Shaft Pillar Extraction as Experienced at Western Holdings Mine

DV STEYN
Assistant Mine Manager
Western Holdings Mine

SYNOPSIS

The process of shaft pillar removal is normally viewed as the final operation prior to shaft closure. The experience at Western Holdings Mine has been that there can be life after shaft pillar removal provided a professional approach is used. This paper attempts to highlight all the critical issues identified that could turn a shaft pillar extraction programme into a success or failure. The critical issues related to the business of realising a return on investment and management of risk is covered in detail.

Preparatory work prior to the commencement of stoping is the cornerstone of a successful extraction program. Sufficient lead-time must be allowed to ensure timeous completion of the preparatory activities in the prioritised sequence prior to the start up of stoping.

Shaft pillar extraction naturally forms part of the business plan of the shaft. The motivation to proceed with the shaft pillar extraction process is invariably found in the potential financial gains. A late start with the pillar extraction process, which is traditionally planned at the end of the life of a shaft, could result in unnecessary financial losses being suffered on a shaft prior to full production from the shaft pillar extraction programme.

The potential to go into a loss-making situation prior to full production from the shaft pillar makes the timeous start up of critical preparatory work essential. Mistakes with premature start up of stoping, prior to the completion of the necessary support work of the shaft barrel, secondary excavations and moving of critical services, can lead to irreparable damage to essential infrastructure and hence increase

the risk. It is thus also essential to time the start of the project from a cash flow point of view.

The experience with shaft pillar extraction at Western Holdings has been that the shaft barrel could be maintained in an operable condition. Shaft pillar extraction could thus be considered prior to the end of the life of a shaft provided that the risk to infrastructure has been identified and appropriate action taken to eliminate it and provided that it is advantageous to the cash flow of the operation.

The diligent application of sound rock engineering principles is paramount to the success of a shaft pillar programme. Rock engineering experience and the involvement of industry experts to critique the layouts and mining strategy at an in-house workshop on shaft pillar extraction at Western Holdings Mine was found invaluable.

INTRODUCTION TO WESTERN HOLDINGS MINE

The shafts on Western Holdings Mine date back to 1948. The mine as it is structured today is made up of shafts from the original Welkom, Western Holdings and Free State Geduld Mines. Figure 1 shows a locality plan of the Gold Mines of the Free State Goldfields. The Basal reef has been extensively mined and the payable Leader reef resource has essentially been exhausted. The main focus currently on Western Holdings Mine is on pillar extraction with limited face length available for mining. The resource in shaft pillars has become a major source of income on most of the shafts on Western Holdings Mine where the shaft pillar has not already been extracted.

Planning for shaft pillar extraction started in 1984. The Number 6 Shaft of Western Holdings Mine was planned to be the first pillar for extraction. Actual stoping of this shaft pillar commenced in February of 1991 and it was completed in September 1995.

The status with shaft pillar extraction on the mine as at February 1997 is as follows:

The mine has nine operating shafts. Three shaft pillars have already

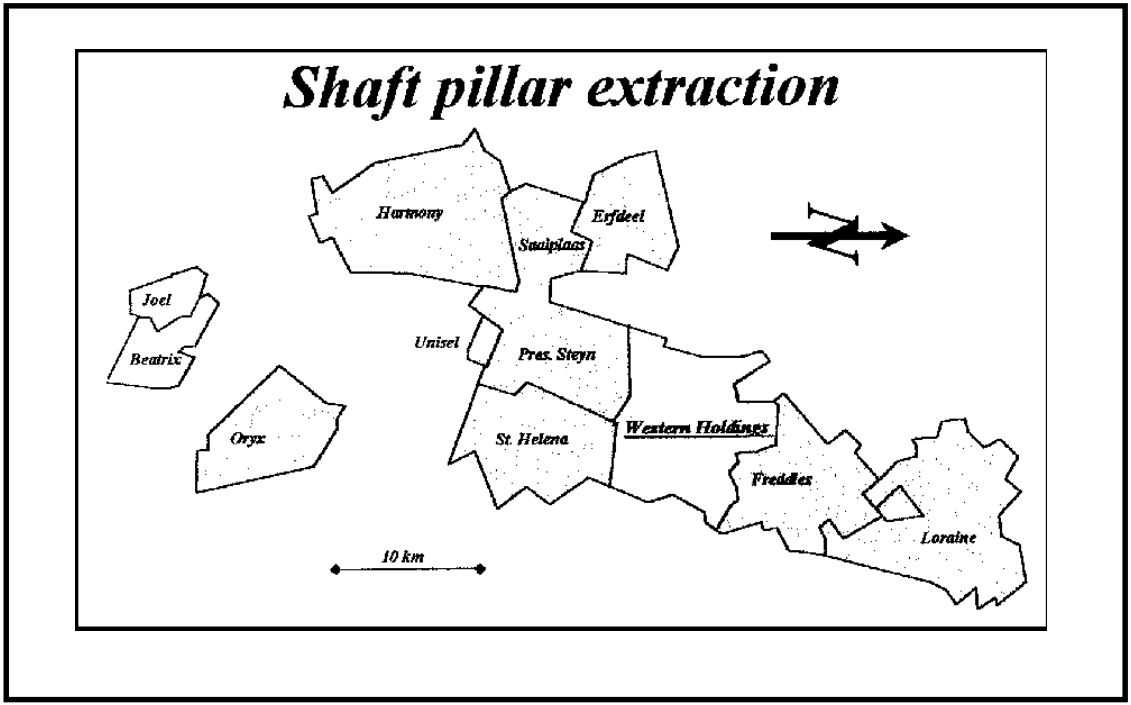

Figure 1

Area plan of the Free State Goldfields

been extracted, three are being stoped at the moment, one is in the preparatory phase for pillar removal to commence in 1998, one is in the planning phase and one shaft pillar will not be mined due to the financial and safety risks involved.

No. 1 Shaft

A rectangular, unlined, partly steel and timber equipped shaft. Pillar extraction is in the planning phase. Preparatory work has started in the shaft barrel and access ways with shaft pillar stoping planned to start in 1999.

No. 2 Shaft

A rectangular, unlined, partly steel and timber equipped shaft. Shaft pillar extraction has been completed in 1996. The shaft does not have sufficient payable reserves to continue mining following completion of the shaft pillar program. The shaft is due for closure in 1997. It will however be kept open on a care and maintenance basis as a second outlet for No. 1 Shaft.

No. 3 Shaft:

A rectangular, unlined, partly steel and timber equipped shaft. The shaft is still in operation. The resource in the shaft pillar is of low and inconsistent grade and will not be extracted from a financial and safety risk point of view. The shaft pillar is adjacent to a major geological fault component. The fault has a known history of seismicity.

No. 4 Shaft

A circular concrete lined shaft equipped with steel buntons and guides. The shaft is not equipped to hoist ore to surface. It is dependent on No. 5 Shaft to hoist its ore to surface. Shaft pillar extraction is approximately 55% complete. The pillar is extremely seismically active. The planned completion date for the shaft pillar extraction programme is the first quarter 1998.

No. 5 Shaft

A rectangular, partly lined and partly steel and timber equipped shaft. Partial extraction of pay portions of the pillar has been completed. The inner pillar has not been removed. The pillar is extensively faulted. Selective mining of the pay zones cannot be done without affecting the stability and integrity of the shaft barrel. Large areas of unpay have to be mined with the payable areas which cause full pillar extraction to be a financial risk. Significant stability problems were experienced with the shaft barrel even whilst mining up dip of the shaft barrel and outside of the traditional shaft pillar boundary as a result of stress changes in the shaft barrel in a weak rock zone.

No. 6 Shaft

A rectangular, unlined partly steel and timber equipped shaft. Shaft pillar extraction has been completed in 1995. The shaft barrel has remained stable and pillar mining outside the shaft pillar area is continuing using contractors.

No. 7 Shaft

Circular concrete lined and steel equipped shaft. Shaft pillar extraction has been completed successfully in 1995. The shaft is in operation and stable after completion of the shaft pillar removal programme. Pillar mining outside the old shaft pillar area is continuing.

No. 8 Shaft

Rectangular, unlined steel equipped shaft. The preparatory work for shaft pillar extraction started in 1995. A considerable amount of work is required to properly secure the shaft barrel prior to commencement of stoping in the shaft pillar. Inner pillar stoping is due to commence in June 1998 following the completion of shaft rehabilitation.

No. 9 Shaft

Shaft pillar extraction is in progress. Approximately 70% of the shaft pillar has been removed to date. The pillar is extensively

faulted making mining to a set sequence difficult. The major fault components however act as stabilising pillars, which are limiting the closure in the shaft barrel. Seismicity has fortunately not been a problem to date.

PURPOSE OF SHAFT PILLARS

Shaft pillars are designed to secure the stability of service excavations such as the shaft barrel, main ore pass system, sub-shaft hoist chambers, pump and refrigeration chambers and dams etc. This is achieved by leaving a sufficiently large pillar intact to ensure tolerable stress levels that would not cause the aforementioned excavations to suffer strata control difficulties due to stress changes in the pillar area over the life of the mine.

The design criteria includes an evaluation of all the excavations required in the pillar area, its position in the pillar relative to the shaft in the horizontal and vertical plane as well as relative to the reef which is planned to be mined (i.e. middling). The vertical and horizontal field stress components are determined for different dimensions of the shaft pillar and in which the service excavations will end up when stoping around shaft pillar has progressed beyond the critical span.

Shaft pillar dimension requirements increase with the depth of the reef below surface. Shaft pillars become impractical in deep level mining due to the size requirements of these pillars. The virgin or primitive state of stress could already approach levels at depth that could cause serious strata control difficulties. Small increases in stress levels above the primitive stress level become significant at depth where the normal UCS applicable to Witwatersrand quartzites apply. The stability of service excavations is invariably at risk when stoping takes place around the shaft pillars at these depths.

The current trend is to remove the shaft pillar early in deep level mines and thus develop and leave the service excavations in over/ under stoped ground and thus effectively de-stressed. The stress levels in the shaft pillar will then theoretically not exceed the original

primitive stress levels at that depth when the pillar is removed prior to the establishment of the shaft infrastructure.

A good example of such a project is Vaal Reefs No. 11 Shaft (MOAB), where the traditional shaft pillar was removed from a neighbouring shaft (Vaal Reefs number 8 Shaft) prior to the shaft being sunk through the reef elevation. The author of this paper was fortunate to be responsible for this project at Vaal Reefs Mine from the development phase through to final extraction of the shaft pillar. The reef was stoped out at a controlled stoping width and totally backfilled before shaft sinking reached the reef horizon. This was made possible due to access to the area from the neighbouring No. 8 shaft.

The future direction with ultra deep mines could include the sinking of the shaft to just below the reef intersection and then first stope out the shaft pillar with the least amount of development prior to continuing with the shaft sinking process.

GEOLOGY

The starting point in the shaft pillar extraction process is thorough interpretation and analysis of the geological structure. This is critical as the identification of mining blocks and decisions on mining layouts are dependent on accurate structural details.

The collation of structural data includes details on the following:

- Faulting

  Details on location, strike direction, dip and throw together with sympathetic faulting.

- Intrusive bodies

  The same information required as for faults with the added need to identify sills as well. Sills could seriously affect the support strategy due to strata control difficulties that could be experienced due to its existence. Knowledge on the thickness

of the intrusive bodies is important as it affects mining strategy.

- Attitude of the ore body and geological structures

- Cut-off positions and intersections of the ore body in existing and envisaged future development ends

- Characteristics of the immediate hanging wall. This includes detail on cross-bedding occurrences, strata layer thickness, and the presence of shale and rock hardness (UCS) of individual strata layers in the hanging wall and footwall of the reef.

- Diamond drilling

  Diamond drilling results form a key source of information towards the understanding of the geological structure of the pillar. The available diamond drilling information should be re-interpreted to ensure the most accurate representation of available data.

  Uncertainties with the geological structure should be augmented with a full diamond-drilling programme. It has been found that development and specifically prospect development could prove extremely costly and furthermore result in major strata control and support problems once developed in the wrong position. It pays to spend money on diamond drilling to accurately determine reef and structural cut off points as well as reef elevations. This allows for optimum layouts that will make the pillar mining process a lot easier.

  Figure 2 shows the completed geological structure plan on which the design for the pillar extraction programme of Number 5 Shaft was based.

