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Narrow reef mechanized mining layout at Anglo American Platinum

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Anglo American Platinum (AAP) is constantly striving to improve safety and productivity in its operations. There are many different initiatives, one of which is mechanization and, in particular, mining with ultra-low profile (ULP) equipment in pre-developed stoping areas.

Initial analysis and modelling work were conducted to understand and optimize the development of the ULP equipment. Currently proof–of-concept and production trials are being conducted to prove this technology in the stopes.

In-depth analysis and workshops held with operations resulted in a mining and logistic layout that created the following opportunities:

1. Safe operations through the reduction of personnel in the high-risk zone of the stopes
2. Separation of machines and personnel through the use of remotely operated machines
3. Creation of focused mining on primary development from the production stoping, thus having dedicated teams on development and stoping
4. Development of primary development ahead of the stoping activity. This enables:
   a. Better understanding of the geology in advance
   b. Ability to install tipping points ahead of stoping, creating 'immediate stoping reserves', thereby enhancing flexibility and reducing production risk.
   c. Improved productivity by having adequate faces available and reduction in re-development to establish faces, which is achieved through the adoption of a scattered breast mining system.
5. Low capital requirement due to recovering revenue from on-reef development
6. Layout allows flexibility between stope sections, thereby enabling better resource sharing and scheduling
7. Optimizing of the long-term ratio of machine makeup of the fleet in relation to the production outputs
8. Creation of an agile mining layout, allowing rapid response to market pressures
9. Low stoping widths, resulting in higher head feed grades
10. High-productivity stopes, resulting in high square metres mined per employee

The extensive modelling exercises demonstrated that improved safety and value can be achieved. The layout and technology discussed in this paper are currently being implemented in test sections at AAP.

Introduction

The objective of this paper is to provide an overview of the narrow reef mining layout as well as the design principles that are being adopted within the Anglo American Platinum (AAP) group of mines.

As experience evolves and suppliers introduce new designs, some practices described in this paper which are not considered ideal should invariably be improved upon.

Purpose of the mine design

The mine design provides the parameters to be used in the layout design of a new logistical mining method. The design criteria will be as practical as possible, and will endeavour to conform and improve upon existing standards and best mining practices. The stoping method that will be used is an on-reef scattered breast mining system, utilizing (ULP) mining equipment that has been designed to operate in stoping widths of 90– 120 cm.

This paper serves as a guideline to the (ULP) mining method; however, a 'fit-for-purpose' study must be conducted for each mine and circumstance prior to implementing this method.

Objectives of the new mine design

- Enhance safety through the reduction of personnel in the 'high-risk zone' of stopes
- Separate machines and personnel through the use of remotely operated machines
- Offset a majority of the capital and development costs through revenue generated by on-reef development
- Establish focused mining by having dedicated teams that focus on primary development and stoping. The primary development team is responsible for ensuring that all the necessary services and infrastructure are in place before stoping commences in the section. The

team is responsible for developing both the strike belt and transport drives as well as the raiselines

- Develop primary development ahead of the stoping activity. This enables:
  - o Understanding of the geology and subsequent implementation of the correct technology ('fit-for-purpose') required to mine that area based upon this geological knowledge
  - o Ability to install tipping points ahead of stoping, thereby creating 'immediate stoping reserves', which in turn improves flexibility and reduces production risk
  - o Improve productivity by having adequate faces available and reducing re-development to establish faces
  - o Quicker return on investment due to recovering revenue from 'on-reef development'
- The layout allows flexibility between stope sections, enabling better resource sharing'
- Optimize the long-term ratio of machine makeup of the fleet in relation to the production outputs
- Create an agile mining layout, allowing rapid response to market pressures.

Mining method

The mining method is based on the concept that on-reef development takes place on the strike, prior to stoping, thereby ensuring that all the necessary services and infrastructure are in place prior to stoping. This results in an improvement in the overall efficiency of the section and will assist in providing a better understanding of the geology, which in turn will help to ensure better planning for the section before stoping commences. The stoping method that will be used is an on-reef scattered breast mining system, which will utilize ULP equipment that has been designed to operate in stoping widths of 90–120cm. The method that is described in this document is based on a reef dipping up to 10°, although initial testing suggests angles up to 16° can be explored.

The mining method described is suitable for both UG2 and Merensky orebodies within the abovementioned range. As this is an on-reef mining method, the more uniform the ground conditions and the more limited the reef rolling conditions the better. On steeper dipping reefs, apparent dip tramming roadways are required.

AAP's existing operations currently operate in reef dip angles ranging between zero and 30° with various ranges in depth. Where applicable, the on-reef predevelopment layout outlined in Figure 1 provides an opportunity to choose the stoping technology that is most suited to the specific operations requirements. For the purpose of this paper, we will focus on a scattered breast mining method utilizing ULP equipment. However, it is important to emphasize that the mining method can change based on the operation's stoping width, mine depth, and angle of reef dip, resulting in condition-based mine design criteria (Figure 2).

Table I gives a high-level summary of the various mechanized mining technologies that can be used for stoping.

Narrow reef mining layout description

The narrow reef mine layout is based on a predeveloped seven-panel strike section that is mined from either side of each raiseline (scattered breast mining) and is capable of producing >4000 m^2 per strike.

The layout consists of three main elements:

- On-reef predevelopment

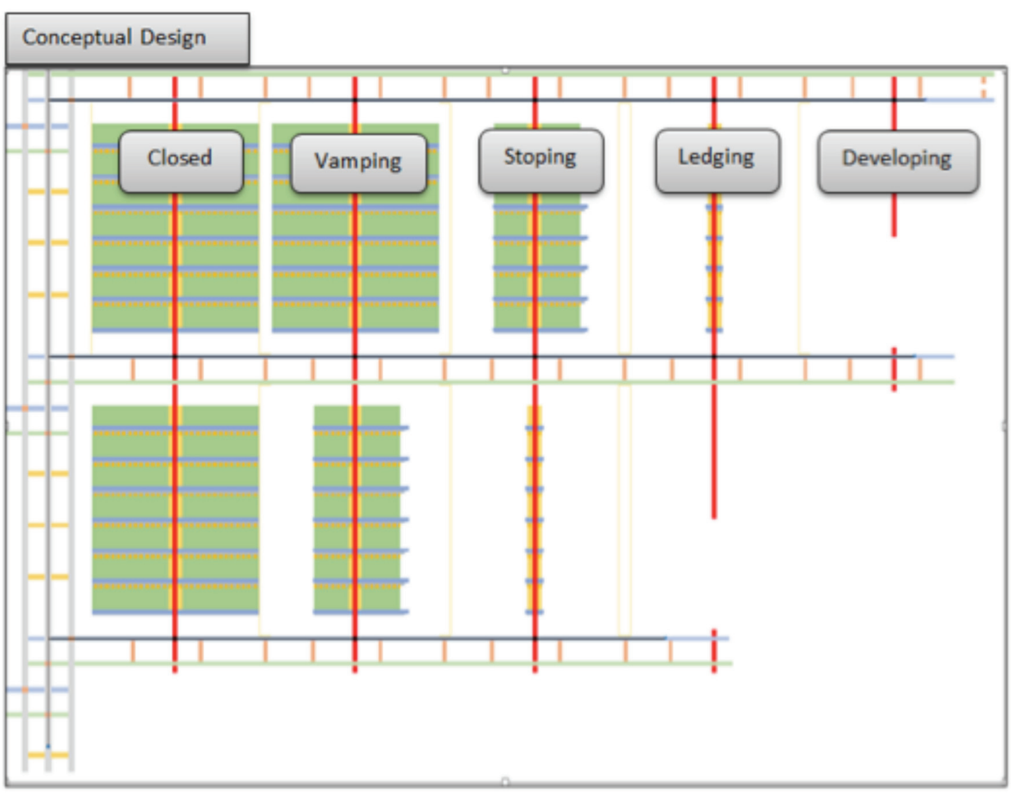

Figure 1. Conceptual design of the mining method

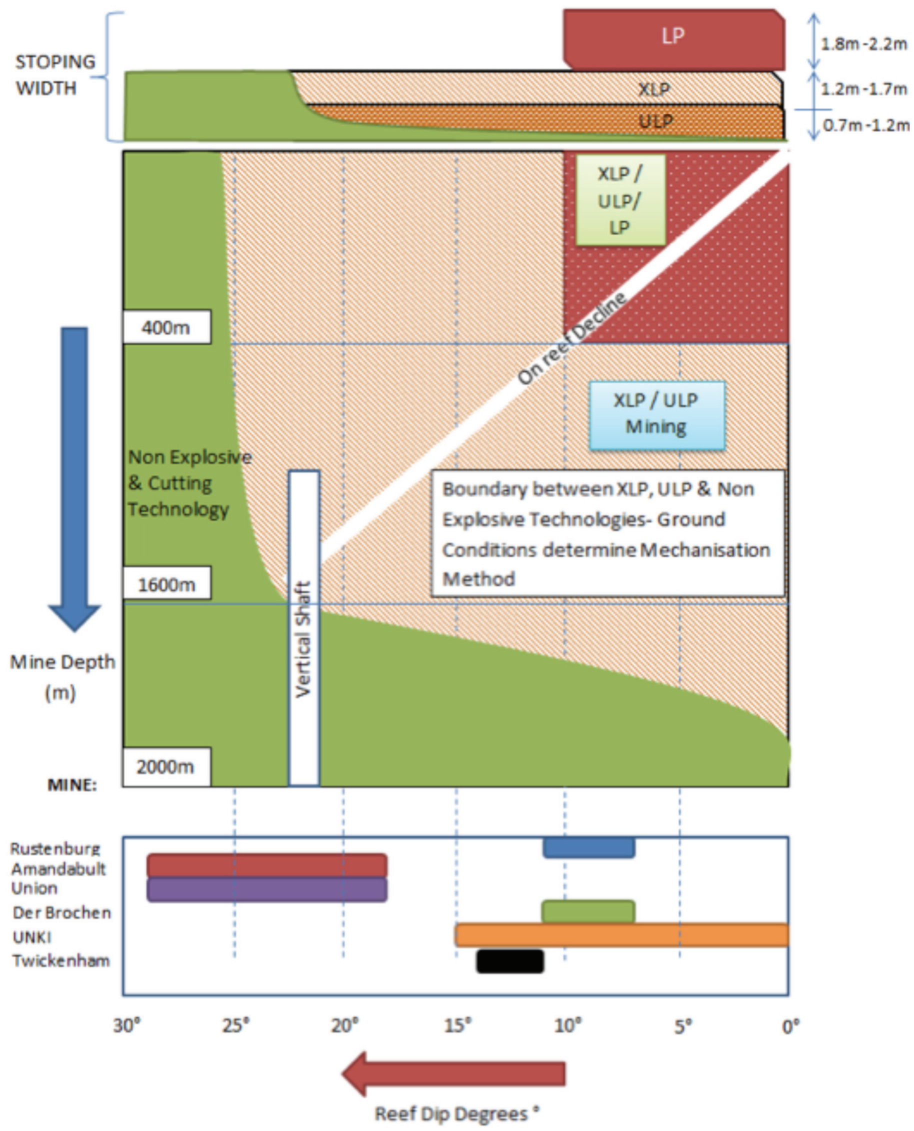

Figure 2. Application of the on-reef predevelopment layout at different depths utilizing different stoping methods

