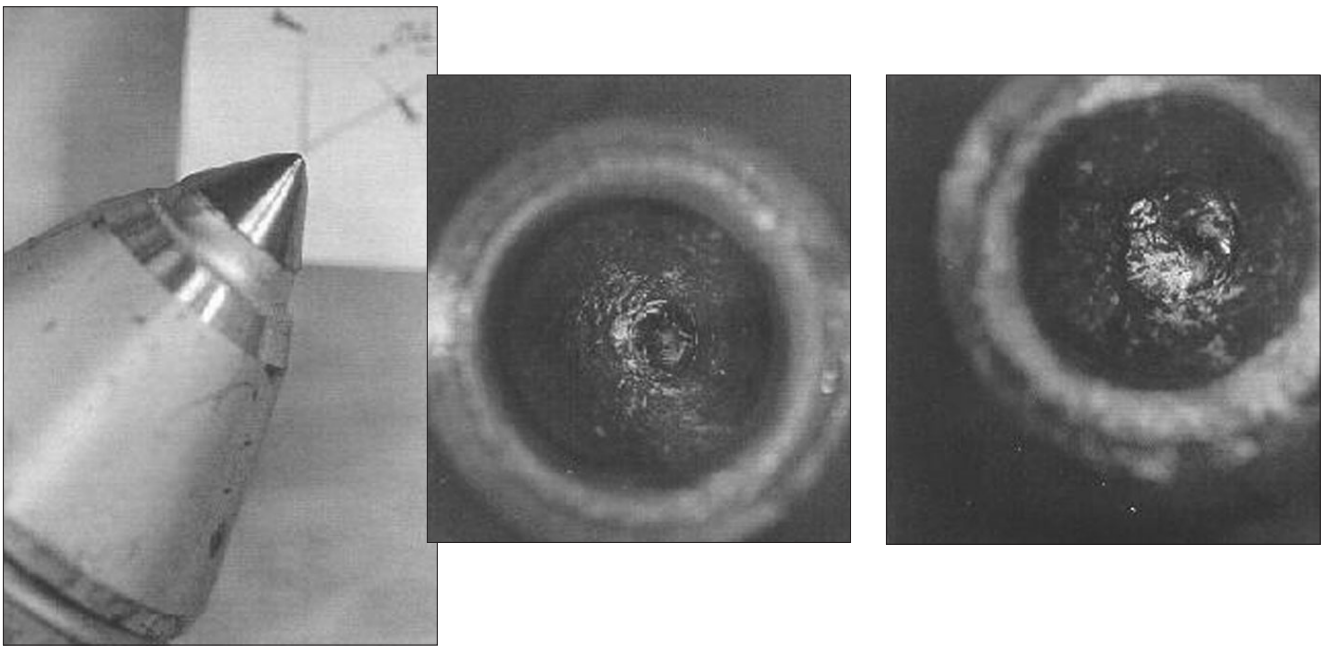

Figure 2—Special test pick and wear after two and four passes

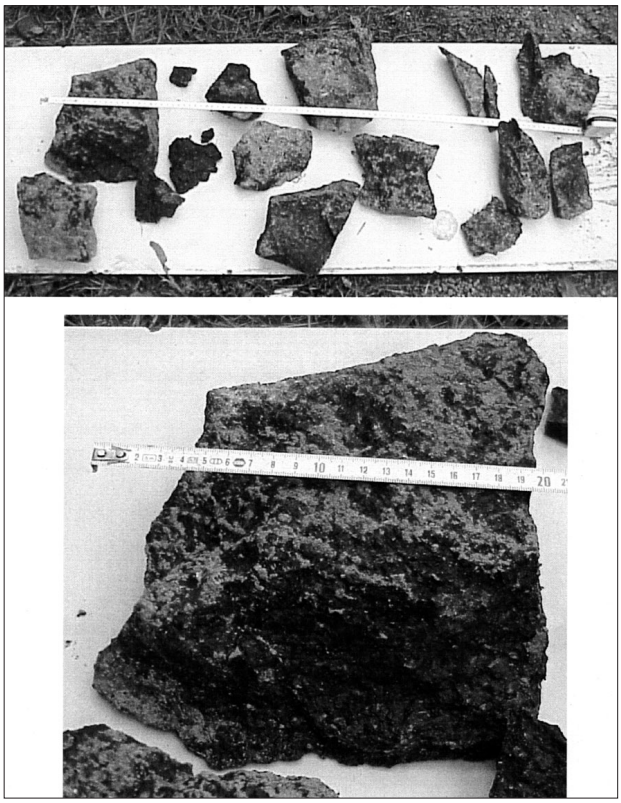

Figure 3— Particle size generated by undercutting the reef with disc cutters

far enough to reach one of the tensile cracks developed from an adjacent cut, or alternatively a free face. In conventional disc cutting rock failure is in the form of chipping. Figure 4 shows this process. In undercutting the crack propagation is to a free face and rock fragments generated are substantially larger. Figure 5 shows the undercutting process.

Reef miner specification

Evaluation of the results from the phase II testing led to the conclusion that the reef miner should have the following generalized specification.

- All the cutting discs would be mounted in the same cutting plane.
- The reef would be cut in an undercutting mode, thus minimizing the power and cutting forces and maximizing the chip sizes.
- The effective undercutting depth was estimated to be between 50 and 60 mm.
- Machine stability and stiffness was essential, thus,
  - the machine must be staked while cutting,
  - the cutter boom must be as short and stiff as possible.
- The machine will not be fitted with crawlers and will walk in the stope using its staking system.
- The machine must be capable of cutting its own entry into the stope and thus minimize the requirement for pre-development.
- The machine should excavate the maximum amount of reef from a single set-up.
- The machine in operation must be flexible enough to follow the major reef undulations.
- All rock cuttings must be removed from the immediate cutting area and then transported out of the stope.

Advantages of the reef miner

This generalized specification was fleshed out and the reef miner conceived is shown in Figure 6 and has the following main advantages.

- The machine design was simple in concept.
- The machine was easy to automate.
- The machine consists of easily maintainable components with most of the main functions being driven by hydraulic cylinders.
- The machine made use of well-known disc-cutting technology that was applied in an innovative manner.

