The risks associated with mines in dolomitic compartments

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Synopsis

The purpose of this report is to assess the risks faced by mines in dolomitic compartments in particular Kloof 8 shaft. The dolomites of the West Rand comprise one of South Africa's most natural water resources, and overlie the reefs of the richest gold mines in the world. The pumping of water from the dolomitic aquifers to prevent flooding has caused the natural water table to subside, and the resulting cavities within the dolomite rock formations that overlie many gold deposits sometimes collapse, causing sinkholes. These impacts of the mining industry could worsen over time if preventative measures are not taken.

This report discusses these impacts in detail, more specifically the risks to which operations in dolomitic compartments are exposed. A risk analysis was carried out to access the risks that the organization could face and it was this analysis that allowed one to examine the best methods to combat the problems.

Other factors such as geological features and seismic events were also considered for the evaluation.

To aid with the completion of this work various resources were utilized. A literature study was undertaken, information was gathered from various experts who specialize in dolomitic studies, evaluations were conducted and conclusions reached.

The results from the project indicated that preventative measures should be implemented and correct procedures put in place to prevent any disasters.

Introduction

The gold-bearing reefs of the Far West Rand underlie 1 200 metres of dolomite, which is the most important aquifer of the West Rand (Bezuidenhout *et al.*). Figure 1 clearly illustrates the area covered by dolomite in Gauteng, where the Far West Rand is situated. It is appropriate for the dolomitic groundwater, stored in separate dyke bounded compartments to flow into the mine workings at enormous rates (Bezuidenhout *et al.*), if the correct preventative measures are not taken.

As a general policy and safety measure, the dolomitic groundwater compartments are dewatered by pumping and the pumped water is disposed in such a way that it cannot return to that particular compartment and recirculate through the mines again. In doing so the safety of the employees working underground is not compromised and a safe working environment is created.

Dewatering, however, results in subsidence of large areas and the formation of sinkholes. Damage to buildings caused by subsidence and the loss of lives as a result of the formation of sinkholes, are just some of the risks that result from dolomitic compartments.

Overview of Kloof

Kloof Gold Mine is situated in the magisterial district of Westonaria 48 km west of Johannesburg, South Africa (as depicted in Figure 2), and is managed by Gold Fields Limited. Kloof lies in the West Wits goldfield, in an area that is bounded by both the Bank Fault to the west and the Witpoortjie Fault to the east (Kloof Code of Practice, 2004).

Historically Gold Fields' mines in the area consisted of four sections, namely Venterspost that has ceased mining, Kloof, Libanon and Leeudoorn. The remaining three sections were amalgamated into one operating division called Kloof Gold Mine during 2001 to 2002. Leeudoorn was renamed 7 shaft, while Libanon was changed to 8 shaft and 9 shaft. The mine operates at depths of 1 000 to 3 500 m and employs more than 14 800 people.

Mining at Kloof

Kloof mines the Ventersdorp Contact Reef (VCR) at depths of between 2 500 and 3 700 m with minor production volumes coming from the Kloof Reef (KR), Libanon Reef (LR) and Main Reef (MR). 8 shaft sources production from the VCR, KR and MR, with the last predominating (Kloof Code of Practice, 2004).

Kloof 8 shaft

Kloof number 8 shaft hosts various orebodies, and various mining methods are used for the extraction of gold. These methods include

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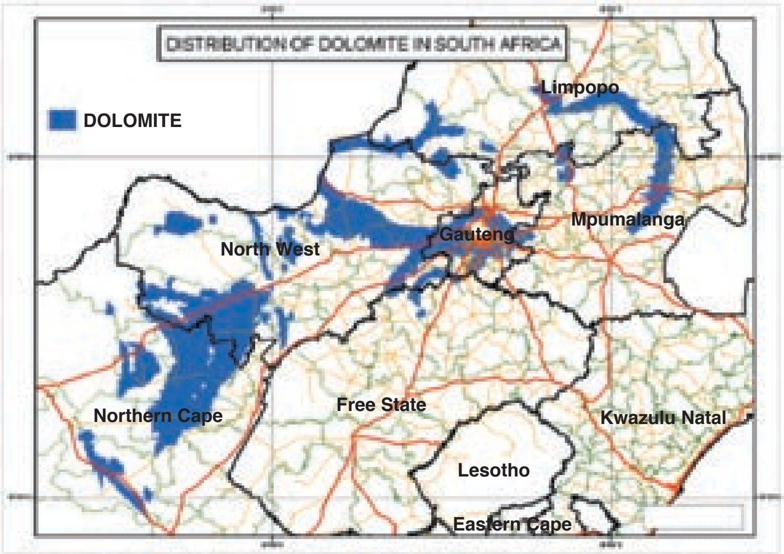

Figure 1—A map showing the distribution of dolomite in South Africa (source: Department of Public Works, August 2004)

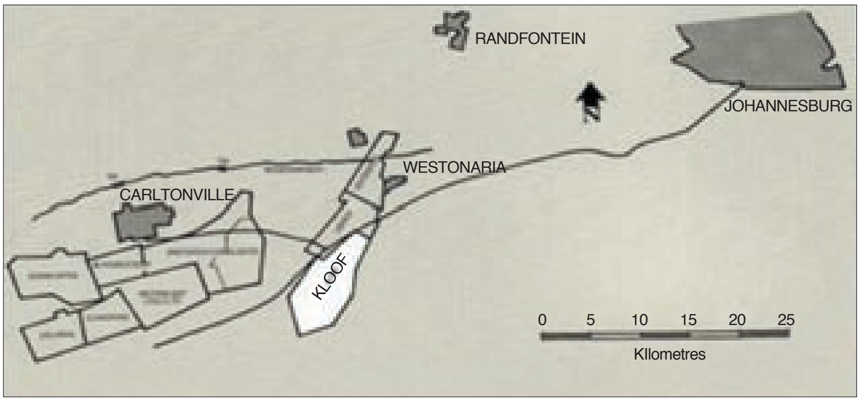

Figure 2—Locality plan showing Kloof Gold Mine in relation to other mines, towns and the city of Johannesburg

longwall mining, scattered mining, and most recently pillar extraction, to extract pillars and small remnant zones left behind from earlier workings.