Table I
Summary of stoping methods

	LP	XLP	ULP
Depth+	0 – 400 m	350 – 1800 m	350 – 1800 m
Stoping width	1.8 – 2 m	1.3 – 1.7 m	0.9 – 1.2 m
Mining method	Bord and pillar	Breast mining	Breast mining
Dip	±10°	0° - 22°	0° - 22°
Production	2 100– 3 000 m^2	2 100– 3 000m^2	2 000– 000m^2
Orebody	Consistent ore deposits without major faults	Consistent orebody, high extraction ratio	Fairly consistent orebody, high extraction ratio
Advantages	Low level operating complexity	Less dilution when compared to LP Low wastage introduced into plant	High-grade ore Able to deal with orebody complexities
Disadvantages	High volume tonnages Low grade High operating cost Complex infrastructure	Robust equipment Labour-intensive Highly skilled workforce Complex infrastructure	Advanced technology Highly skilled workforce Technology in POC phase

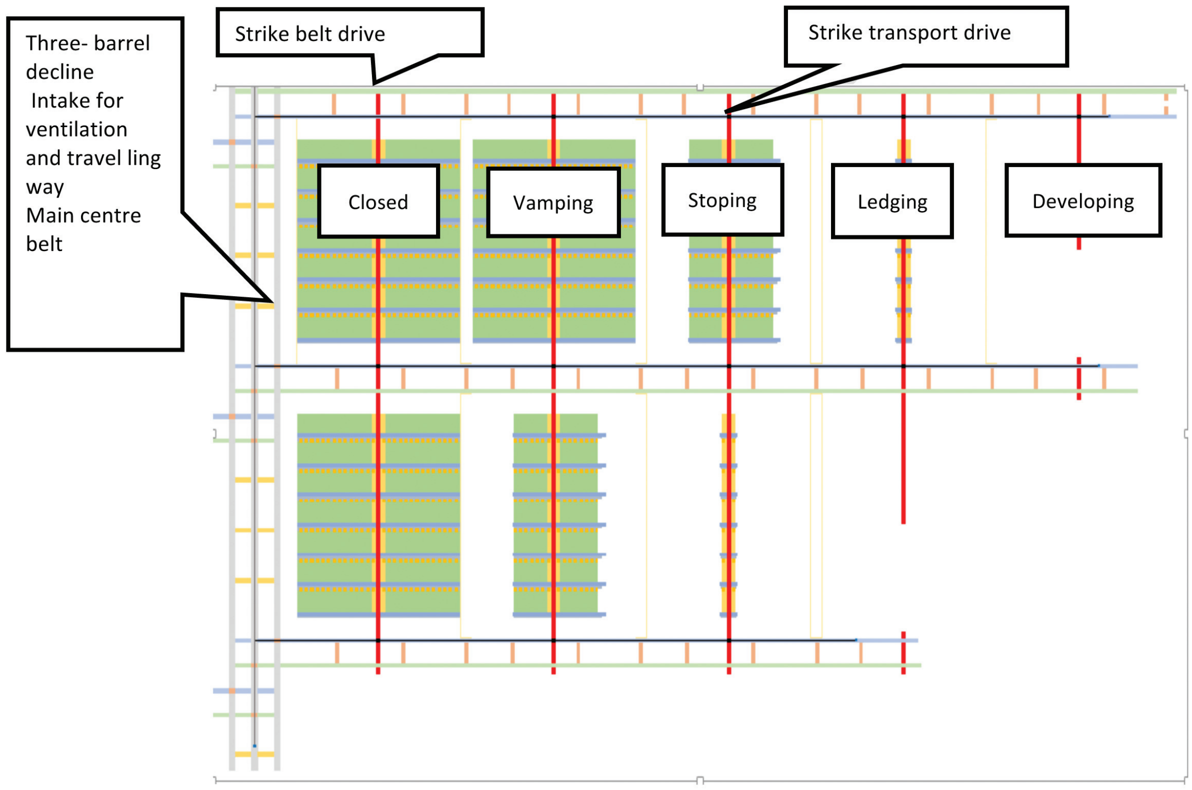

Figure 3. On-reef mechanized layout

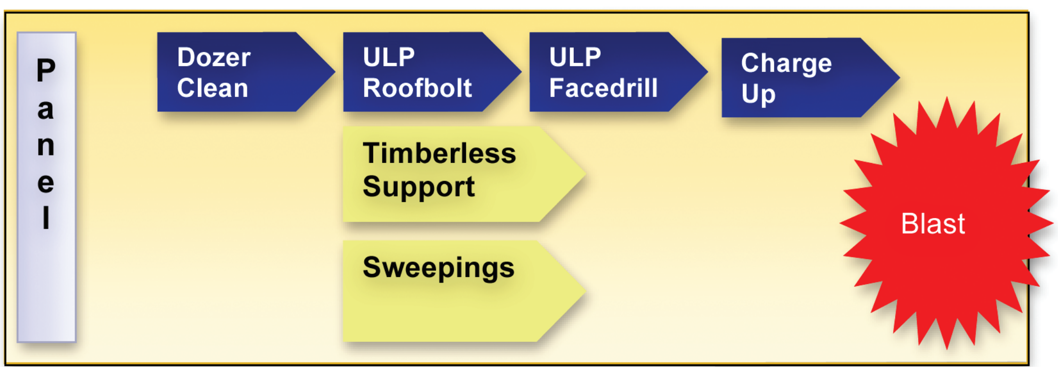

Figure 4. ULP mining cycle

- Ledging
- Stoping (scattered breast mining).

The on-reef pre-development is separate from the stoping activity, which forms an integral part of the stoping layout. The mining layout is designed around the principle of having four active raiselines (development, ledging, stoping, sweeping and vamping) as illustrated in Figure 3. To assist with the rapid development a mobile crushing unit has been developed.

Introduction to ULP mechanized mining equipment

The mine design makes extensive use of mechanized mining equipment for both the on-reef predevelopment as well as for the scattered breast mining stoping method. This section provides a brief introduction to the ULP mining cycle and ULP equipment.

ULP mining cycle

An overview of the ULP mining cycle is given in Figure 4. It is important to note that the ULP equipment will be used to mine the panels and create the ventilation holings, whereas the low profile (LP) mechanized equipment will be required to develop the advance strike drives (ASDs) and sidings.

ULP equipment

In 2003 the first dozer was trialled at AAP. Following this trial, the need to develop a mechanized suite of equipment that would be able to operate in low stoping widths (<1.2 m) was identified. In 2007 a suitable original equipment manufacturer (OEM) was identified and in 2011 an agreement was signed by AAP to develop the first ULP fleet.

The ULP technology is currently capable of operating in stoping widths ranging between 0.9–1.2 m at depths ranging from 350-1800 m at dip angles of up to 22°. The equipment has been designed to operate in fairly consistent orebodies. Figure 5 shows the ULP fleet

Key milestones in the progression of the ULP technology are:

- Full understanding of mechanization principles
- Modelling and optimization (mining cycle) of extra-low profile (XLP) and low profile (LP) mining methods
- Development of a new on-reef mechanized layout (incorporating optimal face length and number of panels).

ULP dozer

The ULP dozer is designed to clean mined material from underground places of work and remove it into the ASD. Figure 6 illustrates the ULP dozer cleaning the panel.

Length – 2300 mm (The dimensions are for the fuel cell dozer)
Width – 1400 mm
Height – 580 mm

Key Performance Indicators (KPI's)

- Dozer required to move 70 t/h, but tests have shown the dozer is capable of moving >150 t/h

ULP roofbolter

The ULP roofbolter is a double-boomed roofbolter that has been designed to operate in stoping widths between 0.9–1.2 m.

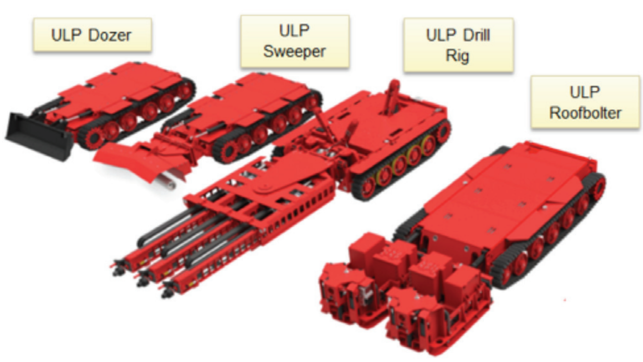

Figure 5. The ULP fleet

The ULP roofbolter (Figure 7) has been designed to perform at a nominal bolting speed of less than eight minutes between collaring one hole and collaring of the following 1.6 m hole. The ULP roofbolter utilizes the SDR (self-drilling roofbolt) technology, which reduces the cycle time per hole to 3.5 minutes. The SDR technology works on the concept of the roofbolt being used to drill and support the hole; this is made possible by injecting a quick-setting resin into the SDR once the hole has been drilled, thereby reducing the amount of time required for the support cycle.