The sedimentological data which need to be confirmed include the following:

- Detail on the reef facies;
- Appearance of mineralisation;

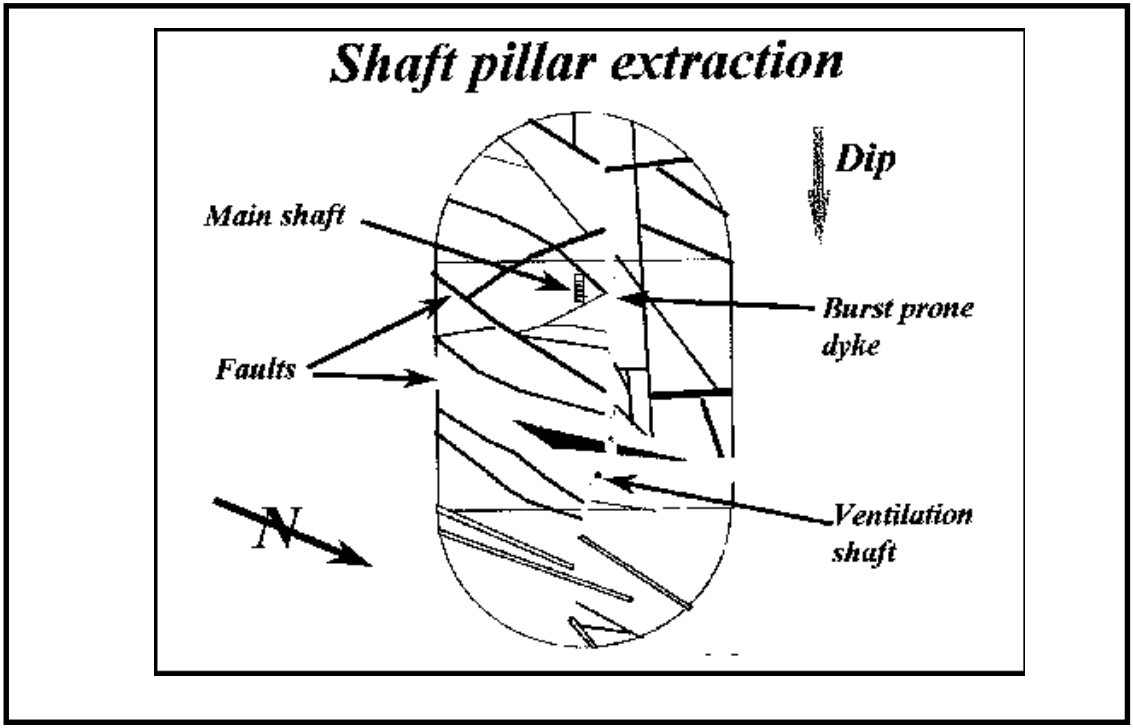

Figure 2

Geological structure of No. 5 Shaft

- Thickness of the immediate hanging wall and footwall strata layers of the ore body. This is particularly important from a support design point of view.

Critical rock engineering facilitation detail from the geologicalinterpretation of the pillar includes the following:

- Geological structures through the shaft barrel as this could have a detrimental effect on the stability of the barrel if potentially unstable features are not identified timeously for contingency actions.

- Identification of potentially unstable blocks and wedges of rock in the shaft barrel particularly in rectangular and unlined shafts.

- The position of the reef intersection or intersections in the shaft barrel. This is important as waste cut requirements to prevent stress bulbs in the shaft barrel could result in the decision to do the inner pillar on a second reef band.

- The identification of weak UCS strata zones in the shaft barrel and its position relative to the reef horizon. This is important, as stress changes due to stoping have been found to result in deterioration in the shaft barrel in weak strata zones, which negatively affected the stability of the shaft barrel.

  Figure 3 shows a section through the barrel of Number 5 Shaft highlighting the weak "Main Bird" series approximately 100 metres above the reef horizon. Extensive scaling has been experienced in the Number 5 Shaft barrel in this area.

- Mining blocks to be delineated from the structural analysis on the plans prepared. This is important as mining boundaries will be established from this and development layouts designed from this information. Good information is critical, as it is important to adhere to strict mining sequences for individual blocks. Poor information results in disruptions to mining sequences as development is delayed and or stoping disrupted

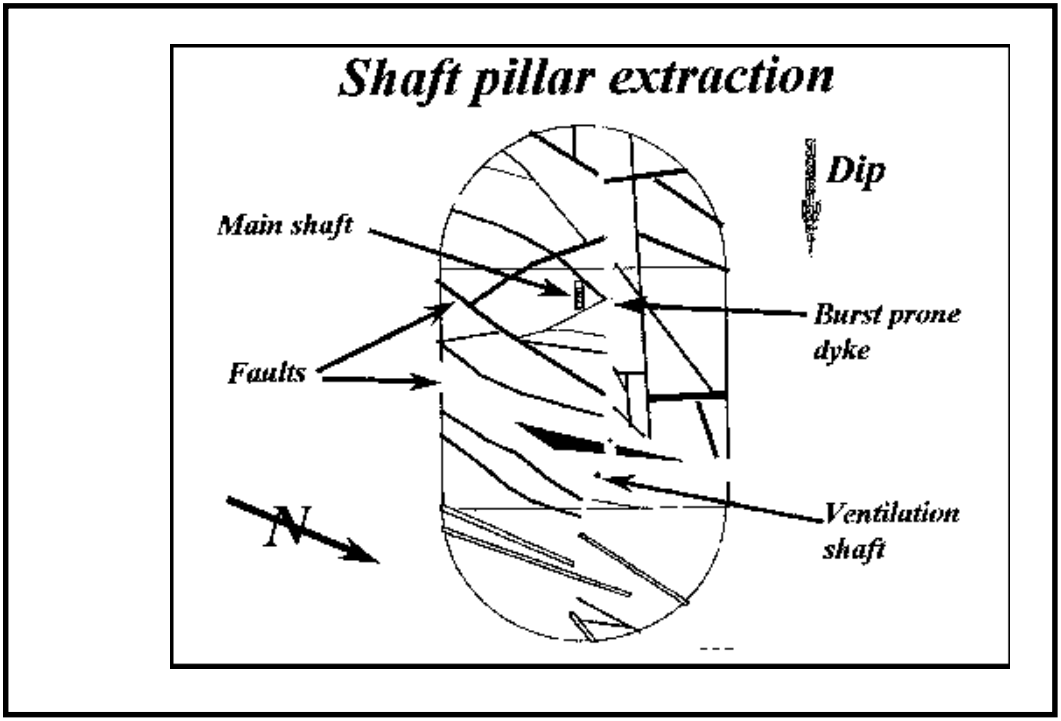

Figure 3

Weak strata zones in the barrel

due to unknown geological disturbances.

All development should be mapped for availability of information that could influence the interpretation of the structure.

It has been found advantageous to use models made from the structural plans to assist with the understanding of the structure and also to highlight anomalies that have not been identified on the plans alone. An alternative to this is 3D modelling (CAD), which was done on the Number 9 Shaft pillar after shaft pillar extraction had already commenced. This pillar is extensively faulted with significant throws on major fault components. The 3D modelling assisted greatly with the understanding of the structure and with the identification and delineation of blocks, which had previously not been known to exist.

RESOURCE VALUATION

Reef mapping and sampling of the areas peripheral to the pillar together with reef intersections in development and the shaft barrel are important sources of information towards arriving at an estimated grade for the pillar. Value trending is important as the location of unpay zones if present could be critical to the financial viability of the project. This is particularly important if vast areas of unpay have to be mined to ensure stability of the shaft barrel and other critical service excavations.

Sampling results from stoping peripheral to the shaft pillar need to be extrapolated into the pillar area. Re-sampling should be done where confidence levels are low wherever this is practically possible and especially where the grades are marginal. Sampling records of the area peripheral to the shaft pillar invariably date back many years to when the mine was started. Dependable records could be a problem.

Values, which have been calculated from diamond drilling, have been found to be unreliable in carbonaceous reefs due to carbon wash out. Over valuation of areas from diamond drill core sampling has also been experienced in carbonaceous areas. Pay and unpay

areas must be delineated on a plan that should fit on top of the structure plan.

A value contour plan is the end result of the sampling process. This plan is essential in the determination of payability of individual mining units together with the geological structure plan.

Total extraction of the shaft pillar might not be planned where the pillar resource has unpay areas. The mining of some unpay areas may however be necessitated to de-stress critical excavations and to prevent stress bulbs in the shaft barrel. The value contour plan together with the structure plan becomes an invaluable tool towards determining the potential extent of mining in individual blocks in the pillar and the revenue that would be generated from mining these blocks.

Mining limits are established by combining the information from the geological assessment, the value contouring, the identification of practical mining blocks combined with the payability of these blocks and Rock Engineering limits. The percentage extraction in the pillar can now be determined and the cost and revenue estimates compiled.

Refer to Figure 4 for a "Value Contour Plan" of Number 5 Shaft. This is a typical example where the total resource in the shaft pillar was not profitable to mine. Pay areas in close proximity to the shaft barrel had to be left due to the extent of unpay mining (both low grade and waste mining) that had to be done along with the pay areas to effectively destress the shaft barrel and other essential service excavations. Figure 5 shows the area that could be mined profitably as a mining unit without having an effect on the stability of the shaft.

ROCK ENGINEERING ASPECTS

The structural information from the Geology Department is essential before any meaningful work can be done by the Rock Engineering discipline.

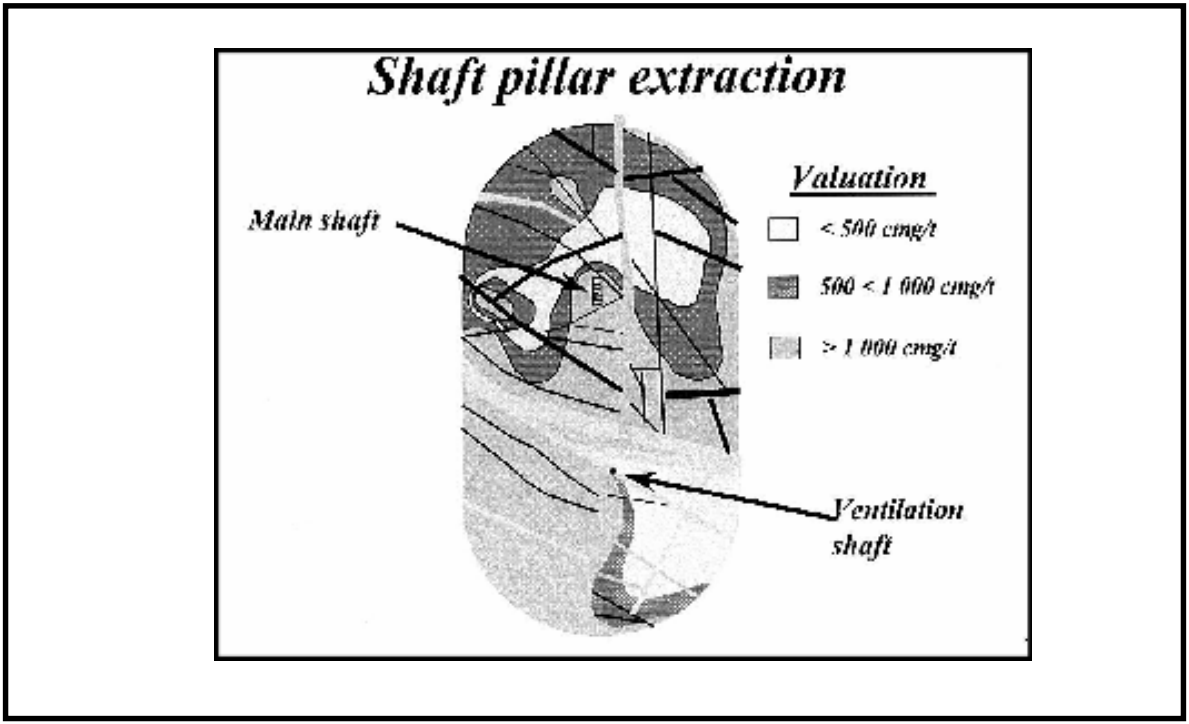

Figure 4

Value contouring No. 5 Shaft

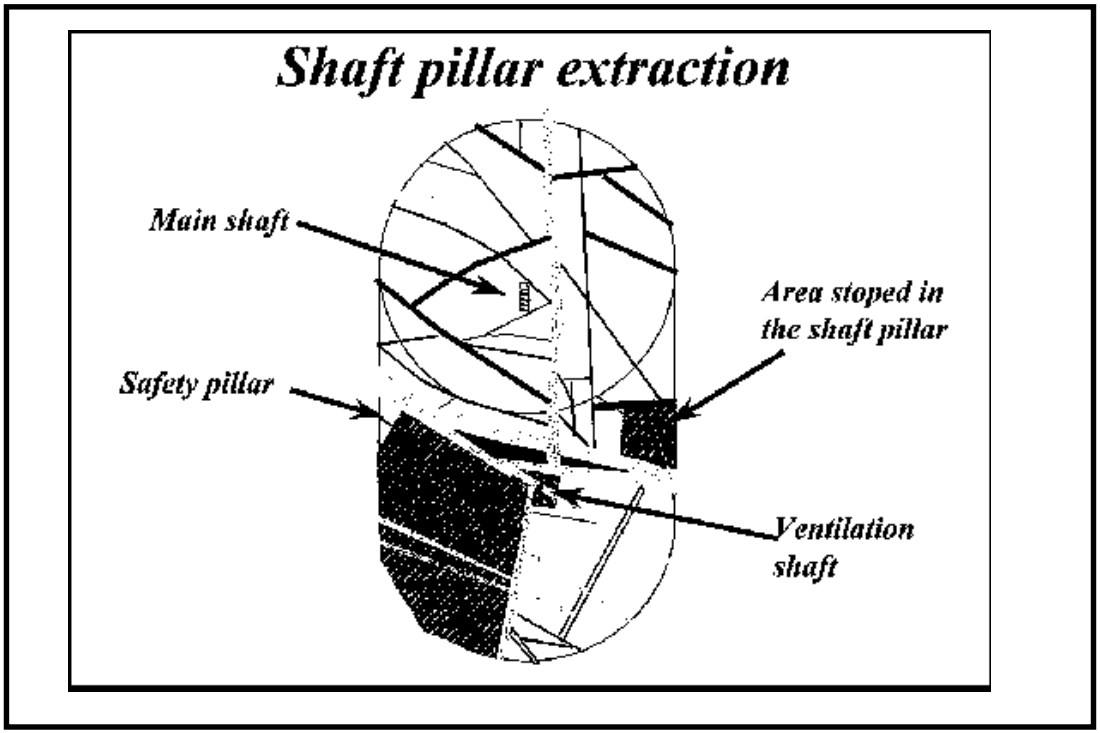

Figure 5

Mining limits No. 5 Shaft

Computer modelling is used to simulate alternative mining sequences and determine the induced stress levels caused by these different mining strategies. Knowledge of the rock types is important for accurate assumptions of key factors used such as Young's Modulus. The answer lies not in the exact stress levels from a specific mining sequence but in a comparison of the stress levels and stress peaks and its locality when comparing the different mining alternatives.

