



Bord-and-pillar mining in inclined orebodies

by J.T. Jordaan* Paper written on project work carried out in partial fulfilment of B.Eng (Mining Engineering) degree

Synopsis

This paper addresses the critical parameters that need to be considered when designing a mechanized bord-and-pillar mining layout for a narrow tabular steep dipping orebody. These parameters are:

- Reef dip
- Reef width
- Geological structures within the orebody
- Physical dimensions of the selection of machines
- Gradeability of the selection of machines.

The main objective in designing such a layout is to maximize machine efficiencies whilst minimizing dilution.

This methodology was then applied in the design of a mechanized bord-and-pillar mining layout for a given piece of ground (Vlakpoort and Moddergat) using a given selection of machines. This piece of ground contains the PGM bearing UG2 Reef with an average thickness of 124 cm and dipping at 18° with adverse strike and dip changes.

Two bord-and-pillar layouts were designed for this area. Layout 1 is characterized by the use of strike conveyors to convey ore on strike with an average LHD hauling distance of 35 m. Layout 2 uses LHDs for all on strike conveyance of ore with an average hauling distance of 75 m.

These two layouts were then technically and financially compared. It was concluded that layout 1 is theoretically superior but layout 2 was chosen due to its greater flexibility and probability of operational success.

Layout 2 was also compared to conventional mining and it was concluded to be more economically feasible. However the latter is a proven mining method in these conditions and has a lower risk operational failure.

Bord-and-pillar mining has some favourable promises such as improving labour difficulties, lowering operating costs and providing safer working conditions. The success of mechanized bord-and-pillar mining in narrow tabular steep dipping orebodies will depend on the extent of the research and development efforts which need to create and innovate technologies to overcome some of the current limitations stated in the above-mentioned parameters.

Introduction

Mine background and general information

Anglo Platinum's Amandelbult Section is situated in the south-western region of the Northern Province 40 km south of Thabazimbi

and 120 km north of Rustenburg. Amandelbult's geological setting is in the Western Limb of the Bushveld Complex, in the Lower-, Critical- and Main Zone rocks overlain by the Upper Zone rocks.

Three reefs exist at Amandelbult, namely the Merensky reef, the Upper Group Chromitite layer no. 2 (UG2) and the Lower Pseudo Reef (P1).

The Merensky reef is approximately 35 m above the UG2 and both dipping between 18 and 23° in a direction 040° east of south.

Project background

Anglo Platinum aims to expand their current operations considerably within the following 5 years. This goal has a series of implications, which clearly indicates that in order to achieve this goal more efficient mining methods need to be applied, for conventional mining will not be able to fulfill the company's aims.

With the improvements in trackless low profile machinery it is now possible to safely produce at a significantly reduced cost, and improved productivity. Mechanized bord-and-pillar mining is thus considered as a supplement to conventional mining, which accounts for the majority of current mining operations on Amandelbult. Bord-and-pillar mining is applicable to horizontal to flat dipping thin tabular orebodies where the surrounding hangingwall and the ore itself are relatively competent and require no extensive support or rock reinforcement. The reasons for mechanization are as follows:

- Minimize the required workforce in order to minimize labour costs
- Reduce human exposure to underground hazards and thus reduce the overall operational risk
- Take advantage of the high platinum price and the favourable rand/dollar exchange rate and capitalize for mechanization now

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- Reduce mining costs by increasing the production tonnage and reducing production costs with the effective mechanized drilling and cleaning method
- Increase the underground labour efficiency (tons extracted per employee)
- Adhere to the vision of Anglo Platinum by enhancing the skills and training of the work force
- Minimize off-reef development in order to gain quicker access to the orebody, thereby eliminating preliminary development costs.

All the advantages of bord-and-pillar mining make this method sound like the ultimate cost effective and efficient mining method, but there are major restrictions to its application, e.g.:

- The thickness of the orebody in relation to the machine dimensions
- The maximum dip angle the machines can handle efficiently and effectively
- The percentage dilution, induced by fitting the proposed machines into the dimensions of the orebody, which raises excavating, transport and milling costs significantly.

The UG2 reef was chosen for bord-and-pillar application due to its higher reef width, which implies less dilution. There are two current bord-and-pillar projects at Amandelbult, 16 West and 43 East.

This project is aimed to design a bord-and-pillar layout section for the lower part of the farm Vlakpoort and the upper part of the farm Moddergat that will minimize dilution and maximize machine efficiency in order to maximize revenue. This area is renowned for its adverse geology, which makes the mining of this area a complicated operation that needs proper evaluation and planning.

16 West project

The 16 West project at Amandelbult and Vlakpoort are situated in similar conditions, shallow-lying UG2 reserves, and the design of the access ways and the excavation dimensions will be designed on the same methodology. The mine plans to continue the Vlakpoort project with the same selection of machines that is currently being used at 16 West.

The dimensions of the 16 West excavations were designed to fit the functional dimensions of machines into

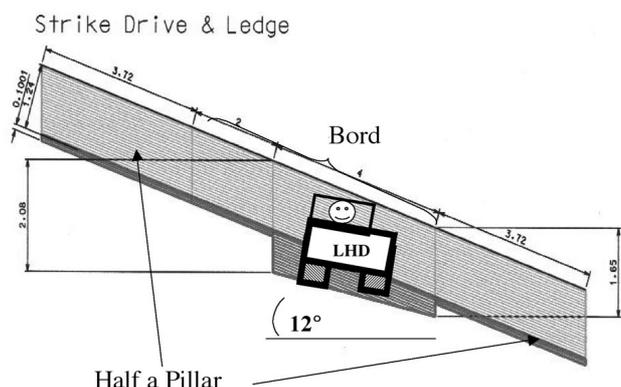


Figure 1—Cross section through bord-and-pillars

the dimensions of the orebody with the least amount of dilution. The average reef width in the 16 West area is 135 cm with an average grade of 4.82 g/t.

