

Extraction of 5 West Sub Vertical Shaft Pillar - the Final Stages

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SYNOPSIS

Preparatory work commenced in early 1982 for the extraction of the No 5 West Sub Vertical shaft pillar. It was not until 1986 that the actual mining of the 168 000m² pillar started.

It had been decided from the outset to keep the shaft and ancillary excavations fully operational for the entire duration of the extraction program or at least for as long as possible.

Over the next ten years 153 000m² representing about 90% of the reserves, have been successfully removed with excellent safety records together with absolute minimum distortion and disruption to the shaft.

During this period that mining was being done, the region experienced high rates of seismicity, typically 200 to 300 events per month. At no time did seismicity cause any significant disruption to the safe operation of the shaft or stoping areas.

On Sunday 11 August 1996 at approximately 14h12 a severe tremor was felt on surface, which later was determined to be a seismic event at the No 5 West Sub Vertical Shaft. It was discovered that severe inward deformation of the shaft lining had taken place as well as distortion of the shaft steelwork. The free movement of conveyances through the shaft was impeded.

This event is discussed together with an account on the remaining mining over the next seven months until March 1997.

INTRODUCTION

A paper on the initial planning, preparatory work and early stages of mining was read to this Association in 1990, and suffice to say, this paper serves to give an overview of events over the last few years now that in excess of 90% of the reserves have been successfully extracted.

The No 5 West Sub Vertical Shaft served the lower western portion of the West Driefontein Gold Mine, a Division of Driefontein Consolidated, a mine within the Gold Fields Group (Figure 1). The economic reef mined in the 5 west area was the Carbon Leader Reef, which underlies the less economic Middelvlei reef by some 60m.

The life of mine plan at the time indicated that the extraction of the 5 West Sub Vertical Pillar was to be serviced from the neighboring 5A Sub Vertical Shaft and that the 5 West Sub Vertical Shaft could be abandoned. This however could not be done for the following reasons and a decision was taken to keep the shaft operational throughout the duration of the pillar removal program.

- Vamping in the 5W area had not been completed.
- Water could not be allowed to accumulate on the common boundary with Western Deep Levels as was originally planned.

DESCRIPTION OF THE SHAFT

The No 5 West Sub Vertical Shaft is situated in the lower western portion of West Driefontein Gold Mine and is serviced from No 5 Vertical Shaft-W some 1 900m away. The shaft is a 6,7m diameter circular concrete lined shaft having a length of 823m. The bank is situated on 18 level some 1 816m below datum and the lowest working level is 34 level.

The shaft comprises four main compartments (two for rock and two for men) with an additional service winder (Figure 2).

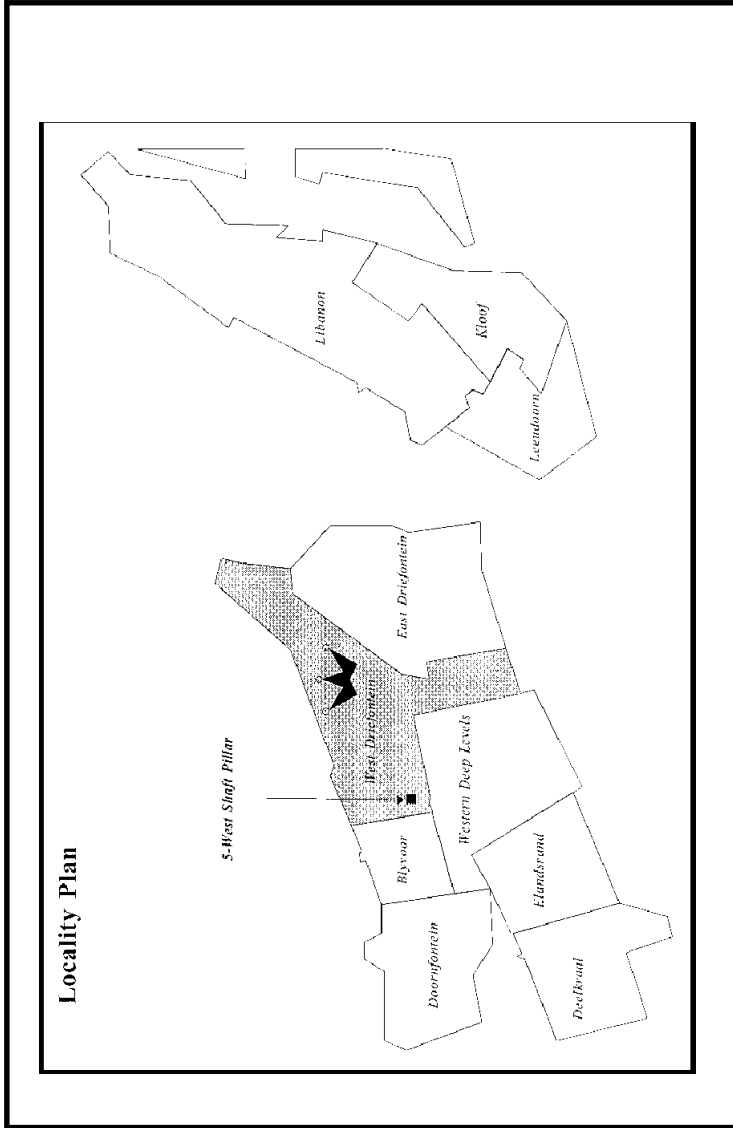


Figure 1

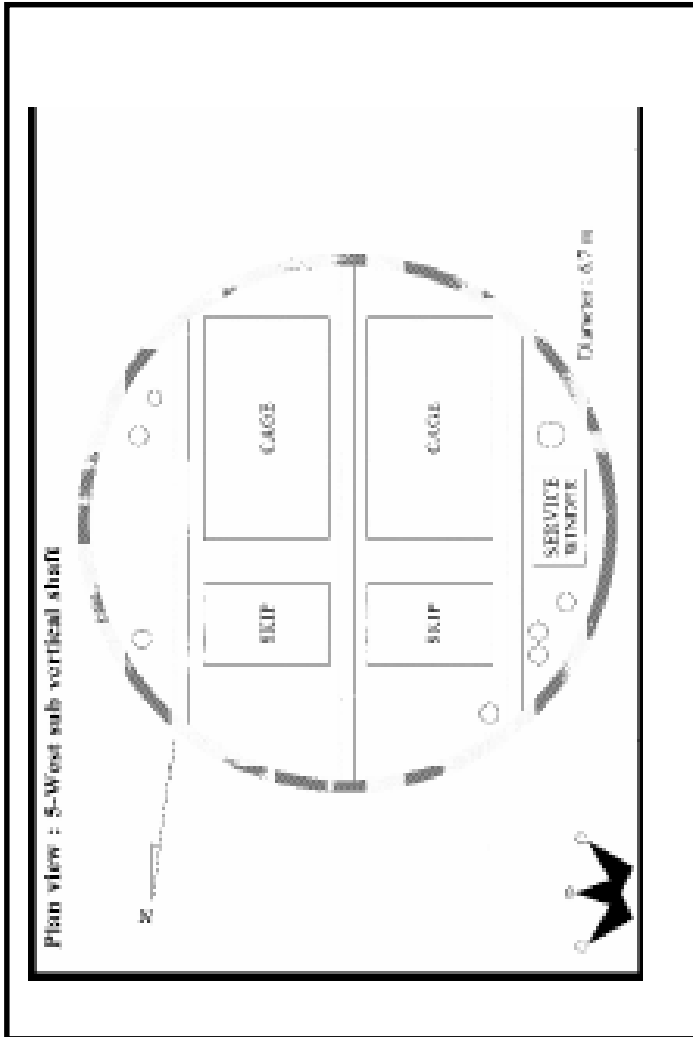


Figure 2

The shaft had the capacity of hoisting 69 000 tons of rock per month as well as to pump 0,3 mega litres of clear water per day.