The information from computer modelling includes details on elastic ground movement both horizontally and vertically. This is required for the engineering design of yielding shaft steel work in the shaft barrel, which should allow for the closure across the reef plane. It also supplies detail for the design of support requirements in the shaft barrel as well as for the on and off reef excavations.

The practical experience has been that the majority of the movement takes place during the stoping of the inner pillar. It supports the need to place the backfill in the inner pillar during the stoping of the inner pillar to get the benefit from the fill when it is required.

Experience has also shown that strata control problems could be expected where there was an induced stress of >13 MPa as determined from the computer modelling.

The following is important when doing the computer modelling:

- Use E.S.S. (Excess shear stress) for modelling purposes;
- Know the assumptions made and use proven factors wherever possible;
- It is better to be conservative in shaft pillar removal programmes;
- Re-modelling should be done when structural changes have been identified.

All of the above design criteria are dependant on the mining sequence opted for. The stress levels and areas affected by stress changes during the extraction process are related to the mining sequence. The optimum mining sequence needs to be determined from a comparison of the alternative sequences modelled.

The following aspects are important in the design of a shaft pillar extraction programme:

Protection of service excavations, access ways and shaft stations

The identification of excavations that will be subjected to initially increased and eventually decreased stress levels due to the over or under stoping sequence are important for the timeous conclusion of support recommendations. The sequence of the over stoping process is as important as the support recommendations. Time dependant failure of the rock is a reality to be appreciated and over stoping could result in significant damage to excavations.

The support recommendations are required to secure the excavations for use as part of the pillar extraction process. It is important to keep as many avenues open as possible since failure of some access ways will invariably occur. A critical aspect to support of the excavations is the timing or sequence of the support work. Support crews invariably go for the easier areas where they can achieve good metres. The most critical areas requiring support are however mostly the more difficult areas that are highly fractured and where it is difficult to get good progress.

It is important to have management systems in place that will assist in the control of the sequence and progress of support work according to a priority list based on criticality. The answer lies in perseverance to conclude the more difficult support areas. Failure to do so will lead to a loss of the infrastructure and the need to redevelop alternative access ways or service excavations. This could delay the extraction programme and could also be practically problematic.

The shaft stations are mostly lined with bulk concrete. The concrete becomes a risk once stoping commences in the shaft pillar due to both compressive, tensile and shear failure. It has been found necessary to do stripping of the concrete lining on the stations and then support the exposed hanging and sidewalls with grouted support tendons. Strategic cutting of slots in the concrete lining has also been found to work successfully on one of the shafts. Stiff concrete packs, which are pre-stressed with grout bags, have been found successful

in wide-open station areas where the need was identified to break the support spans.

Stope width

It is important to determine the stope width at which the shaft pillar can be stoped with relative accuracy. The stope width will determine the total vertical and to a lesser extent the horizontal movement that can be expected. The greater the stoping width the greater the closure that will occur.

The stope width should be kept reasonably constant. Point loading could occur affecting the shaft barrel if the inner pillar is stoped at a significantly lower stope width than the rest of the pillar. The zone directly adjacent to the shaft barrel could rather be stoped at a slightly higher stope width than the rest of the pillar.

The backfill requirement is affected directly by the stope width and the production level to be achieved in the pillar will thus be affected negatively by an increase in the stope width.

Final remnant planning

The planning of the final remnant or remnants is important. The protection of access ways, service excavations and the shaft barrel from increased stress levels, as well as from potentially major seismic events related to unfavourable mining sequences and final remnants, in close proximity to faults and dykes, is the most important.

Detailed analysis is required of the mining sequence simulations done on computer to arrive at the optimum plan. The boundaries of this plan must form part of the detailed mining strategy and business plan. Historical data of seismicity also plays an important part in the planning of the final remnant positions.

Contingency layouts

Risk assessment forms an integral part of the pillar extraction process. Infrastructure that will be at risk, and without which mining cannot

be concluded during the shaft pillar extraction process, must be identified in time to allow the completion of contingency layouts. Typical excavations include main ore pass systems where problems are anticipated, drain hole systems for dirty water handling in the shaft area and particularly those that pass through the reef horizon, ventilation raises in the shaft pillar area, dams, pump and refrigeration chambers etc.

The experience at Western Holdings has been that it is possible to stope through the main shaft ore passes without losing the system. The risk of losing it must however be considered to establish alternative systems in case it fails.

Investigation of all accessible excavations

A full investigation of all accessible excavations in the shaft pillar area is advisable. Plans will be old and it has been found that the plans did not reflect all the information of development that had been done in the shaft pillar. An explanation for this could be that people were not supposed to mine into the shaft pillar as was delineated on the plans. This was experienced at Western Holdings Number 4 Shaft where a stope holed into a raise which was unexpected with problematic results.

The following have been found necessary to replace prior to the commencement of the pillar extraction process:

Figure 6 shows the contingency layouts that were put in place at Western Holdings Number 4 Shaft

- Drain holes which pass through the reef horizon.

- Dams in close proximity to the reef horizon. Dam wall failure becomes a reality during the over or under stoping process.

- Ventilation raises going through the reef. Restrictions result in a loss of production affecting not only the shaft pillar but also mining outside the shaft pillar. It was found that most of these ventilation raises did not have any primary support

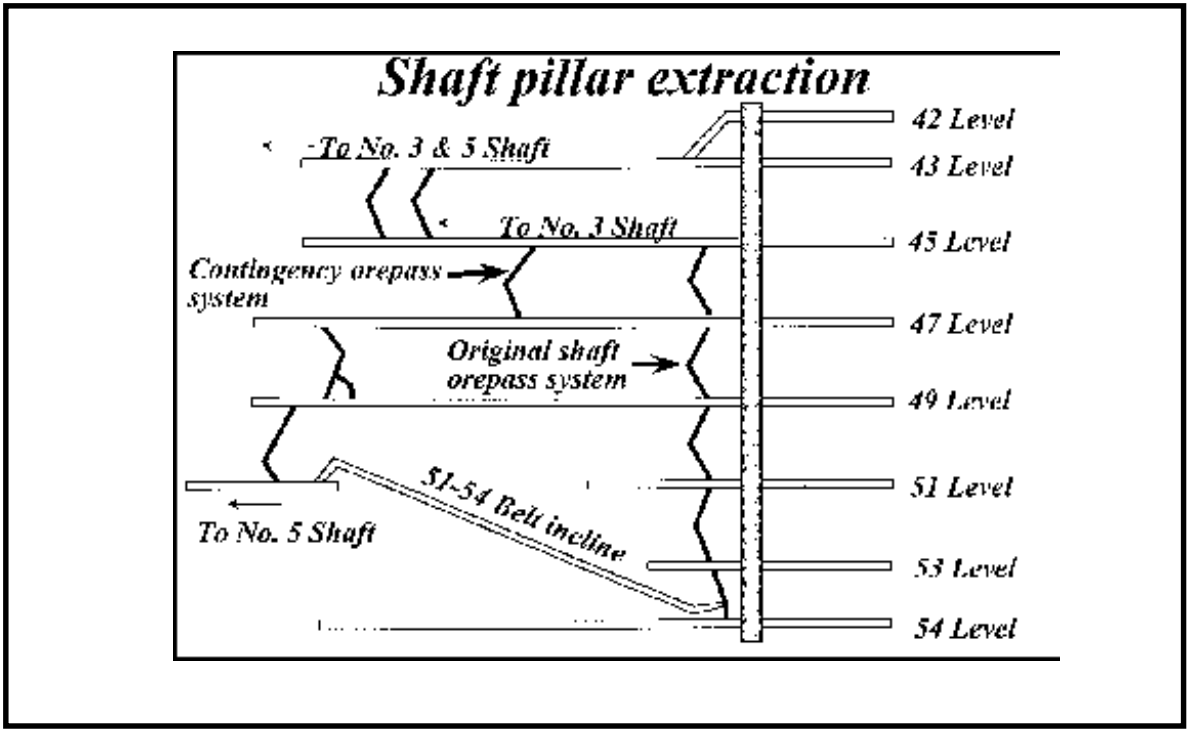

Figure 6

Contingency orepass layout No. 4 Shaft

installed. Weathering of the support on the return airside of mining activities has also been found to be a reality where it had been done previously. Re-supporting of the ventilation raises going through the reef horizon has been found to be extremely difficult due to the extensively fractured nature of the rock.

Maintenance of the ventilation raises is normally restricted to weekends. This delays the opening up process and results in increased losses of production. The opening up process requires the stopping of fans and refrigeration plants before temperatures are safe for people to work in these ventilation raises. Contingency layouts for critical ventilation raises are recommended where the same conditions are envisaged.

- Large service excavations such as pump chambers and refrigeration chambers in close proximity to the reef horizon. The timeous replacement of these excavations is as important as the actual decision to do so. A late completion of a R1,5 million pump chamber changeover at Number 5 Shaft left it stranded without water twice for up to three weeks after rockbursts. The rockburts could not be predicted before hand but failure of the abutments between the excavations was predicted and hence the decision to move the pump station one and a half years prior to actual failure.

Identification of waste cut requirements

The need to prevent stress bulbs that could affect the stability of excavations including the shaft barrel necessitates the stoping of some waste. The experience on Western Holdings Mine was that major faults or dykes were situated close to the shaft barrel with significant displacement of the reef. This necessitated extensive waste mining to prevent stress bulbs in the shaft barrel. See Figure 7 for a section through No. 4 Shaft showing the waste cut that had to be mined to prevent a stress bulb that could affect the stability of the shaft barrel.

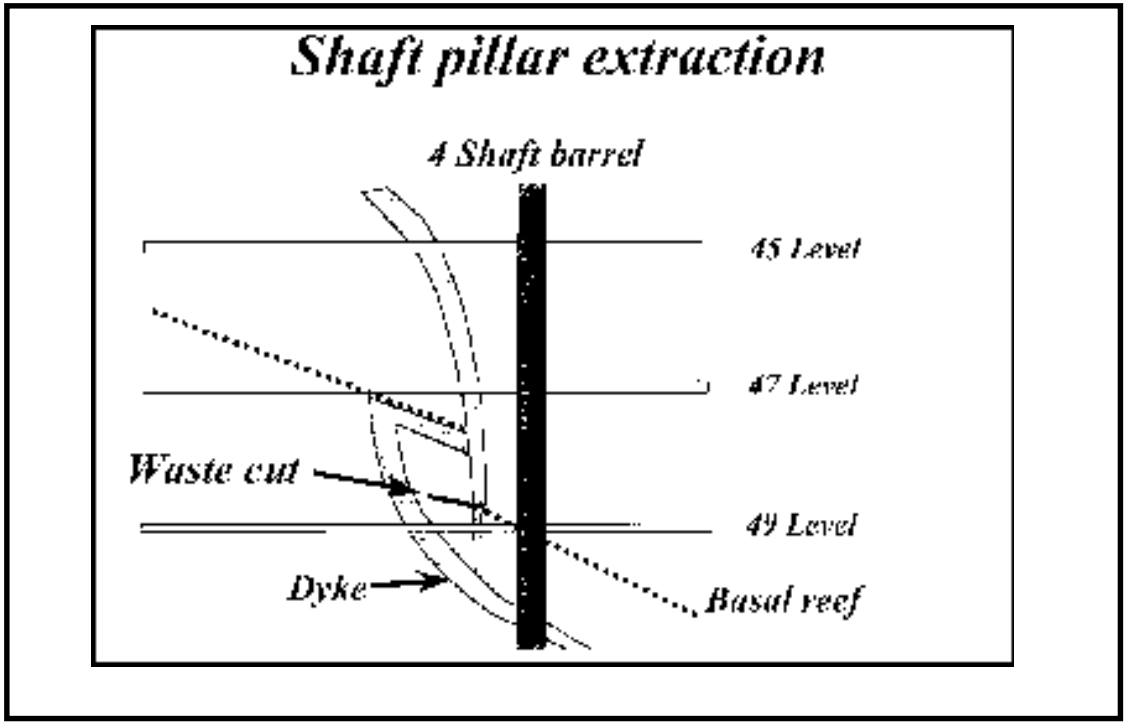

Figure 7

Waste cut to secure shaft barrel

Engineering design parameters for yielding shaft steelwork.

Computer simulation of the mining plan is important to determine the expected elastic components of both vertical and horizontal movement. The results from the computer simulation indicates the movement to be expected and at what elevation above and below the reef intersection in the shaft. This detail is used together with the estimated inelastic movement to determine the area in the shaft requiring additional support and where yielding support is required. It was found that a good rule of thumb was to double the calculated elastic movement when catering for the inelastic component. Changes to the shaft steelwork becomes essential where 0,4 millistrains is expected. Figure 8 shows the vertical strain in the shaft barrel for Western Holdings Number 8 Shaft determined from inelastic modelling.

