Pre-Extraction of a Shaft Pillar on Western Areas Gold Mining Co.

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SYNOPSIS

This paper describes the pre-extraction of the shaft pillar for the South Deep Shaft Complex on Western Areas Gold Mining Company. The paper details the geology of the orebody and the reasons for the choice of shaft positioning. The paper further details the rationale for the extraction of the shaft pillar reef, the design criteria for the shaft steelwork and subsequent deformations. Various considerations relating to the mining process and the subsequent backfilling of the pillar area are addressed. Particular attention is paid to the logistics involved in carrying out operations with limited access and located some distance away from a shaft complex.

INTRODUCTION

Locality

Western Areas Gold Mining Company is located approximately 50km West of Johannesburg near the town of Westonaria. Neighbouring mines include Kloof Gold Mining Company to the West and Randfontein Estates Gold Mining Company to the North. (Figure 1).

Western Areas currently has two surface shaft complexes, namely North and South Shafts, from which four sub-vertical shafts have been established over the last 30 years of operation. Shaft sinking is underway for the third surface shaft complex, which is the South

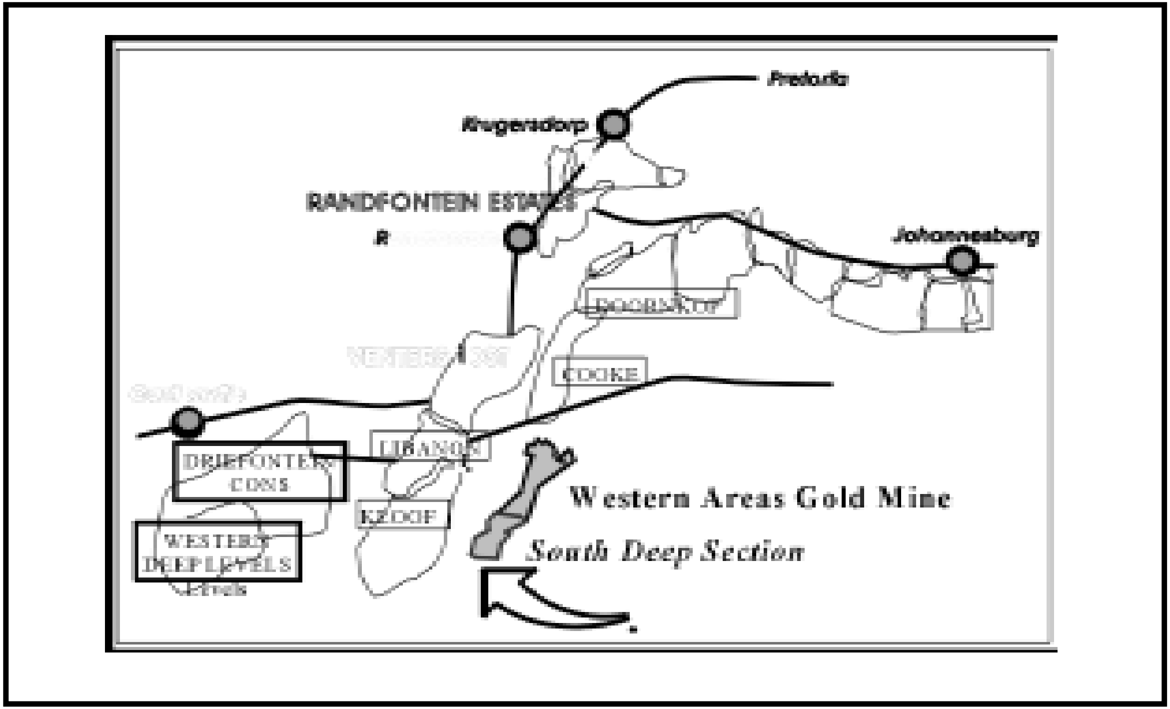

Figure 1
Locality of South Deep

Deep shaft system. The South Deep Section of the mine forms the southern portion of the mining property. The pre-extraction of this shaft pillar is described in this paper.

The South Deep Orebody

The South Deep ore-body consists of two major reef horizons, the Ventersdorp Contact Reef (VCR), and the Upper Elsburg package. The VCR overlays the whole of the mining property and dips at approximately 18 degrees North to South. The average thickness of the package is 160 centimeters.

A significant feature of the geology of the ore-body, is the shoreline, which roughly bisects the property from North to South. This is an unconformity between the VCR and the Upper Elsburg reef horizons. The Upper Elsburg package widens from the shoreline towards the east until it reaches a thickness of approximately 100 metres at the eastern boundary of the mine.

The Upper Elsburg package consists of a number of individual reef bands, which form the bulk of the future mining targets of the operation. The ore-body of South Deep is located approximately 2 400 meters below surface at the Northern boundary of the property and extends to beyond 3 500 meters below surface in the South.

The ore reserves of South Deep are estimated to be able to sustain the mine at full production for approximately 50 years. After the commissioning of the shaft system, monthly production will peak at 210 000 tons per month, with the view of increasing to 280 000 tons per month in the next phase of operations.