The Vlakpoort project will need the same types of excavations in its layout as the 16 West project, although these excavation sizes may differ due to the different reef widths. It is expected that the Vlakpoort project will have more dilution due to its narrower reef width. It is assumed that the flattening of the footwall to 12° is the maximum angle of efficient and productive operation for the trackless machines as currently being applied at 16 West with ease of operation.

The stoping will consist of three phases.

- *Phase 1* will be the developing of the strike drives and ledges and of each panel to the mining limits with the ventilation holings between the strike drives and ledges being established at 12 metre intervals. The ledges and holings need to be established on the updip side of the strike drive.
- *Phase 2* will comprise of cast blasting, of the ledge sidings on the updip side and the strike drive sidings on the downdip side, the rock will be thrown into the strike drive, in order to cut pillars on a retreat basis (This topic is discussed in detail in the section on rock mechanics).
- *Phase 3* will be the vamping and final sweeping of the mined-out panels.

The major reason for basing the design of Vlakpoort and Moddergat on a similar design as 16 West lies in the training of the workforce. Most of the workforce will be acquired out of conventional mining conditions and this creates operational problems, due to a different approach in trackless mining. The biggest problem is thus the resistance to change. By the time the Vlakpoort and Moddergat project is established, 16 West will have a database of operational expertise to tap, thus preventing the same mistakes and using 16 West's facilities and people for training. This will imply a faster gain of experience and knowledge and save on training costs.

Methodology

This project is a theoretical exercise, and thus the only field data that could be collected was in the form of observations during underground bord-and-pillar mine visits.

Three underground mine visits were made, RPM Amandelbult Section's 16 West and 43 East Projects and RPM Union Section's Piggy Project. During these visits the following factors were addressed:

- True dip
- Footwall gradients
- Angle of attack on the orebody, true dip and strike or apparent dip and strike
- Machine efficiency and effectiveness in observed conditions
- Practicality of the current layout
- Difficulties encountered in the current layout.

The manufacturers of the current selection of machines were contacted and they supplied the technical specifications of the current selection of machines. Operators and supervisors in the bord-and-pillar operations were also consulted about the validity of the manufacturers claims.

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Once the abovementioned visits were made and the technical machine specifications were received, conclusions could be drawn to rate their operational success.

All the geological data available on the Vlakpoort and Moddergat area were collected from Amandelbult's Geology Department and was then discussed with the Manager Geology to fully understand the current status of geological certainty.

All the abovementioned data were then studied and two different bord-and-pillar layouts were designed. These layouts were then evaluated according to dilution, productivity, cost implications, profit and mining flexibility and the most suitable layout was chosen.

Bord-and-pillar mining was then compared to conventional mining according to the following: financial analysis, dilution and flexibility.

Conclusions could now be drawn to the appropriateness of bord-and-pillar mining in Vlakpoort and Moddergat.

Results

Geology of Vlakpoort and Moddergat

The UG2 Chromitite Layer sub-outcrop strikes approximately north-west-south-east and occurs over a short strike distance, ± 800 m before it cuts out against the Transvaal Sequence rocks. The exact nature of the UG2 sub-outcrop/Transvaal Sequence contact is poorly understood.

A geological investigation was conducted on Vlakpoort in 1991 to evaluate the UG2 Chromitite Layer for possible opencast mining by drilling three surface boreholes and tracing the sub-outcrop with trenching. Due to extensive potholing the Merensky Reef is of little significance in this area. The UG2 Reef seems to be well developed up to the Transition Zone.

It was found that there were a number of geological disturbances, potholes, faults and a series of dip and strike changes in the Vlakpoort area as seen in Figure 2. Note the very steep dip near the sub-outcrop $\pm 75^\circ$ and flattening of the reef to a more normal dip $\pm 18^\circ$ approximately 50 m below surface as seen in Figure 3.

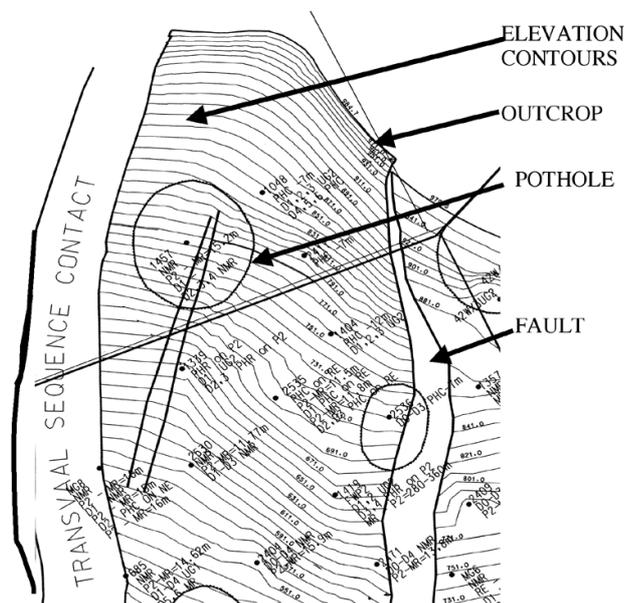


Figure 2—Geological plan of Vlakpoort and Moddergat

The Moddergat area is less disturbed than Vlakpoort with a relatively constant dip and minor strike changes. All data from Moddergat were combined with that of Vlakpoort to create structure model of the area. The structure is depicted in Figure 2. The projected pinching of the 100 m fault in Moddergat to 30 m at Vlakpoort is doubtful, but fits the currently available data. A number of small potholes also occur in this area but nothing significant (See Figure 2).

Grade

The three surface boreholes are the only direct information that is available regarding the grade of Vlakpoort. Two of the boreholes have intersected 'normal' UG2 while the third intersected potholed UG2.

Considering these values it seems that the UG2 grade on Vlakpoort is comparable to that found at Moddergat and Amandelbult. Due to the lack of sampling information no attempt was made to model either grade or reef width. The Geology Department at Amandelbult recommended that an *in situ* grade of 4.61 g/t over a reef of 124 cm be used for a preliminary evaluation. This estimate was obtained from the northern part of the Moddergat grade model.