One of the critical factors is the maintenance of a controlled stope width. This affects the effectiveness of the backfill to be placed which will influence the total closure to be expected in the shaft. The design of the backfill volume requirement is also influenced by the stope width.

Table 1 below shows the results from computer simulation on which the shaft steelwork design and support requirements were based for Western Holdings Number 4 Shaft.

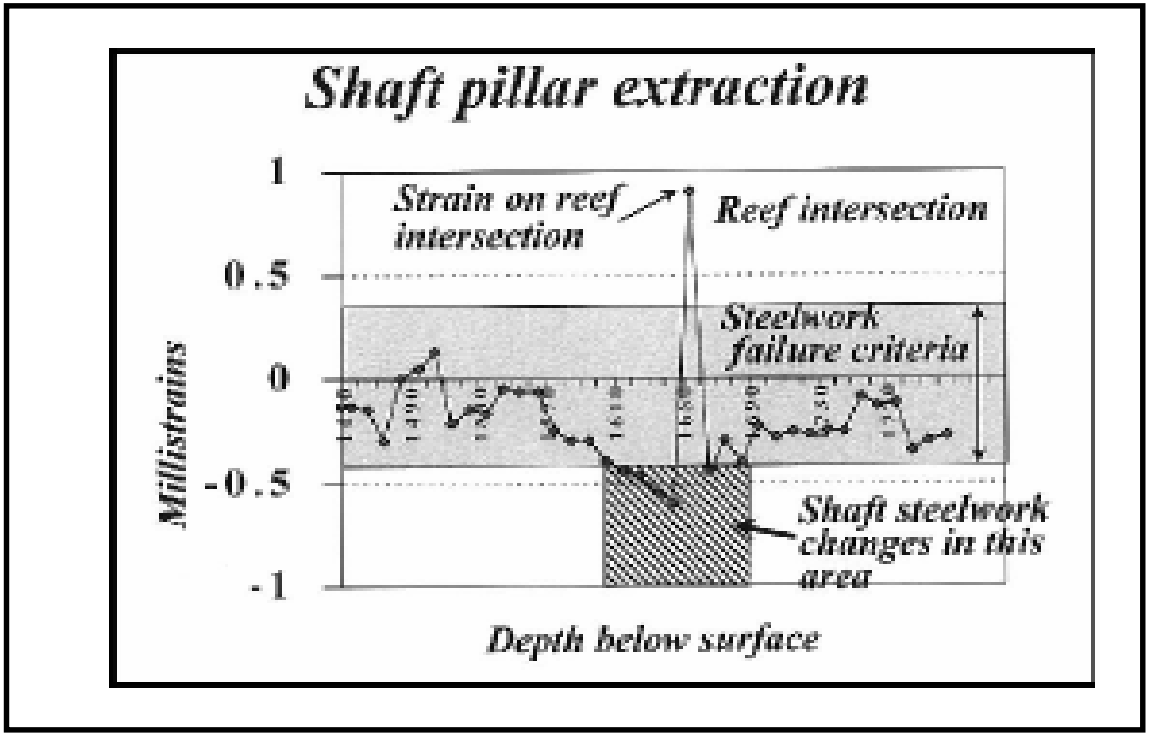

Figure 8

Vertical strain on No. 8 Shaft

Table 1

Expected elastic movement in Number 4 Shaft barrel determined from computer simulation of the mining plan.

Depth (BD)	Vertical movement (mm)		Horizontal movement (mm)			
	Down	Up	South	North	West	East
-1844	136	0	25	0	12	0
-1854	136	0	27	0	11	0
-1864	137	0	28	0	11	0
-1874	139	0	30	0	11	0
-1884	141	0	32	0	11	0
-1894	144	0	32	0	13	0
-1904	146	0	31	0	18	0
-1914	151	0	31	0	24	0
-1924	155	0	31	0	33	0
-1934	155	0	31	0	41	0
-1944	156	0	31	0	51	0
Basal Reef intersection						
-1954	0	180	0	29	0	6
-1964	0	176	0	24	0	9
-1974	0	172	0	20	0	12
-1984	0	168	0	15	0	15
-1994	0	165	0	13	0	18
-2004	0	161	0	10	0	21

Closure and stress meters have been installed in the backfill in the inner pillar area to assist with the assessment of the performance of the backfill support and to monitor the actual closure.

The effect of geological structures on the stability of the shaft barrel, service excavations and access ways

The geological structure plan must indicate where significant geological features traverse the shaft barrel and other excavations. It has been found that faults could cause unstable wedges in the shaft barrel once mining has commenced and that movement on these features had to be controlled by long anchor support. A second important point is to install instrumentation across these features even if it

is only measuring stations to monitor movement along the discontinuity plane. Extensometers have been found useful in monitoring movement augmented by fixed measuring stations in the shaft barrel. Creep meters have been found useful on faults to identify risk and abnormal movement on fault planes.

Brattice wall removal

Several of the rectangular shaft pillar removal programmes included the management of a concrete brattice wall. It has been found that some of these brattice walls had already started failing due to horizontal closure across the shaft barrel before shaft pillar removal had even started. It was found that brattice wall failure not only occurred in close proximity to the reef intersection in the shaft barrel but also in weaker strata formations above and below the reef elevation.

The identified sections of brattice wall which would become unstable during the shaft pillar mining process were removed by drilling short holes closely spaced on a square pattern and which were blasted with light explosives charges. This required exemption from the DME to allow for the cutting of standard explosive cartridges.

The process of blasting the brattice wall into fine fragments has been found to be the most productive and safe method, provided adequate precautions are taken. Part of the precautions taken include bringing all conveyances to above the elevation where blasting is about to take place. It also includes a full shaft examination after the blast to ensure that there has been no unplanned damage to the shaft.

Sill removal

The rectangular shafts were found to be equipped using horizontal sills for the securing of the buntons. The buntons are grouted in position in these sills. These sills are not reinforced with steel and are also not anchored to the sidewalls of the shaft in any way. It can almost be stated that the sills are glued to the sidewalls and only held in place by the buntons, which keep them against the sidewalls assisted by the unevenness of the sidewalls. The buntons

bending due to shaft closure also contributes to the failure of the sills.

The instability of these sills has necessitated two phases of action. Sill removal necessitated the replacement of the bunton sets, which is time consuming. The initial phase was to secure the sills with rope lacing from grouted anchors, installed above and below the sills, in order to prevent uncontrolled breaking up of the sills. This was followed by a systematic process of removal of the sills through blasting. Removal of the sills includes the immediate support of the exposed sidewall in the shaft barrel with grouted support anchors and the replacement of the bunton set. Figure 9 shows a side view of a horizontal sill with a bunton grouted in place.

Support requirements

Light weight aerated cement in the shaft barrel:

Severe strata control problems were experienced in the 1 and 2 compartments of Number 5 Shaft. This was the compartment behind the reinforced concrete brattice wall. This compartment was never supported during the sinking phase some 48 years ago. Deterioration over the years could not be handled practically and safely.

Platforms were installed in the number 1 and 2 compartments to prevent rocks falling down the shaft. This was a very high risk operation.

An alternative method proposed by W Plotz, the then Mine Manager, consisted of the erection of a safety platform followed by a second platform on which light weight aerated cement could be placed. A timber brattice wall had to be constructed next to the bunton set of the third compartment in place of the old and largely removed concrete brattice wall. This timber brattice would result in a paddock which could contain the aerated light weight cement in the old upcast compartment until the cement had dried and set in place. We believed that the cement fill would be self supporting once set and that it would stop any further scaling of large unstable blocks.

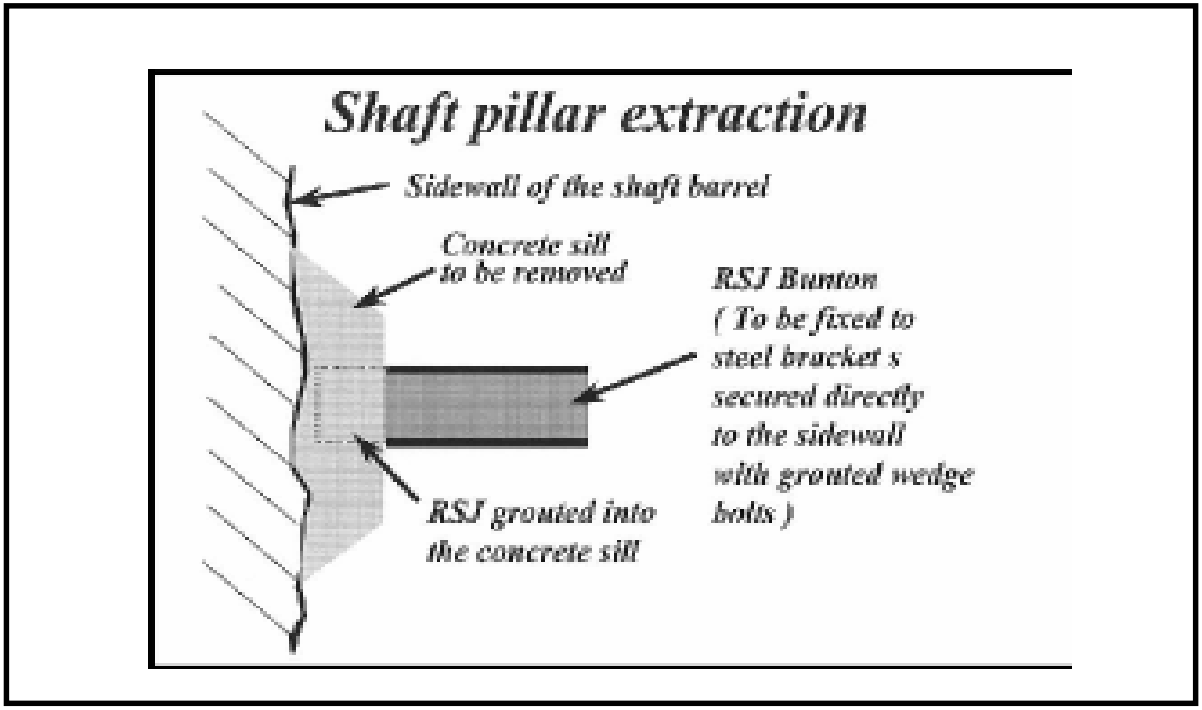

Figure 9

Removal of concrete sills

The total distance of between 38 level and to a level 40 metres below 41 level was covered in 5 lifts. The cement was mixed on the station immediately above the platform. The cement was pumped and placed in the constructed paddock in the shaft using air-operated pumps. The lightweight aerated cement had a final SG of 1,4 tons per cubic metre when set and dried. This process proved to be a major breakthrough in preventing falling rocks in the shaft.

Service excavations and access ways

The support recommendations for service excavations generally comprise of grouted support tendons with meshing and lacing. It is important to identify the excavations that are no longer critical particularly where inter tunnel spacing is less than the required minimum. Backfilling of some of the tunnels might be necessary to control pillar failure between tunnels as will be discussed later in this report.

On reef support in stopes

The design of the on reef support is important from both a safety and cost point of view. It is of no use to design a support code that would increase costs to the extent that the pillar removal becomes uneconomical. The correct support method is critical to enhance safety economically.

The design of the support on the reef horizon must cater for rock burst conditions, which is a reality in most shaft pillar extraction programmes. This includes the use of rapid yielding hydraulic props together with the strategic placement of backfill. Experience has proved that it is much faster to re-establish the face after a seismic event and to maintain access ways on reef where backfill was used even though backfill does not act as an active support in the face area.

Strategic placement of backfill together with hydraulic props combined with other support types proved to be successful.

All shaft pillar panels are classified as "Special Areas" and the support requirement and compliance is reviewed monthly at the planning

reviews. Active support is very important at all stages of the pillar extraction process. Timber packs traditionally classified as passive support are used as active support using pre-stressing methods.

The plan, Figure 10, shows two options for the placement of backfill together with hydraulic props and elongates with packs on the gully ledges. The unit cost for the two alternatives is reflected in 1996 money terms. It is clear from this example that money could be saved if backfill is strategically placed.

Backfill

The backfill used on the shaft pillar projects consist of tailings mixed with cement. The designed strength of the backfill is 1 MPa in 28 days. The admixtures to the tailings are 4-5% binder and 1% accelerator.

The need for backfill is not only restricted to the reef horizon but also extends to service excavations and redundant access ways. Station development layouts of old mines have not taken basic rock engineering principles into account when inter tunnel spacing was planned. Inter tunnel spacing in the station area of the older shafts were found to be insufficient causing failure of the pillar between the tunnels.

The placement of backfill in some of these tunnels, which is not critical to the extraction process, has assisted greatly in strata control in those tunnels which had to be maintained. Interaction between tunnels was found to be reduced and confirmed by physical measurement of closure trends and observations after backfill was placed in one of two closely spaced horizontal tunnels. Figure 11 shows a plan view of 27 level station at Number 1 Shaft indicating the backfill that has to be placed to secure the stability of the station area.

The minimum backfill requirement must be determined and designed for at full production in the shaft pillar as this could become a constraint if adequate flexibility is not allowed for down time together with delays that are synonymous with backfill operations.