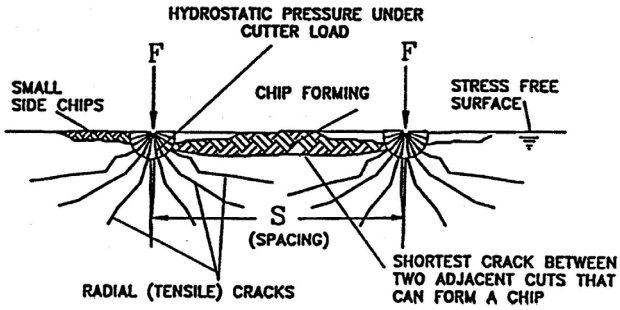

Figure 4—Theoretical rock breaking process for conventional disc cutting

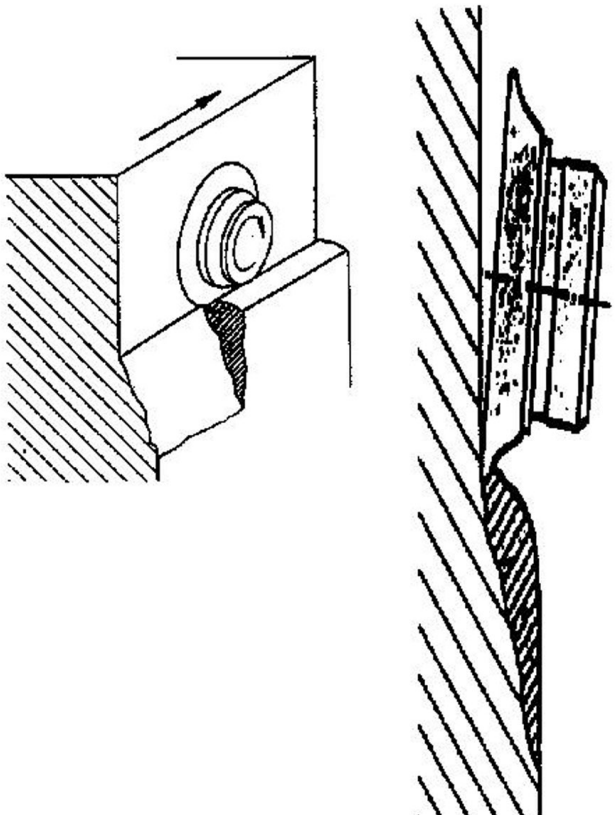

Figure 5—Orientation of disc cutter for undercutting

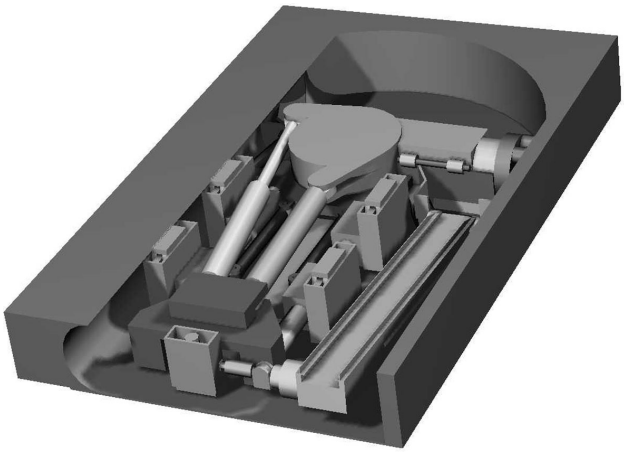

Figure 6—Conceptual model of narrow reef miner

- Most importantly, because the total system is simple and flexible, the machine was designed to work in a wide variety of mining layouts.

It was considered that the ideal operating methodology for the reef miner would be as follows. Raises would be cut approximately 100 metres apart. The reef miner could cut these raises. The reef miner would then mine in a strike direction cutting an opening one metre high and 3,9 metres wide. The height of 850 mm was the minimum cutting height for the proposed machine and with different heads it could cut up to 1,2 metres. The reef miner incorporates rock handling in its immediate vicinity; it was considered that rock handling from the machine to the raise could be achieved efficiently with a simple scraper system. The operation of the reef miner would be largely automated with the operator staying in the raise. After mining for 100 metres on strike the reef miner would hole into the adjacent raise. Because the reef miner can cut its own entry pillars these could be left at a spacing of any multiple of 3,9 metres.

Reef miner system benefits

It was estimated that the following system benefits could be achieved.

- Improved safety as a result of fewer people and operators not working in the stope. Thus, those exposed to risk and the extent of the risk would be reduced
- Increased labour productivity
- Improved head grade
- Reduction in off-reef development
- Reduction in support costs
- Mining operation flexibility
- Continuous mining.

Table I

	Original	Modified	Expected
Cutter cutting diameter (metres)	0.85	1.0	1.0
Cutter cycle (min/cycle)	3.5	3.5	2
Production rate (tons/cycle)	0.8	0.95	0.95
Net mining rate (tons/hour)	12.8	15.2	26