The reefs that are currently being mined at 8 shaft are the Main Reef and the VCR. Both the Libanon and the Kloof Reef are also being mined, but to a lesser extent.

- *The Main Reef*—The Main Reef, otherwise known as the Middelvlei Reef, occurs approximately 60 metres above the green bar (shale layer) and is the primary orebody for 8 shaft.
  The reef zone consists of a sequence of conglomerates, quartzites and pebbly quartzite. It is divided into three bands, namely the bottom, middle and top bands. At 8 shaft only the bottom band is economical, and is therefore mined.
- *The Kloof Reef*—The Kloof Reef zone occurs at 8 shaft, just above the Libanon Reef, and consists of conglomerate bands and interbedded quartzites.
  The geological features found within these orebodies were obtained from the Code of Practice to Combat Rock Falls and Rockbursts, and are shown in Table I.

Project background

Gold mining is the principal economic activity on the West Rand, and is the basis of the economy and socio-economic development of the region. Gold mining on the West Wits Line contains the biggest and richest mines in the Witwatersrand Basin (Robb, 1997).

One of the most important aquifers in South Africa is the dolomitic aquifer of the West Rand and Far West Rand areas and it is in these aquifers that naturally occurring water is stored. The dolomitic rock is composed of the mineral

Table I

Major geological features at 8 shaft

Orebody	Geological features
VCR	Venterspost Dyke, Running Dyke
Kloof Reef	Venterspost Dyke, Running Dyke
Libanon Reef	Venterspost Dyke
Main reef	Venterspost Dyke, Libanon Dyke

dolomite, which is a carbonate of calcium and magnesium. Dewatering of the dolomitic aquifers overlying gold-bearing reefs has resulted in the lowering of the water table, and this has contributed to ground instability.

The formation of sinkholes from dewatering can result and these can have catastrophic results. The death of 29 people at West Driefontein in 1962 as a result of a sinkhole shocked the mining industry and necessitated that precautionary measures be implemented to prevent such occurrences.

This report highlights the risks faced by mines in dolomitic compartments, but firstly one needs to define explicitly what a risk is.

Risks

The Oxford English Dictionary defines risk as a chance of danger or injury. On the other hand, Athearn and Prichett define risk simply as a condition in which loss or losses are possible. One can also define risk as the probability of an occurrence of an event multiplied by the cost associated with the event (MINN427 course notes).

The different mining risks

Mines situated in dolomitic compartments are faced with the risks of flooding from the dolomitic water, and associated ground instability and sinkholes are another major problem. Seismic events also contribute to the risks as they not only aid in the formation of sinkholes due to sudden ground movement, but also open joints and create cracks in rocks, which later act as conduits for water.

This report focuses on all the above-mentioned aspects with greater emphasis being placed on the impacts of dewatering and the corresponding environmental effects.

Problem statement

The purpose of this research is to investigate the risks associated with mines in dolomitic compartments.

Objectives

In order to carry out the project the following objectives were set at the beginning of the research. These objectives included:

- A background investigation
- Evaluation of the factors that influence the problem
- Analysis of the results
- Findings
- Conclusions
- Recommendations.

Scope of the study

An investigation into the various factors that pose serious risks to mines in dolomitic compartments was carried out. This investigation included an analysis of the geology, geological features and their contribution to the problems. Seismicity was another aspect that was investigated as seismic events were discovered to be major contributors when it came to issues of sudden ground movement. A subsidence and sinkhole survey of the area surrounding the mine of concern was carried out to assess the impacts of dewatering.

Methodology

In an effort to achieve the preset objectives, various methods were employed and these included:

- *Literature research*—this was conducted to highlight similar problems from other mines in dolomitic compartments.
- *Consultations with on-mine personnel*—ground Stability experts were consulted at the Gold Fields Geological Centre.
- *Review of mine plans*—mine plans were reviewed to aid with the understanding of the geology and general underground infrastructure.
- *Identification of hazardous geological structures and analysis*—identification of the geological features was important as it highlighted the extent of the fractures in the dolomite.
- *Seismic analysis*—a seismic analysis was conducted to evaluate the seismicity at the mine.
- *Data collection*—data was collected from the mine to assist with the completion of the project.

Literature study

A literature study forms an important part of the research, and supplements the project background. The aim of this study is to highlight problems or similar problems that were experienced on various other mines and how they were managed.

In this literature review, mines such as Driefontein and Western Deep Levels were studied, as flooding occurred at these mines. The geology of 8 shaft was reviewed to assess if a correlation existed between 8 shaft and the above-mentioned mines.

Geology at Kloof 8 shaft

Figure 3 shows the lithology on Kloof Gold Mine. The lithology of this area comprises the Malmani dolomite from the Chuniespoort group of the Transvaal Supergroup. Rocks from the Witwatersrand Supergroup can also be found at 8 shaft (Kloof Code of Practice, June 2004).

The VCR represents an angular unconformity, and it is this unconformity that results in the successive sub-cropping of the Central Rand Group against the VCR. Both the Westonaria and Alberton Lava Formations of the Klipriviersberg Group overlie the VCR that sub-crops against the Black Reef Formation within the 8 shaft area.