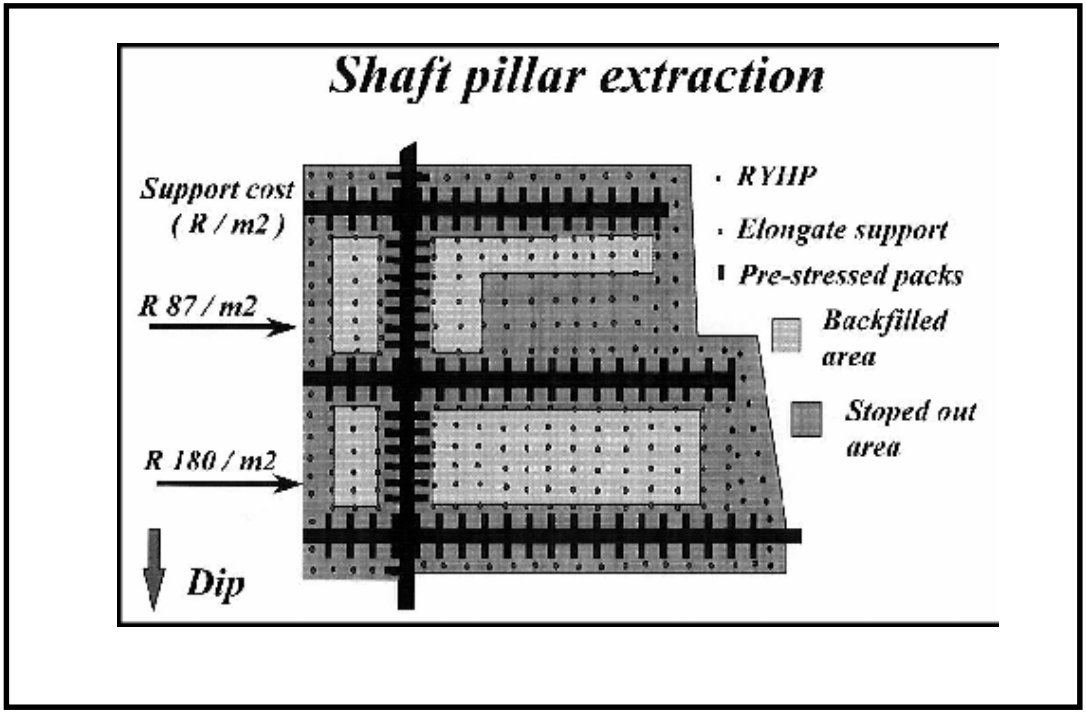

Figure 10

Backfill support alternatives

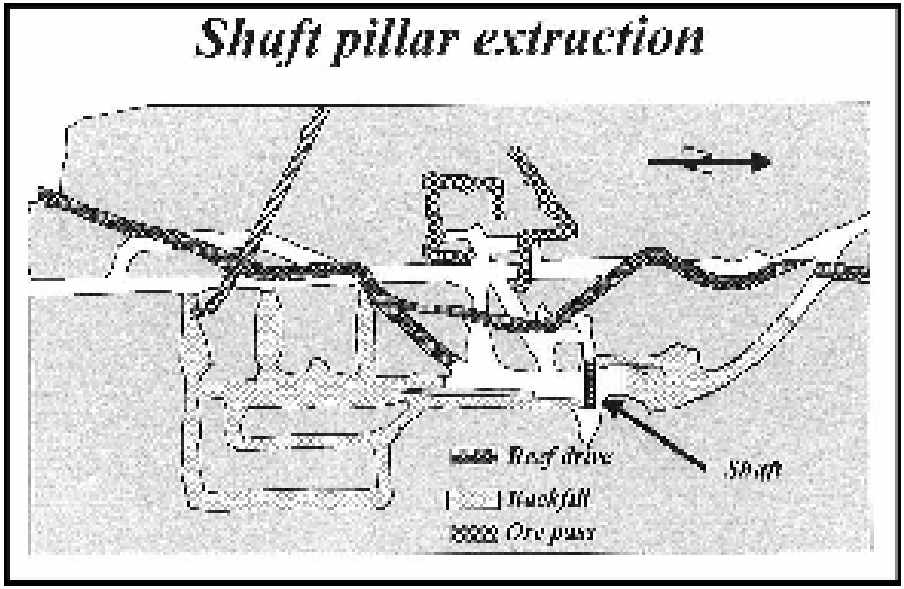

Figure 11

27 Level Number 1 Shaft support & backfill

Seismicity

Shaft pillar extraction goes hand in hand with an increase in seismicity. The experience at Western Holdings has been that seismicity increased as pillar extraction progressed. Seismicity only normalised after the back was broken in the pillar removal process close to total extraction of the pillar.

The place to start in the management of seismicity is to ensure that the shaft pillar area is adequately covered with geophones in space and area. This facilitates the availability of quality information that can be used to identify hot spots and assist with the process of issuing alerts and alarms. The seismic sensitivity at Western Holdings was reduced to less than 1,5.

Figure 12 shows the placement of seismic stations on Western Holdings Mine.

The identification of "Hot spots" can assist with the effective management of and strategy formulation with regard to seismicity. Hot spots could be burst prone dykes etc. identified from historical data and abnormally high stress areas in the pillar associated with potentially unstable geological structures.

Classification and re-classification "Special areas, support remnants etc." of working places is done diligently on a monthly basis using the latest available knowledge and information.

The process of issuing and reacting to alert and alarm warnings is diligently followed using the change in apparent volume and energy index theory.

Support strategy and recommendations should take the identified seismic risk "hot spot" areas inside the shaft pillar, that is often linked to geological features and or remaining pillar size, into account. Some geological structures that have been identified as potential high risk, "Hot spots", have been preconditioned by either strain softening with a set stoping sequence next to the structure or by blasting and fracturing dykes specifically.

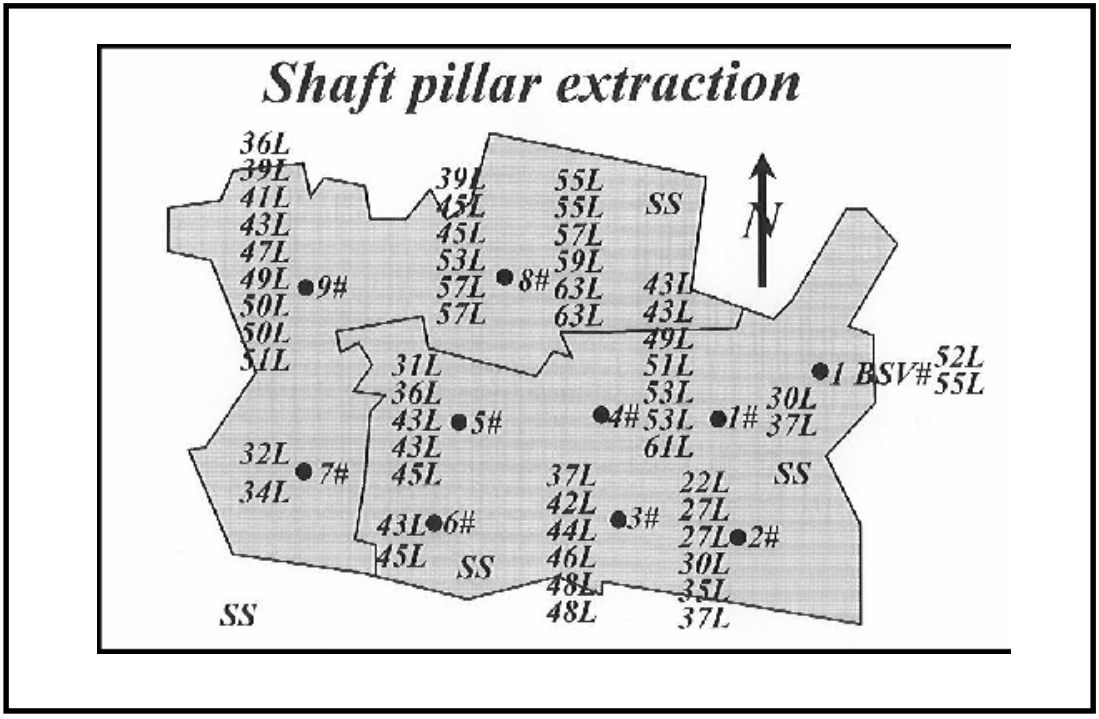

Figure 12

Placement of seismic stations

ENGINEERING ASPECTS

The shaft sections normally form part of the Engineering section on Western Holdings Mine. Work done in the shaft barrel in preparation for the shaft pillar extraction program is done with mining assistance. This section of the paper deals with that work related to the preparation of the shaft steelwork and other services before the stoping programme starts.

An accurate and adequate monitoring of shaft stability and movement is required well before shaft pillar extraction commences and during shaft pillar stoping. This information from accurate measurement of movement and closure in the shaft becomes invaluable to the Rock Engineering specialists in calibrating the computer models for forward modelling. It is also necessary for identification of unfavourable trends and timeous corrective action.

Shaft steelwork and services

The steelwork design differs for the various shafts. Two principal design options were used; firstly suspended steel and secondly steel secured to the sidewalls in the shaft barrel. The steelwork secured to the sidewalls is designed to allow for closure in the shaft during the shaft pillar extraction process.

Along with the need to redesign the shaft steelwork in the reef intersection area of the shaft is the need to re-evaluate the practical and safe size of the shaft conveyances. The cage sizes were reduced to ensure safe clearances in several of the shafts where the shaft pillars were extracted. The reduction of the cage dimensions was a wise decision in most of the cases with the advantage of being able to look back and evaluate.

Suspended steel

The guides and bunton sets in the Number 4 Shaft barrel were designed to be free from the shaft sidewalls. The reef intersection is on 49 Level. The shaft steel is suspended from 47 Level, which is approximately ninety meters above 49 Level. Bearer sets were installed on 47

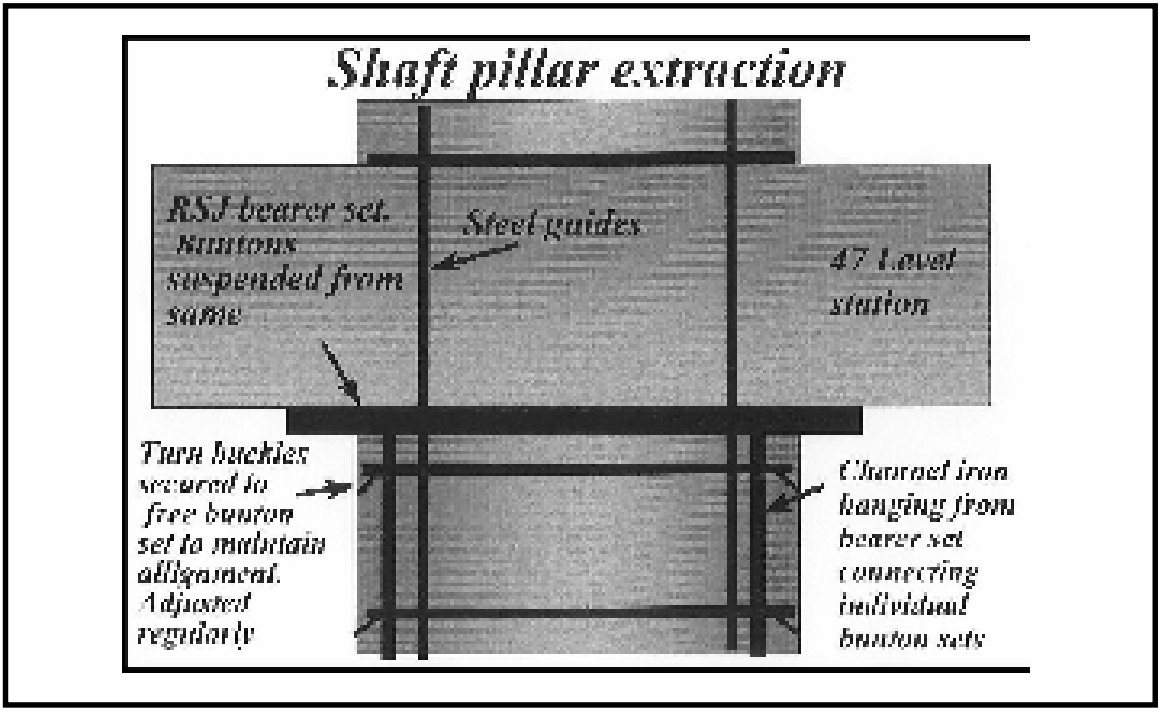

Figure 13

Suspended steel in the shaft barrel

Level from which the freestanding bunton sets were suspended. Sliping was done in the shaft barrel to allow clearance between the shaft barrel sidewall and the bunton sets. Figure 13 shows the design of the suspended steel and free standing bunton sets at the Number 4 Shaft of Western Holdings Mine. Figure 14 shows a plan view of the bunton sets as used at Western Holdings Mine Number 4 Shaft.

Steel secured to the shaft sidewalls

The design used in the rectangular shafts includes the use of RSJ buntons secured to knee brackets. The knee brackets are secured to the supported sidewall using four grouted studs. The holes in both the knee brackets and the RSJ buntons are slotted to allow for horizontal adjustment of the buntons in all directions. Vertical movement / closure is taken up by the telescopic guides installed.