There were nine working levels in the shaft with the Carbon Leader Reef intersecting the shaft on 26 level station at an elevation of 2 258m below datum (Figure 3).

GEOLOGY

The payable reef mined from the area surrounding No 5 West Sub Vertical Shaft was the Carbon Leader. The reef dips at 24° from north to south.

The ground left in-situ within the confines of the shaft pillar is structurally uncomplicated but from a mining point of view is quite complex because of the presence of two post Transvaal Diorite Dykes.

The first of these dykes strikes N 40°E and has a thickness of some 40m and a down throw to the north of 45m. The second, which merges with the first in the NE corner of the pillar strikes at N 14°E and has a thickness \pm 26m and a down throw of 5m to the north.

The Carbon Leader contained in the shaft pillar is of very high grade and as can be seen from the above description, is essentially broken up into three distinct and separate blocks for mining (Figure 4).

The hangingwall of the carbon rich heavily mineralised conglomerate band, consists of a well bedded argillaceous quartzite with little cohesion on the bedding planes themselves for a distance of \pm 1 m, whereafter the Green Bar, a green chloritoid - bearing siltstone is encountered and which extends up to 4m or 5m.

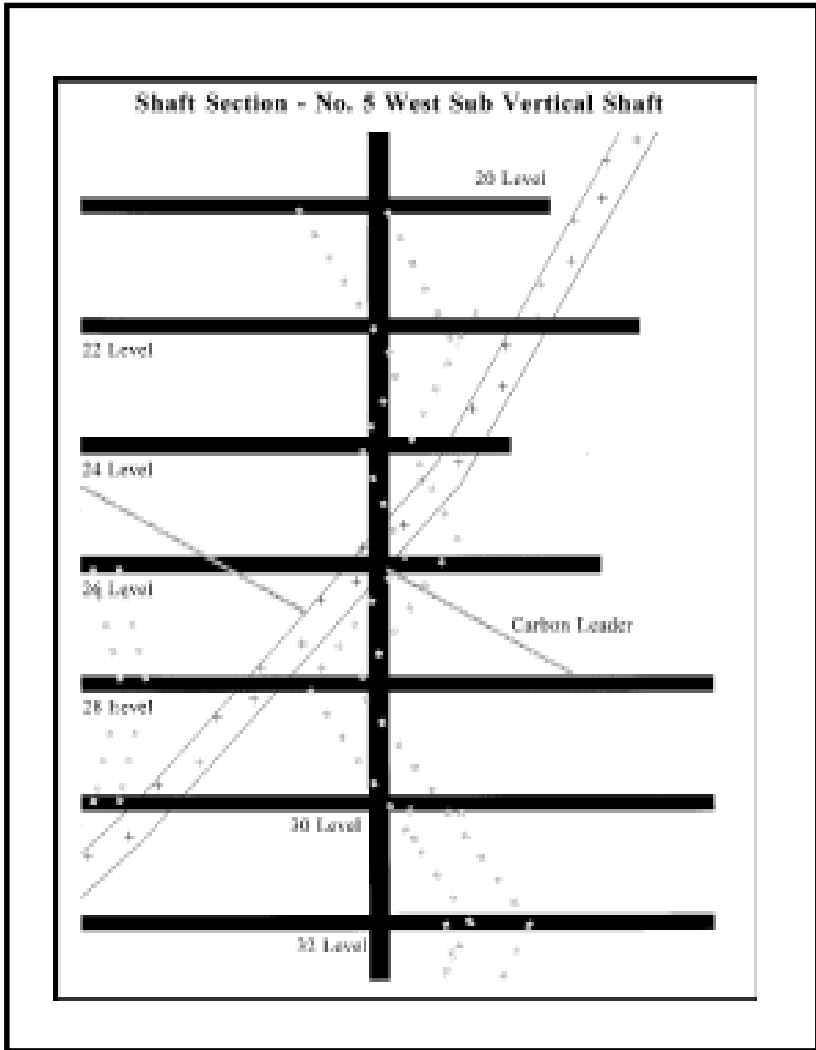


Figure 3

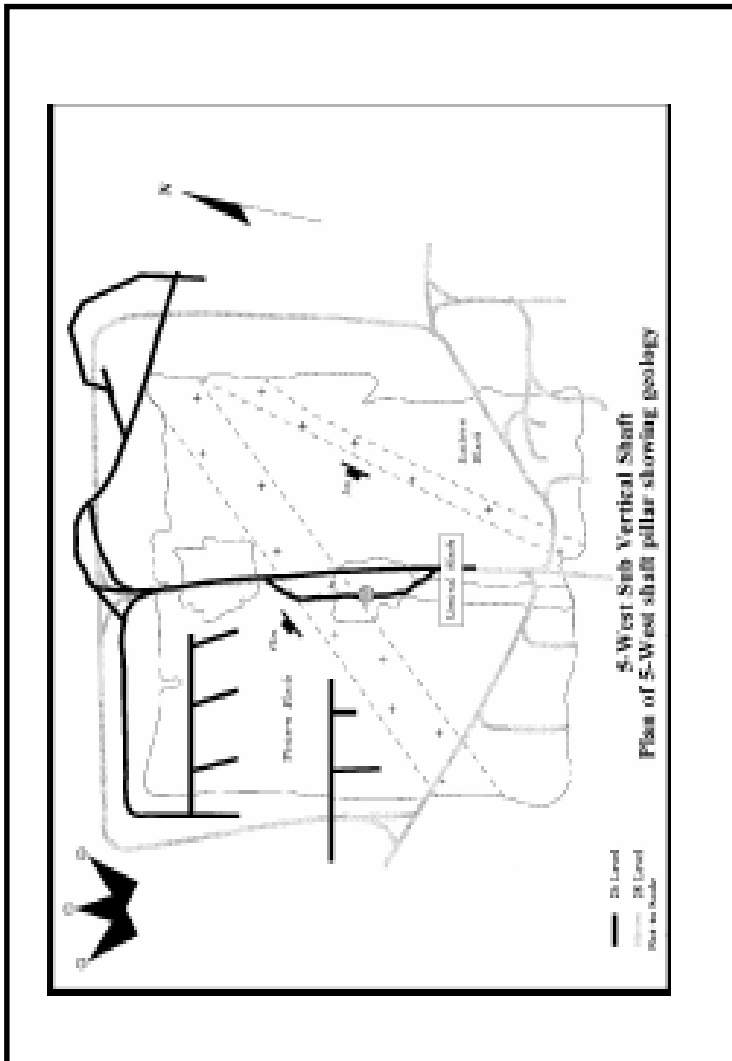


Figure 4

ROCK MECHANICS CONSIDERATIONS

The No 5 West Sub Vertical Shaft was sunk in order to serve the lower western portion of the mine, and by 1982 most of the reserves had been depleted. At this stage the shaft plus all ancillary excavations such as pumps, settlers and pump chamber were still in very good condition and showing, no signs of deterioration.