Length – 5679 mm
Width – 2230 mm, including booms
Height – 750 mm

KPIs

- The total cycle time to drill 30 bolts (1.6 m extension drilling) shall not exceed two hours. In order to achieve this, the roofbolter makes use of twin booms as well as rotary drilling
- Two 20 m panels should be drilled in one production shift
- The machine has been designed to operate in stoping widths of 0.9–1.2 m
- Power for the roofbolter movement and positioning is provided by an on-board battery. For production drilling a mobile battery charger/power supply is used. This is to be upgraded to an on-board 550 AC to 300 DC inverter
- Connecting voltage shall be 550 VAC, 3 phase, 50 Hz. Maximum distance from connection to face shall be 80 m
- DC electric motors are utilized as prime movers. The number, size and, positioning of the motors will be determined by the supplier's design
- Radio remote control shall be the standard equipment for control and operation of the machine.

ULP drill rig

The ULP drill rig (Figure 8) is a three-boomed drill rig that has been designed to operate in stoping widths between 0.9–1.2 m.

Length – 8396 mm
Width – 1928 mm
Height – 650 mm

KPIs

- The drill rig has been designed to drill a minimum of

Figure 6. ULP dozer cleaning a panel

Figure 7. ULP roofbolter

Figure 8. ULP drill rig

two panels in a five-hour working shift. Each panel is expected to have 150 drilled holes, each 2 m long – these consist of three lines of face holes plus 14 pillar holes. The approximate minimum speed of drilling shall be 1 m/min
- Power for the drill rig movement and positioning is provided by an on-board electric battery. Depending on the deployed drilling technology and if technically possible, the same battery should be used as a source of energy for drilling. If this is not possible, an electro-hydraulic drilling system shall be deployed. In that case, this system shall be powered by the mine power grid
- If the electric power from the mine power grid is used for powering the drills, the connection voltage shall be 550 VAC, 3-phase, 50 Hz. Maximum distance from connection to face shall be 80 m.

ULP sweeper

The ULP sweeper (Figure 9) is a cleaning tool intended to facilitate sweeping tasks in locations where the ULP dozer would not reach. These sweeping tasks are currently performed manually.

Length – 2300 mm
Width – 1400 mm
Height – 580 mm

Figure 9. ULP sweeper cleaning a panel

KPIs

The mobile sweeper shall clean the following locations:
- The footwall of the stope between the face and the first line of support
- The accumulated remnant broken rock between the support structures of the first line of support
- The corner where the rock face and the footwall meet. The unit is thus intended to sweep 10 m behind the face position.
  The sweeper has been designed to remove remnant rock broken under the following conditions:
- Broken ore volume ratio is 1.75:1
- Rock density is 1.7 t/m^3
- Angle of repose is 55°
- Maximum height of the remnant broken rock to be swept is 100 mm
- The overall height of the sweeping machine does not exceed 0.65 m
- The overall length of the sweeping machine does not exceed 4 m
- The overall width of the assembled sweeping machine should not exceed 1.6 m
- Battery driven.

Mining layout

Main access design

The orebody will be accessed via a barrel decline cluster as illustrated in Figure 10 (for the purposes of this paper a three-barrel decline cluster has been used). The decline consists of a centre main dip conveyor decline and two transport declines, all of which are used for intake ventilation.

The dip of the three-barrel decline will be a maximum of 10º to accommodate trackless mobile equipment (TME). The spacing of the three-barrel decline cluster and regional and protection pillars will be in accordance with rock engineering requirements.

The principle is that one of the transport declines will be a dedicated mine ‘entry transport rout’e and the other a dedicated mine ‘exit transport drive’. The drive under the belts will connect the decline transport system to the strike transport system.

Predevelopment

The purpose of predevelopment is to ensure that all the necessary services and infrastructure are in place prior to

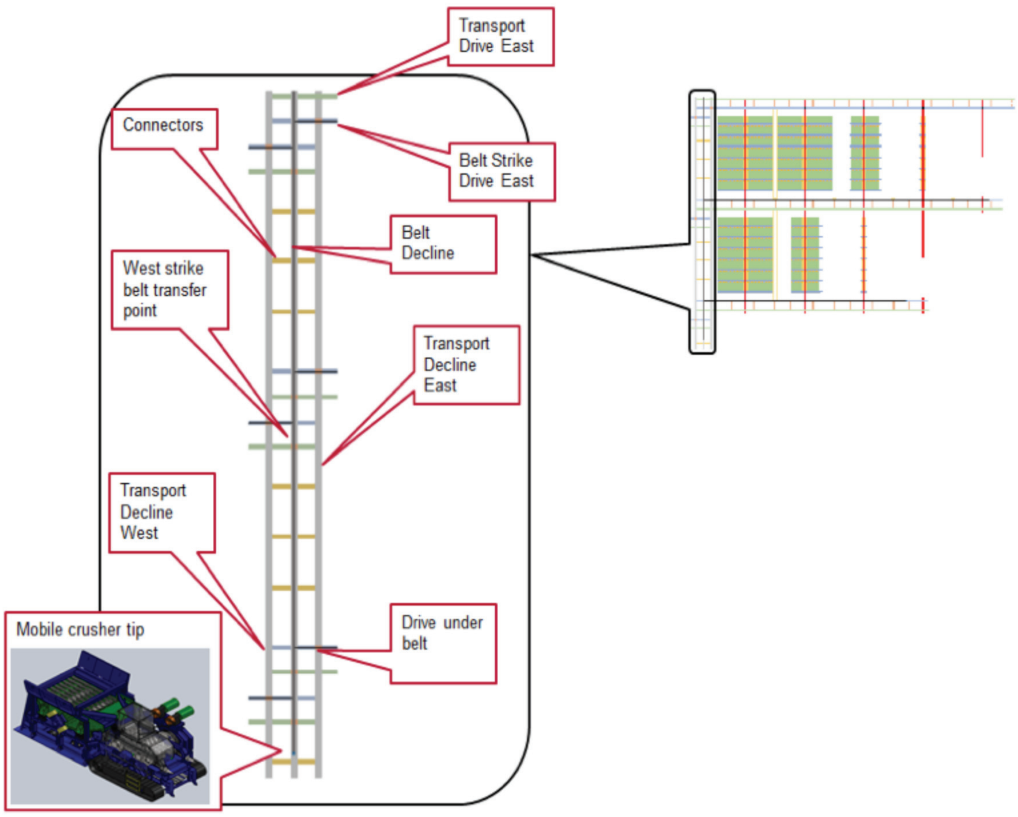

Figure 10. Typical three-barrel decline

ledging or stoping taking place. The predevelopment incorporates two strike drives, a raiseline, as well as pre-installed footwall (FW) tips. The layout has been designed to improve the overall efficiency as well as the logistics within the section. By predeveloping the strike before stoping takes place one is also able to garner a greater understanding of the geology, thereby improving overall.

The predevelopment layout comprises the following design elements:

- Strike belt drives
- Strike transport drives
- Winze and raiselines
- Connectors
- Double-sided footwall tip.

Figure 11 provides an overview of the design.

The strike belt drive and transport drive are developed concurrently at intervals above and below the seven-panel mining area with a footwall tip situated in the strike belt drive on the top and bottom of each raiseline.

The strike belt drive is a designated drive for the belt and mine personnel, while the strike transport drive is a designated drive for machinery. The design makes use of connectors (interconnecting roadways) to facilitate movement between the strike belt drive and strike transport drive during predevelopment. The interconnecting roadways ensure the tram distances during the development of the strike belt, transport drive, and raiseline are kept to a minimum. This is achieved through the introduction of a mobile crushing unit fitted with a sacrificial belt, which is positioned in the strike belt drive.

A summary and brief description of the key design elements is given in . A more detailed description of the footwall tip and mobile crushing unit is given in the section that follows.

Footwall tip

The double-sided footwall tip has been designed to create flexibility between stope sections thereby enabling better 'resource sharing'. This is achieved by placing the tip in the footwall, thus making it accessible from either side of the raise. The tip has been designed to allow mechanized equipment to drive over the deck plates, allowing for quick and easy access into other stope sections. The tip has been designed to accommodate tipping by LHDs from both the updip and downdip sides of the raiseline. In order to reduce the tipping time as well as the need to go into the hangingwall, each LHD is fitted with a pushplate. Figure 12 and Figure 13 illustrate the footwall tip and spoon feeder assemblies.

The spoon feeder has been designed to be applied in all AAP's underground operations. The design of the spoon feeder allows for material from underground workings to be tipped onto the strike belt at a low trajectory angle by a vibrating or oscillating feed. The oscillating action of the spoon feeder controls the amount of ore that is deposited on the belt, ensuring that there will be no lumping and thus improving the lifespan of the belt.

The tip grizzly is designed to allow blasted rock smaller than 300 mm by 300 mm in size to pass through the tip into the spoon feeder (unless otherwise stipulated). The tip is equipped with a mobile pecker, which is able to break the oversized rock into manageable pieces that will fit through the grizzly.

Figure 14 provides a cross section of an installed footwall tip in the strike belt drive.

