Mine design of The Argyle underground project

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Abstract

Argyle Diamonds operate a 10Mtpa open pit diamond mining operation in northern Western Australia. Current schedules show the open pit finishing production by the end of 2007, having reached its economic depth.

Some 60Mt of resource is below the ultimate pit bottom and consequently Argyle Diamonds is undertaking a Feasibility Study on the underground mining of this resource. The 'Vision' for the project is based on setting benchmarks for safety, productivity and sustainability. This will be achieved through the application of best practice designs and techniques, high levels of automation and remote operation and a commitment to the vision by all those involved. In essence, the Argyle Underground Mine will be designed and operated as a safe and predictable 'rock factory'.

This paper presents various aspects of the mine design philosophy, underground conditions and their management and the incorporation of the Argyle vision into the design.

1. INTRODUCTION

Argyle Diamond Mine, a 100% owned subsidiary of Rio Tinto Limited, operates the Argyle mine located in the eastern Kimberley region of Western Australia (Figure 1). The operation comprises a large open pit mine, centred on the lamproite AK1 orebody, feeding a processing and recovery plant. Diamond product is shipped to Perth for sorting, further processing and marketing.

Figure 1 – Location Map

Currently, the AK1 operation moves over 80 million tonnes of rock to treat 10 million tonnes of ore annually.

The current schedule, sees completion of open pit mining of the AK1 orebody by 2007. The AK1 and associated mineralistion is known to extend some 600m below the planned pit bottom.

Underground mining of this resource has been investigated a number of times between 1995 and 2000. In July 2000, an Order of Magnitude Study was conducted to provide a fresh look at underground mining given the alternative of a deeper open pit plan and the confirmation of further resources at depth. This study indicated good potential for underground extraction. In light of this, a Pre-Feasibility Study was undertaken between July 2001 and January 2003, examining various underground mining strategies, approvals processes and organisational options.

In February 2003 approval granted by the Rio Tinto Investment Committee for Argyle Diamonds to undertake a two year Feasibility Study into underground mining of the AK1 orebody. Approval was also given for the development of an Exploratory Decline to further improve knowledge of the underground environment.

2. THE VISION

In embarking on the Feasibility Study, all aspects related to the project were to be undertaken with the following requirements in mind:

- Argyle will set the benchmarks for safety and productivity in underground mining through:
  - Commitment to safe design and risk assessment throughout the design stage;
  - Application of best practice designs and techniques;
  - High levels of automation and remote operation, thereby removing people from hazardous work areas; and
  - Commitment to this vision.
- Argyle will be designed and operated as a safe and predictable 'rock factory'.
- The project will provide sustainable outcomes for Argyle and for the people of the East Kimberley region.

In keeping with this Vision:

- frequent risk assessments and updates have and will continue to be undertaken;
- safety experts/personnel have been employed from the early stages of the project to ensure sufficient resources are available to proactively deal with safety issues;
- communication with equipment suppliers is frequent to ensure that technological developments are known and incorporated into the design as appropriate;
- Argyle is represented at the International Caving Study which continues to pursue improvements in the understanding and processes used in the design, planning and control of cave mining;
- a 'Lessons Learned' methodology has been incorporated into the Argyle project which draws on learning's and experience from other Rio Tinto operations and projects;

- Argyle is undertaking the transition to a 'Kimberley Centric' workforce, with increased local employment; and
- where possible, local Kimberley based companies will be used for on-going work at the mine.

3. REGIONAL GEOLOGY

The AK1 deposit is a volcanic intrusion of Lamproitic tuff and magmatic Lamproite intruded into a stratigraphic sequence of interbedded quartzites, siltstones and mudstones that overlie dolerite and basalt units

The deposit extends below the base of the final pit, plunging steeply towards the south and dipping to the west at approximately 70o. The main area of the AK1 orebody, where a majority of the mine production will come from, thins and bifurcates with depth. Figure 2 shows a Long Section of the orebody and LOM Pit.