At the time the decision was taken to extract the shaft pillar, the protection of pumping arrangements did not have to be considered as far as their future stability was concerned. The main thrust in the Rock Mechanics approach in protecting the shaft was therefore to limit displacements, both elastic as well as non elastic to the absolute minimum. The rationale being that smaller displacements should limit the extent of shaft steelwork deformations within the axis of the shaft as well as restricting ride movements.

Computer modeling of the various options of mining sequence that were considered produced graphic plots of the induced vertical and horizontal strains in the vertical axis which were then used in assisting to make predictions exactly at which location within the shaft, tolerances on steelwork would become critical. These included vertical compressional strain misalignment, which has an influence on guide gauge, and horizontal compressional strain, which squeezes the buntons.

Also considered in the investigation were the mining, induced distributional stress changes within the pillar for various sequences of stoping. These changes have a direct bearing on the failure mechanisms of the surrounding rock mass and the monolithic concrete lining,

In addition to the above, the access ways to and from the pillar stoping area had to be investigated in order to assess their potential for remaining serviceable throughout the duration of the extraction program. This was necessary because of their proximity to the stoping abutments that would be created.

During, the entire investigation and planning stage, cognisance had to be taken of the fact that two dykes had to be dealt with, structures which are notorious for being carriers of stored seismic energy which

can be released violently at any stage.

Extensive use was made of a three dimensional stress analysis program called "DREEF" which could numerically model a single reef and had the facility to perform stress calculations for various off reef locations.

Numerous stoping configurations were modeled and for each of these, off-reef stresses were calculated at various strategic points within the axis of the shaft as well as on the off-reef access ways, especially on 26 level and 28 level. In addition, the on-reef stress distribution within the pillar together with energy release rates were calculated in order to assist in selecting the most favorable sequence of mining.

The design criteria used for the prediction of severe compressional damages to shaft steelwork are that the mining induced strains in the vertical axis of the shafts be kept to less than 0,4 millistrains (After Esterhuizen 1980). Types of damage resulting from compressive strain have been observed to be buckling of guides and buntons, distortion of steelwork on stations and pipework being lifted off the shaft bearers. Extensional strain has been observed to result in failure of concrete lining in a shaft. The direction and magnitude of the strain will determine the type and magnitude of the damage to the shaft. A Back analysis together with visual inspections of existing operational shafts within the group resulted in a relationship being established between observed damage and the theoretical calculated strain. The damage was described for each shaft and is also expressed in terms of hours per week required for maintenance and this allowed for the criteria to be set.

The accepted design parameters were as follows:

- Horizontal strain to be between $-0,02$ and $+ 0,02 \times 10^{-3}$;
- Vertical strain to be less than $+ 0,4 \times 10^{-3}$;
- Field stresses crater than 70 MPa will cause uncontrollable damage.

From the outset, it was never intended for obvious reasons, to mine concurrently in any of the three previously mentioned clearly defined blocks.

As far as the sequence of mining was concerned, the model dictated that, after the removal of the inner pillar (30m x 30m around the shaft), the mining should progress concentrically outwards from the centre of the pillar to its eastern and western extremities.

This however was not entirely possible because of the displacements and orientation of the three independent blocks of reef, but the next best option proved to be that of first mining the central block, followed by the western block with the eastern block coming, out last.

Due to circumstances, however, it became evident that it was not going to be possible to follow the optimum sequence and mining had to commence in the eastern block. On completion of mining in the eastern block the western block was mined, followed lastly by the central block. (Figures 5 & 6).

PLANNING

In order for the pillar extraction program to proceed unimpeded and after due consideration of the modeling results, certain strategic issues had to be addressed and which included the following:

- The 28-7 crosscut south would have to be overstoped at the earliest stage possible and so a wide raise was planned to be advanced up through the centre of the pillar to hole on 26 level, which would also facilitate the mining of the inner pillar.
- It became evident that the 26-7 crosscut north would become subjected to severe levels of induced stress and in view of it's importance as an accessway, had to be protected. To this end, a waste cut above the level where it traverses the dyke and in line with the 26-7 CL raise north of the dyke, was advised. This mining would de-stress the excavation.
- A replacement haulage on 28 level had to be developed much deeper in the footwall to the north of the shaft that would interconnect with No 5 A Sub Vertical shaft for the reason