The South Deep Shaft System

The current infrastructure on Western Areas provides access to the upper portion of the South Deep orebody via a main shaft from surface and a sub-vertical shaft system (SV2/3) down to 95 Level (+/- 2650 m below surface). The capacity and condition of the current access system will not support the new mining operations for the expected life of the orebody as the distance from the centre

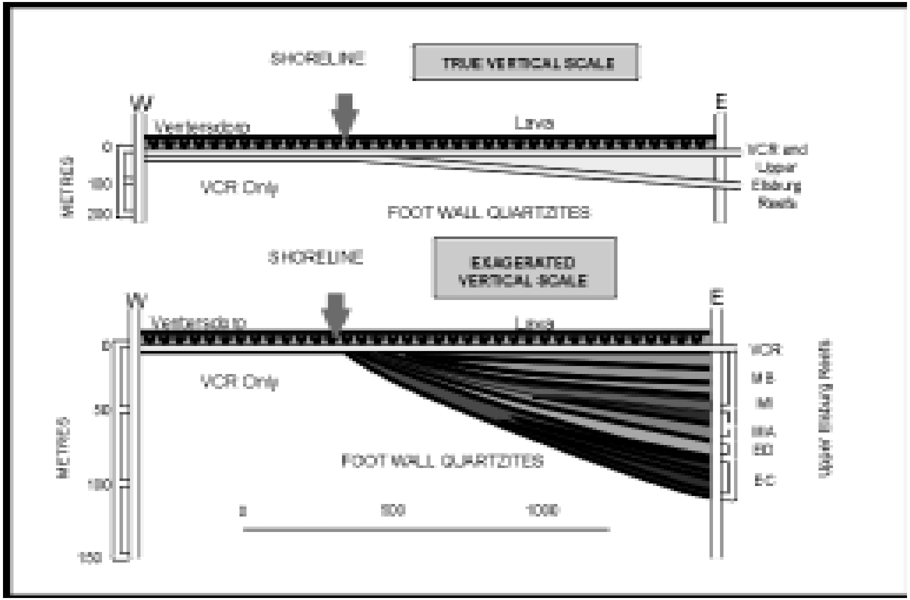

Figure 2
South Deep Stratigraphy

of gravity of the orebody to the shaft system is in the region of 5 kilometers. These conditions have lead to the decision being made that it is necessary for a new shaft system to be sunk from surface.

The resulting design process has lead to an innovative new design that has broken new ground in the shaft sinking and hoisting fields. The design consists of a twin shaft system reaching a final depth of 2 750 meters below surface in a single wind. These shafts will provide all access, ventilation and logistical requirements for South Deep in order to create a totally independent mining operation.

This system accesses approximately 30 % of the total orebody and future exploitation will require access to deeper portions of the mine through sub-vertical shafts and inclines.

The shaft system is positioned towards the north-western portion of the mining property so that it will intersect the orebody where it consists of the VCR only. This will minimise the volume of reef effected by a shaft pillar compared to the wider Elsburg package.

RATIONALE FOR SHAFT REEF EXTRACTION

At the depth of 2 550 metres below surface, which is the depth of the intersection of the Ventersdorp contact reef and the South Deep shaft system, the design of a conventional shaft pillar would have had to be designed with a radius of almost 1km. This would have been done by modeling various pillar geometries and assessing them, using the normal criteria for stresses, strains and tilts in the shaft barrels and service excavation. Alternatively the shafts could be sited in unpay or sterile areas. This would have either tied up considerable areas of the orebody or have led to the siting of the shafts far from the centre of gravity of the orebody with subsequent excessive lengths of development.

It has long been proposed that shaft pillar extraction at the beginning of a mines' life would be the more correct design and this approach has been adopted by several mines during this century.

The proximity of the Western Areas South shaft complex with its lowest operating level (95 level) on its SV2 and SV3 sub-vertical shafts at 2 650m below surface has allowed the upper Northernmost part of the South Deep Ore body between 90 and 95 levels to be pre-developed. More importantly the shaft reef intersection area of the South Deep Shaft complex can be pre-extracted and backfilled thereby eliminating the need for a shaft pillar.

This has several other advantages:

- Early gold production for the shaft complex;
- Predevelopment for the first decade's mining reserve allowing a rapid buildup of production once the shaft system is sunk and commissioned;
- Avoiding the problems of a highly stressed shaft pillar later in the mine's life;
- Training of a nucleus of management and skilled employees prior to full production capacity being available.

The planning of this pre-extraction had to include the limited additional capacity of the South shaft system to hoist more than 30 000 tons of ore per month and to supply the logistics and transportation for the mining of the shaft reef area and its predevelopment.

The design had to include limiting ongoing movements in the new shaft system once commissioned and ensuring unaffected hoisting through the mined out reef zone which will be done by ensuring that sufficient mining span is extracted and backfilled with high quality backfill prior to shaft reef intersection and commissioning. Subsequent movements will be limited by ongoing backfilling and the creation of stability pillars on suitable geological structures

SHAFT POSITIONS

Geology

The Ventersdorp contact reef is the only reef developed west of the upper Elsburg shoreline. This reef has average width of 1,6m and maximum width of about 3m. It was considered optimal for the shafts to be placed in this area rather than to the east of the shoreline where the reef package thickness varies from 3 to 30m.