The Black Reef Formation unconformably overlies the Klipriviersberg volcanics. Dolomites of the Chuniespoort Group overlie the Black Reef Formation and are in turn capped by sediments of the Pretoria Group. The Chuniespoort and Pretoria Groups are part of the Transvaal Supergroup.

Figure 4 shows a cross-section of the geology at Kloof and the position of the Black Reef in relation to the dolomite. The Black Reef consists of a thin small pebble conglomerate, quartzite and carbonaceous shale.

Tectonic activity resulted in folds and faults. The pre-dolomite formations have been fairly extensively faulted. There are three major faults: the Witpoortjie, Panvlakte and Bank faults. Although much of the faulting was pre-dolomite, there are faults that continue into the dolomite either due to rejuvenation of the pre-existing faults or continued activity. It is these faults and open joints that connect the water-bearing features in the dolomites to the mine openings, which have been developed at depth.

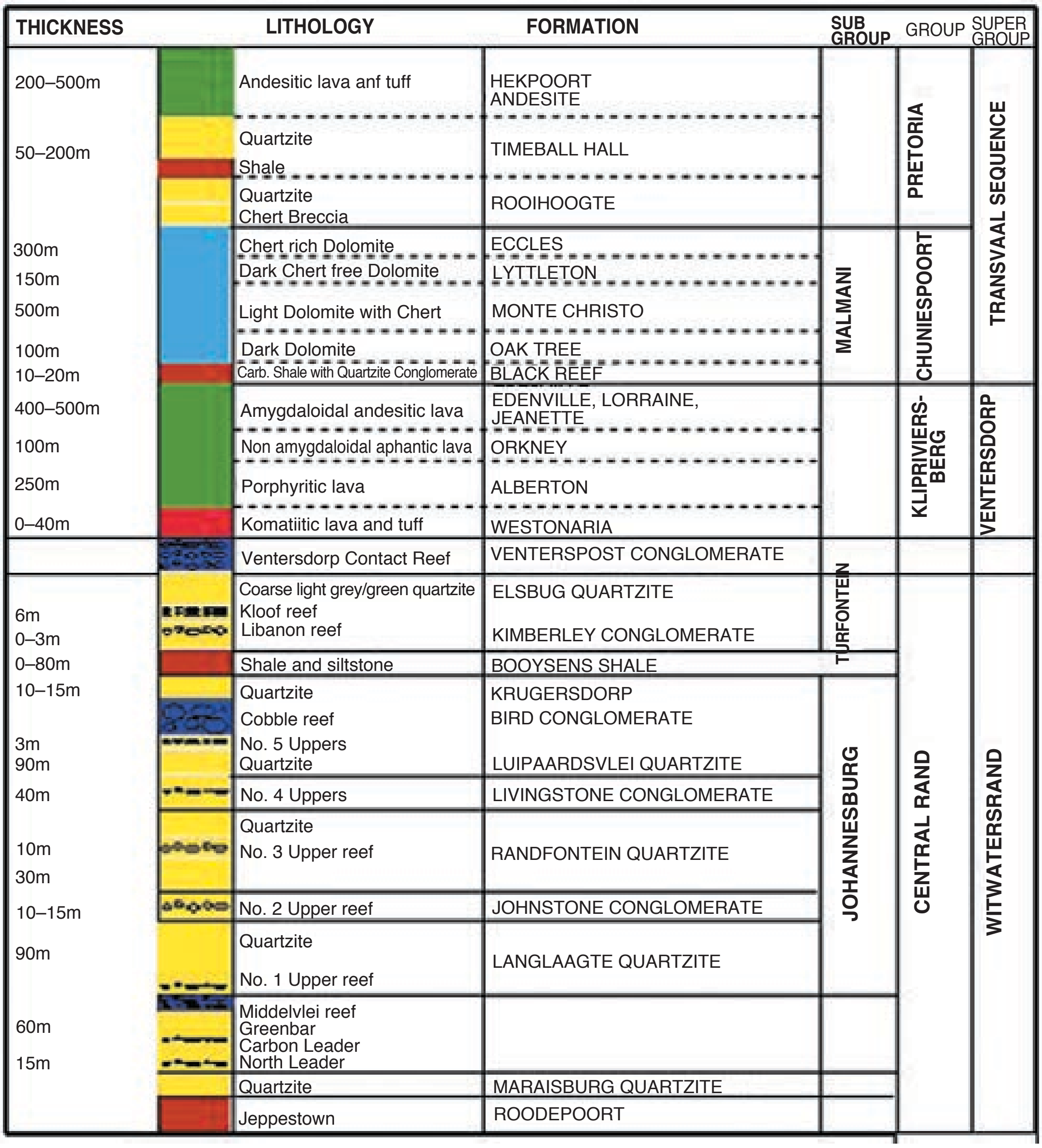

Figure 3—Stratigraphy of Kloof (Kloof Code of Practice)