Geological losses are estimated at 35% and the mineable *in situ* tons are calculated in Table I.

Low profile trackless machinery

All mining processes consist of a number of operations that have to be executed in order to keep the process running. Mechanization of these operations attempts to maximize the efficiency of the process as a whole and eliminate bottlenecks. In order to achieve this, the whole process is best mechanized. The mining process consists of the following operations:

In a mechanized mining process, success is determined by the machine-layout interface. Designing mining layout and attempting mechanization without considering the physical capabilities and constraints of the machines that are going to be used will operationally be likely to fail. The general machine capabilities and constraints are given in Table III.

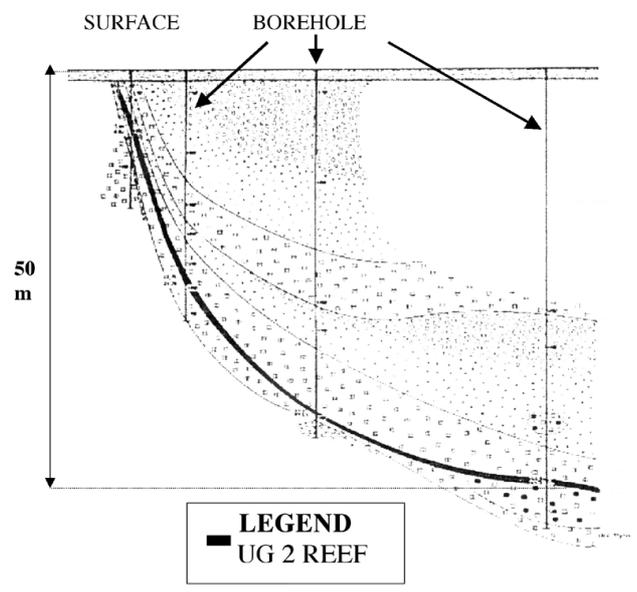


Figure 3—Section view of the UG2 sub-outcrop on Vlakpoort

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Table I

Mineral content Resource in proposed area.

Plan area	257478 m ²
Average dip	18°
Inclined area	1009404 m ²
Geological losses	30%
Geological losses area	302821 m ²
Net area	706583 m ²
Stoping width	1.3 m
S.G.	3.8
Tons	3329270 t
Ounces PGMs	542560 oz

Table II

Mining operations

Mining operation	Machine used
Drilling	Low profile drill rig
Charging up	Explosives utility vehicle
Blasting	Electronic blasting
Cleaning	LHD
Support	Low profile roofbolter

Table III

Machine capabilities and constraints.

Machine	Height (mm)	Width (mm)	Length (mm)	Gradeability (°)	Outside turning radius (mm)
Drill rig	1800	2000	11830	18° max	6724
Utility vehicle	1400	2300	6800	18° max	6724
LHD	1300	1600	7035	24° max	5210
Roofbolter	1400	2025	9175	18° max	8000

The gradeabilities of 18° and 24° respectively are not applicable to designing criteria. Even though these machines are capable of handling these gradients, it has to be kept in mind that these are maximum capabilities and the machines will not be able to operate efficiently at these gradients.

Limits to Bord-and-pillar mining with the current selection of machines

Dip

The dip of the orebody has a huge influence on the operational efficiency of the selection of machines. If the dip angle is too steep for the machines to handle, the angle of attack on the orebody needs to change. This problem can be partly solved by applying two basic principles:

- ▶ Apparent dip angles of attack
- ▶ Flatten footwall.

The apparent dip approach will not work when applied alone because the machine will still experience the true dip angle in a lateral direction if the footwall is excavated on true dip. This footwall is therefore also flattened in order to minimize the effect gravity has on the machines in the dip direction. This will therefore increase dilution as cuts will have to be made in the footwall to improve the operating gradient.

Table IV

Bord-and-pillar layout footwall gradients

Mine	Gradient	Successful
Kroondal Chrome	9°	Yes
Thornecliff Chrome	12°	Yes
RPM Union Section	18°	No

As the determination of the maximum efficient gradient of these machines is not in the scope of the project it is necessary to look at other applications of the same machinery in order to obtain an idea of what range of gradients need to be looked at.

As the maximum known footwall gradient on which bord-and-pillar mechanized mining has been successful in narrow tabular flat dipping hard rock orebodies is 12° it would be considered wise to apply the same footwall gradient in the Vlakpoort/Moddergat scenario.

Reef width

The reef width and machine operational height interface will determine if it is physically possible to fit the machine into the dimensions of the orebody with the least amount of dilution. The UG2 reef in the proposed mining area is 124 cm wide. This is far too low for the current selection of low profile machinery to operate in and a certain amount of dilution has to be tolerated.

Face length

The face length in this case is a function of the lateral reach of the drill rig. If the face length exceeds the lateral reach, more than one set up needs to be made in order to cover the whole face area. Each setup takes a certain amount of time and reduces the drill rig productivity significantly. To optimize drill rig productivity it is necessary to maximize the number of holes drilled per setup. This can be achieved by making the face length a multiple of the lateral reach distance of the drill rig. The lateral reach of the selected drill rig is 7.453 m and the vertical reach is 4.636 m above the footwall. The face length will be 6.0 m for optimal drill rig application within reasonable tolerances.

Dilution

Dilution is a detrimental factor that can make any mining operation an unprofitable venture. Cost and revenue in any operation is determined per unit produced, and South African mining operations are costed in rand per ton. When the dilution increases the mineral content per ton mined is reduced. Revenue is generated per fine ounce of mineral, and the result being a reduction in revenue created per ton that can reach a point where the mining costs and revenue created per ton are the same.

Dilution is a complicated issue and is a function of the orebody's dimensions and the machine operational dimensions; dip, and stoping width. The dip of the orebody forces dilution to be designed into the layout if the dip is greater than the dip the selection of machines can handle efficiently. Flattening the footwall to the desired gradient does this. The minimum machine operating heights determines the minimum stoping width.