Available time (% of total time)			65
Available time (hours)			15.6
Operating cycle time (% of available time)			70
Utilization (% of total time)	38	38	45
Other cutting and maintenance time (hours)			4.7
Daily production (tons/day)	116	137	280
Monthly production (tons/machine/month)	3 500	4 100	8 500
Monthly production (square metres/month)	1030	1 025	2125
Production operators (three shifts + one shift)	8	8	8
Labour productivity (square metres/ man/month)	129	128	265

All tonnage calculations are based on an assumed specific gravity of 4

Reef miner performance

Voest Alpine and Tamrock have extensive experience of operating equipment in underground environments and Voest Alpine has a history of hard rock cutting. Our collective best estimates for an initial and an expected cutting performance of the reef miner in the pyroxenite/norite of the Merensky Reef and the UG2 Reef, including immediate footwall and hanging, are shown in Table I.

The cutting cycle time was based on the assumption that initially each cutter will penetrate 5 mm per pass in the cutting direction though it was expected that the cutters would have the potential to penetrate 10 mm per pass. Early testing of the cutting process has vindicated this view.

Production rate assumes that a slice 60 mm thick is cut from the face and that the stope width is one metre.

Net mining rate includes the time required for moving and re-staking the reef miner.

Available time was the time that is available for the machine to carry out its normal cutting operational cycle plus other machine-related operational activities. It is VAB's experience that as much as 70% of total time can be lost due to items such as:

- Non-supply of power, water, air and other utilities
- Men not at work and legal rest periods
- Other mining activities
- Unforeseen geological conditions, etc.

It will be a challenge to achieve the target of 65% of total time available. However, with good planning it should be possible.