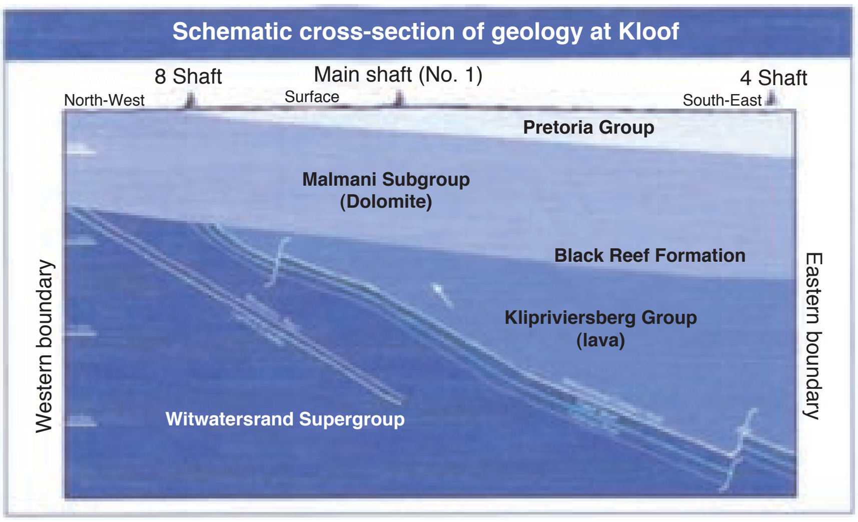

Figure 4—Cross-section of the geology at Kloof (Kloof Code of Practice)

Dykes of younger age than the previously described features have intruded the area; many are roughly parallel with a north-south orientation. These dykes have divided the dolomites into compartments and controlled groundwater movement in pre-mining times.

The dolomitic compartments

Before mining, the dolomite of the area was divided into a number of watertight compartments by a series of impervious dykes. These dykes, which divide the dolomite into specific groundwater compartments, are approximately 50 metres wide and are spaced 5–15 km apart. The compartments were named after the downstream boundary dykes; for example the Venterspost Compartment is bounded on the west by the Venterspost Dyke (Figure 5).

Kloof 8 shaft is situated in the Bank Compartment, and mines in this compartment have experienced significant inflows of dolomitic water. It was also discovered that the geology of 8 shaft was similar to that of Driefontein.

Uncontrollable volumes of water were encountered in mines like Driefontein and these mines were given permission to dewater the dolomites. The dewatering of the dolomite led to the lowering of the water table and surface subsidence in the form of broad depressions (dolines) and catastrophic sinkholes resulted.

The dewatering of the dolomitic compartments

In the absence of any other alternative methods of preventing the dolomitic water from finding its way into the mine workings, there appeared to be no other alternative but to dewater the dolomite (Bezuidenhout *et al.*).

The dewatering of a compartment entails not only the removal of the water contained in the dolomites, but also the disposal of that water to ensure that it does not return.

This prevents water recirculation and progressive depletion of the water stored in the dolomite (Bezuidenhout *et al.*).

As a result of the implementation of the policy of dewatering, the groundwater stored in the compartments decreased and the groundwater levels dropped progressively resulting in the occurrence of slow surface subsidence and sinkhole formation.

According to Bezuidenhout, a study of the sinkholes, which formed in the Far West Rand since mining operations began, was conducted, and it showed very clearly that sinkholes formed concurrently with the lowering of the water table.

Sinkhole disasters

Dolomite is soluble, which means that it dissolves in water. Rainwater and infiltrating groundwater gradually dissolve the rock over time as it seeps through joints, fractures and fault zones in the rock. The dissolution of the dolomite gives rise to cave systems and voids in the rock. Soils covering the rock can collapse into these caves or voids, resulting in sudden disastrous ground movement on the surface, and in sinkhole disasters (Department of Public Works, 2004).

There are three important mechanisms that contribute to the formation of sinkholes that should be avoided at all costs. These include:

- Excessive water seepage
- Water level draw down
- Seismic events.

Sinkholes are catastrophic and many sinkhole disasters have occurred in the past. In the Westdene area 5 people died when they disappeared down a sinkhole, and in December 1962, a three-storey crusher plant building was swallowed into a sinkhole on the West Driefontein Mine. None of the twenty-nine occupants was seen again (Brink, 1984). Figure 6 shows the location of sinkholes in the Johannesburg area.

Sinkholes in the Far West Rand

More sinkholes were found on the far west rand, (Figure 7 to Figure 10), and this is a clear indication of the severity of this problem.

The flooding of mines in dolomitic compartments

Western Deep Levels (WDL) is situated in the foothills of the Gatsrand, 70 km west of Johannesburg, on the West Wits Line. For 20 years WDL operated via its number 2 and 3 shafts. In 1980 a decision was taken to sink a new shaft, the number 1 shaft.

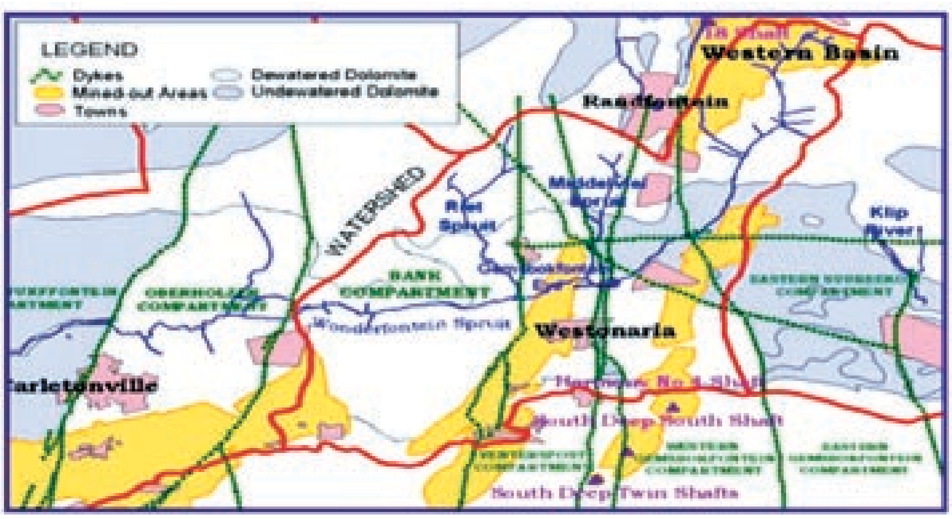

Figure 5—The dolomitic compartments (source: *South African Mining World*, September, 1982)