The shaft system was positioned in the VCR block to the north of the South Deep ore body where the VCR is shallow enough to be accessed and mined from the lowest level of the WAGM south shaft system i.e. 95 level (2 650m below surface).

The shoreline feature and the previously mentioned overbank zone of poor VCR development were also to be avoided, as the pre-extraction of a barren reef zone would be uneconomical and affect the viability of the project. The difference in stoping widths close to the shoreline could lead to excessive tilts in the shaft barrel.

The Panvlakte and Waterpan fault systems lies further to the west and the mining out and destressing of these large faults was not feasible in a shaft reef extraction; thus the shafts had to be placed sufficiently far from these structures. The shaft positions, therefore, were geologically constrained by the 2 650m VCR reef contour, the shoreline, the overbank zone and the fault systems to the west, which places them firmly in the position chosen.

Seismic Hazard in the Shaft Reef Area

The design of the mining methods, backfill and pillars on South Deep was carried out so that, significant seismic events would be minimized. However, not all of the regional effects of mining can be quantified, and thus the effect and possibility of a reasonably large event in the vicinity of the South Deep shafts was assessed.

DESIGN CRITERIA

Shaft movements

The extraction of shaft pillars in the South African mining industry has led to the creation of a considerable data base on the criteria to prevent damage to the various aspects of shafts, i.e. lining, steelwork and barrel (McKinnon, 1988). The criteria for stability of shafts derived from this data base are shown in Table 2.

The relationships between actual damage and a damage criteria are usually empirical and may not be directly related to the mechanism of failure. In addition, most of the criteria have been derived from analysis of older shafts, which have sustained damage through over extraction or under design of their shaft pillars. Back analysis of these cases provides various criteria of strain and stress, which seem to be associated with damage to shaft barrels, linings or steelwork. Certain workers have utilized criteria, which result from direct calculation of the strength of lining, for example the maximum permissible vertical strain, which the concrete used, can accept, to which a factor of safety is added. The lack of understanding of the failure mechanism of shaft linings make this a more hazardous procedure, as examination of failure type in failed shaft linings indicates that the mechanism of failure is not purely due to vertical strain, but a number of possibilities - including the generation of excessive hoop stresses by the horizontal strain generated in the unconfined rock of the shaft barrel by Poissons effect from the increase in vertical strain (Esterhuizen pers. comm., 1997).

In this design exercise therefore, it was decided to rather rely on the empirical experience of back analysis of failed cases, as this approach to a large degree accounts for the possibly complex mechanisms of failure. This had led to the selection of a conservative set of design criteria for the shaft stability. (McKinnon, Esterhuizen)

Thus Table 1 gives a conservative set of maximum values which, if exceeded will require additional measures to be taken to ensure the stability, operational reliability and minimal maintenance of the shaft systems.

Modeling Input Parameters

The empirically derived criteria chosen for the shafts have been back analysed by various authors using elastic boundary element type numerical modeling. To use these criteria the South Deep shaft movements had to be calculated using similar tools, i.e. the MINSIN W or the BESOL MS suite of programs. These programs allow the numerical modeling of large complicated tabular orebodies and the calculation of the rock mass response at any point or over any area in three dimensions.

The input parameters for the rock mass are as follows:

Youngs Modulus - 50 GPa
Poissons Ratio - 0.2

In order to determine an accurate stress tensor for the South Deep VCR area three sites were chosen for installation and overcoring of CSIRO strain gauge cells. Using strain relaxation techniques the total stress tensor was determined. The results of this exercise are presented in Table 1.

Table 1
Resolved stress values at 2 650m below surface

SZZ	***SYY***	***SXX***	***SYZ***	***SXZ***	***SXY***
71.49	64.53	43.40	-8.55	13.55	-8.29

The backfill input parameters are taken from the laboratory test work done in the preliminary stages of the project (COMRO, 1990) and subsequently ratified by the weekly test results on the backfill product as carried out by CSIR Miningtek; and also from laboratory tests carried out on the cemented classified tailings backfill (FOSROC, 1996). The backfill is modeled accurately as placed in correct sequence with the mining.