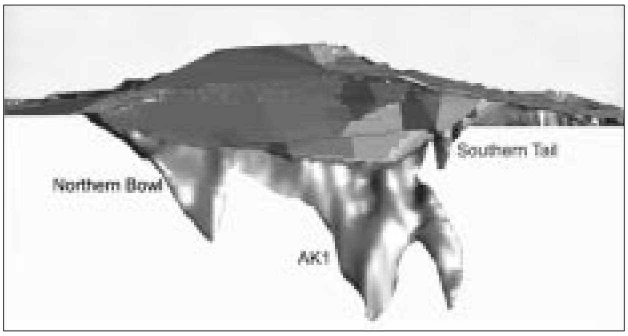

Figure 2 – Long Section of the Argyle Deposit

4. GEOTECHNICAL CONDITIONS

There are numerous regional faults within the area however the dominant structural feature expected to be a major controlling factor for any mining is the NNW trending Gap Fault, which is located at the northern end of the AK1 orebody.

Infrastructure development is likely to intersect at least three main geological structures, namely the Gap Fault, Lamboo Thrust Fault and Eastern fault. The proposed development will also pass through the contact margins of the AK1 pipe, which in many places is a wide zone of healed brecciated lamproite and host rock.

Table 1 below indicates the rock types and associated indicative UCS and IRMR results.

TABLE 1 – Indicative UCS and IRMR Values

Rock Unit	Rock Type	UCS (Mpa)	IRMR
RCFM (Pvb)	Basalt	50	46 - 49
RCFM (Pvd)	Dolerite	50	46 - 49
LCG (Pb)	Granite	110	
RCFS	Interbedded	35	40 - 45
AK1 (orebody)	Lamproite Sandy Tuff	80	51 - 57
RCFS	Mudstone	20	35 -40
RCFS	Quartzite	120	47 - 50

It can be seen that, in general, the orebody is more competent than the surrounding stratigraphic units, especially the mudstones. This is a major consideration in determining optimum locations for permanent infrastructure such as crusher chambers.

Acoustic emission and Hydraulic Fracture stress measurements were taken from boreholes drilled within the pit. These methods gave conflicting results however and consequently design flexibility is considered essential. Additional stress measurements will be undertaken from the Exploratory Decline.

5. MINING METHOD

In keeping with 'The Vision' defined for the Argyle Underground Mine, selection preferences of mining methods tended towards non-entry methods such as block caving and sublevel caving. These methods make it possible to implement high levels of automation, control and monitoring, thereby minimising the number of people required to work in potentially hazardous conditions. They also create an underground 'rock factory' environment, which can be operated in a safe and predictable manner.

Earlier mining studies identified that open stoping options led to poor recoveries (low percentage extraction) as well as having the risks associated with entry methods, the stope and fill methods were not economically viable and it was concluded that only the caving methods, more particularly block caving, could be seriously considered for mining of the AK1 ore body. The grade, size, geometry and rockmass conditions of the AK1 deposit are also such that it is most appropriate to mine using bulk extraction mass mining methods.

During the Pre-Feasibility Study, a number of mining scenarios where assessed. From these, two options were taken forward. Further work undertaken as part of the Feasibility Study identified that the option of an extended block cave, whose footprint extends out into the less competent footwall sedimentary units, holds the greatest value. Below the cave extraction level, a sublevel cave mining method will be used.

6. BLOCK CAVE

The block cave area is some 230m in depth, below the base of the final pit, 450m along strike and 190m wide, giving a mining block of approximately 50Mt. The extraction level itself is 466m below the surface.

Undercut

Strategy

An advanced undercut strategy is proposed. In this strategy a limited amount of extraction level development is done prior to the start of undercutting. At Argyle, this development will consist of the establishment of the footwall and hangingwall perimeter drives, extraction galleries and drawpoint stubs. Undercutting on the level above will then begin and the extraction level drawpoints and drawbells will be developed once de-stressed conditions have been established. De-stressed conditions are assumed when the drawpoint development lags behind the undercut advance by 45o (15m).

Profile and Footprint

The undercut footprint for Argyle is an irregular rectangular shape with dimensions 450m x 190m. The hydraulic radius considered necessary for caving at Argyle is ~40m. The proposed footprint has a hydraulic radius of 67m, and as such cave propagation is not considered to be an issue.