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Cost implications

When dilution increases the mineral content per ton of ore declines. This implies that less revenue will be generated per ton mined, and lower profits. At a 1.0-g/t reduction in grade the revenue generated reduces with R215.00/ton mined. Dilution is calculated as a percentage of the *in situ* grade and not as a reduction in grade per ton. Each percentage point of dilution induces a R10/ton reduction in revenue. These figures were calculated at a rand/dollar exchange rate of R11/\$1, a platinum price of \$450/oz, and an in-grade of 4.61 g/t.

Productivity implications

A LHD operates at maximum productivity and efficiency at 0° grade, if considering a haul-return cycle that follows the same route. The productivity is a function of the machine capacities and capabilities, hauling distances, and the operational gradient. Calculations of this nature can only be done if all of the above-mentioned constants are known, i.e. productivity is very case specific and will differ from situation to situation.

Analysis

Designing layouts

When designing a mining layout it is necessary to consider the mining method which is going to be applied and decide what types of excavations are needed to serve the layout in order for it to function effectively and efficiently. In this case the method is bord-and-pillar mining which originates from the coalmines.

Bord-and-pillar mining comprises excavating boards and leaving a grid of pillars at predetermined intervals for stability purposes. These roadways are cleaned with LHDs that transfer the broken ore onto a conveyor belt system, which transports it to the surface rock handling facilities. The layout consists of primary on-reef development systems used to obtain access to the orebody and for travelling and conveyance.

Any bord-and-pillar layout for Vlakpoort will consist of a double barrel decline shaft system from surface that will split into four declines at a depth of ±50 m below surface. The reason for the initial double barrel system will be to establish two accesses to the workings and to create through ventilation. The decline system will consist of the following:

- ▶ Nos 1 and 4 Declines used as ledging panels as preparation for stoping
- ▶ No. 2 Decline as the main belt decline in which the ore is conveyed to surface
- ▶ No. 3 Decline as a travelling-way for machines travelling between surface and underground.

These excavations will be linked up by ventilation holings. The decline system will be developed at an apparent dip angle. The stoping panels will consist of strike drives with ledges and strike belt drives. These will be developed at apparent dip angles above strike.

Description of Layout 1

Layout 1 will consist of 2 decline footwall shafts developed from surface to intersect the UG2 reef horizon at a depth of 50 m. Upon the reef intersection the two declines will split into four on-reef declines developed at an apparent dip of 9°,

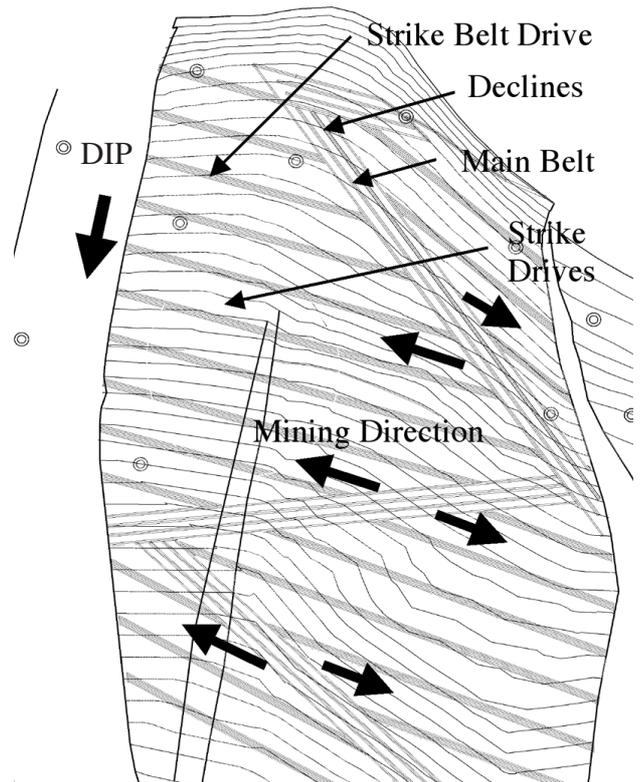


Figure 4—Macro view of Layout 1

zigzagging downdip. Nos. 1 and 4 declines are established as ledging panels, No. 2 is a belt decline and No. 3 is a travelling-way. The declines are interconnected with ventilation holings every 30 m and the lateral spacing is 20 m.

The next phase will be to stope, establishing the bord-and-pillar layout. Strike drives with ledges are developed at an apparent dip of 5° up dip. Every five strike drives have a strike belt drive also developed at an apparent dip of 5° up dip. These strike drive and ledges will have an average length of 360 m.

Layout 1 incorporates the following features:

- ▶ LHDs clean the strike drives and ledges
- ▶ LHDs tip on a strike fishbone conveyor system.
- ▶ Strike conveyors transfer the broken rock onto the main conveyor in the belt decline
- ▶ Main conveyor transports the broken rock to surface

This process can be seen in Figure 4.

Description of Layout 2

Layout 2 will consist of two decline footwall shafts developed from surface to intersect the UG2 reef horizon at a depth of 50 m. Upon the reef intersection the two declines will split into four on-reef declines developed at an apparent dip of 9°, zigzagging downdip. Nos 1 and 4 declines are established as ledging panels, No. 2 is a belt decline and No. 3 is a travelling-way. The declines are interconnected with ventilation holings every 30 m and the lateral spacing is 20 m. This part of Layout 2 is the same as for Layout 1.