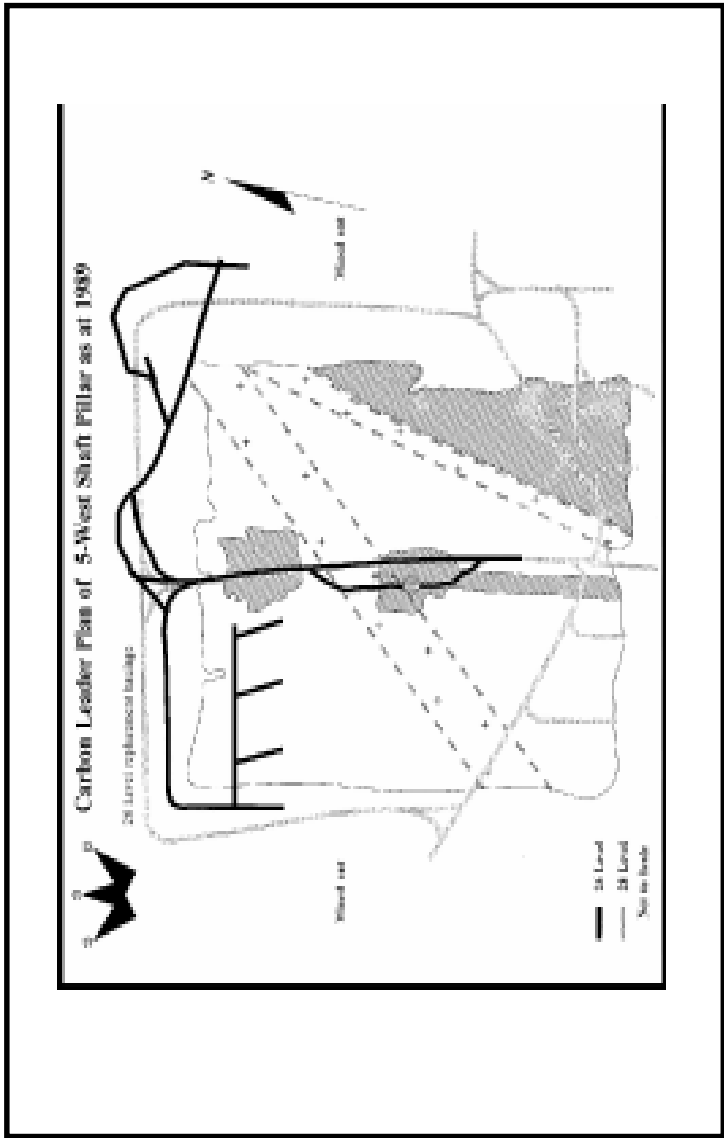


Figure 5

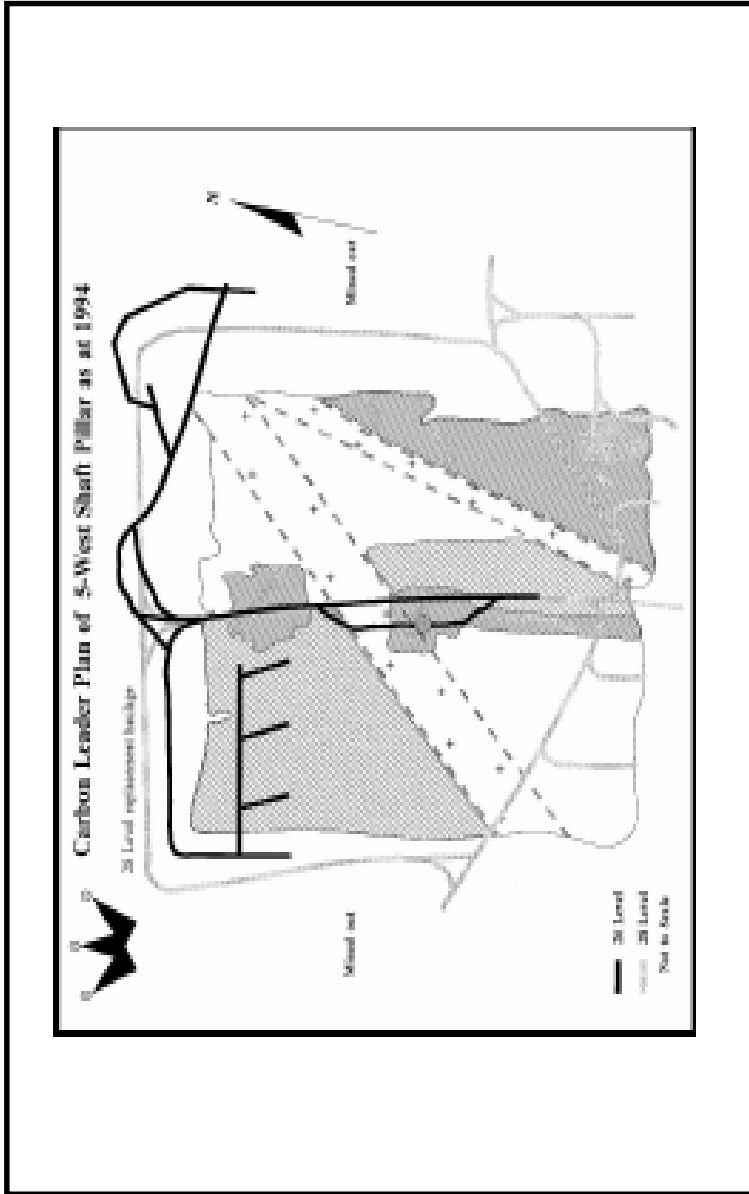


Figure 6

that the pillar mining would destroy the original footwall drives east and west. (Figure 6).

- The mining of the inner pillar would of necessity traverse the main shaft orepass system rendering it unserviceable. This however did not pose any problems, as an additional orepass system had been established outside of the influence of the shaft pillar, in overstoped ground, when the original orepass system became troublesome in the early 70's. The planning was for the waste generated in the waste cut on 26 level to be tipped into the main orepasses between 26 and 28 levels and pressure grouted with cement.
- All stoping in the pillar would be supported with hydraulically placed backfill and hydraulic props because this had previously proved very successful in the extraction of the final remnant in the 5A western longwall.

PREPARATION WORK TO THE SHAFT

It was believed that mining in the pillar would result in considerable movement in the shaft and precautionary measures had to be taken to prevent the resultant damage, and maintain the shaft in a serviceable condition.

Support

The mining simulations showed that strain induced damage could be expected between 24 level station some -2 157m below datum, and the -2 317m elevation some 60m below 26 level station. This represented a total distance in the shaft of 160m.

In order to contain the predicted movements of the shaft walls over the 160m, it was supported with meshing and lacing comprising 2,4m long grouted re-bars and 8 gauge square welded mesh held back by 10mm destrandred hoist rope lacing. In addition 6m long x 40 ton capacity steel rope cable anchors pre tensioned to 20 tons and fully cement grouted were installed around the periphery of

the shaft (Figure 7).

The cable anchors were installed in rings around the shaft, each ring being 2,286m apart down the shaft so as to fit in with the bunton spacing, of 4,572m. Horizontal spacing of bolts was 2,0m resulting in 11 bolts per ring (Figure 8).

In order to install the required support it was necessary to have access to the whole perimeter of the shaft and this was achieved by the design and manufacture of a special drilling platform, which could be easily and quickly attached to the top of the conveyances. By strategic positioning of each conveyance, the whole shaft could be completely and effectively closed off so that drillers could access every portion of shaft sidewall.

The daily procedure for the installation of support was as follows:

- After blasting time each day when the shaft was cleared, the platform would be rolled onto the top of the conveyances and together with the support crew lowered to the relevant ring to be completed that shift.
- Once in position the entire ring of support, i.e. 11 x 6m cable anchors and 29 x 2,4m re-bar would have to be installed before the commencement of the following shift, at which stage the platform would be removed.

STEELWORK

In order to control the effects of vertical induced strain on the shaft steelwork and to isolate it from the concrete lining, the following modifications were done, (Figure 9).

- 50m Above 26 level (i.e. midway between 24 and 26 levels) the concrete lining, was moiled out and a set of 3 bearers comprising 457 x 191 x 92,8kg universal beams installed;
- An identical set of three bearers was installed 501.n below