Operating cycle time is the time available for cutting, loading ore from the cutting area, advancing the machine and re-gripping and as such is the productive part of the cycle. Another way of describing operating time as a percentage of total time is utilization, which in the expected performance column is 45%.

Other cutting activities include re-alignment, entering the slope, turning, replacing cutters and maintenance.

Daily and monthly production is based on 24 hours per day and 30 days per month respectively.

Labour requirements are based on two people per shift and three shifts per day, with the fourth pair providing time off. It is envisaged that the two people per shift will be responsible for all in stope activities.

Partnerships

Up to this stage in the development of the reef miner Sandvik Tamrock and Voest Alpine had worked alone. It was recognized that it was now imperative that they enter into a partnership relationship with a platinum mining company. Presentations were made to the three primary platinum

producing companies in South Africa. One of these companies expressed no interest, a second was interested but unwilling to contribute to the cost of the first prototype, the third company was Lonmin Platinum. They whole-heartedly supported to concept and Sandvik Tamrock, Voest Alpine and Lonmin Platinum entered into an agreement to develop and trial the reef miner. The basic agreement consists of the following components.

- *Narrow reef miner design*—Sandvik Tamrock and Voest Alpine will design the prototype narrow reef miner entirely at their cost. They will own the intellectual property arising from the design of the prototype.
- *Narrow reef miner manufacture*—Lonmin Platinum have agreed to fund the cost of manufacturing the prototype. This prototype will be manufactured in Zeltweg, tested in a representative manner on a concrete block, modified as and where necessary and shipped to South Africa. The design and manufacture schedule was estimated to be twelve months and the prototype machine is expected in South Africa early in November 2001.
- *Narrow reef miner evaluation*—The prototype narrow reef miner will be tested at a site to be agreed by all parties and at the Western Platinum Mine of Lonmin Platinum. It is envisaged that the trial will last for six months. For the first four months testing will be underground on a single shift basis. For the final two months testing will be on a double shift basis. All activities shall be by mutual agreement and the partnership cost-sharing basis shall apply.
- *Project management*—A project team comprising participants from Lonmin Platinum, Western Platinum, Sandvik Tamrock South Africa, Voest Alpine Bergtechnik and the Rotary Division of Sandvik Tamrock meet on a regular basis to review progress and determine future activities.

High risk elements

Throughout the discussions between Lonmin Platinum, Voest Alpine and Sandvik Tamrock it has been emphasized that the reef miner makes use of existing technology. The various components of the basic machine concept are all tried and tested. However, discussion has identified two high-risk elements, either of which could cause failure of the narrow reef miner to achieve the desired objectives.

- Cutter life and consequently cutter cost per ton is the major technological issue. The technology of hard rock cutting is well understood and there is extensive experience of TBMs using disc cutters, with and without carbide inserts. The reef miner uses disc cutters in an undercutting mode of which there is limited experience.
  The feasibility of developing a test rig has been investigated. Such a rig would have to operate in a mine and provide quantitative information on cutter performance. However, such a test rig would have to be as stiff as the prototype machine and have a similar cutting action. In other words it would have to be substantially the same as the prototype machine. It has been concluded that the limited benefits from such a test did not justify the investment in time or money.
  The issue of cutter life has been addressed from a more theoretical basis; trials of single cutter discs operating in an undercutting mode have been carried out and use has been made of available design expertise in the practical application of discs operating in an undercutting mode.
- Mining operations and the integration of the reef miner into the mine activities. The introduction of technology change on a mine is always difficult and in this project change will affect everyone from senior management to operational staff. The planning of the immediate project will be a trivial issue when compared to the large scale introduction of the reef miner. In VABs experience other mine activities can take up as much as 70% of the available time, limiting the machine operating time to 30% of total time. Good operational controls by the mine will result in substantially increased machine operating time.
  The joint project team are currently determining the effect of rock cutting on mine layout and down-stream processes, e.g. the use on instope conveyors, and how these can be optimized. An effective solution is only likely to be achieved through integrated and interactive planning processes.

Conclusion

'The proof of the pudding is in the eating.' The project team developing the hard rock narrow reef miner have followed a systematic approach to develop a machine concept and an embryo mining system that could have a massive impact on current narrow reef hard rock mining operations. Early in the year 2002 we shall know how successful our efforts have been. ◆