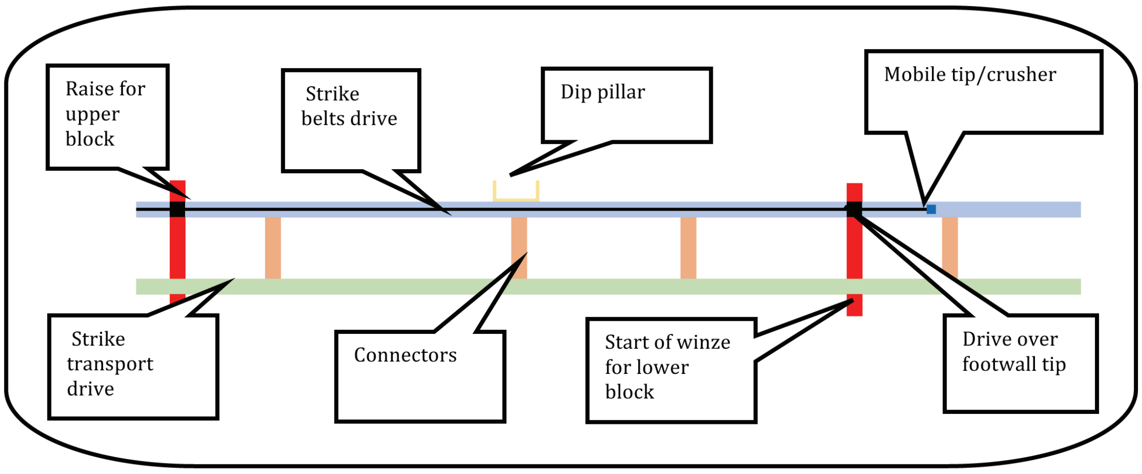

Figure 11. Plan view of predevelopment layout

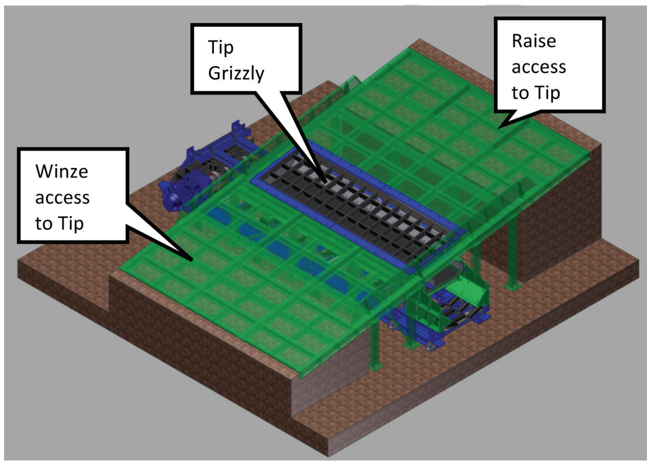

Figure 12. Footwall tip design

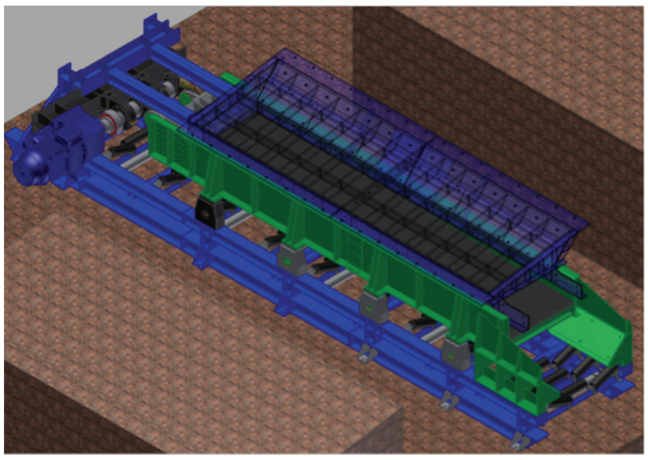

Figure 13. Footwall tip spoon feeder assembly

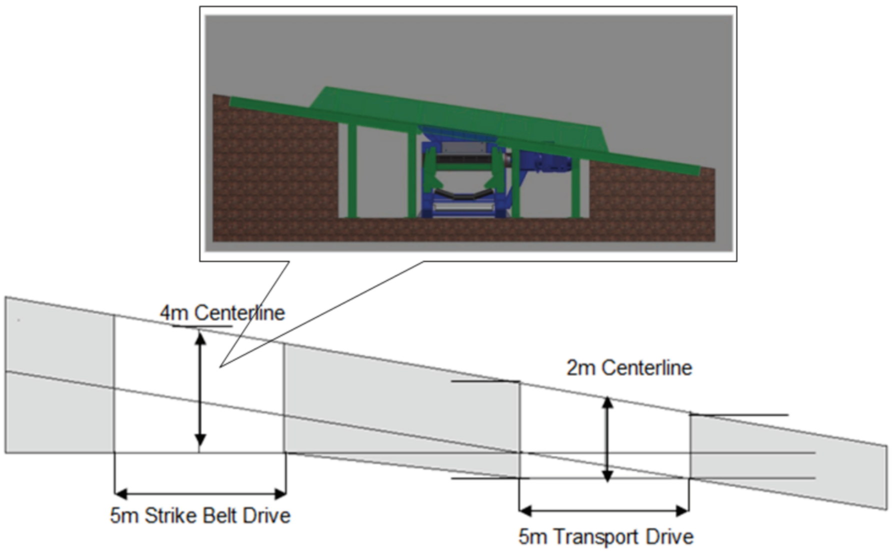

Figure 14. Footwall tip, section view

Table II
Key design elements of the new layout

DESIGN ELEMENT	SAFETY	PRODUCTIVITY
Predeveloped and proposed stoping layout	• Minimized interaction between machinery and personnel • Designated areas for labour, machinery and handling lines • Create safe operations through the reduction of personnel in the high-risk zone of stopes • In-stope remotely operated equipment Minimize travelling, people, and machinery in an excavation due to development of designated drives for travelling and for the belt	Predeveloped layout ensures logistics infrastructure is ahead • Tips are always in place • Separate predevelopment and production tipping points • Max. distance of face to tip not exceeded • Designated crew and fleet for primary development (focused mining) • Better appreciation of geology due to predevelopment being well ahead of stoping • Separate primary and secondary development (in conjunction with stoping). Checkerboarding, increasing productivity and utilization • Specialist development teams • Assists planning (better geological information) • Improved m^2 • Better face availability • Construction crew is part of the development crew **Raiseline** Optimal tramming distance of LHDs resulting in a better utilisation due to multiple tipping points (updip and downdip tips resulting in less congestion in the raiseline) **Tips** Tip are able to be leapfrogged once the tip is no longer required to serve the section Ore handling line transporting ore from primary development and stoping continuously
Mobile crusher	**Safety Standards** • Mine Health and Safety Act – Act 29 of 1996 • SANS 10104 • ISO 7731: 2003 • EN 954-1:1998 • AFRS GUIDELINES • SRMP GUIDELINES Dials and gauges are visible	• Design reduces or eliminates re-handling of big rocks • Mobile crusher unit • Modular design ensures that major components can be easily replaced
Double-sided tips	• Designed to create a safer environment around tip **Safety standards:** • Mine Health and Safety Act – Act 29 of 1996 • SANS 10104 • ISO 7731: 2003 • EN 954-1:1998 • AFRS GUIDELINES • SRMP GUIDELINES	• Double-sided tips, therefore accessible either side of the raise • Handles large LHDs without any delay • Quick, easy, and cost-effective tip moves • Major components are easily accessible • Tips are always in place • Predevelopment and production tipping points are separated, therefore reducing congestion
Ventilation	Equipment to use low-sulphur diesel Sufficient time to ensure the necessary ventilation infrastructure is in place prior to stoping	• Ventilation-on-demand System • Machines equipped with catalyst, particulate filters, and Tier 2 type diesel engines
Rock mechanics	Predevelopment layout provides the ability to predict ground conditions and potholes timeously	• Development and stoping are separated, ensures that the support always meets the support requirements
Strike transport drive	Designated drive for machinery (strike pillar separates the two drives)	• Due to predevelopment, roadway quality can be assured, resulting in better tramming speeds and fewer breakdowns
Strike belt drive	Designated drive for the belt and for mine personnel to travel through	• Dedicated area for the belt • Services run • Strike pillar protects the belt

Mobile crusher

The mobile crusher (Figure 15) has been designed for underground mines, and will be installed in the centre of the strike belt drive.

The crusher is intended to feed crushed material from development workings in a low trajectory angle onto the strike belt. The mobile crusher has been designed to reduce the tram distances of the LHD, thereby improving the overall development cleaning cycle. The mobile crusher is accessed from the transport drive via the interconnecting roadway as shown in Figure 16.

Figure 17 illustrates the LHD tipping onto the mobile crusher. The LHD should be fitted with a push plate to reduce the tipping time.

Predevelopment requirements

Predevelopment will follow the mining cycle that is summarized in Figure 18. It is important to note that predevelopment is done parallel with, and independent, of stoping.

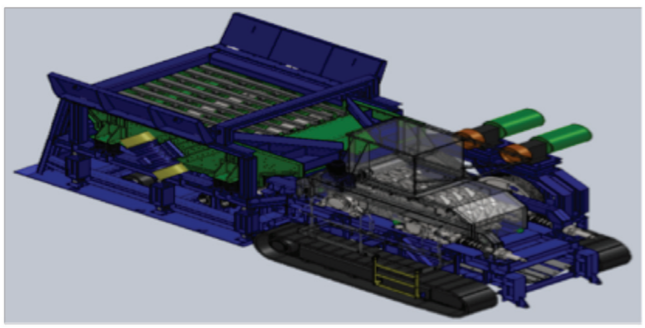

Figure 15. Mobile crusher

The predevelopment crew's role is to ensure that everything is in place for the stoping team to commence. Thus the crew will be responsible for the following:

- Development ends
- Cubbies
- Winzing and raising of the raiseline
- Satellite workshops
- Crosscuts (interconnecting roadways)
- Movement and installation of the tip and belts
- Reticulation extension
- Ventilation extension
- Vent holings (if required)
- Initial drainage.