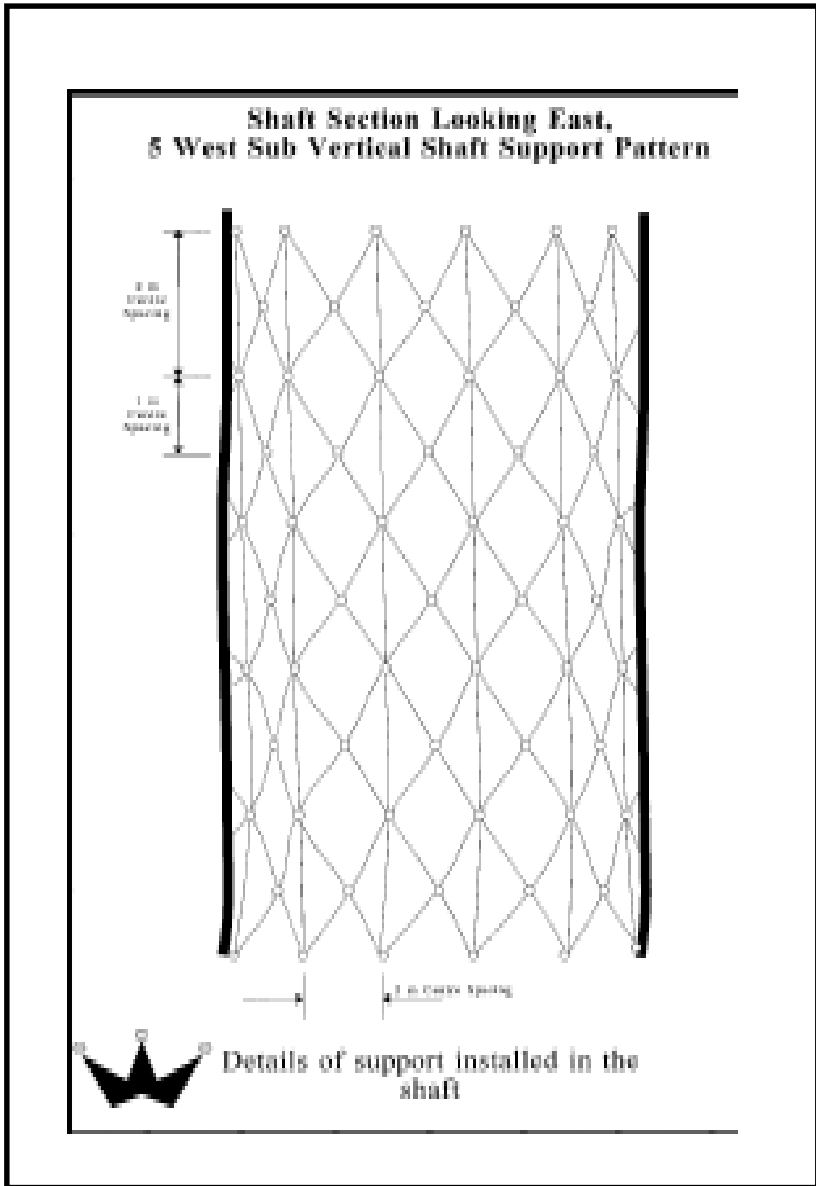


Figure 7

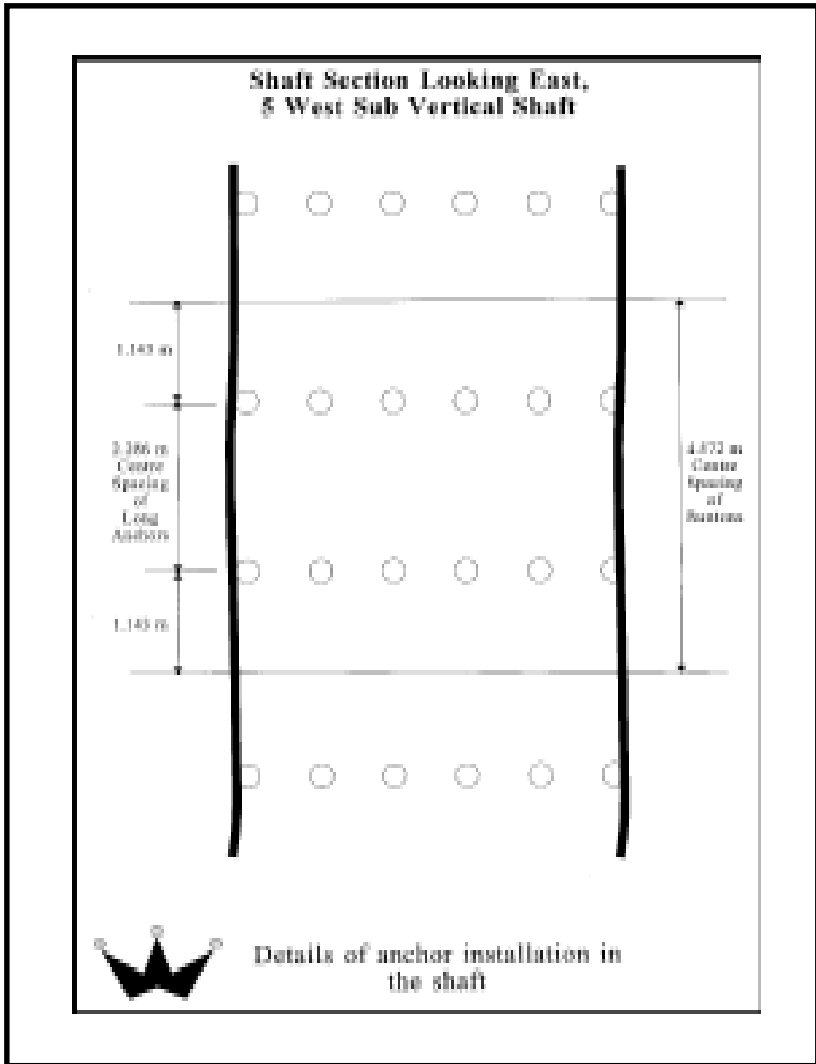


Figure 8

- the 26 level station;
- The ends of all the remaining buntons between the two bearer sets were milled out and freed from the concrete (66 in all);
- The buntion heads in each set were tied together by means of horizontal spacer channels installed between the buntions to prevent distortion of the set.
- 152mm x 152mm RSJ hanger posts were installed vertically between each buntion head and secured by means of four long bolts. These hanger posts extended all the way down from the bearer above 26 level to the lower most bearer.
- The dividers in the service winder compartment were kept in a secured position by installing slipper plates bolted to the shaft lining after the divider heads were milled out.
- The station king posts were replaced with new posts made 75mm shorter than required, with packer plates. This was done so as to compensate for any shortening that took place due to closure or movement by systematically removing a plate when necessary. Each king post was kept vertically in position by means of a guide box bolted onto the station footwall.
- Water and air service pipes were fitted with 1,5m lengths of high pressure reinforced rubberhose to take up any closure that might occur. These hoses were installed on 24 and 26 level stations.

STOPING AND STOPING METHOD

As mentioned earlier, circumstances dictated that mining, be commenced in the eastern block, which was successfully extracted between June 1986 and August 1989. (Figure 5) This was followed in September 1989 to February 1994 by the removal of the western block. (Figure 6)

All this mining was accomplished using conventional breast mining, deploying 30m panels with scraper cleaning. Access was by means of footwall and/or hangingwall drives developed in overstoped ground.

Prior to 1988, all the stoping in the shaft pillar was supported by

means of dewatered backfill placed between lines of 1,1m x 1,1m sandwich packs, spaced 1,8m apart on dip and strike.

Backfill was not allowed to be more than 8m from the face at any time. Face support was provided by three rows of rapid yielding hydraulic props at 1,0m centers and a maximum of 2,0m from the face. Gullies were supported with 1,65m x 1,1m solid timber packs, 1,8m apart (Close and Klokow 1985).

Increasing maintenance costs on the centrifuge units resulted in a change made to the systems being used, and in about mid 1988 the West Driefontein deslimed tailings backfill method was introduced for all future mining.

In the new backfill method, only one single line of 400kN hydraulic props spaced 0,5m apart on dip and 2,5m from the face was used as face support. Backfill was placed into geotextile bags immediately behind the extended line of hydraulic props and the previously placed backfill on a blast for blast cycle. Gully support remained the same with 1,65m x 1,1m solid timber packs spaced 1,8m apart. Blasting is done directly onto the filled backfill bag, which is protected by a gate stull installed between the new bar and the line of props. (Figure 10)

Five years of mining in the pillar using the stoping methods described above, indicated that the damage caused by seismicity was more severe in the gullies than in the stope faces themselves. This led to a decision to extend the backfill right down to the gully shoulders in an attempt to reduce the span over which differential support loading took place. This practice was then followed for a further four years, and although a vast improvement on what previously occurred, did not appear to have entirely solved the problem (Figure 11).