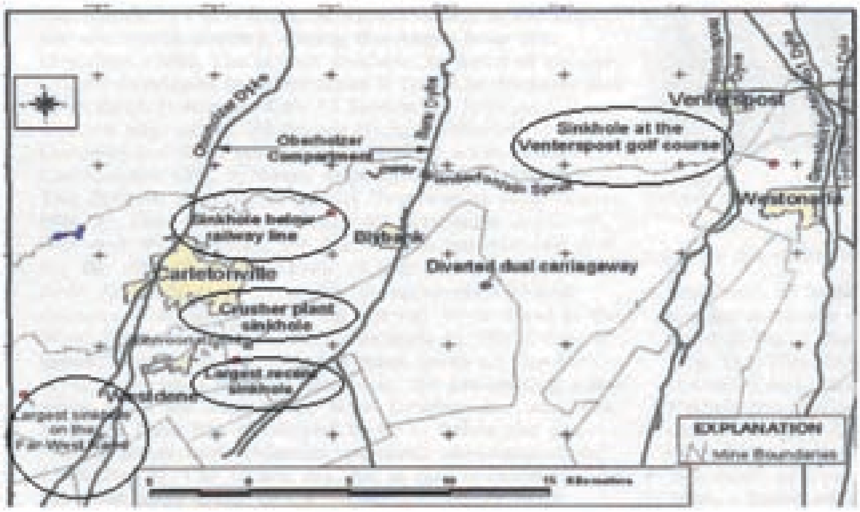

Figure 6—Location of sinkholes (C.J.U. Swart *et al*.)

Figure 7—Sinkholes on a farm, in the Far West Rand

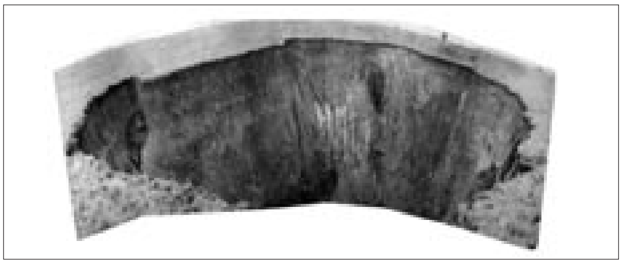

Figure 8—A sinkhole near Bank Station, West Rand

On the 9 July 1982, the number 1 shaft at Western Deep Levels gold mine flooded, causing a setback of eight months to the shaft sinking operations that were in progress. What was puzzling about this occurrence was that two pre-cementation holes had been drilled, one next to each shaft, to supplement the normal eight cover drill holes that had been drilled ahead, for shaft sinking purposes, so such water should have been detected beforehand (Solms 1984).

Another disturbing factor concerning this occurrence was the fact that water was intersected in a dewatered compartment. Dewatering is a state where the inflow to the mine is reduced by removing water that is in storage in the dolomite (WRC Report No 699/1/01).

Figure 9—A sinkhole sited on a farm adjacent to South Deep (photo taken by Pieter Groenewald)

Figure 10—A 50 m deep sinkhole on a farm that is situated adjacent to a mine (photo taken by Pieter Groenewald)

The dewatered compartment

Number 1 shaft, as depicted in Figure 11, is located in the dewatered Oberholzer compartment of the West Wits Line. The shaft is bounded on the east by the Bank Dyke and on the northwest by the Wuddles Dyke, which are both impermeable.

There were several geological discontinuities that were situated within the compartment. Faults and sills within the Pretoria sediments served as water distributing agents.

The discontinuities within the geohydrological regime contributed to the network that allowed the water to be transported to fractures within the dolomite. The major contributor was the Transvaal fault that passed through the Malmani dolomite and the Pretoria group. Redistribution of water within the dolomite was aided by the presence of fracturing and jointing.

Another factor that was later investigated was that a borehole drilled in 1977 may have provided a conduit for the water between the dolomite and the Pretoria series (WRC Report, 2001).

The West Driefontein flood

The mine flooded on 26 October 1968 as a result of stoping that took place at the base of the undewatered dolomite of the Bank Compartment (Swart *et al.*). A small part of the roof of the stoping area collapsed.

The source of the water was the overlying dolomite of the Bank Compartment and a fault zone acted as the conduit. The water flowed into the mine through two haulages and into the Oberholzer Compartment.

Conclusions from the literature review

The information gathered from this literature review indicated the importance of:

- Understanding the geology of the compartments
- Accurate methods for the detection of underground water
- Accurate methods for the detection of possible conduits
- The consequences that result from dewatering.

The experience that Western Deep Levels and Driefontein had with water inrushes is one that has a possibility of occurring given the nature of the location of 8 shaft. 8 shaft is situated in the Bank Compartment, where the water table is seen to be steadily increasing. Subsidence within close proximity to 8 shaft was observed by the author, and this will demand that regular ground stability monitoring be conducted.

Data acquisition and analysis

Rainfall data, pumping rates and the water table measurements at 8 shaft were taken in an effort to evaluate whether a relationship existed among the three. The idea was to assess whether the rainfall influenced the pumping rates, and if so, to assess how the water table responded. The water table is important as it has an influence on the ground stability.

Rainfall

Figure 12 represents the rainfall data for the period 1966 to 2003. This information was obtained from the surface surveyor (Frost, 2004) from a weather station situated at Kloof.

The graph gives an indication that there have been high and low rainfall seasons, as is indicated by the fluctuation of the data. The most rain was experienced during 1987, 1993 and 1997 as more than 250 mm of rain was recorded at the weather station.