Ledging

- On a true dip layout the stoping team will perform ledging. For ledging on apparent dip a separate ledging team will be required
- Ledging will start from the top to the bottom of the raiseline
- Checkerboarding will be used for ledging to reduce long unsupported spans. The concept of checker-boarding is illustrated in Figure 19
- Off the raiseline, the ASDs and sidings will be blasted 6 m in (two blasts) using LP equipment
- At each alternative ledge face, a 1 m round followed by a 3 m round will be drilled by a LP drill rig positioned in the raiseline. This will be drilled to the required stope height between 0.9–1.2 m
- The blast will incorporate a ramp from the bottom ASD into the ledge so that the ULP equipment can access the

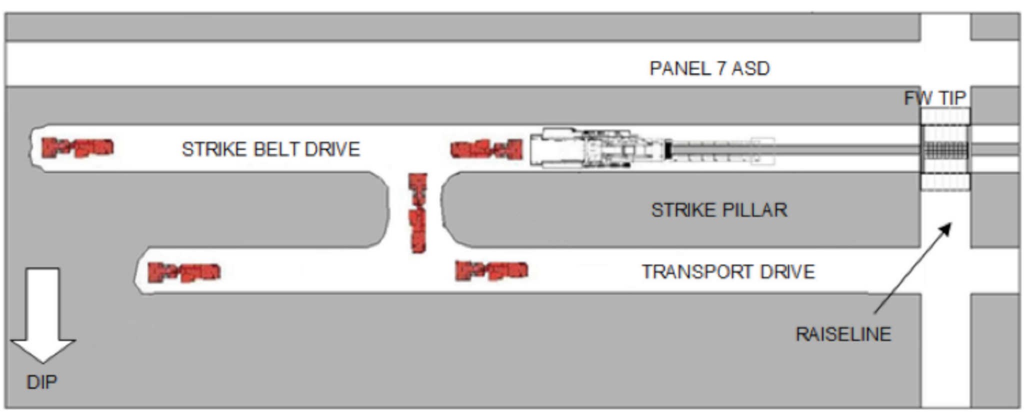

Figure 16. Development in conjunction with a mobile crusher

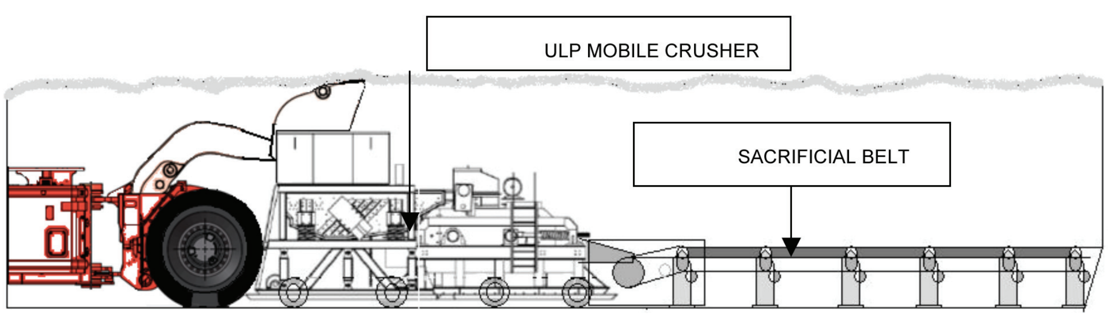

Figure 17. Typical crusher installation indicating the position of the mobile crusher

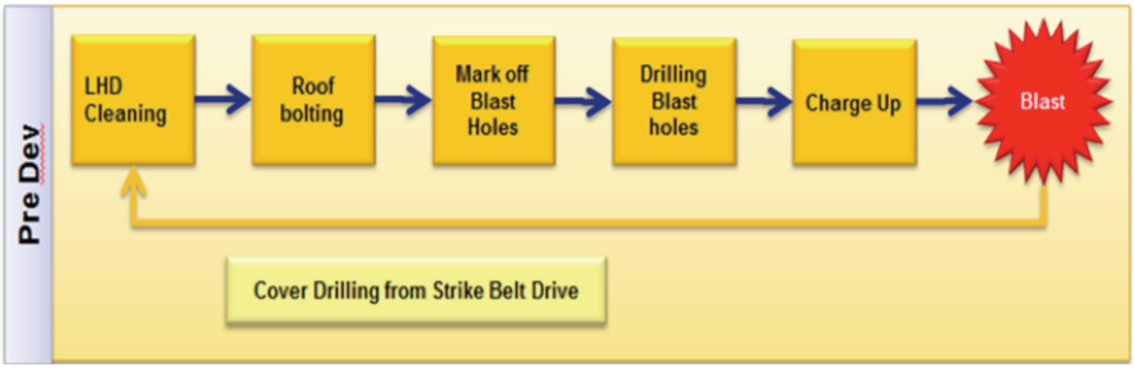

Figure 18. Predevelopment mining cycle

ledge. This will predominately be throw-blasted into the ASD, the remainder will be cleaned with the ULP dozer

- The first 1 m of ledging will be supported using the LP bolter
- Once cleaned, the ledge will be supported using the ULP roofbolter (according to rock engineering specifications)
- From the third round onwards, the ULP equipment will be used to advance the ledge until the final primary support has been installed
- While the ledging is taking place the ASDs are kept ahead using the LP equipment (at least 2 m ahead and not more than 10 m ahead of the ledge)
- Permanent strike support is then installed along the raise according to rock mechanics standards
- Once the ledge is completed, then the ledge on the opposite side of the raise can be completed
- Once all ledging has been completed on either side of the raiseline, equipping can commence.

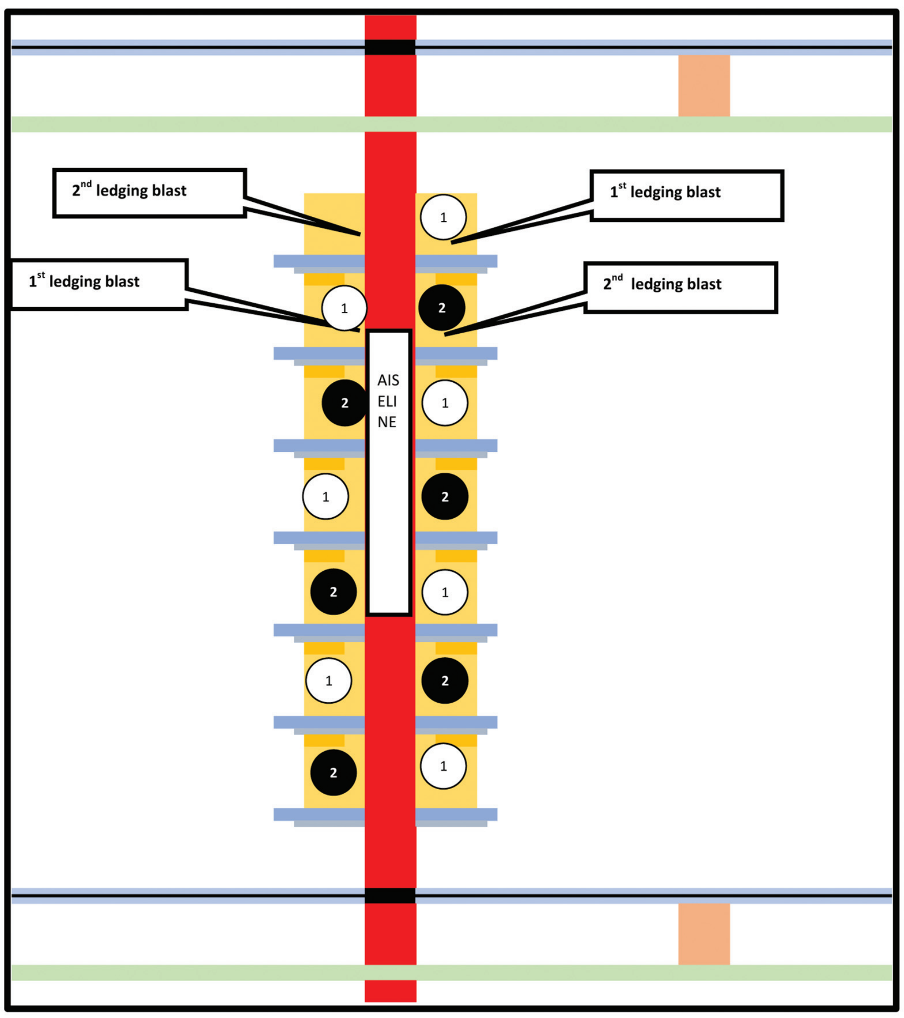

Figure 19. Ledging off the raiseline using checkerboarding

Stoping

Stoping description

The mining method that has been adopted for this layout is scattered breast mining utilizing ULP equipment with stope panels lagging the ASDs by a maximum of 10 m.

The face will be drilled 90° and allow throw blasting of at least 40% of ore into the ASD. Tamping and emulsion explosives will be used for charge-up and blasting.

The stoping layout described in this paper is based on a mining depth of >500 m and therefore a siding has been incorporated into the layout. The stope face is to be drilled using at least a 2 m drill steel and advanced at the very least 1.8 m per blast while operating within stoping widths between 0.9–1.2 m (in this paper a stoping width of 1.1 m has been used).

The ASDs and sidings will advance at least 2.8 m per blast and should be drilled using a 3 m drill steel. Three 8-hour shifts will be worked per day. Blasting is planned to take place twice (morning and evening shifts) in the three shifts per day – although the layout offers an opportunity to create multi-blast conditions. Re-entry period will be as determined by the ventilation department. This results in an effective face time of six hours per shift.

Figure 20 and Figure 21 are schematic representations of the ULP layout detailing the design parameters that were used.