Numerical Modeling History

The numerical modeling of the shaft reef extraction has been repeated many times since the initial conceptualization of the South Deep project. Each succeeding modeling approaches closer to the actual situation, and this process will continue even after the shaft system

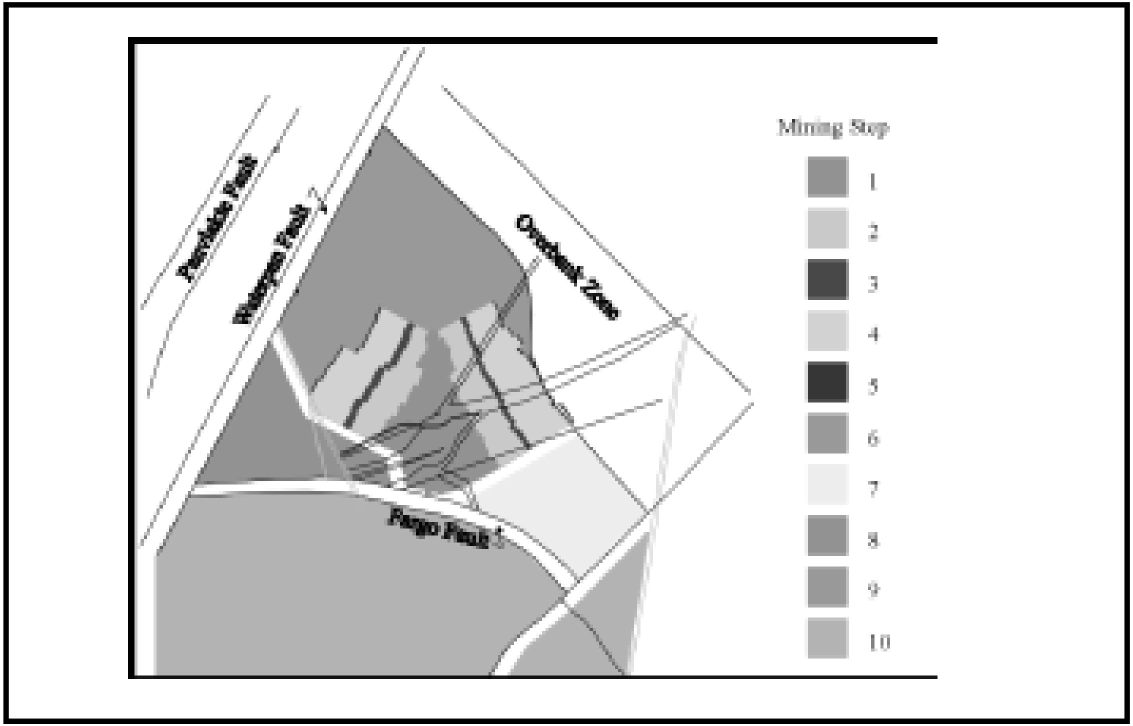

Figure 3

Modelled mining geometry

is completed, to predict shaft movements and ensure the overall stability of the system. In-situ backfill and closure measurements combined with off reef leveling allowed the ratification of the input parameters and the modeling methodology. The latest modeling thus has a high confidence value. It also takes into account the replacement of the crushed waste backfill by cemented classified tailing in the upper longwall and outside the 150m radius around the shafts is reached. Most importantly it considers the shaft sinking schedule as currently planned.

Shaft Sinking Schedule

Table 2 and Figure 4 indicate the key dates with respect to the rock engineering design.

Table 2

Shaft sinking key dates (Allan, 1997)

Event	Main Shaft	Vent Shaft
Reef intersection	September 1998	June 1998
Shaft bottom	June 1999	December 1998
Steelwork at reef intersection	April 2000	May 2000
Steelwork at shaft bottom	May 2000	August 2000
Commissioning	June 2000	October 2000

Predicted Shaft deformations

The results are presented in terms of the two critical design areas, the stability of the alternative concrete lining or shotcrete lining and the shaft steelwork requirements. Definite conclusions are drawn for the lining, however, the design of the shaft steelwork requirements falls outside the scope of this paper although the predicted deformation results are supplied.

Shaft Lining

The shaft lining requirements are based on vertical and horizontal strain deformation criteria. Where the residual strains in the shafts