The undercut profile, as shown in Figure 3, is described as a narrow inclined undercut and is the profile adopted by both Northparkes and Palabora.

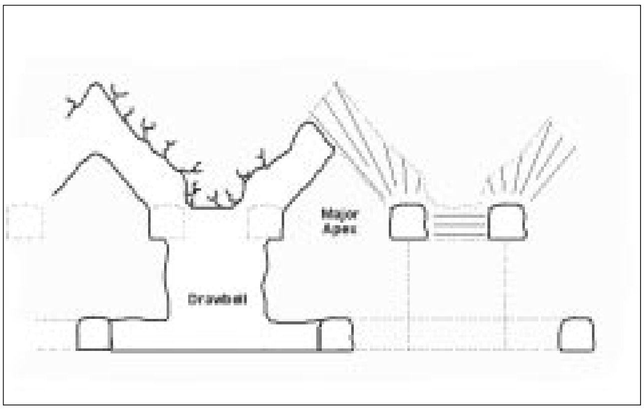

Figure 3 – Undercut Profile

Direction

An analysis was undertaken using FLAC3D to determine the best direction in which to advance the undercut. Six different undercut directions were assessed with the preferential direction for undercutting being from the north-west corner to the south-east. This recommendation was based on:

- the undercut progressing from weaker to stronger rock giving improved cavability.
- the orientation to major structure is such that major wedges should not be formed.

Extraction Level

In defining the design layout of the Extraction Level, a number of considerations were taken into account, the main ones being automation, ground support, ventilation and production flexibility.

In order to comply with the Argyle Vision, a high level of automation is needed. The single extraction horizon makes it relatively easy to setup and maintain the communication infrastructure required for the automated systems currently being developed. Rio Tinto, through its Northparkes operation, have already been trialling the Autotram system and given positive developments of this technology into the future it is intended that the Argyle underground mine will utilize a fully automated loader fleet. Secondary breaking remains an issue given the hazardous conditions often encountered. It is unlikely that much of this work will ever be fully automated but wherever possible teleremote operation will be used to remove personnel from the underground environment. A central control room will be located on surface from which all major activities will be controlled and monitored.

Given hot and humid surface conditions, high ambient rock temperatures and the introduction of heat through ground and surface water, ventilation is of prime importance. As such, in order to minimize the ventilation requirement for equipment and in line with positive experience at Northparkes, a fleet of electric loaders will be used for ore production.

Based on these requirements, it was determined that the Extraction level would comprise the following:

- a transverse layout to give production flexibility given a relatively elongated orebody.
- an offset herringbone drawpoint layout to facilitate the use of electric loaders.
- extraction galleries with an orepass at the hangingwall end and a ventilation/drainage raise at the other thus allowing each gallery to be isolated from the perimeter drives and minimizing interactions between automated and manual activities.
- ventilation and drainage raises connect directly into the mine exhaust system on the Transfer level such that all heat generated on the Extraction level is removed quickly and efficiently.

Ground support design and implementation will be a major consideration in the construction phase of the Extraction level with emphasis being placed on 'getting it right the first time' in order to avoid costly rehabilitation and delays.

A workshop/cribroom complex will be located within the orebody at the southern end of the Extraction level. Regular servicing and minor maintenance will be carried out at this facility with all major maintenance work being undertaken at the surface workshop. The Extraction Level Layout is shown in Figure 4.