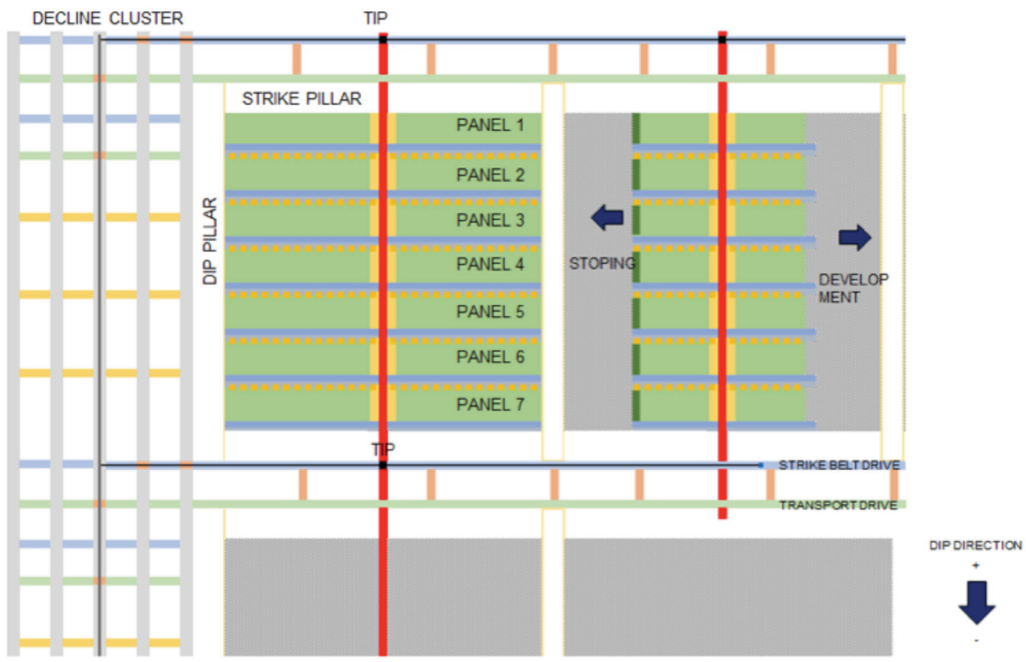

Figure 20. Stoping mining layout

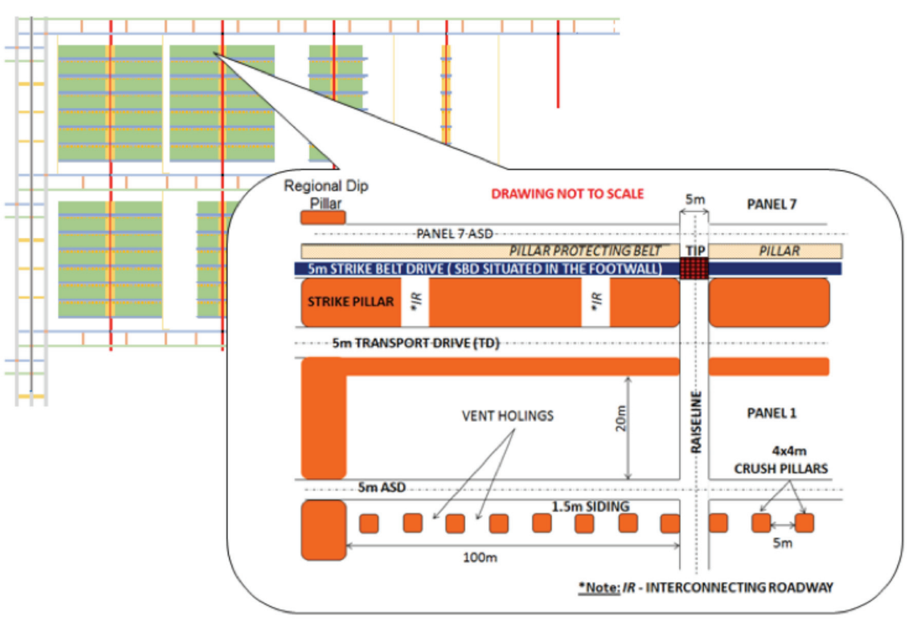

Figure 21. ULP stoping mining method

The stope panels and ventilation holings will be drilled using a ULP three-boom drill rig. A LP single boom drill rig will be used to drill the ASD and siding. The ASD will be carried 2–10 m ahead of the stope. An overview of the stoping layout is given in Figure 22 and Figure 23.

After the blast, the remaining ore that has not been throw-blasted into the ASD is dozed into the ASD from the stope panels using the ULP dozer. This ore is then trammed using the LHDs to either the updip or downdip footwall tips.

In order to reduce the tram distance, the ore from panels 1–3 will be trammed to the updip footwall tip while the ore from panels 4–7 will be trammed to the downdip footwall tip (refer to Figure 24).

During the first 30 minutes of stope face dozing the LHD must continue with other work so as not to interrupt the dozer cleaning the panel.

Stoping production outlines the anticipated production figures. The parameters used in this production table are inclusive of siding as the mining depth increases beyond 500 m.

ULP mining cycle

The mining method will follow the ULP mining cycle that is summarized in Figure 25. It is important to note that the predevelopment is done in parallel to and independent of the stope and ASD development.

To blast 4000 m², inclusive of the panel and ASD areas, 3.5 to 4 blasts per day (depending on the face configuration) are required for a three-shift cycle operating over 23 days per month. To achieve these blasts the resources available need to be scheduled to best fit within the seven-panel layout and mining logic. Consideration also