The next phase will be to establish the bord-and-pillar layout. Strike drives with ledges are developed at an apparent

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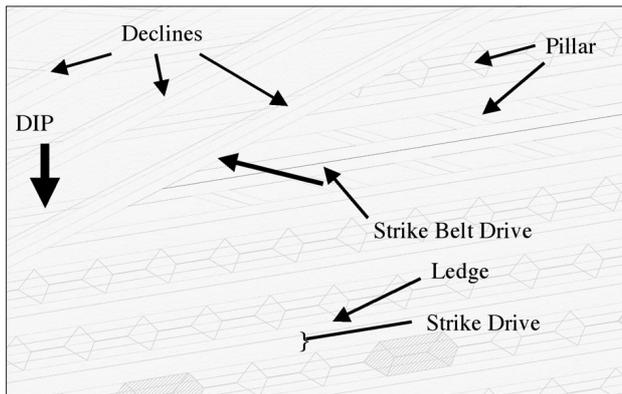


Figure 5—Micro view of Layout 1

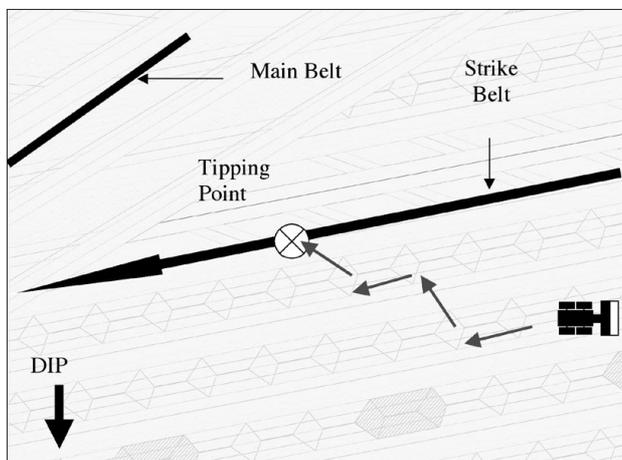


Figure 6—Typical LHD tramming route for Layout 1

dip of 5° up dip. This layout does not have the strike belt drives incorporated into it. The strike drives and ledges will have an average length of 150 m.

Layout 2 incorporates the following features:

- ▶ LHDs clean the strike drives and ledges
- ▶ LHDs tram the broken ore to the decline system
- ▶ LHDs tip on short transfer conveyor systems
- ▶ Transfer conveyors transfer ore onto the main conveyor
- ▶ Main conveyor transports the broken rock to surface.

This process can be seen in Figure 7.

Excavation sizes

The size of each excavation needed depends upon the function of the excavation determined by the interface of the machines that are going to operate in it and the excavation itself. Functional dimensions of machines are directly linked to dilution and additional costs when these functional dimensions exceed the dimensions of the orebody. These excavation designs are based on the 16 West design methodology.

Alternative design

The 16 West project's stoping excavations look like a good proposition, but requires a complicated mining method that

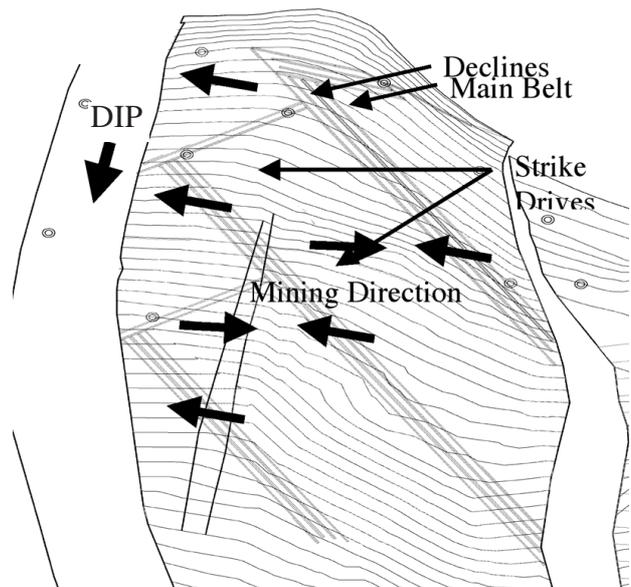


Figure 7—Macro view of Layout 2

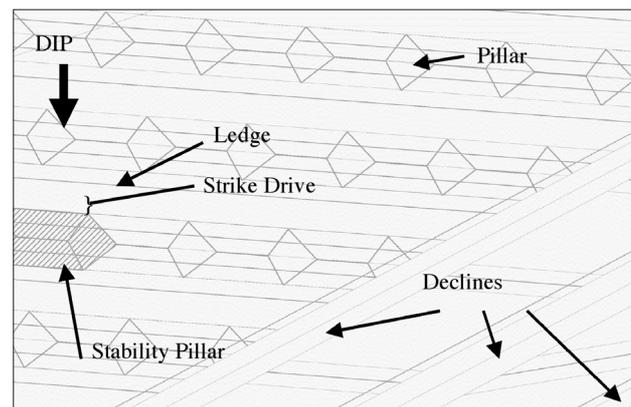


Figure 8—Micro View of Layout 2

has not been proven yet. An alternative design needs to be made to evaluate the 16 West design against it. It is also considered wise to have a backup plan to minimize the risk of failure. The decline system and the strike belt drives will always have the same dimensions as proposed for 16 West when the current selection of machines is used. These excavations are being developed and it seems that this part of the design has been proven possible to excavate and to be functional.

Pillar dimensions and rock mechanics

The proposed bord-and-pillar layouts were designed to have kite-shaped stability pillars. The sharp points of these pillars will scale away over time leaving a more rounded shape pillar. A kite-shaped pillar thus has a low effective areal coverage; i.e. the whole area of the pillar does not effectively carry the load of the overburden, but only a fraction of the area. Thus smaller square shaped pillars could be left, which would have equivalent strength to larger kite-shaped pillars,

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and increase the extraction ratio. There must thus be good reasons to leave larger kite-shaped pillars if smaller square-shaped pillars could be left which have the same strength and increase the extraction ratio.

The main reason is attributed to the drill rig boom dimensions, manoeuvrability, reach and hole length capabilities of the drill rig. The pillar sides on the face side were designed to be the same length as the length of a drill hole to optimize the drill rig efficiency by minimizing the ratio of holes drilled to the total distance drilled. This means that the boom has to move less frequently and the drill rig can be better utilized in the working time available. The drill cut for a pillar is illustrated in Figure 10.