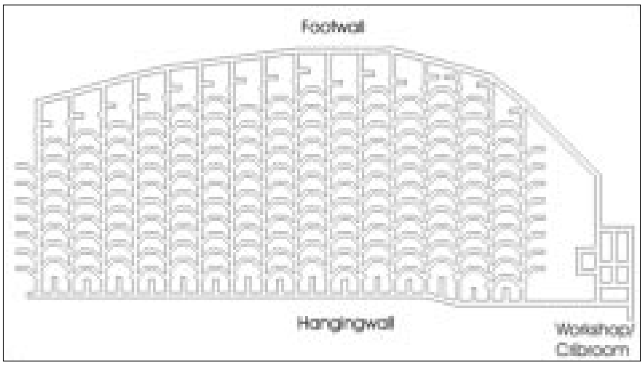

Figure 4 – Extraction Level Layout

Transfer Level

The lower level of the block cave has the multipurpose use of ore transfer to the crusher and transfer of exhaust air and drainage away from the mining area. It is proposed to use large capacity loaders for ore transfer. Each of the Extraction Level orepasses report to the western side of the Transfer level and are accessed much as a drawpoint. Twin transfer drives are proposed facilitating the use of multiple loaders operating on concrete roadways. The transfer drives report back to a centrally located gyratory crusher. The eastern footwall side of the level is quite separate from the ore transfer facility. Each of the ventilation/drainage passes from the extraction level terminates on the footwall perimeter drive of the Transfer level. This drive collects drainage water and return air, passing them south to the main ventilation exhaust and primary pumping infrastructure. All loading, crushing, conveying and pumping activities will be monitored and controlled from the central control room. Figure 5 shows the layout of the Transfer level.

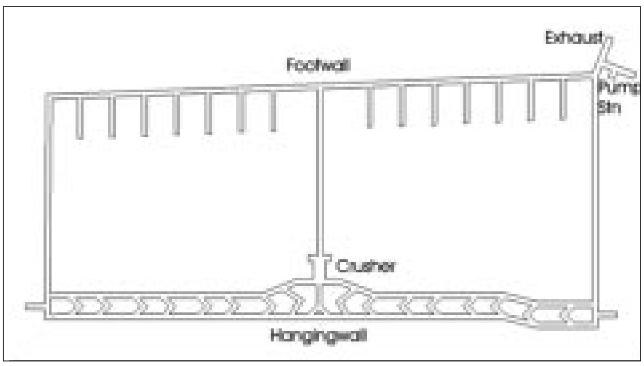

Figure 5 – Transfer Level Layout

7. ORE-HANDLING

Requirement/Duty

Mining studies have identified a sustainable underground production rate of 7.5 million tonnes per year during Stage 1 – Block Cave operation. Given the need to design for some waste handling capacity and providing some room for mining productivity improvements, a design capacity of 8.0 million tonnes per year (wet) has been selected for ore handling components.

Crusher

Numerous crushing options were investigated as part of the Pre-Feasibility Study. These ranged not only from underground versus surface primary crushing but also jaw versus gyratory versus hybrid crushers. Through this assessment, it was established that an underground primary Gyratory Crusher with surface secondary crushing was most appropriate for the Argyle Underground operation.

A gyratory crusher in the order of 54-74 size, fed with ROM ore supplied through 900 millimetre to1200 millimetre orepass grizzlies and orepasses will be used. The crusher has been selected to suit the feed size and provide the required throughputs.

The crusher itself will be located centrally relative to the block cave footprint. It is currently proposed to be within the orebody, given the unfavourable ground conditions anticipated in the hangingwall sediments. Locating this infrastructure within the orebody does however complicate the transition in production from the Stage 1 block cave to the Stage 2 sublevel cave.

Conveyors

A variety of ore haulage systems were evaluated, including conveyor, shaft and truck haulage. Ultimately however the relatively shallow nature of the underground mine, together with the staged nature of orebody development and the requirement for significant lateral haulage away from the orebody, has pointed towards a conveyor solution for ore handling to surface (Figure 6).

Recent advances in underground conveyor design, installation and operation has seen the planning and commissioning of long, steep underground conveyors at Palabora, Ridgeway and Northparkes. The 'lessons learned' from each of these sites will be incorporated and referenced in the Argyle design and operation.

8. DEWATERING

Expected Inflows

The monsoonal nature of the climate in the Argyle region results in the potential for severe tropical rainfall events. Combining with this is the location of the open pit directly above the proposed underground mine, which comprises a substantial catchment area ultimately funnelling surface water into the underground workings.