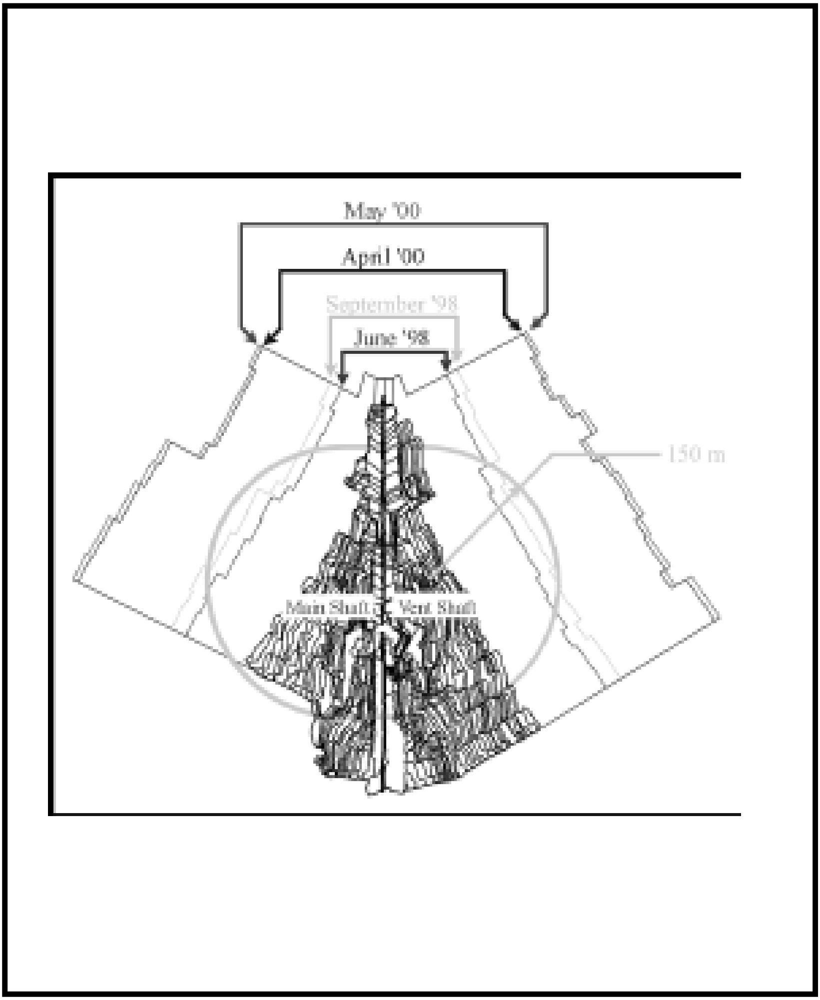

Figure 4

Mining geometry at key shaft sinking dates move outside the range - 0.2mm/m to + 0.2mm/m the concrete lining will have to be replaced by a high quality fibre reinforced shotcrete lining. Although conservative, the criteria above were confirmed by consultation with industry experts.

Figure 5 shows the predicted stress change and residual vertical and horizontal (dip parallel) strains, which will act on the shafts during their lifespan. The graphs indicate the final stress and strain states of the shaft lining at the end of the mining of the VCR blocks shown on Figure 4. Since the reef intersection dates of the two shafts are within three months of each other, the actual difference in residual strain between the shafts is minimal. The vertical strain exceeds the criteria from 2 310m to shaft bottom while the horizontal strain exceeds the criteria just above and below reef intersection and between 2 260m and 2 458m. The stress change exceeds the design criteria of 20 MPa within the area exceeded by the strain criteria.

A total length of 490m, from 2 260m to shaft bottom, requires a fibre reinforced shotcrete lining.

Shaft Steelwork

Steelwork design is based on the generally accepted criterion that strains exceeding the range - 0.4mm/m to + 0.4mm/m cause problems of varying degrees to shaft steelwork. These problems, depending on the orientation and magnitude of the induced strain, can be manifested as tight joints, buckling buntons or guides and in extreme cases jamming conveyances.

Figure 6 shows the residual vertical and horizontal strains, which will affect the steelwork during the life of the shafts. As the steelwork is planned to intersect the reef plane in both shafts within one month of each other the differences in deformation are negligible thus one set of results is presented.

The steelwork design must however cater for relatively small changes over a very long period of time, potentially for the next 20 years, rather than for rapid changes in the early stages of the shafts' lives.

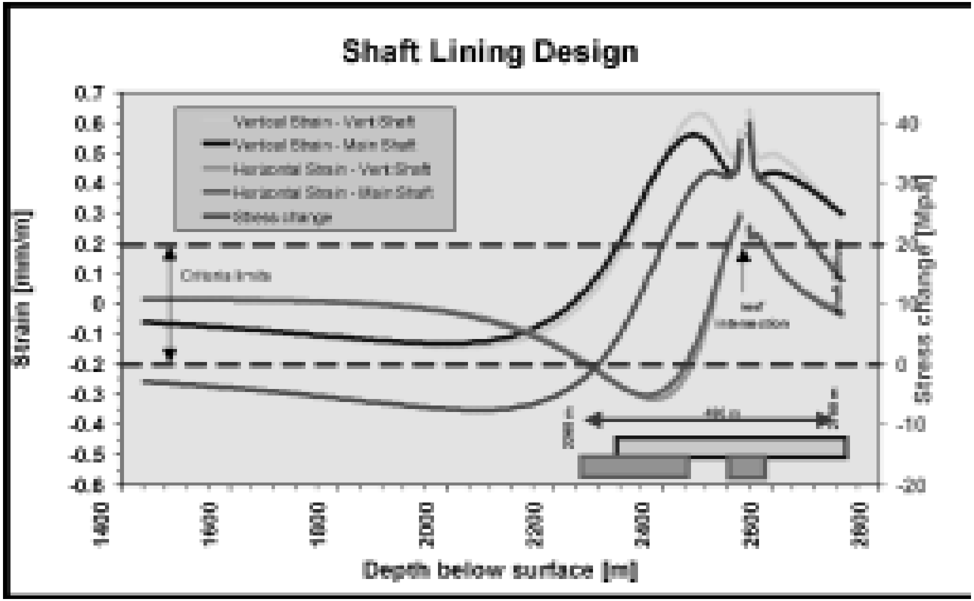

Figure 5

Stress change and residual strain for lining design

A comprehensive instrumentation programme using robust, easily maintained and read equipment will be designed to monitor the steelwork.

Table 3 indicates the residual reef plane displacements, which will affect the steelwork at each mining step following steelwork intersection with the reef plane.