This design has been found to work well provided the concrete sill removal programme has been completed and the shaft sidewalls secured with grout support. Figure 17 shows a side view of the knee bracket and RSJ bunton and Figure 18 shows a plan view of the knee brackets with the slotted holes.

Cables

Stoping of the inner pillar and holing into the shaft requires the protection of the shaft cables. The closure as a result of the shaft pillar stoping results in slack in the cables in the shaft barrel. Provision must be made to take up the slack in the cable in the shaft to prevent fouling of the shaft winding compartments.

Service columns

Service columns must be fitted with expansion joints to allow for the closure that is expected in the shaft barrel during the pillar extraction process. Re-enforced rubber hoses are used on the take off of the pipe columns into the stations where significant movement is predicted from the modelling done.

Figure 15A&B shows the telescopic guide and butt strap details.

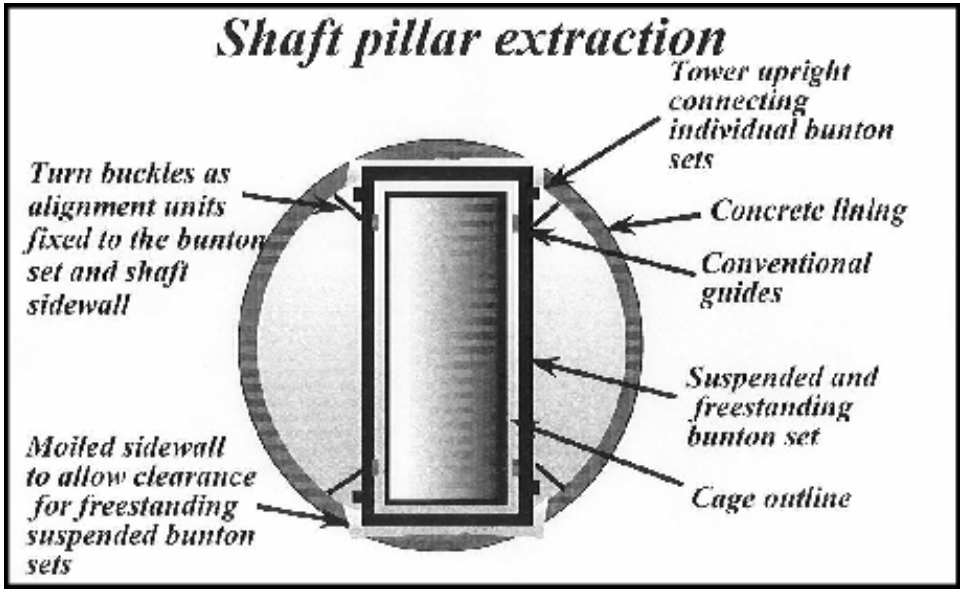

Figure 14

Freestanding bunton sets No. 4 Shaft

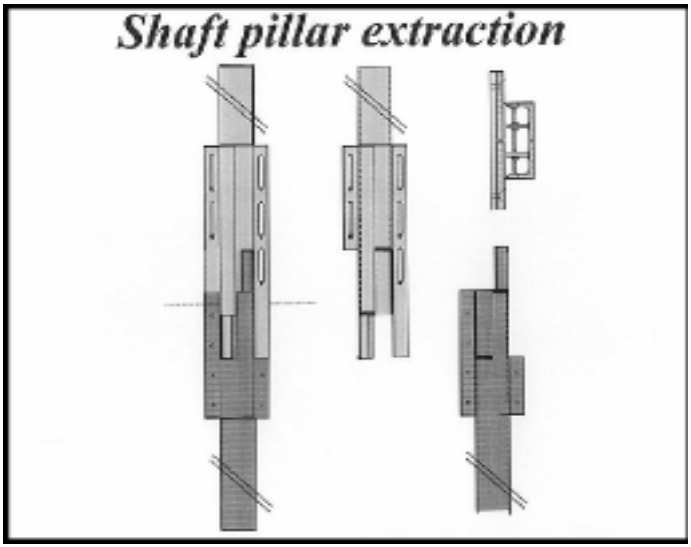

Figure 15A
Telescopic guide arrangement

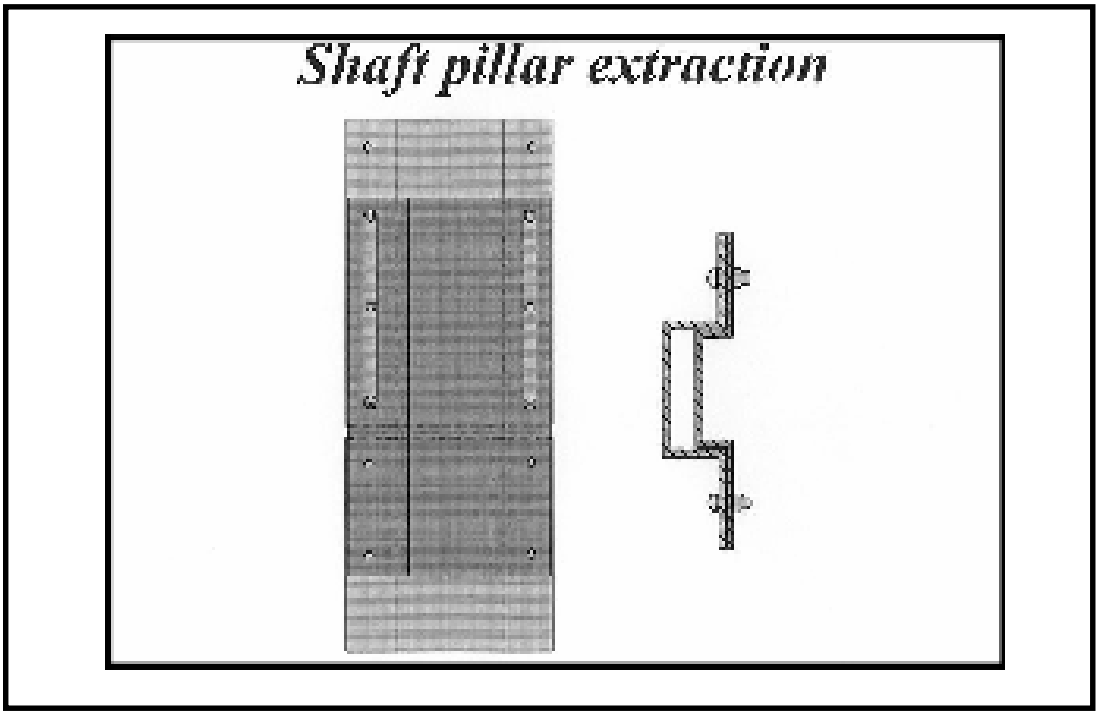

Figure 15B

Slotted butt strap design

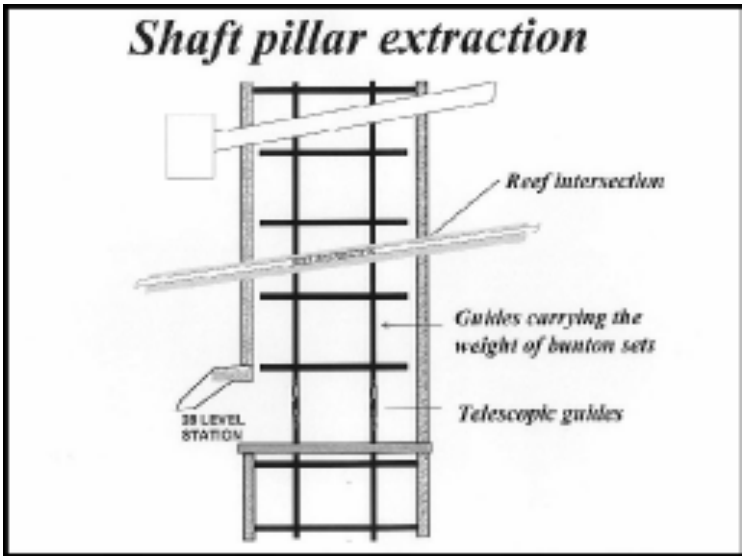

Figure 16

7 Shaft steelwork at reef intersection

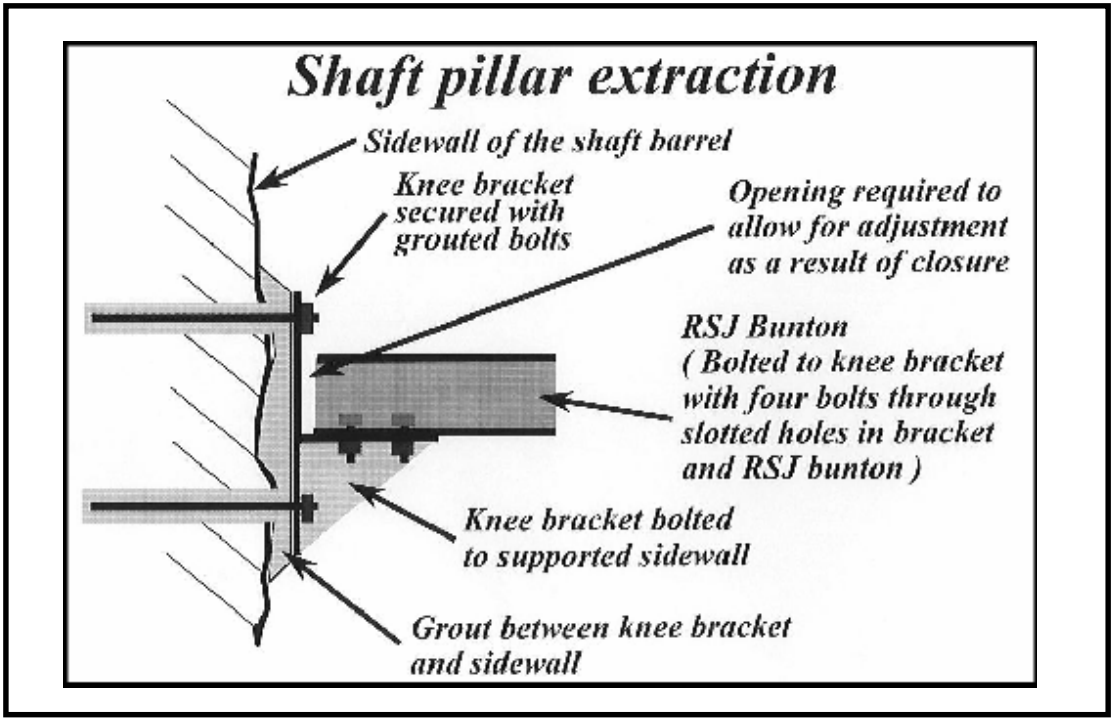

Figure 17

RSJ bunton fixed to knee brackets

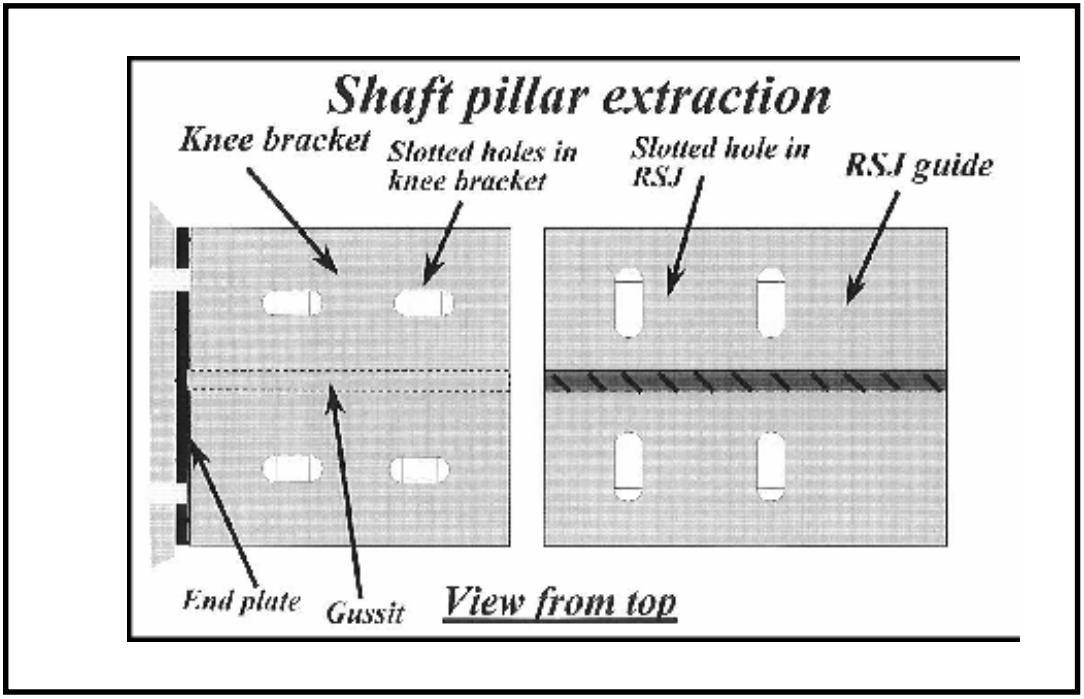

Figure 18

Slotted holes on knee brackets and guides

Figure 16 is a side view showing the placement of the telescopic guides in the shaft.

General

The design of the steelwork should be kept simple but functional. Slotted butt straps should be used and fifty millimetre holes to be cut in the sole plates to allow for adjustment. Condition monitoring of the shaft steelwork, regular adjustment and realignment becomes a routine requirement.