Dewatering Strategy

Given the wide range of potential inflows and uncertainty of the expected inflow quantities, a three part dewatering strategy has been developed. After cave breakthrough into the pit, three pumping conditions have been identified:

- normal conditions, representing typical day to day pumping requirements;
- seasonal conditions, where summer rainfall may increase pumping requirements substantially for a period of time; and
- flood conditions, where unexpected intense inflows occur.

Normal water inflow to the mine, including average rainfall, ground water and collection of raw water used for mining processes amounts to flows of between 40 to 120

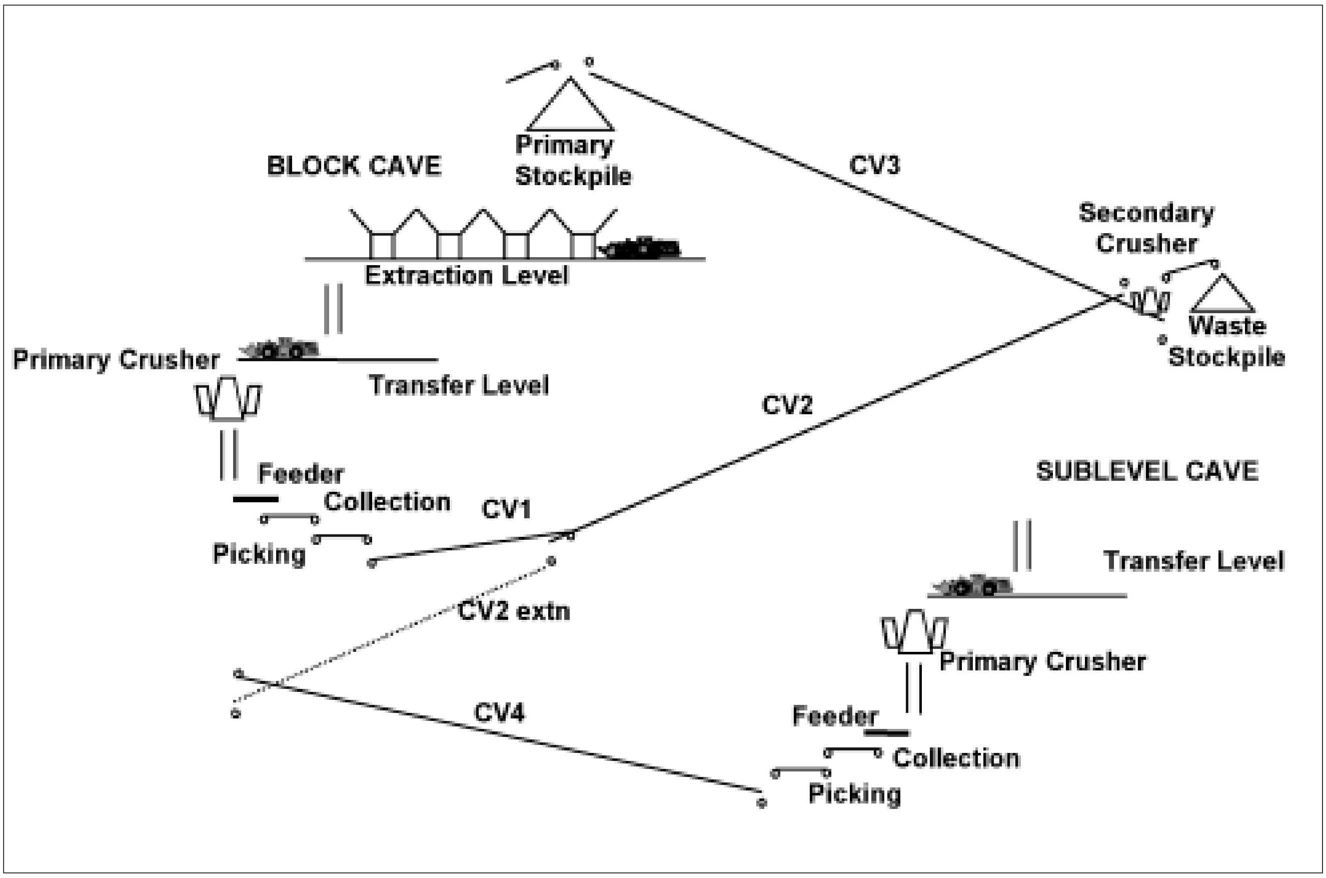

Figure 6 – Schematic of Underground Orehandling System

litres per second. This will be handled by two Geho TZPM 800 positive displacement pumps, each of 60 litres per second capacity, with over 750 metre head lift capability.