The wet seasons occurred during January to April and again from September to December, while the dry seasons were experienced from May until August (refer to Figure 13). The trend is seen to be similar during all these years.

Pumping rates

Figure 14 demonstrates the pumping rates at 8 shaft, this data being obtained from the Gold Fields Geological Centre. There are various factors that influence the pumping rates at 8 shaft and include amongst others rainfall and water coming from other mines.

The graph is accompanied by a cumulative graph that indicates the change in gradient.

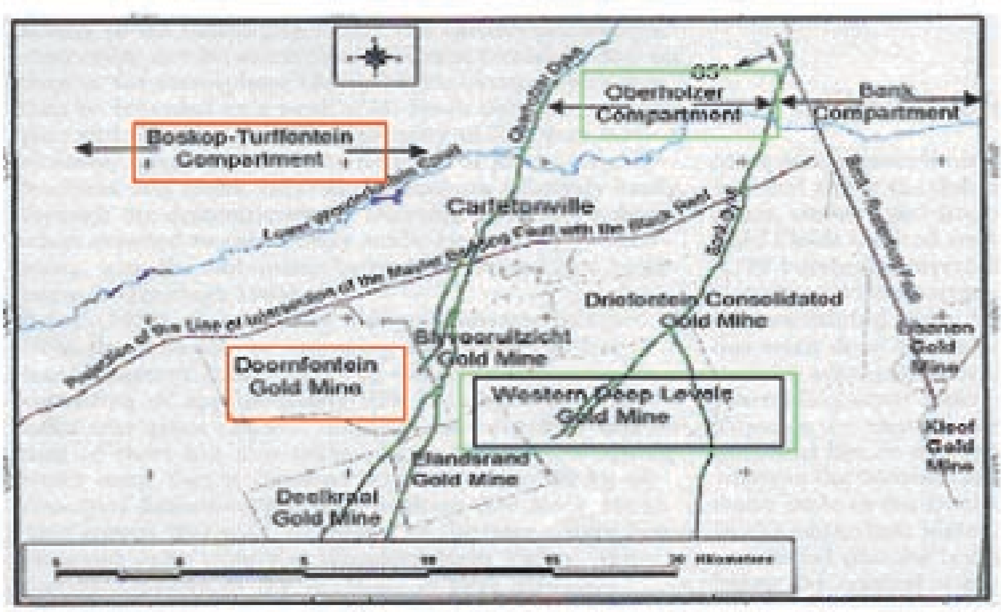

Figure 11—Location of the mines in relation to the compartments

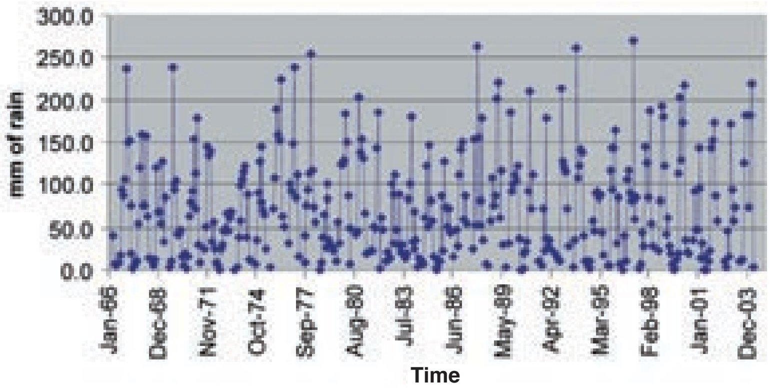

Figure 12—Rainfall at Kloof from 1966 to 2003

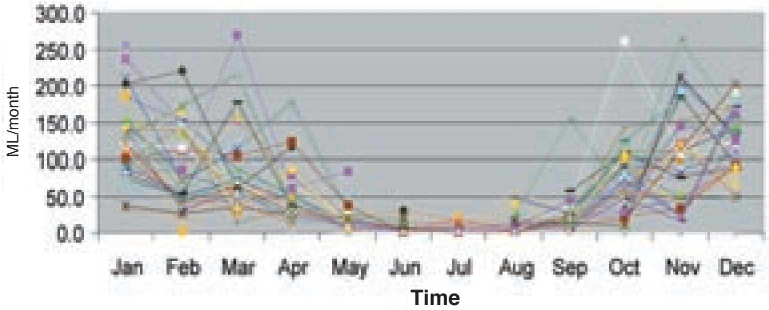

Figure 13—Monthly rainfall from 1966 to 1993

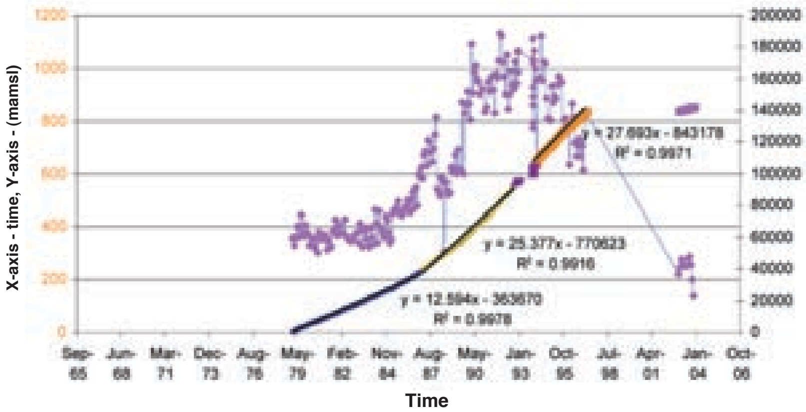

Figure 14—Pumping rates at 8 Shaft

May 1979 to November 1984 was a time where a moderate amount of pumping took place. A sudden increase in pumping was experienced from August 1987 up to January 1993. It was during 1994 that a decline in the pumping rates was observed, which carried through until January 2004.