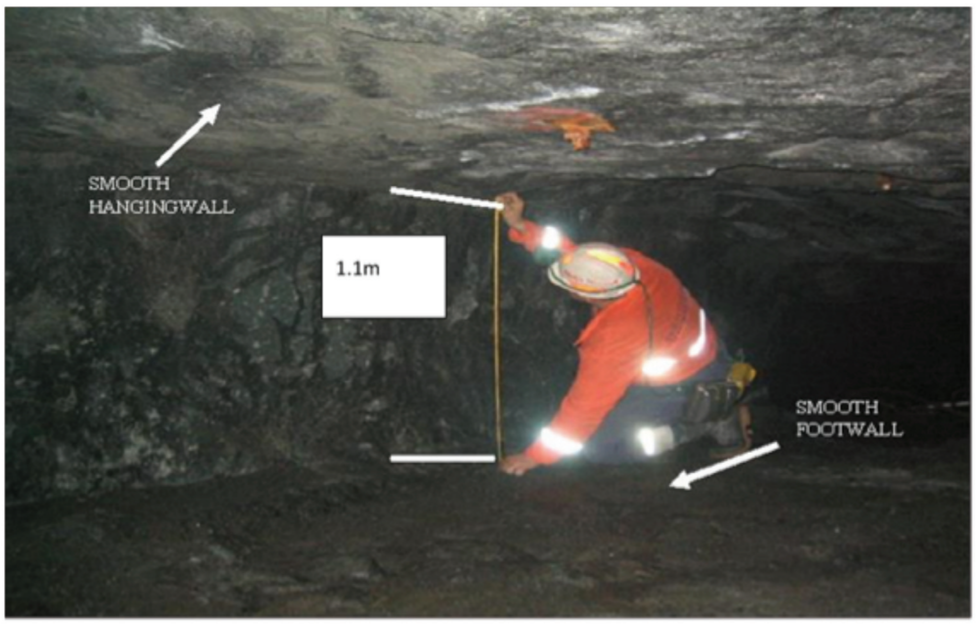

Figure 22. ULP breast mining, stoping width 1.1 m

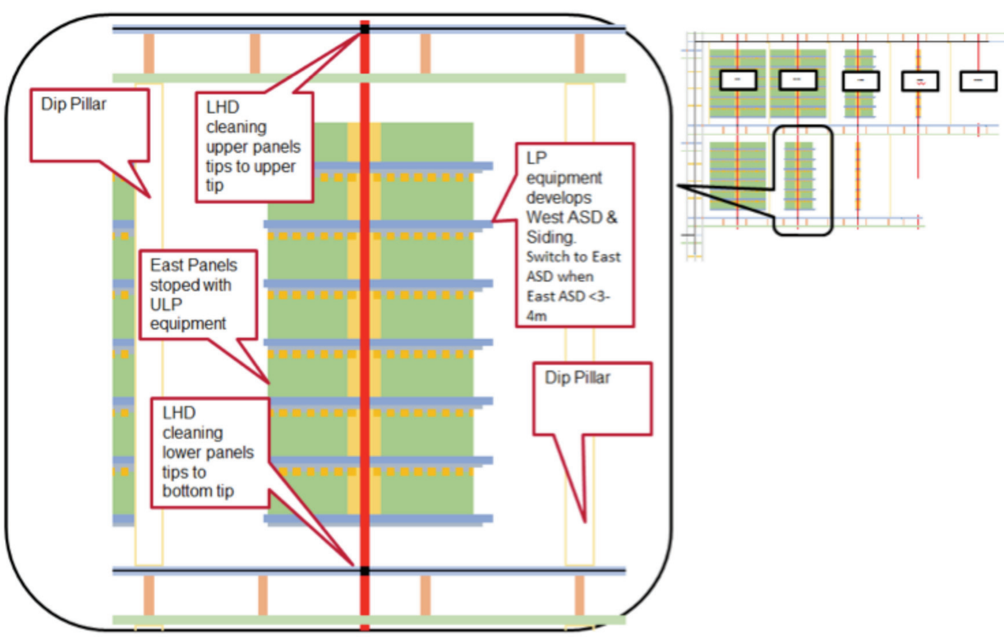

Figure 23. Schematic of ULP stoping layout

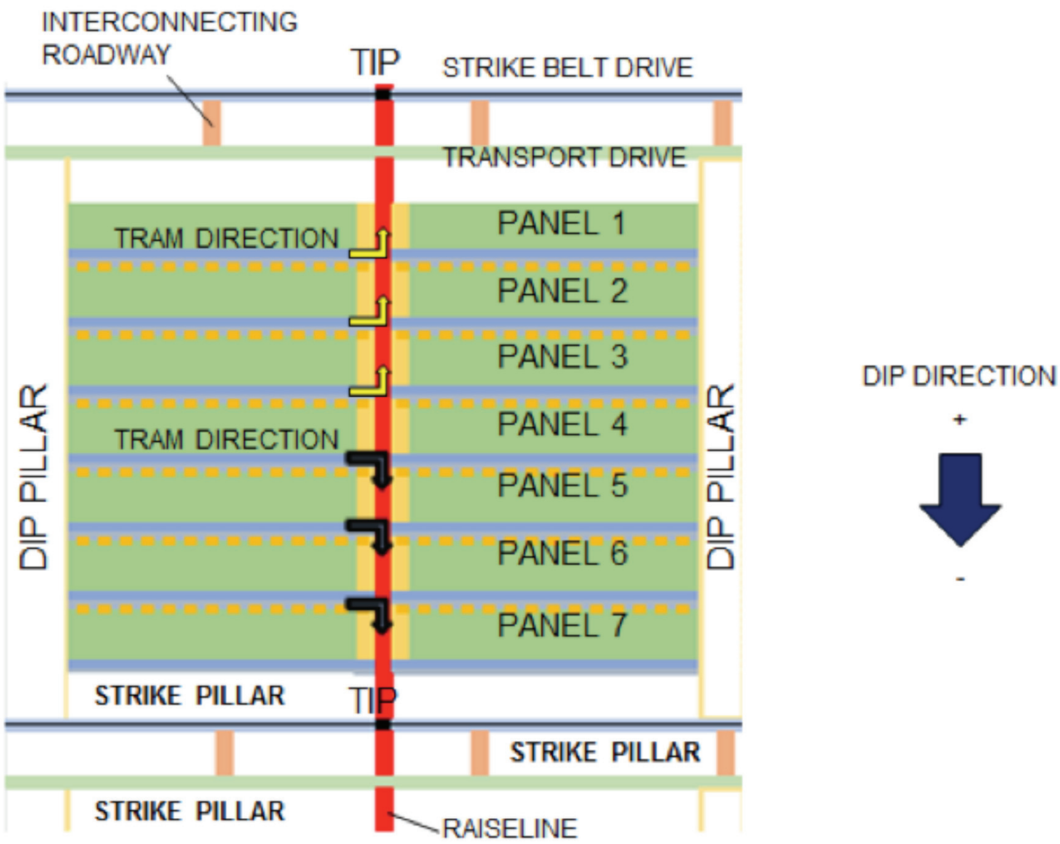

Figure 24. LHD tramming

Table III
Stoping production tables

Mining equipment	Stope element	Ht	Effective face length	Advance per blast	m² per blast	Mining rate	Panel face advance	Stoping system advance before geoloss	Total
		m	m	m	m²	m²/month	m	m	m²
ASD development	ASD	2.0	5	2.8	14.0	50.7	10.1	20.27	709
with LP	Siding	1.0	1.5	2.8	4.2	15.2	10.1	20.27	182
equipment	**Total LP***	**1.8**	**6.3**	**2.8**	**17.6**	**63.7**	**10.1**	**20.27**	**892**
Panel stoping	Panel	1.1	20.0	1.8	36.0	202.7	10.1	20.27	2 838
with ULP	Vent holing	1.1	2.2	1.8	4.0	22.5	10.1	20.27	270
equipment	**Total ULP***	**1.1**	**21.9**	**1.8**	**39.4**	**222.0**	**10.1**	**20.27**	**3 108**
Total stope and gully (excl. RSE)*		**1.3**	**28.2**	**2.0**	**57.0**	**285.7**	**10.1**	**20.27**	**4 000**

*** Weighted averages have been applied to this table in order to accommodate the two top panels not requiring any sidings or vent holings.**

Description	Units	ULP equipment	LP equipment	Total/average
Effective face length	m	21.9*	6.3*	28.2
m² per month	m²	3 108	892	4 000
Tons per month	t	20 886	5 994	26 880
Face advance	m	1.80	2.80	2.02
No. of blasts		79	51	70
Tons per blast	t	265	118	383
Days per month		23	23	23
Blasts per day		3.4	2.2	3.0
Tons per day	t	908	261	1 169
m² per day	m²	135	39	174
No. of faces		14	14	14
Face advance	m	10.1	10.1	10.1
Blasts per face / month		5.6	3.6	5.0

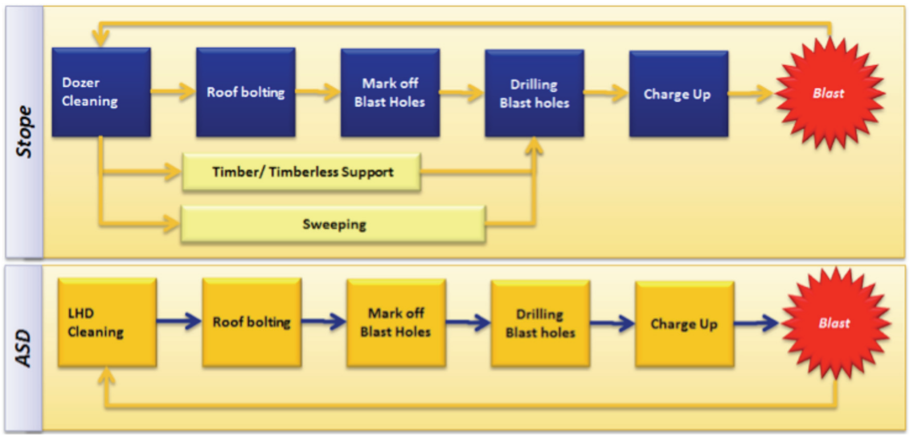

Figure 25. ULP mining cycle

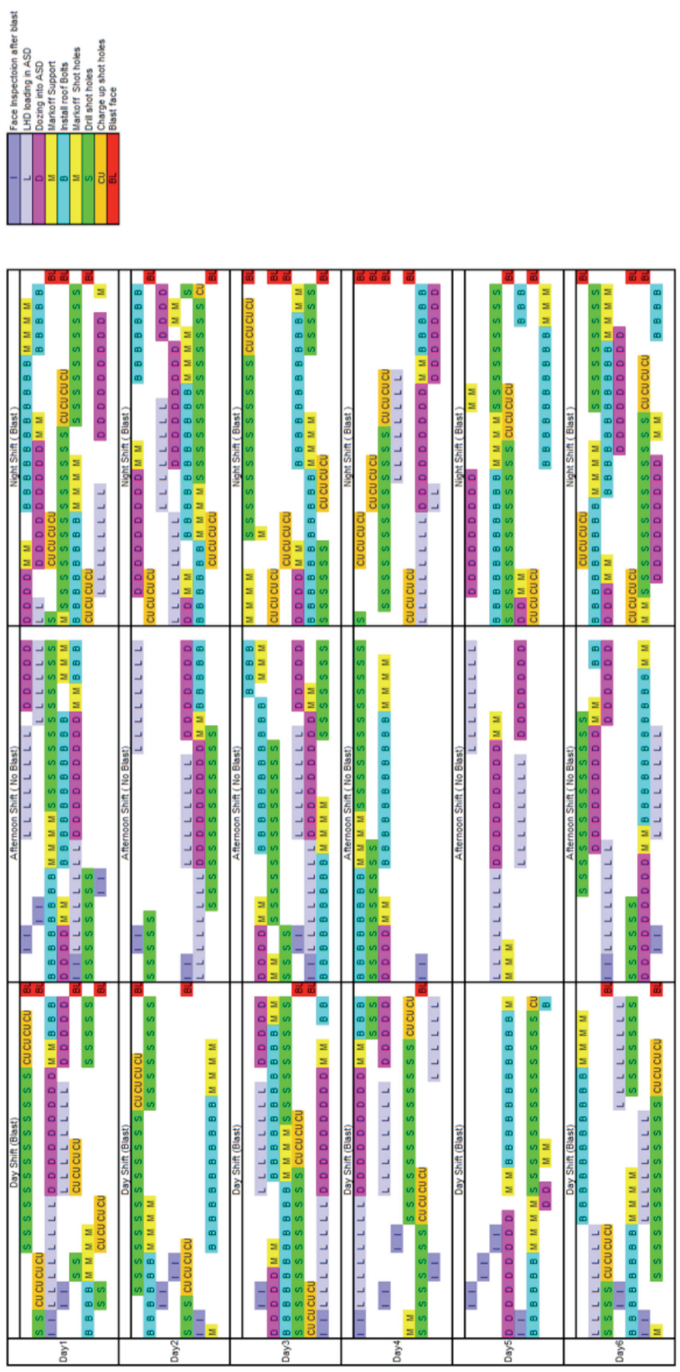

Figure 26. ULP shift cycle

needs to be taken of the respective machines cycles and availabilities.

The general stope mining cycle is summarized in the ULP mining cycle depicted in Figure 26. It is important to note that although the modelling shows that 4 800 m² is achievable, a conservative approach has been applied as this is a new mining method. An 80% confidence factor has therefore been applied to arrive at the production figure of 4000 m² upon which this paper has been based.

Some key sequencing concepts that were used to arrive at the production figure of 4000 m² are as follows:

- Panels 1 to 3 to be trammed to the upper tip, 5 to 7 trammed to the lower tip, and panel 4 can tram to either tip. This is done to reduce and optimize the average tramming distance
- Throw blasting of 11 m is assumed in the stope panels due to:
  - o breast stopes
  - o electronic detonators
  - o improved explosive technologies (emulsion explosives as well as tamping)
- The ASD needs to be of sufficient size so as to not choke the throw-blasted ore. The LHD needs to load the panel ore from the ASD for at least 2 hours (80–100 t) to create sufficient space within the ASD for the dozer to doze the remaining ore into the ASD
- Note that in mechanized mining optimization, when a panel activity is complete, e.g. stope roofbolting needs to start at the next planned panel even if the activity will not be completed in the remainder of the shift. The concept is to get as much work as possible done by the machines within the available face time. To optimize and control this scheduling, an intelligent Management Operating System (preferably a real-time system) is required to 'dispatch' the machines and resources optimally. This should be managed from a control room.

Table IV detail the cycle times for the cleaning, support, and drilling cycles. Existing LP and XLP equipment was modelled and a 15% lost time factor was added, as underground time studies of both the LP and XLP equipment yielded an additional lost time portion of approximately 15% of the total time. This time includes time delays caused by changing drill bits, connecting water and power cabling to the machines, and other operational delays.

The design called for at least two 8 t LHDs to be used as optimization studies as well as Arena modelling showed that the tons per hour reduces as the tram distance increases, which impacts the total tons that can be moved (Figure 27 and Figure 28).