In 1993, it was decided to do away with solid timber packs on gully ledges and to replace them with specially engineered light weight concrete packs, which would provide roughly the same support characteristics as the backfill. This change resulted in the general hangingwall conditions becoming much more stable, and it was noticed that the

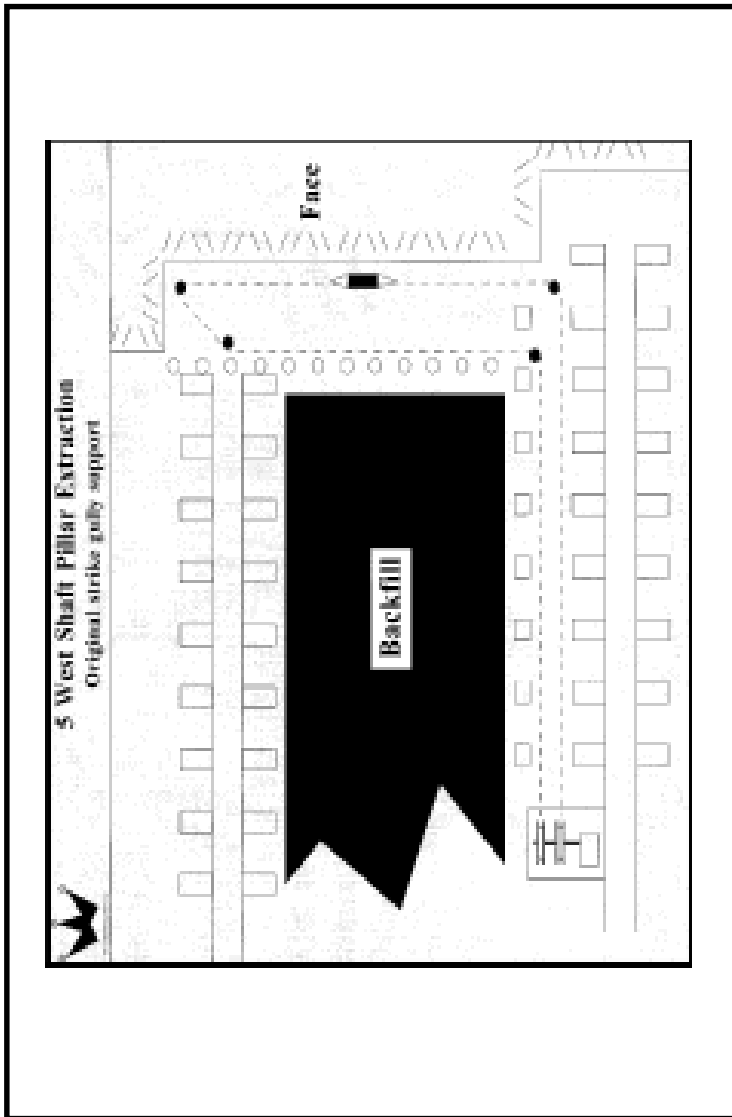


Figure 10

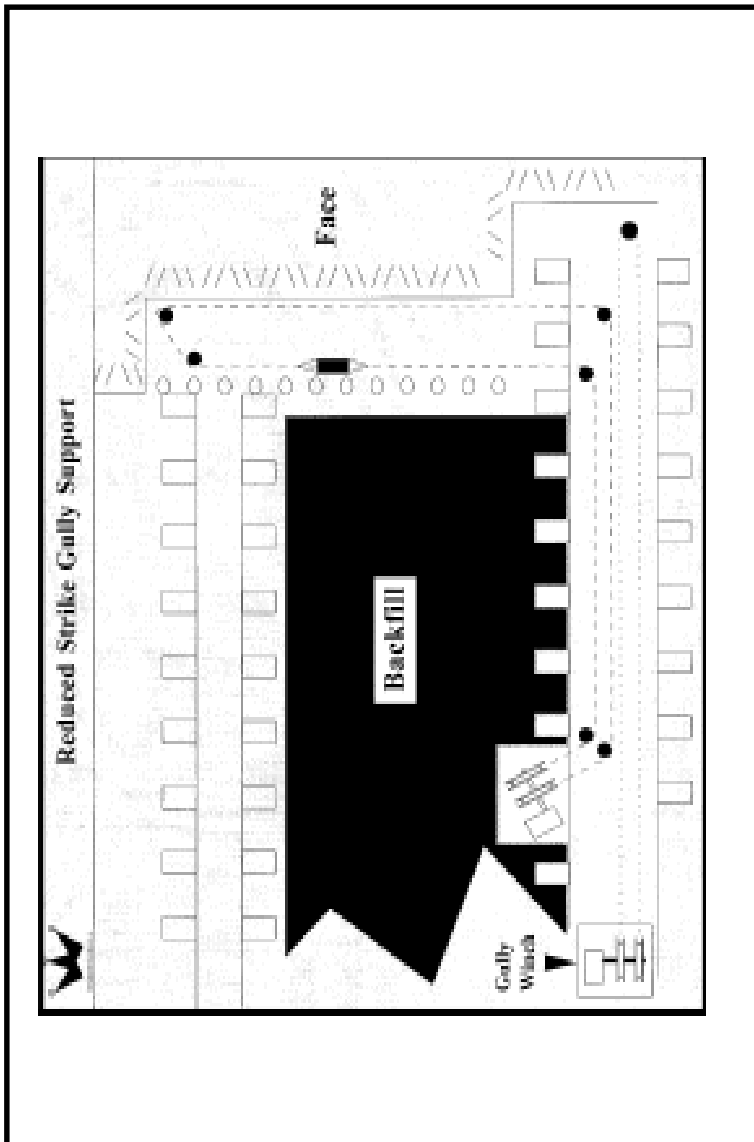


Figure 11

stopping induced fracture planes became much less intense and were tightly closed, indicating that closure was better controlled, and that compressional forces were being set up in the hangingwall. This change did not, however, eliminate falls of ground over gullies subjected to seismic events in the higher orders of magnitude, especially when the pack height exceeded 1,6m.

RESULTS TO DATE

A total of 153 000m² has been mined from the 5 West Shaft Pillar, representing 90% of the available reef. This mining has taken place over a period of ten years with satisfactory safety results, which are on a par with the rest of the mine.

It was known from the outset that an operation of this nature would generate high levels of seismicity, a reality that is supported by historical data from the group seismic network. There was evidence to show that the larger the volumetric extraction, the higher the frequency rate of seismic activity.

Furthermore the possibility of damaging seismicity occurring on one of the two dykes could not be ruled out, hence the decision to mine only one block at a time.

Figures 12 & 13 (K Riemer, 1997) show the plots of monthly production (sq-m) and seismicity for the period January 1982 to December 1996 using a 13 month moving, average. The seismicity data has been adjusted to coincide with production measuring months. These two graphs show the strong correlation between volumetric extraction and seismic event rate. A further point of interest was the occurrence of the largest seismic event to date at the very initial stages of the pillar extraction. An event of magnitude 4.3M1 in December 1983 located in a mined out area on a diabase dyke to the Northeast of the actual shaft pillar. This event caused serious damage to the 26 level crosscut and occurred at a time when the initial updip, from which the east block mining was to commence, was being mined.