Water distribution

All water utilized by 8 shaft is fissure water pumped from underground. 8 shaft does not pump water from surface into the shaft, as the water obtained from the fissures has proven to be sufficient for the mining activities. Figure 15 demonstrates the path taken by the water.

- On average 16 megalitres of fissure water is pumped from 23 level each day
- 6 megalitres of water is recirculated back into the mine and 10 megalitres is taken to surface
- The pumping system has a design capacity of 34 megalitres of water per day
- On average water pumped each month amounts to approximately 259 megalitres
- The 6 megalitres of water is utilised by the various levels for mining purposes
- The 10 megalitres is utilized by 1 shaft and 10 shaft, where 1 shaft consumes about 8 megalitres and 10 shaft about 2 megalitres
- 37.5% of the water pumped is returned underground and 62.5% of this water is taken to surface to be utilized by the two shafts
- On average 8 shaft spends R434 000 on pumping costs per month.

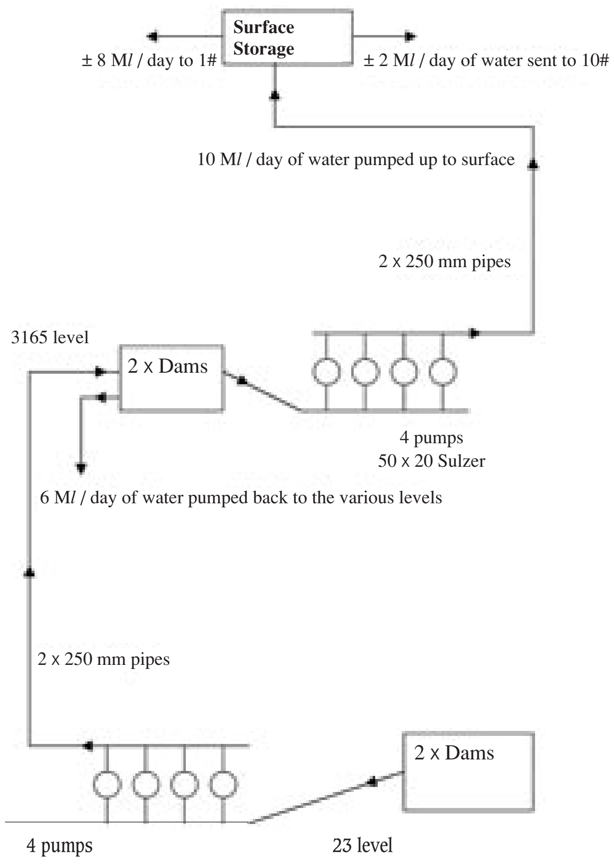

Figure 15—Pumping at 8 shaft

Future water distribution

In the future 8 shaft hopes to simplify their pumping and contribute to the cooling of the underground environment by installing a fridge plant, as can be seen in Figure 16. The 16 megalitres of water will be pumped to surface to the fridge plant and the same quantity of water as specified above will be returned underground, but this time it would be chilled water. 1 shaft and 10 shaft will still receive their water, the only advantage being that the water will now be cooler.

The pumping at 8 shaft seems to be under control at present, but a problem could arise should Driefontein decide not to pump. Most of the water management at 8 shaft is aided by the pumping from Driefontein.

Driefontein is situated in the Bank and Oberholzer Compartments and the part of Driefontein that is in the Bank compartment aids 8 shaft by reducing the amount of water present in the compartment. Kloof 8 shaft is at a lower elevation than Driefontein so should Driefontein stop pumping, the water would flow down to 8 shaft.

The water table

Figure 17 was also obtained from the Geological Centre and portrays the change in height of the water table over time. The water table is measured by means of a pressure gauge that is positioned at 2250 level, which is at 958,997 m.a.m.s.l. (refer to Figure18). If the pressure in the gauge is high, this indicates that large amounts of water are present, especially after heavy rains, and should the gauge indicate low values, it means that less water is present.

The water table has been progressively decreasing from 1965 up to 1998. A negative downward slope was observed and this confirmed the decrease.

What was also noted was that there seems to be a rise in the water table since 2000 and it is still increasing. The water table at 8 shaft is currently at 1 239 m above sea level.

The relationship between the rainfall and the pumping rates

When Figures 14 and 17 were compared a relationship between the two figures was observed. The change in gradient between the two graphs was used for the purpose of the analysis, as depicted in Table II. These were compared for the same time period.

From December 1993 to April 1997 the pumping was at its highest with a steep gradient of 27.693 and the water table gradient was observed to have a negative slope of 0.0283, an indication of the decrease. As from August 1987 to May 1990 another time of high pumping was evident as indicated by a gradient of 25.377 and the water table was seen to decrease. Moderate pumping occurred during May 1976 up to December 1986, as the water table gradient was almost constant with a negative slope of 0.0058. During this period (1979–1986) the pumping decreased by almost 50% when compared with the period from 1987 to1990.

Another reason that could contribute to the water table drop is the use of water by farmers for agricultural purposes. Boreholes are drilled and used as a means to aid in the extraction of water.