Table 3
Residual reef plane displacements affecting shaft steelwork [in metres]

Step	Vertical		Dip		Strike	
	H/W	F/W	H/W	F/W	H/W	F/W
6	-0.0039	-0.0008	-0.0128	0.0180	-0.0027	-0.0109
7	-0.0026	0.0027	-0.0244	0.0149	0.0049	-0.0074
8	-0.0128	0.0003	-0.0363	0.0299	-0.0183	-0.0432
9	-0.0179	-0.0024	-0.0318	0.0455	-0.0150	-0.0404
10	-0.0233	-0.0032	-0.0356	0.0570	0.0117	-0.0176
Negative	*Downwards*		*Up dip*		*East*	
Positive	*Upwards*		*Down dip*		*West*	

The total deformations, which must be designed for, are as follows:

Closure (vertical)	2.01cm
Dip parallel shear	9.26cm
Strike parallel shear	2.49cm

Results of Modeling Exercise

As a result of the good correlation between numerical modeling and instrumentation results, a high degree of confidence can be placed in the shaft deformation predictions. The results are summarised as follows:

A total of 490m of the shaft are to be lined with fibre reinforced shotcrete as opposed to conventional concrete lining.

The reef plane deformation, which must be catered for in the design

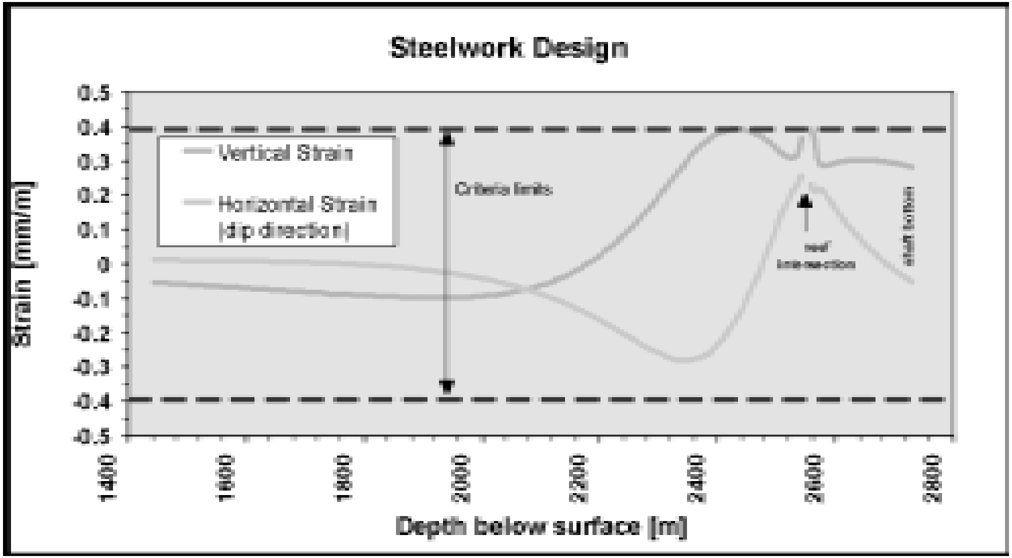

Figure 6

Residual strain for steelwork design

of the shaft steelwork, are relatively small. As such it seems that a suspended tower in the shaft will probably not be required and that the deformations can be accommodated using telescopic guides and an adjustable bunton arrangement.

The capability for adjustment of steelwork up to 180m above the reef plane should be included in the design to account for the strain reaching the design criteria of +0.4mm/m in some areas.

BACKFILL

Design

The use of CCT/Crushed Waste as backfill was initiated by the need for an extremely stiff backfill to limit closure in the shaft system, and the length of the unlined portion of the shafts and floating steelwork. Secondary considerations were to limit the ERRs in the VCR mining without the use of additional regional pillars and to reduce waste hoisting. To do this, within the planned mining and shaft sinking schedule, the backfill specification below was derived by Lieh (1989):

$a = 16 - 25$ MPa

$b = 0,2 - 0,23$

where a = stress value at half asymptotic strain ($b/2$)
b = asymptotic value of strain.

In addition the following factors were desirable:

- All under ground waste was to be used in the backfill. This will increase future hoisting capacity of the shaft.

- The material was to be transported and placed hydraulically, as this is the most cost effective and least labour intensive method for narrow tabular stopes.

- Drainage water was to be minimized.
- The use of classified tailings from WAGM was to be kept to a minimum, to reduce effects on the slimes dam and grouting.

The backfill plant caverns and installation were designed to accommodate the increasing backfill needs of South Deep as the mining of the wide reef ore body came on line.

Mixing and Supply

The backfill chosen to suit the above criteria was a mixture of crushed run of mine waste and classified tailings from Western Areas' Metallurgical plant.

The mine waste is trammed from development or waste passes, to the underground crusher station on 265 level where it is held in a 50 ton surge bin. It is then crushed and screened to -20mm by a primary jaw crusher and a gyrosphere (cone) crusher with double deck screens. The crusher plant operates at 100 tons/hour. It is then stored in a 1 000 t silo.