Firstly, note that the face is drilled and cleaned in one operational procedure and the ledge in another procedure. Secondly, the pillar drill holes are at an angle to the siding, and this also gives the benefit of cast blasting this rock off the ledge into the strike drive, which will make the cleaning operations less difficult and more efficient. Thirdly, the area on strike between the pillars needs to be drilled and blasted from both the updip and downdip sides.

The pillars are 12 m and 14 m centre-to-centre on strike and dip respectively. The pillar dimensions and angles are illustrated in Figure 11. The sides of the pillar with a length of 5.2 metres are equal to the maximum length the selected drill rig is capable of drilling to maximize machine efficiency by optimal layout design as previously mentioned.

Amandelbult's Rock Mechanics Department, Snowden Mining Consultants and Rock Mechanics Technology have evaluated this bord-and-pillar mining layout. It was found that the pillars have an equivalent width of 6 metres and a width-to-height ratio of 3.64. The current pillar design gives the mining layout an extraction ratio of 88 %. As the reserves of these projects are relatively shallow, the pillar sizes are adequate for mining depths in the scope of this project.

Due to the weak cohesion on the chromitite layers in the hangingwall of the UG2 and the shallowness of the mining excavations, implying a k -ratio greater than one, large slabs are expected to fall out between the pillars. This is to be controlled by systematic roofbolt and resin support, which is to be installed by a low profile roofbolter. This machine is currently being used at 16 West, and is the only one of its kind in the world.

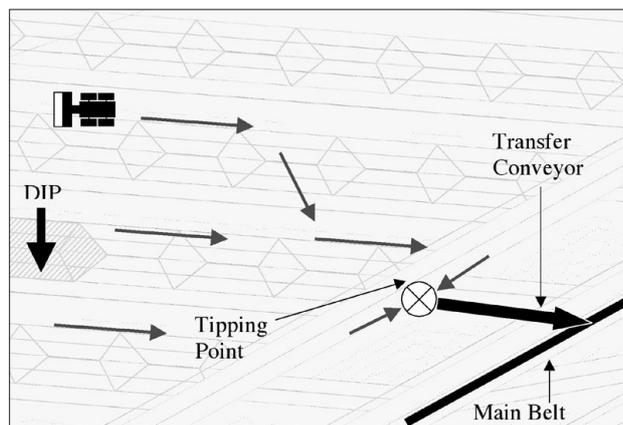


Figure 9—Typical LHD tramming route for Layout 2

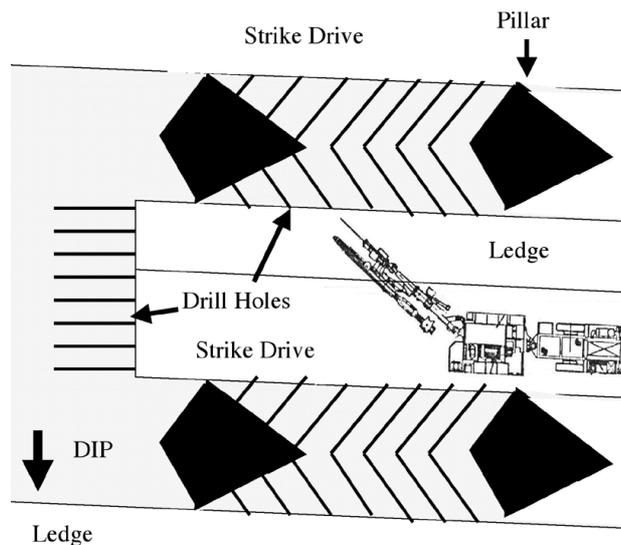


Figure 10—An illustration of how the pillars are cut

There are no major stability problems experienced at 16 West, but due to Vlakpoort and Moddergat being in a more geotechnically disturbed area it is not known if this will be the case here.

Evaluation of layouts

In order to choose the layout with the most advantages it is necessary to evaluate each layout according to specific criteria.

Dilution

The proposed mining area has a grade of 4.61 g/t. To obtain access and working space for machines and make sure that no ore is left *in situ*, some dilution must be tolerated. Dilution can be seen as an additional cost and it can seldom be ignored or regarded as insignificant. Since Layouts 1 and 2 have different mining approaches the development layouts differ. The development has more dilution than the stopping part of the layouts.

The conventional mining has less dilution, but this figure, as in Table V, does not account for the development waste tons, only for stopping. The bord-and-pillar has no off-reef development and is thus better if considered in a global perspective.

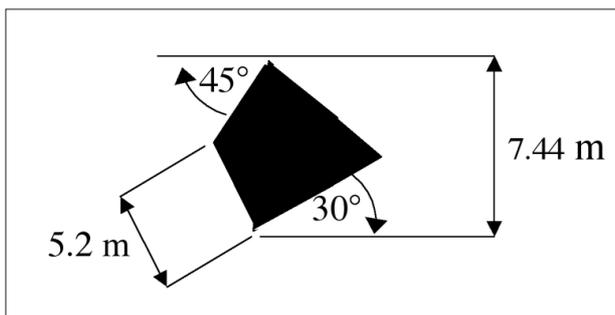


Figure 11—Dimensions and angles describing a pillar

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Figure 12—The low profile roofbolter used at 16 West

Productivity

The interaction between the layout and the machines determines the productivity through factors such as tramming distances, tramming gradients, etc. The major difference between Layout 1 and 2 is the absence in strike conveyors in Layout 2. The LHDs will have longer tramming distances and the success of this layout will be partly determined by the productivity of these machines. The longer the tramming distance the lower the machine's productivity will be at a constant roadway gradient and rolling resistance.

Every mining project is planned at a certain production rate known as the call. In order to reach this call a number of LHDs is needed. The number of LHDs needed depend on the productivity per LHD (as seen in Figure 15).