Shaft barrel support

There are essentially two different approaches. The support used in rectangular shafts is a standard diamond pattern for lacing on grouted support. The important factor is to ensure that adequate clearance exists between the support and the conveyances in the shaft. Moiling of the shaft sidewalls is required unless the size of the conveyances is reduced as has been done on several of the shaft pillar removal programmes.

The lacing ropes are secured vertically in circular shafts in order to prevent the ropes from moving away from the shaft sidewalls and interfering with the moving conveyances in the shaft. Figure 19 shows a plan view of the grouted support pattern used in circular shafts such as Western Holdings Number 9 Shaft.

Shaft barrel support work gets done over weekends when spare time is available in the shaft. The experience at Western Holdings Mine was that more time was required for shaft barrel support than originally estimated. This applied particularly to some of the rectangular and unlined shafts due to the extent of fracture growth that had occurred in the shaft sidewalls.

Moving of service infrastructure

Service excavations such as dams, pump stations, refrigeration chambers, sub-stations etc. are at risk due to increased stress levels in the

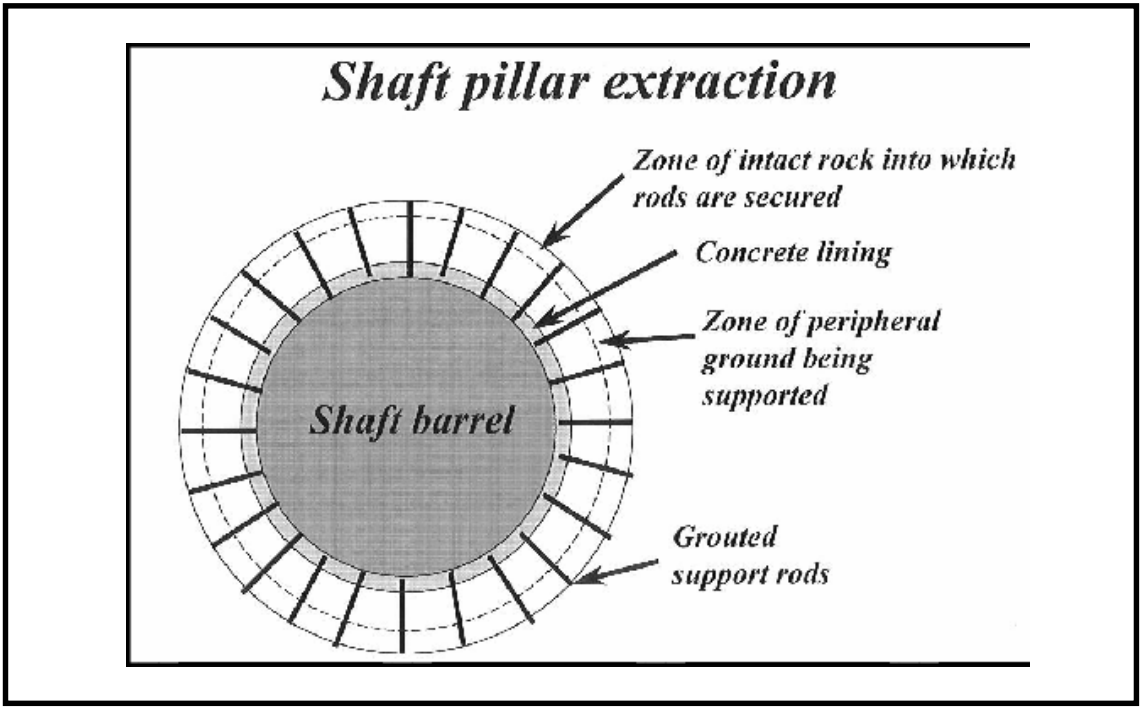

Figure 19

Shaft barrel support

shaft pillar area. Timeous identification of the areas of risk and implementation of a contingency action plan together with the diligent management of the contingency plan to ensure timeous completion is critical. Failure of dam walls, damage to pump chambers etc result in losses not only to the shaft pillar programme but also to the shaft as a whole.

The following routine was used for shaft examinations at Western Holdings Mine:

The frequency of shaft examination increases considerably once the shaft pillar extraction programme starts. Shaft examinations are scheduled during the week to allow more time for shaft work over the weekends. The weekly shaft examination includes taking measurement of movement in the shaft at strategically positioned measuring stations. These measurements should start as soon as it is practically possible to identify changes in the shaft barrel timeously and to secure a good database for future calibration of computer modelling. Information from the measurements is used to assist with the identification of the priority areas requiring special and priority attention. The condition of the concrete lining is checked to identify any deterioration such as fracturing etc.

- A routine weekly examination of the shaft is done during mid week. This allows more time for shaft work over the weekend.

- A full examination of the shaft from approximately twenty metres above the reef intersection to the shaft bottom to ensure that the shaft is safe after every blast taken in the inner pillar.

- Load cells are installed on the winders to assist with the identification of tight spots in the shaft. A shaft examination is done when a tight spot is indicated in the shaft barrel irrespective of the time at which the tight spot is detected. Slack rope devices are also fitted to the winder installations and this is also utilised to assist with the detection of tight spots in the shaft barrel.

  Winding speed is reduced through the reef intersection area to 7,5 metres per second.

- A shaft examination is done if a seismic event is recorded in the shaft pillar area.

FINANCIAL VALUATION OF THE PROJECT

Assumptions on economic factors over the life of the shaft pillar extraction programme are critical because it is invariably a long-term project. The other reality is that the project cannot be stopped at any time since it could lead to the formation of stress bulbs affecting the shaft barrel and strategic tunnels once stoping has started. You could be effectively locked into mining a minimum area once stoping has started in a specific mining block. A balance must be obtained between the estimated financial gains from the project and the risk of damage to the infrastructure.

Several decisions have to be made early in the project with regard to expenditure of capital. Typical examples are the manufacture of steel for replacement in the shaft barrel, establishment of a backfill infrastructure, supporting of service excavations and moving of critical services to alternative sites such as pump stations and dams etc.

The following factors need to be considered:

- Capital expenditure required to set up the infrastructure to enable a successful extraction program. Good estimates of expenditure are required together with a professional plan to ensure an accurate estimate of cash flow. The time value of money must be considered.

- The inflationary effect of cost must be considered. Unit labour cost increases over the life of the project could be significant especially if productivity levels are reduced due to mining difficulties.

- Gold price fluctuations remains the mining engineer's challenge but could result in financial disaster during shaft pillar extraction if the project is in a critical phase and cannot be stopped in a loss making situation.

- Operating cost which includes the fixed and variable cost element of labour and consumables could be significantly higher due to lower efficiencies and increased support requirements both on and off reef per unit area mined. It is important to accurately estimate the anticipated support cost requirements in the shaft pillar. Under design of support requirements results in a forced drop in return on investment which is recognised when it is too late to change the decision to mine or not.

- Return on investment of the shaft pillar extraction project need to be determined by calculating the difference between the return on investment of the shaft with and without the cash flow of the shaft pillar project. Risk assessment of the project must form an integral part of the financial valuation process.

  The return on investment should be determined and expressed in NPV, IRR and / or DCF with due consideration of pay back period using a hurdle rate which takes the financial and safety risk elements into account.

The decision to proceed with the shaft pillar extraction project can only be considered after a detailed financial valuation process and with due consideration of the risks involved following a full risk assessment.

Table 2 shows the capital estimate for the shaft pillar extraction project at Western Holdings Number 8 Shaft in 1995 money terms. The capital estimate for the backfill plant includes the cost of refurbishing and relocating an existing plant only.

Table 2
Capital estimate for Number 8 Shaft

Details on estimated capital expenditure	Total cost
Shaft barrel support	301 000
Support of existing excavations	1 789 400
Geological drilling	109 000
Development, support &construction	1 206 300
Alternative tramming systems	111 000
Shaft steelwork	1 424 700
Measuring and detection equipment	244 000
Backfill plant (Relocation & refurbishment)	580 000
Station steelwork	105 000
Power reticulation	556 000
Pipe work	78 000
Sundry specialised equipment	357 400
Escalation, contingencies, reimbursables and fees	1 441 500
Total capital estimate	***R8 293 300***

MANAGEMENT OF THE PILLAR EXTRACTION PROCESS

Planning and critical path scheduling

A total project schedule is required which includes all activities connected to the project. The identification of concurrent activities and activities on the critical path is essential. A late start of the shaft pillar program could result in the shaft going into a financial loss situation prior to the kick in of contributions from the pillar if critical path activities are not completed in time.

An overall master plan has been found helpful in directing future detailed planning. Managing against this plan assists in keeping the eye on the ball during the extraction process.

Figure 20 shows a master schedule for shaft pillar extraction at Western Holdings Number 4 Shaft.

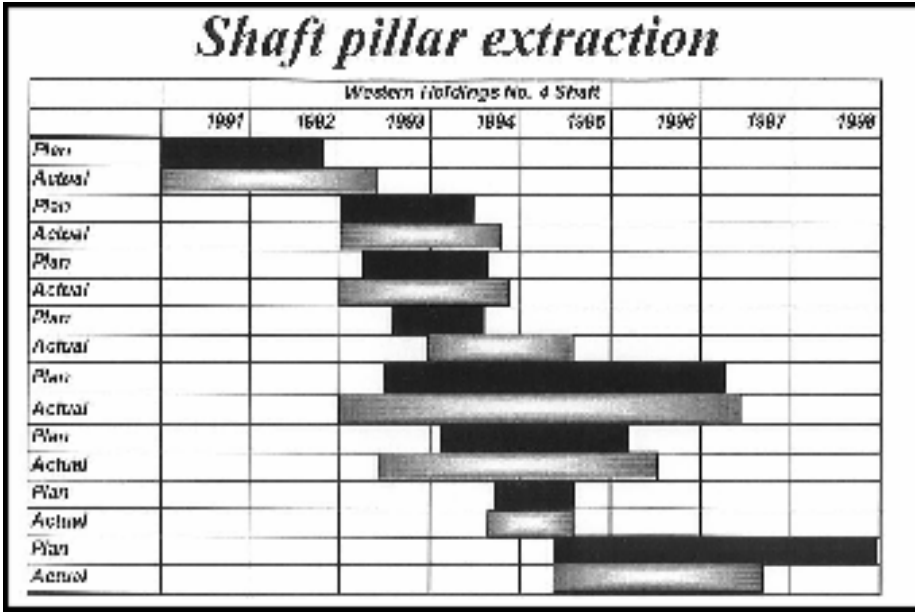

Figure 20

Master schedule of No. 4 Shaft

Lead-time

Preparatory work prior to the start of full scale stoping could take two years to complete. Allowance for adequate lead-time prior to the required date of revenue from the pillar extraction process is critical. Short cuts are not always possible and contingency plans which have become a way of life for mining men does not leave much room for movement in a shaft pillar extraction programme.

Resourcing the team

It is important to identify the correct management team to take the shaft pillar process through from planning to completion of the stoping process. The persons selected should have the right temperament and ability to persevere without becoming impatient. Shaft pillar removal requires a special discipline and many traditional production men with a "bore and blow" background will not fit in; a lot of patience and nursing is required.

Professionalism in the management of the total process from planning to actual stoping is vital. Certain preparatory activities are critical prior to the start up of the next step. Discipline of the team then becomes critical as frustration creeps in.

Continuity of the team members is important towards the successful completion of a pillar extraction process. Changes in the management team could lead to changes in priorities and loss of focus on the critical activities with negative effects on the total programme. It is thus advisable to select the team that could start and take the pillar extraction programme through to conclusion wherever possible.

Formalised reviews

Formalised reviews proved invaluable towards timeous identification of slippage on activities that are on the identified critical path. It also assists with the identification of activities that have lagged to the point that it has become a critical path activity for urgent and focused attention.

The availability of an up to date project schedule is the most important tool to enable effective management of such a project and facilitate fruitful project review meetings.

Operations management

Mining sequence needs to be adhered to. The first step in the process is the removal of the inner pillar. This is normally done concurrent with a sequential overstoping of the main shaft orepass system. It is only once the inner pillar has been stoped and supported with backfill that stoping commences beyond the inner pillar.

The initial approach with the Number 6 Shaft inner pillar was to approach the shaft barrel with a face parallel to the long axis of the rectangular shaft. This was found to be problematic, causing excessive dilation / bulging of the shaft sidewall into the shaft with this approach. The next shaft was done with the advancing face of the inner pillar approaching the shaft from the short axis of the rectangular shaft and then mining up dip with the face normal to the long axis of the shaft. See Figure 21A&B for a plan showing the sequence of mining the inner pillar.

The mining sequence should preferably be away from the shaft barrel in all directions to prevent the formation of stress bulbs in the shaft barrel and the potential resultant ride that could follow a non-symmetrical mining sequence.