The total face cycle time for both the LP and ULP equipment is a representative time that would apply to the total time it would take to support and drill panels 2 to 7, as these panels all carry a siding as well as vent holing. For the first panel, only the ASD and panel cycle times would be applicable as the first panel does not carry a siding or vent holing (Figure 20 and Figure 23).

Table V details the support cycles for:
- ASD
- Siding
- Panel
- Vent holes.

Table VI details the drilling cycles for the:
- ASD
- Siding
- Panel
- Vent holes.

Table IV
LHD cleaning cycle

LP cleaning cycle			
Description	**Units**	**LP ASD**	**LP Siding**
Tram tons	t	5 516.1	12 752.57
Effective loader payload	t	6	6
Load time	min	1.5	1.5
Tip time	min	1.5	1.5
Av. speed	km/h	4	4
One-way tram distance	M	138.4	138.4
Cycle time	min/cycle	7.2	7.2
Cycles per hour	h	8.4	8.4
Tons per hour	t/h	50.3	50.3
LHD hours per month	h	109.6	253.4
Plus 15%	h	126.0	291.4
Scalping and re-handle	h	0.02	0.02
LHD hours per month	h	128.6	297.2
Face advance	M	2.8	1.8
m² per month	m²	891.9	3 108.1
No. of blasts per month		49.0	77.7
Hours per blast	h	2.6	3.8
Hours per loader per blast	h	1.3	1.9

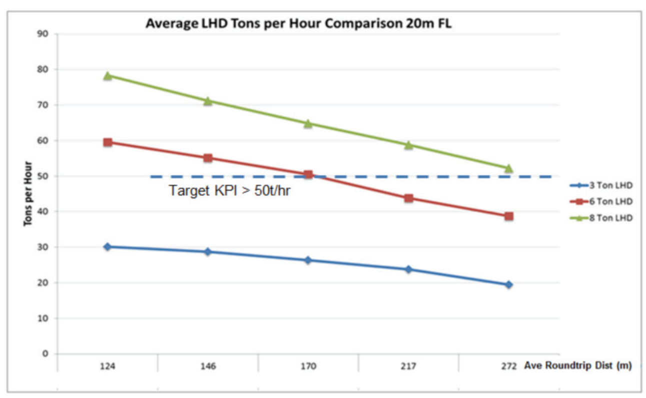

Figure 27. LHD tons per hour comparison

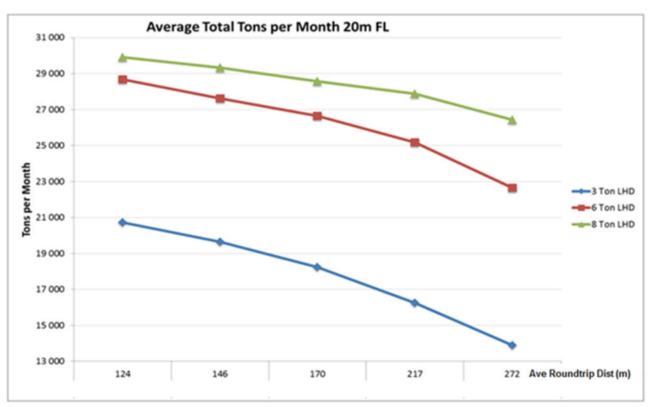

Figure 28. Total tons per month

Table V Roofbolter support cycle							
LP and ULP equipment support cycles							
Description	**Units**	**LP ASD**	**LP siding**	**LP (ASD + siding)**	**ULP panel**	**ULP vent holing**	**ULP panel + vent**
Dip spacing	m	1.2	1.2	1.2	1	1	1
Strike spacing	m	1.5	1.5	1.5	2	2	2
Face advance	m	2.8	2.8	2.8	1.8	1.8	1.8
Av. panel width	m	5	1.5	6.5	20	2	22.2
Holes per blast	holes						
7.8	2.3	10.1	18.0	2.0	20.0		
Hole length	m	1.61	1.61	1.61	1.61	1.61	1.61
Total holes per month	holes	394	101	495	1 419	135	1 554
No. of booms		1	1	1	2	2	2
Effective booms		1	1	1	1.6	1.6	1.6
Time per hole	**min**	**11**	**11**	**11**	**4.3**	**4.3**	**4.3**
Hours of support	h	72	19	91	102	10	112
Travel per month	h	50.68	-	50.68	51.34	-	51.34
Total hours plus 15%	h	141	21	162.74	176	11	187.36
Single boom time per blast	h	2.79	0.49	3.28	2.24	0.17	2.40
Face cycle time	**h**	**2.79**	**0.49**	**3.28**	**1.46**	**0.09**	**1.55**

Table VI Drill rig drilling cycle							
LP and ULP equipment drilling cycles							
Description	**Units**	**LP ASD**	**LP siding**	**LP (ASD + siding)**	**ULP panel**	**ULP vent holing**	**ULP panel + vent**
Lines		3	3	3	2	2	2
Horiz. spacing	m	0.6	0.6	0.6	0.5	0.5	0.5
Vert. spacing	m	0.6	0.6	0.6	0.5	0.5	0.5
Burn cut	holes	9	9	9	0	2.5	2.5
Av. panel width	m	5	1.5	6.5	20	2.2	22.2
Holes per blast		37.7	13.8	51.5	80.0	11.4	91.4
Hole length	m	3	3	3	2	2	2
Total holes per month		1 910.8	598.2	2 509.0	6 306.3	767.4	7 073.7
No. of booms		1	1	1	3	3	3
Effective booms		1	1	1	2.4	2.4	2.4
Time per hole	**min**	**2.25**	**2.25**	**2.25**	**2.61**	**2.61**	**2.61**
Hours of support	h	71.7	22.4	94.1	274.2	33.4	307.6
Hours per boom	h	71.7	22.4	94.1	114.2	13.9	128.2
Travel per month	h	25.3	7.2	32.6	44.6	0.0	44.6
Tot hours plus 15%	h	111.5	34.1	145.7	366.7	38.4	405.0
Single boom time	h	2.20	0.79	3.0	4.65	0.57	5.2
Face cycle time	**h**	**2.20**	**0.79**	**3.0**	**1.94**	**0.24**	**2.2**

Conclusions

The mining layout has been designed around (and focuses on) the following four key areas:

1. Safety
2. Sustainability
3. Productivity
4. Cost-effectiveness.

Safety

- The mining layout is designed to remove personnel from the high-risk zone of the stopes
- The ULP technology has been designed to separate machines and personnel through the use of remote-controlled technology
- The layout introduces a dedicated drive for machinery (strike transport drive) as well as a dedicated drive for personnel and belt system (strike belt drive)
- The layout allows for future automation of the mining process, which will be managed using a Management Operating System based in a control room on surface
- Through predevelopment the orebody is better understood, resulting in better planning
- The layout requires a skilled workforce that is highly trained and highly safety-conscious
- Mechanized mining method improves underground conditions through the introduction of well controlled hangingwall and sidewall conditions.

Sustainability, productivity, and cost-effectiveness

- The layout supports concentrated and dedicated mining within a section by divorcing the predevelopment from the secondary development and stoping activities. The primary development team is responsible for ensuring that all the necessary services and infrastructure are in place before stoping commences within the section. The layout also offers the potential to switch between explosive (LP/XLP/ULP) and non-explosive stoping

methods depending on the dip, depth, and resource width of the orebody
- Higher production levels and greater efficiencies can be achieved using mechanized equipment
- On-reef mechanization delivers early ounces (higher head grade). A majority of the capital and development costs are offset by revenue generated by on-reef development
- Flexible layout – the 14-panel layout has been designed to create flexibility within operations (the layout improves productivity by having adequate faces available and reduces the amount of re-development that is required to re-establish faces). The mining layout is designed around the principle of having four active raiselines (development, ledging, stoping, sweeping and vamping)
- The layout incorporates logistical elements (optimal tram distances, improved footwall conditions, tips, services, and IT infrastructure are in place prior to stoping)
- Predevelopment results in upfront geological information
- The layout provides effective ventilation and support
- The ULP technology is able to operate in stoping widths of 0.9–1.2 m, thereby reducing the dilution and increasing the grade of the product to the plant.

Through proper planning and the understanding of mining principles as well as the introduction of new technology, safer, more productive and sustainable operations are possible in narrow-reef tabular mining systems.

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During Frik's tenure at AngloGold Ashanti Frik achieved more than 4 Million FFS Shifts & was twice the Runner-up for Mining Engineer of the year award. During this time Frik also won the Dick Fisher Global Safety Award and was named president of AMMSA in 2009.

Following the restructuring of AngloGold Ashanti in 2010 Frik was afforded the opportunity to take up the Head of Mining Position at Anglo American Platinum. Frik's current areas of responsibility includes:

- New Mining Technology
- Best Practice (Procedures, Standards & Training)
- Technical Mining Consulting to Production Units and Projects
- MRM / Business Planning
- Systems and electronic integration

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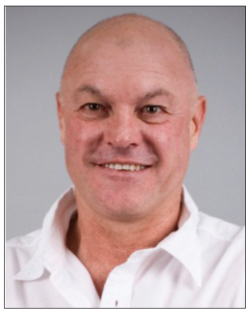
Petr commenced his mining career at the Odra Mine in the Czech Republic in 1986 after completing his Mechanical Engineering degree at the Ostrava University of Mining and Metallurgy. Petr joined Anglo Platinum in 1991 following the completion of his doctorate on the design of cutter heads for hard-rock mining conditions. He is currently responsible for managing all of the New Mining Technology (NMT) projects within Anglo American Platinum, including the development of new technologies and layouts for the hard-rock mining industry. His scope of work includes the financial evaluation, implementation, and roll-out of new mining technology projects within the Group.



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George graduated from Wits mining school in 1985 and was a graduate mining engineer with Anglo Gold in Welkom. He transferred to De Beers, worked at Cullinan and Namdeb mines till 1997, progressing from mining graduate through to mine overseer, pit superintendent, and finally head of mine projects and planning at Namdeb. He spent 8 years as a management consultant locally and internationally before joining Cyest in 2005, where he has successfully developed a leading consulting practice specializing in new mining technologies.

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