Classified tailings (cct) are pumped from the hydro cyclones on surface via a Pachuca to the underground cct storage dam.

The ingredients are mixed in proportions of crushed waste/classified tailings of 70/30 to 50/50, in a 30 cu m mixing tank. The mixing process is fully telemetered and can be manually batched or automatically continuously mixed.

The backfill is pumped, after a minimum mixing period of 22 minutes, using a GEHO hydraulically driven, horizontal, twin cylinder, and positive displacement pump. This has the capacity to pump backfill at 40 cu m/hr through 140mm ID pipelines. Relay pump stations are needed approximately every 600m along the pipe route.

The backfills produced by the above process have porosities of about 30% and thus the required stiffness; a= 16-20, b= 0.2-0.23 is readily achieved. The backfill remains hydraulic for up to 24 hrs. The shrinkage of the backfill once placed is only 2%, which minimizes the need to top up backfill bags.

In the stope the backfill is placed into 30m x by 5.8m backfill paddocks, installed on the face and supported by hydraulic props and HDPE blast barricades.

The placing backfill in paddocks as an activity divorced from the normal mining cycle was initiated as a solution for the unanticipated problems experienced with changing over pipelines and non-continuous pumping of the backfill.

Planned modification to the plant and system

A project team looked at the overall needs of WAGM South Shaft and particularly South Deep to take a wider look at the solutions to the problems so far encountered. From this a series of modifications both to plant and strategies have followed:

Stiff backfill was still planned to be used for most of the VCR shaft reef area. However, cemented CCT is to be used in the massive cut and fill and second cut mining. CCT will also be used in the upper part of the VCR longwall. Other areas of VCR will also be mined with CCT backfill.

The Impact on Backfill Developments on Mining

With a very few exceptions in the early phases, the longwall faces have been restricted from advancing more than 10m ahead of backfill, and are also restricted from leading or lagging by more than 6m. This has had some delaying effects on face advances. This may however have been exaggerated as close examination of the rates of advance of development infrastructure, which is not affected by backfill shows that this had been delayed to a similar extent largely by the difficult and undeveloped logistics infrastructure of South Deep.

The inability of the current backfill placement system to place backfill above panel 10 (figure showing panels) has definitely affected the gold production. To alleviate this, the affects of placing a fill cem

- cemented classified tailings in the panels 11 - 15 east and west, were numerically modeled and approved to alleviate the time pressure to stope out the shaft reef prior to reef intersection and financial pressures

Despite the problems described above, the entire stoping area of South Deep has maintained an aerial percentage fill of over 60% since a few months after mining began. The percentage of fillable area (i.e. excluding raises, gullies and faces) filled has consistently been above 80%.

The WAGM South Deep section is the only SA gold mine, which has achieved and maintained this percentage filling from the start of mining in a new shaft area.

In addition, the crushed waste - CCT mixture fill is new to the industry and as far as the authors are aware, South Deep is the only SA mine to maintain production and consistently mine and place a stiff backfill at this scale.

The research being carried out by JCI Ltd in this field may well have benefits for ultra deep mining and wide orebody mining at depth.

In addition, regular Rock Engineering audits show that mining conditions in the backfilled stopes are measurably better than in the shallower un-backfilled VCR stopes on WAGM South Shaft.

The benefit of stiff backfill is also corroborated by the low levels of seismicity experienced in the longwalls and by the reduced closure in the stopes.

MINING CONSIDERATIONS

Stoping Method

The mining of the shaft pillar is done as a conventional narrow reef longwall. A primary raise was established, running through the centre of the pillar in a North-South direction. A longwall face, consisting of 14 panels each, approximately 30m long was established on either side of the raise and mining proceeded from the raise towards the East and West.

The southern portion of the stoping has progressed faster than the northern portion due to backfill placement delays and mining sequence. The longwalls have been split into two mini-longwalls, on both the East and West sides, from the tenth panel.

Normal longwall follow on development has been established towards both the East and West, on 93 and 95 Levels.

Logistics

Communications

The shaft pillar area is situated 3,5 kilometres from the SV3 shaft complex from where it is serviced with regards to men and material as well as the hoisting of ore and waste. All services as well as all transport are presently being provided for in the single track Main Intake Haulage (MIH). To enable the rolling stock to function effectively, it was imperative that a communication system be installed that would enable the loco drivers and supervisors to optimise the movement of men material and rock.

After investigating different systems in use within the industry both nationally and internationally, it was decided to install a system operating on the UHF band.

All the loco drivers on a specific shift are issued with radios from a central control room where operations are monitored and controlled throughout the shift.

The system is controlled to the extent that the loco drivers can communicate with the control room only, whilst supervisory personnel can communicate with the drivers and the control room.

A further extension to the existing system has enabled supervisory personnel to phone other personnel on surface via the Leaky Feeder system.

Subsequent to the installation of the system, a dramatic improvement was noted in the total logistic system on 95 Level.

Material Transport

All material cars are booked to a specific "central loading point" (CLP) underground after being loaded.