For seasonal/abnormal conditions, when inflows into the pump stations exceed the capacity of the two Geho positive displacement pumps, a series of 3 to 4 Warman 16/14 TYFC APH slurry centrifugal pumps will be used to dispose of the extra water, up to a total rate of 920 litres per second.

Flood conditions prevail when inflows exceed the designed pumping system capacity. In this circumstance the mine will go into a shut-down mode. A series of water-tight doors installed in bulkheads will be used to protect key infrastructure such as pumping stations, crusher stations, workshops and conveyors. These doors will separate this infrastructure from level drives and declines, which would be allowed to flood and subsequently pumped out.

9. VENTILATION

The ventilation design for the Argyle Underground Project has been undertaken with the following considerations in mind:

- Air quality must comply with Occupational Exposure Limits of Australia's NOHSC 1003.
- As specified by the WA Mines Safety and Inspection Regulations 1995:
  - Re-circulation of air is minimized and air is drawn from the purest source available (single pass ventilation)
  - Where diesel units are used for production, a general criteria of 0.04 to 0.06 cubic metres per second per kilowatt of rated engine output will be applied to each ventilation district.
  - A minimum air velocity of 0.25 metres per second is maintained where electric vehicles are used.
  - If wet bulb temperature exceeds 25oC, a minimum air velocity of 0.5m/s.

Block Cave

The greatest ventilation requirement for the block cave is when both production and construction activities are occurring at the same time. The block cave production rate at its peak is expected to be 7.5 million tonnes per year. Even though electric loaders are expected to be used, diesel loaders have been assumed to ensure sufficient capacity for flexibility.

Table 2 summarises the ventilation requirements.

Table 2: Block Cave Ventilation Requirements

	9715 BLOCK CAVE
Production Drives	150 m^3/s
Transfer Drives	60 m^3/s
Crusher	35 m^3/s
Conveyors	40 m^3/s
Lower Infrastructure (Pump stations, etc.)	15 m^3/s
Level Workshops	30 m^3/s
Leakage	45 m^3/s
Level Development/ Undercutting	100 m^3/s
TOTAL EARLY PRODUCTION	**395 m^3/s**
TOTAL PRODUCTION	**375 m^3/s**

Ventilation Circuit

For all stages of underground operation, the primary ventilation system comprises fresh air being drawn down the Main Decline and the Fresh Air Decline, through the various mine workings to the Main Return Airway. Schematic of the ventilation circuit is illustrated in Figure 7.

The ventilation system has been designed as a push-pull circuit. In doing so the extraction level is maintained under positive pressure such that contaminants and air will not be drawn through

the cave into the mine workings. The disadvantages of the system are the additional heat generated by the location of fans underground and additional capital and operating costs.

It is considered however that the benefits of this system outweigh the disadvantages.

It is proposed that exhaust fans be installed at the collar of the exhaust shaft. It should be noted that due to the length of the intake and exhaust declines, the fan would operate at high ventilating pressures.

Establishing the primary ventilation system is on the critical path of the project and as such it is essential that the Main Return Airway is developed as soon as possible.

10. REFRIGERATION

Design of the refrigeration system was undertaken with the objective of providing acceptable working conditions at major workplaces throughout the mine during fluctuations in climatic conditions. Expectation is that a majority of the underground workforce will operate within the confines of air-conditioned mobile equipment cabs. There will of course be occasions when work outside of such equipment will be necessary.

Heat Load

Heat is generated from a variety of sources including:

- Climatic conditions
- Heat from development walls and broken rock
- Heat from machinery
- Auto-compression of air
- Heat from ground water

Ground water is a major contributor to the mine's heat load and as such it is important that water is removed from the underground environment as quickly as possible.

Initial indications are that the mine will require between 9MW to 10MW of cooling capacity for operation of the block cave.