Each strike drive will yield approximately 290 tons per blast. It is important to know beyond which tramming distance the face will not be cleaned by a single machine per shift. In this case if the face is to be cleaned within one shift, rehandling must be done. Rehandling comprises of one LHD loading the rock tramming it to a temporary storage place where it will be loaded and trammed to the main conveyors.

Table V

Dilution and grade of different layouts.

Layout	Dilution (%)	Grade (g/t)
1	13.95	4.00
2	15.19	3.94
Conventional	7.46	4.27

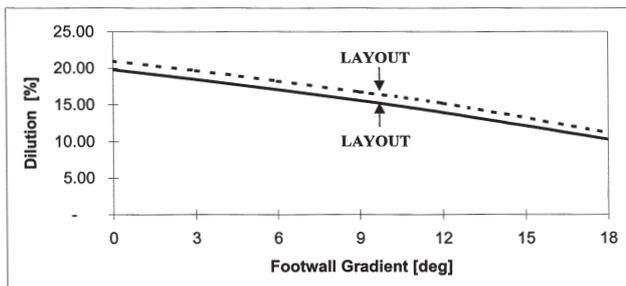


Figure 13—Dilution versus footwall gradient

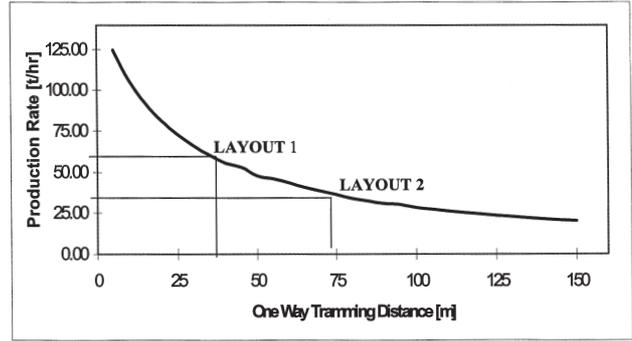


Figure 14—Production rate (t/hr) versus tramming distance at 12° dip

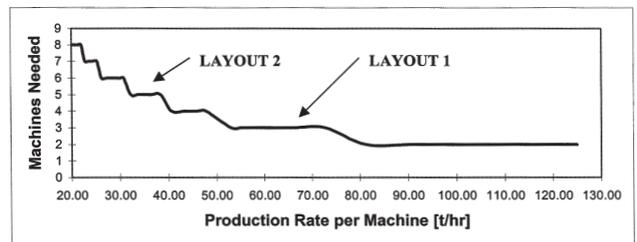


Figure 15—Number of LHDs needed versus production rate per machine to obtain a total production rate of 30,000 t/month

In Figure 14 it can be seen that approximately 75 m is the maximum tramming distance to clean one face with a LHD, beyond this distance rehandling is necessary; this corresponds to the verbal maximum tramming distances quoted during the underground visits.

Cost implications

Layouts 1 and 2 will have different operational costs due to the different approaches that are followed. The difference in operational costs will largely be in the conveyance of broken rock up to the main conveyor system.

Layout 1 consists of LHDs which tip on a strike conveyor system that transfers the ore from the drives to the main conveyor system. Layout 2 consists of LHDs which tip the

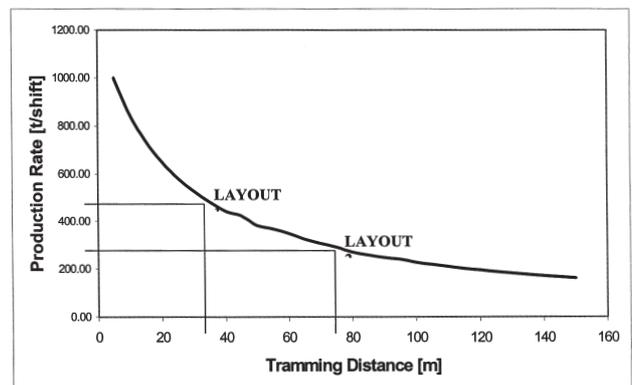


Figure 16—Production rate (t/shift) versus tramming distance at 12° dip

Bord-and-pillar mining in inclined orebodies

ore on the main conveyor system. The cost difference will mainly be in the maintenance and running costs of the different machinery.

Choosing a bord-and-pillar layout

Layout 1: The strike conveyor system makes this layout quite rigid due to the physical constraints of conveyors, e.g. strike changes that can change the mining approach from updip to downdip. The production rate would be flexible due to ease of rock conveyance. The moving of conveyor systems can cause delays.

Layout 2: This layout is very flexible when considering geological variances such as strike changes. A major constraint can be the production rate, due to the criticality of longer tramming distances with LHDs.

Evaluating layouts in order to choose the best option for a certain application can be tedious. In this case an objective mathematical model is used. Each aspect is weighed according to importance and the layout with the highest weighted average is considered the best option.

In theory Layout 1 will yield less dilution than Layout 2, but in practice Layout 1 will yield worse dilution in the adverse geological conditions experienced in Vlakpoort and Moddergat.

Layout 2 is chosen for the mining layout for Vlakpoort and Moddergat. This is due to the greater degree of flexibility that is obtained by the absence of the strike conveyor system in this area with its adverse geology. This also reduces the risk of the project failing due to lack of flexibility.

Cost implication	Layout 1	Layout 2
Total on mine cost (R/t)	141.95	152.23
Net profit (R/t)	519.82	500.69
Machinery capital expenditure per 30,000 tons production capacity (R)	13,648,615	12,742,317

Criteria	Weighted importance	Performance	Rating
Dilution	30%	60%	18.0%
Productivity	20%	70%	14.0%
Mining Costs	10%	80%	8.0%
Flexibility	40%	50%	20.0%
			60.0%

Criteria	Weighted importance	Performance	Rating
Dilution	30%	80%	24.0%
Productivity	20%	45%	9.0%
Mining Costs	10%	75%	7.5%
Flexibility	40%	70%	28.0%
			68.5%

Table IX

Comparison between Layout 2 and conventional mining

Criteria	Layout 2	Conventional
NPV @ 12%	R795.01 Million	R759.80 Million
IRR	154%	136%
Payback period	11 Months	2.17 Years
Equivalent annual cost	R36.48 Million/Year	R5.81 Million/Year

Comparing Layout 2 to a conventional mining layout for Vlakpoort and Moddergat

The comparison was done to quantify the new mining layout (bord-and-pillar) against a proven layout (conventional) in order to see which of the two is the suitable and feasible.