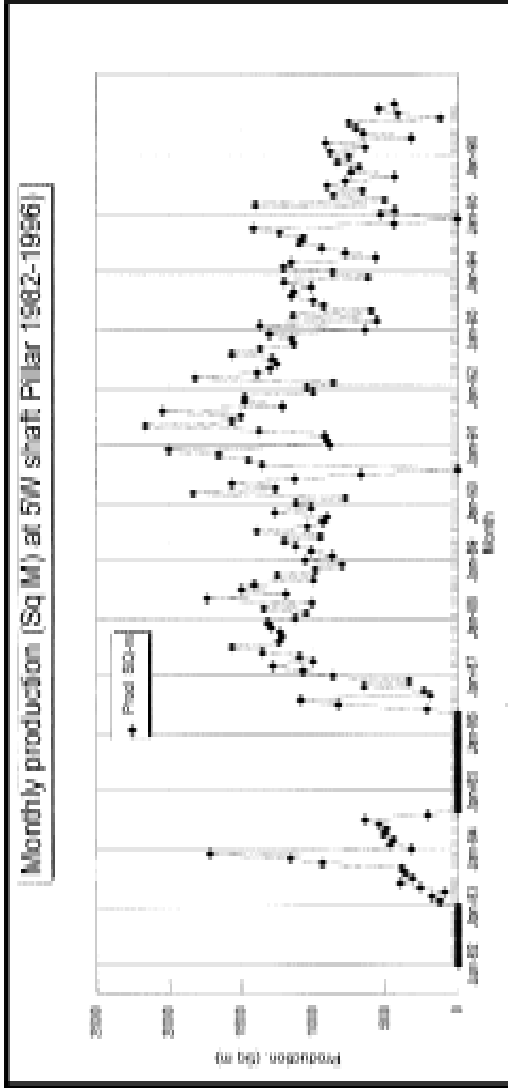


Figure 12

Graph showing production figures at 5 West Shaft pillar for the period 1982 - 1996

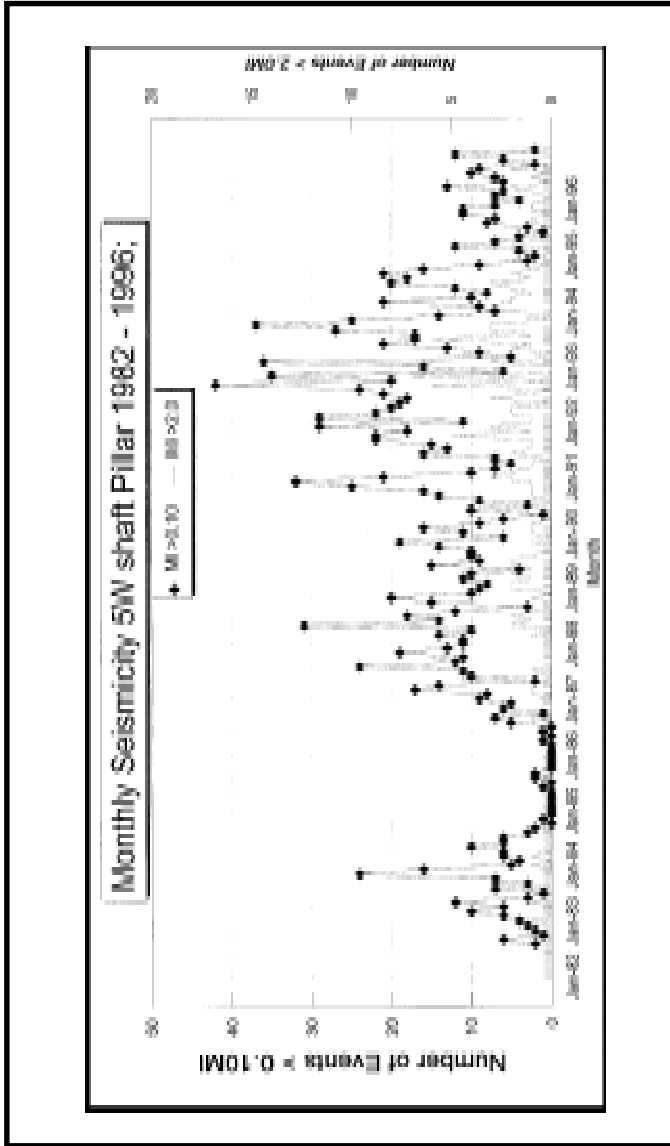


Figure 13
 Graph showing monthly seismicity at 5 West Shaft Pillar for the period 1982 to 1996

From the outset, all stoping excavations in the pillar were supported with hydraulic props in conjunction with backfill, to which can be attributed the successful extraction of the mineable reserves.

As far as the shaft and shaft stability is concerned, it would seem as if the shaft diameter has decreased 40mm at a point some 20m above 26 level. This was determined by weekly extensometer measurements, which were taken at specified points to determine horizontal displacement in the shaft lining.

Vertical displacement over this period amounted to a total of 440mm, which was mainly manifested on 26 level station where the king posts were constantly having to be shortened. Higher up in the shaft, however where the model predicted elastic movement would take place, none or very little was detected.

The actual vertical movement recorded, which was most probably the inelastic component, was less than the 650mm originally predicted.

Successful extraction of the pillar was progressing well in August 1996, with the shaft still in very good condition and operating smoothly. $\pm 15\ 000\text{m}^2$ of highly payable reserves were left to be mined prior to closing down and decommissioning of the shaft.

At 14h20 on Sunday 11 August 1996 a severe tremor was felt on surface, which was later that evening, determined to be a seismic event at the No 5 West Sub Vertical Shaft. The following morning, it was discovered that severe inward deformation of the shaft lining had taken place, as well as distortion of the shaft steelwork, to such an extent that the free movement of conveyances through the shaft was impeded.

The bulk of the concrete movement into the shaft was found to be in the north western sidewall rendering the western rock and man compartments unserviceable. The wire meshing and cable anchor support had moved out into the shaft by some 300mm to 500mm over an area of some 5m^2 ($\pm 3\text{m}$ in the circumferential direction by $\pm 1,5\text{m}$ in the axial plane). The damaged area was estimated to be somewhere between 3m and 5m above the 26 level station, i.e. where

the Carbon Leader intersects the shaft. The rest of the shaft lining, on the same elevation and on the north east around to the south eastern side showed only signs of minor cracks and appeared generally stable.

Steelwork damage was more severe, with three bunton sets, which under normal circumstances are aligned in the north south axis, being compressed by some 250mm causing them to bend. In addition, the vertical displacement of the concrete lining, four sets up from 26 level, had caused the stabilizer to fail and had disorientated the whole set by some 2° to 5°. Numerous guides in all compartments were bent with the curved section protruding some 300mm into the compartment. Guide damage extended for some 15m to 20m along the vertical axis of the shaft in the vicinity of 26 level reef intersection.

All the observations made of the damage described above were from a basket suspended some distance from the conveyance at a position in the shaft, about 30m or 40m above the effected area. The 26 level station was completely closed up and totally inaccessible for a distance of ±25m, extending from the shaft towards the station "D".