Refrigeration & Cooling Plant

Given the relatively shallow nature of the Argyle underground operation, a surface refrigeration plant will be used as it gives the advantages of ease of access, unlimited capacity for expansion and the ability to use refrigerants such as ammonia.

Through the use of bulk air cooler serviced by a surface refrigeration plant, cooling of the mine can be accomplished in the most economical manner possible using a relatively simple system.

The bulk air cooler should be positioned at the top of the intake ventilation shaft, with the refrigeration plant a further 200m away. The use of a number of refrigeration modules allows:

- A build-up of refrigeration capacity consistent with the underground requirements at the time.
- Flexibility in adjusting the amount of refrigeration given seasonal and diurnal variations in ambient temperature.
- Capacity to maintain cooling during the maintenance of refrigeration units.
- Easily expandable system.
- Minimization of early capital expenditure.

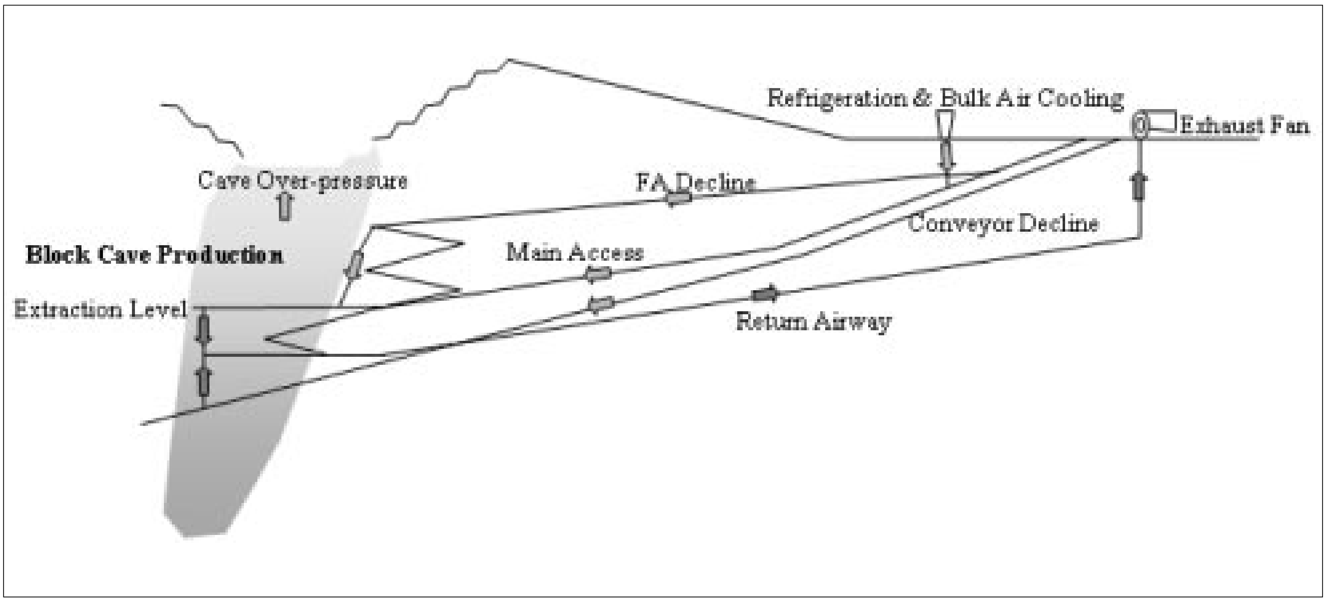

Figure 7- Block Cave Ventilation Circuit

11. CONCLUSION

The major technical issues associated with the project are:

- ventilation, given hot and humid surface and underground conditions,
- dewatering, given a monsoonal environment and mining under an open pit; and
- ground conditions associated with numerous structural features and relatively weak host rock units.

These technical issues, whilst still posing a risk, are being addressed within the mine and infrastructure design processes of the Feasibility Study. In all aspects of the study, 'The Vision' for the Argyle underground project has been referenced and used as a point of focus.

12. ACKNOWLEDGEMENTS

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