Layout

All layouts should follow a route of detailed scrutiny by all the relevant departments involved to ensure that the best available data has been used and that the optimum layout design has been proposed with the available information. Structurally complex ground could require an intensive drilling programme during the pillar removal program to ensure optimum layouts as has been experienced at Western number 9 Shaft. The use of a three-dimensional CAD system was also found necessary to assist with the geological interpretation of the ground. The use of the CAD system assisted with the identification of a significant block of reef, which has subsequently been drilled

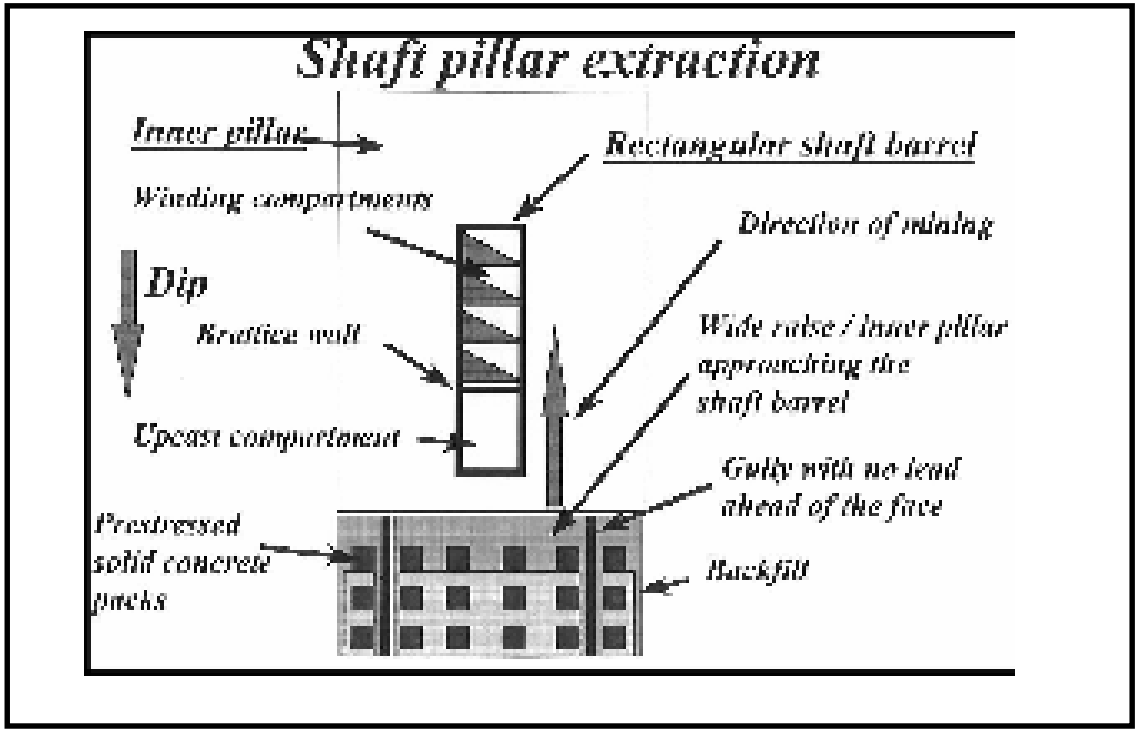

Figure 21A

Inner pillar removal

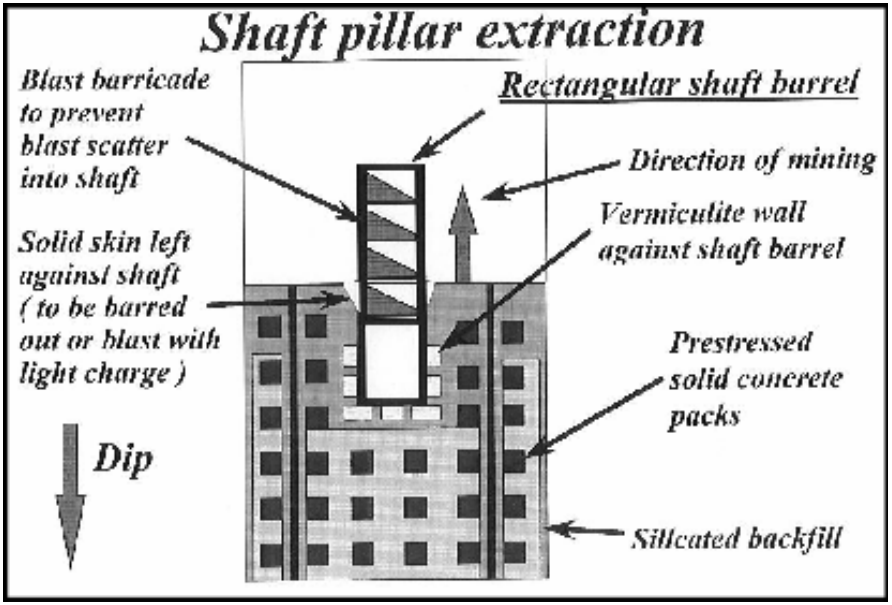

Figure 21B

Inner pillar removal

and developed. Figure 22 shows the structural plan of Western Holdings number 9 Shaft and the H-Block, which was identified after the shaft pillar programme had already advanced significantly. Figure 23 shows a section through the same shaft looking north showing the extent of faulting, unstable wedges in the shaft and the area that had to supported in the shaft barrel.

Securing of access ways

It is invariably not possible to complete all the support work of access ways prior to the start up of the stoping process. It remains critical to manage the progress with support of the critical accesses. We have experienced that a loss of focus on the area of grout meshing and lacing leads to good square metre results but not necessarily in the prioritised sequence. This has resulted in the abandonment of certain access ways because a late start resulted in sidewall damage beyond the point where the tunnel could be supported successfully. Mining of a shaft pillar is in a higher than normal stress environment with a significant amount of time dependant fracturing that has taken place over many years due to stress changes.

The supporting of access ways should thus rather start sooner than later as induced stress conditions due to stoping in the shaft pillar have been found to affect the stability and deterioration of tunnels more than in virgin rock conditions.

Rescheduling

Review of the shaft pillar programme on a routine and regular basis leads to the identification of areas of slippage and new information that could require a re-prioritisation of the programme. Rescheduling and re-identification of critical paths and other priorities together with the setting up of updated control systems form an integral part of the process.

Cash flow management

A considerable amount of risk is involved with a shaft pillar removal programme. A shaft pillar will only be planned for extraction if

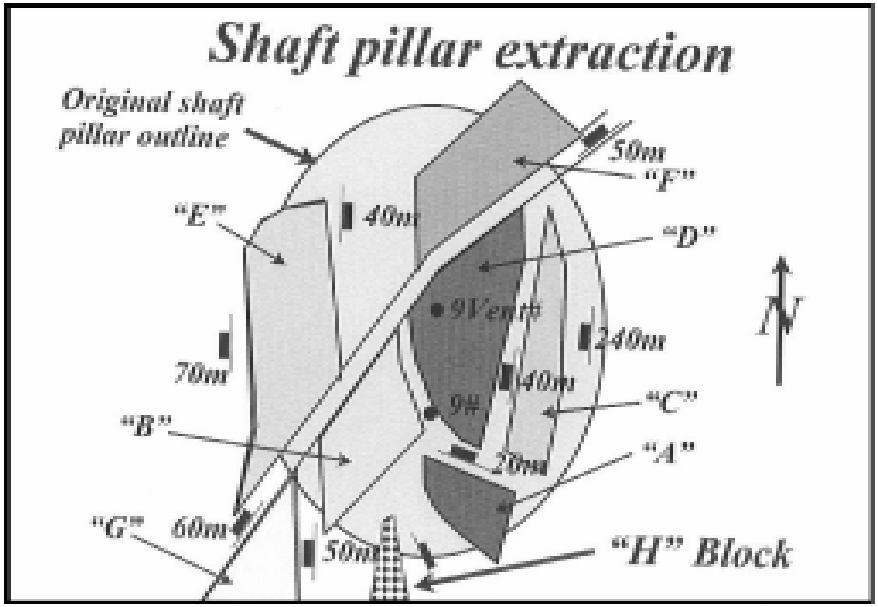

Figure 22

Structural plan of Number 9 Shaft

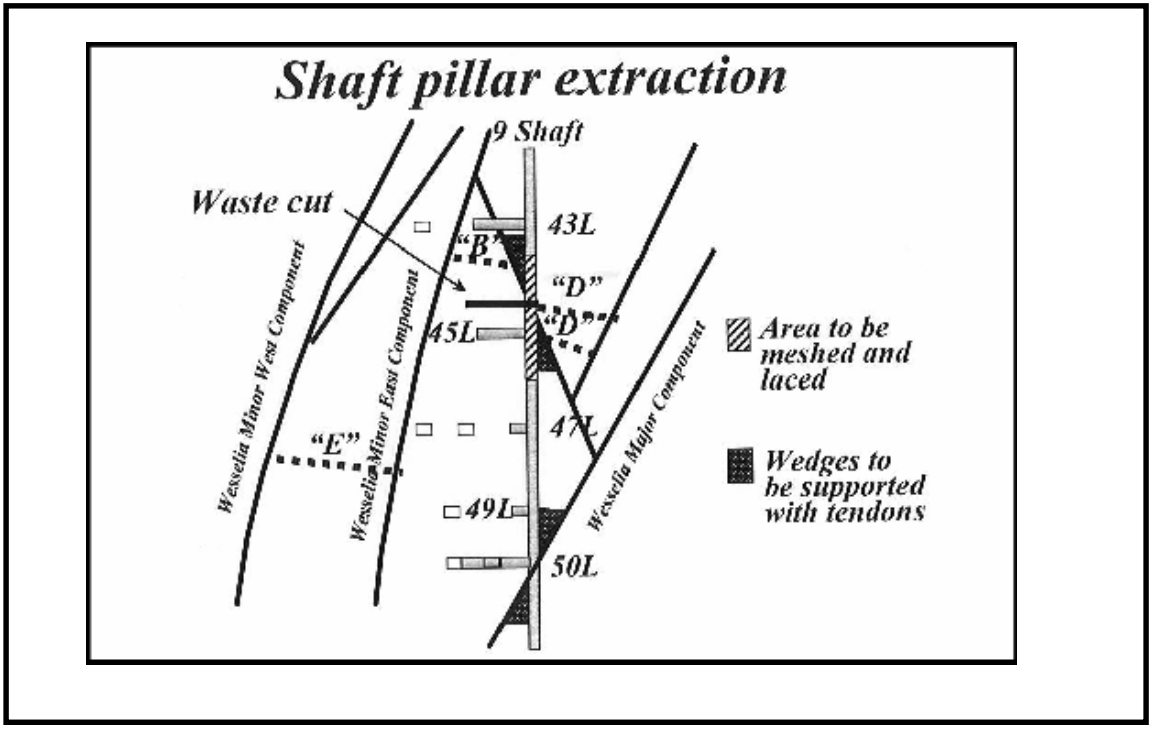

Figure 23

Section through No. 9 Shaft

the potential profits to be made are greater than the potential risk. Adherence to the project schedule is the one way of ensuring compliance to the original cash flow estimate. Cash flow management is however important enough to warrant an accounting process that captures the relevant information towards managing the project financially.

Detailed record keeping of the first shaft pillar removal programmes has certainly assisted the Western Holdings team in improving the accuracy of budgeting for the subsequent shaft pillar removal programmes. Projects like this are based on a return on investment principle and comparing the return to the risk involved. Failure to manage the pillar extraction programme as separate entity results in the cluttering of information and the inability to assess the end result of the project compared to the initial return on investment criteria on which the project approval was granted.

CONCLUSION

Shaft pillar extraction need not be considered only at the end of the life of a mine or shaft. The one requirement is spare capacity in the shaft to allow for the additional time required in the shaft barrel for rehabilitation and support prior to the commencement of stoping. Inner pillar stoping requires more regular shaft examinations and additional shaft time is thus consumed.

The first issue is a proper risk assessment to consider the safety aspects related to the extraction of a specific shaft pillar. A single recipe for shaft pillar extraction cannot be given as the conditions to individual shaft pillars differ. Differences between individual pillars include depth below surface, geological structure, nature of the ore body to be mined including multiple reefs, characteristics in rock hardness above and below the reef, proximity of the service excavations in relation to the reef, the dip of the reef, risk of seismicity from records of seismically active structure etc. All of these issues need to be considered.

The one reality with shaft pillar extraction is that you cannot start with the process and stop at any point or time without risking damage

to infrastructure. Stope faces might well have to be advanced further to ensure the effective over stoping of critical excavations before a decision to stop can be concluded. It must thus be appreciated that a minimum amount of stoping would have to be done in individual blocks once the decision is made to commence with stoping.

Shaft pillar extraction need not be a nightmare causing sleepless nights for the Mining Engineer provided that sufficient up front engineering has gone into the pillar extraction design. It is a process that runs over many years from start of planning and preparatory work to completion. It requires the involvement of all the specialists referred to in this paper and the establishment of a well-disciplined team that appreciates the criticality of following a strict and systematic process to conclusion.

Shaft pillars can be extracted safely and the shaft infrastructure can be maintained to allow safe utilisation of the shaft barrel after the completion of the shaft pillar.

ACKNOWLEDGMENTS

The author wants to thank the management of Freegold and Western Holdings Mine for permission to publish this paper. The following members of the Western Holdings team have contributed significantly through valuable input and comments during the writing of this paper. Their assistance is acknowledged and appreciated.

- M.J.Prinsloo Mine Manager
- S. Conradie Engineering Manager
- J. Lategan Section Head, Rock Engineering
- J. Zietsman Rock Engineering Officer
- H. Basson Resident Geologist

REFERENCES

1. M.N.Dix, 1997; Shaft pillar removal strategies employed at Western Holdings Mine

2. A.J.S. Spearing, 1995; Handbook on hard-rock strata control

3. S. Budavari, 1983; Editor of Rock Mechanics in Mining Practice