The seismic event, which registered 3,4 on the Richter scale was focused on the BV 74 dyke some 90m west of the shaft and 100m above the 26 level elevation. The dyke has a strike orientation NE-SW and dips at a relatively flat angle of 60° - 70° towards the north, and actually intersects the shaft on the 26 level station. Figure 14 depicts the extent of mining on the day the event took place.

After careful consideration of the damage it was decided that the shaft be abandoned because the remaining block of ground contained 15 000m², which could be accessed from the adjoining 5A Sub Vertical Shaft 1 900m away, and successfully extracted.

Between August 1996 and March 1997 mining of the last remaining block in the pillar continued via the 5A Sub Vertical Shaft. During this time the area experienced moderate levels of seismicity which invariably resulted in the collapse of hangingwall across gullies and access ways.

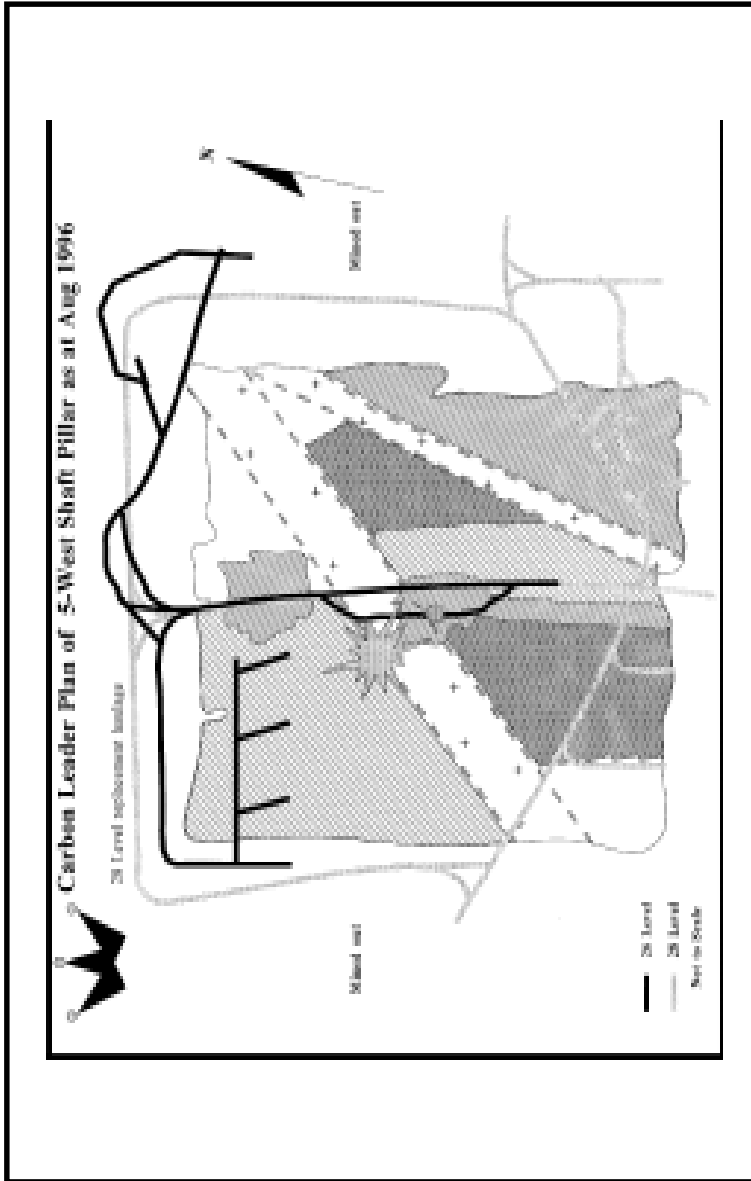


Figure 14

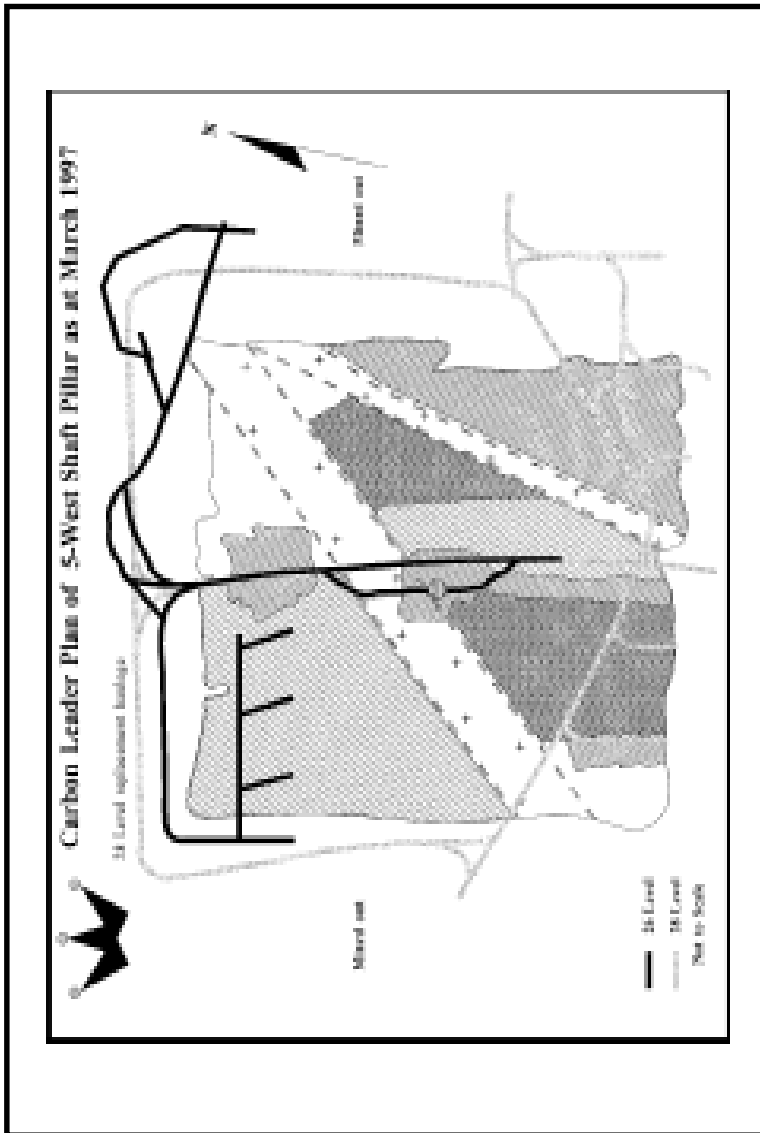


Figure 15

In total, only 4 000m² were mined during this time, when in March 1997, a seismic event was recorded in the area which caused severe falls of ground affecting a large area.

Although no serious damage was seen in the stope faces themselves, the access ways to the stope as well as most dip and strike gullies were severely affected making access to the working areas virtually impossible.

At the time only two panels were still working, due to poor face shapes that had been brought about by previous incidents of seismicity, and it was then that a decision was taken to stop mining in the pillar altogether. (Figure 15)

CONCLUSION

The extraction of this high grade shaft pillar traversed by two highly stressed and seismically active geological features of unfavorable orientation is considered to have been technically successful. The original objective, with respect to the safe removal of the reserves while still keeping the shaft operational, can be said to have been met. Decisions are to be made to remove the last remaining portion of ground by means of vacuum cleaning.

ACKNOWLEDGEMENTS

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