These CLPs are situated centrally to specific working areas. On the arrival of the material cars underground the cars are grouped together according to the specific CLPs for which they are intended, and transported accordingly.

Passive transponders will be attached to all the material cars in the near future, which will enable the operator in the control room to report on the status and position of material cars at any time.

Transfer and Tramming of Rock

The rock broken in the shaft pillar is transferred to either 93 Level from where it is cross trammed and tipped in an internal tip system to 95 Level, or directly to 95 Level from where it is trammed to the SV2 shaft system 3,5 kilometres away.

Logistical Constraints

The major constraint in the extraction of the shaft pillar is in the logistics system required to supply the longwall with men and material. The longwall spans a vertical height of 150 metres between 95 and 90 Level elevations and a backlength of 470 metres. All access is from the lowest point, on 95 Level.

Access is achieved via a chairlift and a material incline to 93 level and traveling ways from 93 Level to the stoping horizon.

An haulage is currently being developed on 90 level to provide a top access to the pillar longwall, which will alleviate some of the constraints. The Return Airway on 95 Level is currently being tracked in order to provide an improved logistical service to the South Deep operations.

Additional clear water dams and booster pumps have been installed on 93 Level to ensure a reliable and adequate supply of water to the top of the longwall.

Ventilation and Refrigeration

Intake and Return Airways

The VCR longwall is ventilated by the 95 Level twin haulage system that connects the working place with the SV2/3 shaft complex. The twin haulage system consists of a Main Intake Haulage and a Return Airway through which all ventilating air passes.

Ventilating air enters the top and the bottom of the stope and is collected and returned to the return airway by a raisebore hole located centrally in the back area of the stope. (see Figure 7)

Refrigeration Supply

Cooling is supplied to the South Deep Section by a refrigeration plant located on 80 Level in the SV2/3 shaft complex. The plant supplies chilled water that is used to run cooling cars located at strategic points in the section. This allows the re-use of air and the maintenance of acceptable environmental conditions in the working places.

CONCLUSION

To date 60 per cent of the shaft pillar has been successfully extracted. The pre-extraction of the South Deep Shaft Pillar has been proven to be a viable project that will provide long-term benefits to the

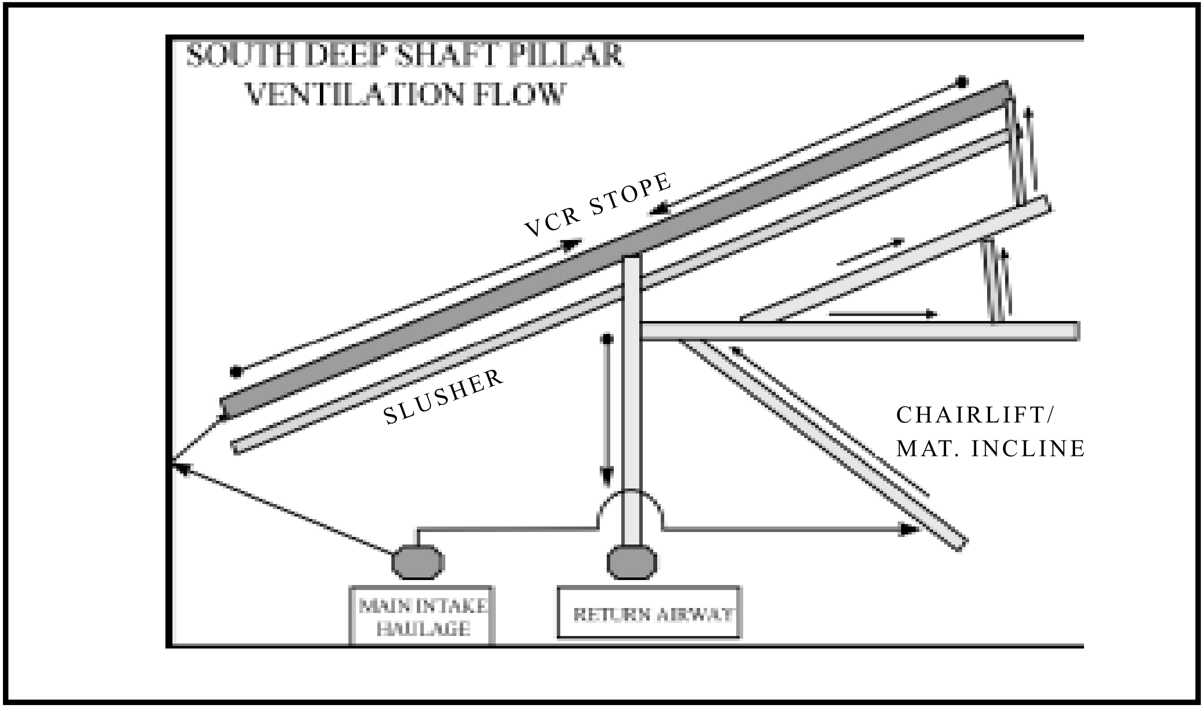

Figure 7
Schematic Ventilation Flow

mining operation as a whole over its life.

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