Layout 2 has a greater NVP and IRR of R35.21 million and 18% respectively, more than the conventional layout. The payback period for the conventional mining is 1.25 years longer than for Layout 2, which means the risk period is longer for conventional mining. This indicates that the risk of Layout 2 failing is less than that for conventional mining.

However, it must be kept in mind that this comparison does not take any technical difficulties into consideration. The Vlakpoort and Moddergat area has adverse geological conditions, and a bord-and-pillar operation has greater technical risk of failing if the conditions experienced become severely variable. A conventional layout is thus more flexible in adverse geological conditions.

The decision to switch to mechanized mining methods is driven by the difficulties currently experienced and expected in future related to the growing labour problems in South Africa, secondly by the increasing labour costs and difficulties experienced by large-scale industrial action, and last but not least, mechanized mining is safer and with the technological advancements in development will become more so in future.

Conclusions

Bord-and-pillar mining in steep dipping narrow tabular orebodies is still new and committed research and development is needed to ensure that this mining method will be effective.

The geological certainty of the proposed area is quite low due to it being based on three boreholes, a series of trenches and geological models from adjacent mining areas. Exploration drilling needs to be done on Vlakpoort and Moddergat before this project can be seriously considered.

The UG2 reef in the proposed mining area has quite similar geological properties as the rest of Amandelbult. The 16 West project at Amandelbult is a success and is set in a similar geological setting. The geology of Vlakpoort and Moddergat is suitable for bord-and-pillar mining according to the information available at this stage.

The visits conducted at RPM Amandelbult- and Union Section indicated machine efficiencies in working conditions encountered there. At Union Section the Piggy Project failed due to the attempt of using a true dip, true strike arrangement. Xstrata Thronecliff, a chrome mining operation in the

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Lydenburg area, has a 12° footwall gradient and is a successful operation. The current selection of trackless machines can operate efficiently at 12° dips. The Vlakpoort/Moddergat project will also be successful as its footwall gradient is carried at 12°.

Layouts 1 and 2 aim to reduce the footwall gradient that the LHDs operate in to 12° or less by flattening the footwall and working in apparent dip directions. The disadvantage of flattening the footwall and working on apparent dip is dilution, which must be minimized.

Layouts 1 and 2 have similar economical implications as their on mine working cost differs only by R10.28/ton, net profit differs R19.13/ton and a R906,298 difference in capital investment. Layout 2 is chosen as the better option to mine the proposed area due to its greater flexibility in adverse geological conditions and its superior practical applicability.

Layout 2 has a larger NVP, lower IRR, shorter payback period but a higher equivalent annual cost than a conventional mining layout for Vlakpoort and Moddergat. Layout 2 is thus, according to theory, financially a lower risk investment than a conventional layout would be. It must be remembered that a

conventional mining layout has a lower risk of operational failure in adverse geological conditions, as expected in Vlakpoort and Moddergat, due to a superior degree of flexibility over a bord-and-pillar mining layout, but is financially inferior. However mechanization is a partial solution for the safety, and labour problems experienced in the mining industry.

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South Deep introduces an innovative behavioural safety process*

South Deep, a Placer Dome managed gold mine, has introduced a five-year behavioural safety process to eliminate at-risk behaviour by creating risk competence within the entire workforce, instilling visible leadership as a value, recognizing and rewarding safe behaviour and providing a more enabled environment by removing system barriers and negative consequences to safe behaviour. This innovative programme and a first in deep-level mining, is a move away from previous safety methods that have had little impact on reducing accidents.

Believing that safety is non-negotiable and a key value on its mines, Placer Dome is committed to implementing this comprehensive, all encompassing process to achieve zero fatalities and accidents. By creating an enabled safety climate that will develop sustainable attitudes, a safety culture will start to emerge. The programme will position it as a top-of-mind activity. As 75 to 80 per cent of all accidents and fatalities are associated with at-risk behaviour, changing how people think and react to safety is imperative.

An entire day (Saturday 1 March, 2003) was set aside recently to launch the concept to the industry, key stakeholders, the media as well as the 5000 mineworkers and staff. 2000 contractors will be integrated in time to come.

Australian-based company SAFEmap has been appointed to drive the first phase of the programme. Using four integrative training processes simultaneously, a 'top-down bottom-up' approach will be adopted spanning all employees from supervisors, operational crews to the workforce. Throughout the process, progress will be managed, monitored, and performance will be assessed to see that training is being properly implemented and on track

This is the first time that this method has been used in deep-level mining.

'Traditionally the mining industry has measured lag indicators such as fatality and lost time injury rates. We will be focusing on the positive aspects that will be measured by lead and preventive indicators, and by removing system barriers, a more enabled environment will be established', said Ralph Rossouw, Risk Manager of South Deep.

On-the-spot cash incentive, gifts, tokens and monthly draws using a scratch card (Scratchy) will be awarded to those who are seen to be practicing proactive and continuous safety excellence. Supervisors will be able to use this as a means of acknowledging and recognizing safe behaviour.

'At present our percentage safety runs at 25%. Within the first five years we hope to raise that to 78/90% and within two-and-a-half years our safe behaviour target should reach 92/94%. One of the key processes is not just addressing the person, but creating an environment, making it easier for people to comply with safety standards. On the one hand we are looking at behaviour, attitude, culture and perceptions, but our key objective is to remove barriers and negative consequences to safe behaviour through problem solving, and at the same time change perceptions to positive at-risk behaviour', he said. ♦

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