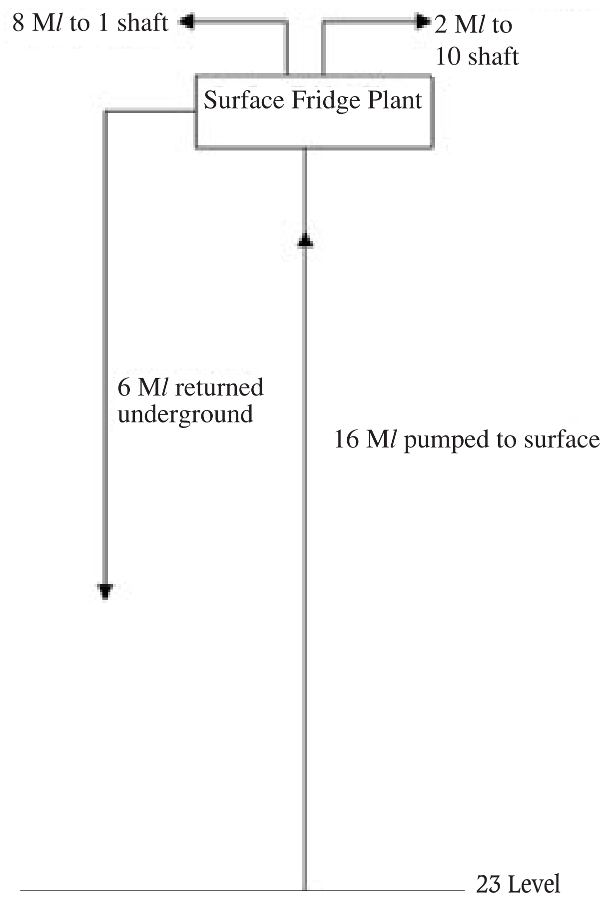

Figure 16—Future pumping at 8 Shaft

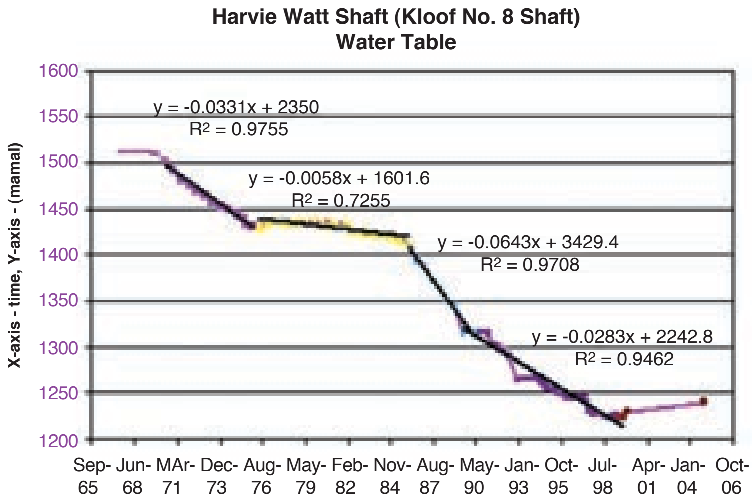

Figure 17—Water table position

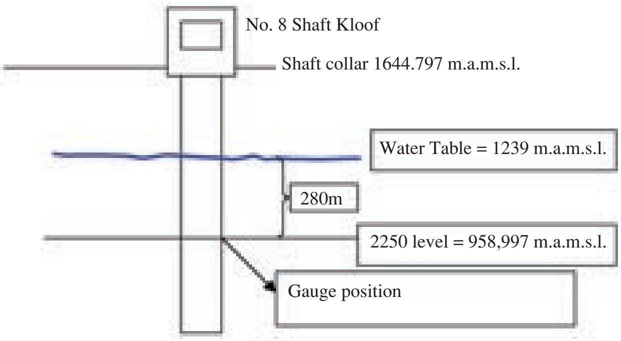

Figure 18—Position of the water table

Table II

The water table and pumping rate comparison

Water Table gradient	Time	Pumping gradient
-0.0058	May 1979-December 1986	12.594
-0.0643	August 1987–May 1990	25.377
-0.0283	December 1993–April1997	27.693

From a mining perspective, a lower water table is desirable as the possibilities of flooding are minimal. On the other hand, a low water table cannot be seen as desirable from a ground stability point of view. If the water table is low, the ground above is left unsupported and this can lead to the formation of sinkholes.

Seismological analysis at 8 shaft

In an effort to assess the seismic history of the work area, a record of all the past seismic history was requested from the seismologist responsible for 8 shaft. Seismic events also contribute to the formation of sinkholes in the dolomitic compartments.

All graphs and plans were obtained from the Seismic System located at the Kloof Main offices.

From the results obtained one had to evaluate, firstly:

- The magnitude of largest seismic event that occurred
- The magnitude of the largest seismic event that might be expected to occur in the future
- The likelihood of that occurrence
- The consequences of these events.

What is a seismic event?

A seismic event is a transient earth motion caused by a sudden release of strain energy stored in rock. There are two types of seismic events:

- Slippage
- Burst-type events.

Slippage is associated with movement on geological discontinuities, and burst-type events occur as a result of mining when the rock stress exceeds the rock strength.

The number of seismic events that occurred during 2000 to 2004 are depicted in Table III. The data obtained indicated that the largest seismic event on the whole of Kloof occurred at 8 shaft with a magnitude of 3.5. This event took place on 13 of July 2000 on the VCR and locate on a geological feature.

Another interesting observation was that the single incident with a magnitude of 3.5 distributed 8 970 GJ of energy, which was more than double the total energy of all the other events combined with 4 437 GJ. This clearly indicates the dangers that are associated with these large seismic events and the impacts they can have on the surrounding environment. (The data was obtained from the seismic system (ISS) that is located at the Kloof Seismic Department.)

The seismic event rates at 8 shaft for April 2003 to April 2004 are shown in Table IV. From the table it appears that the VCR was more seismically active than the Main Reef; however, in general seismicity is influenced by four factors:

- Depth
- Geometry of mining
- Production
- Geology.

An increasing number of seismic events is related to an increase in depth (Gibowicz, 1988). The mining layout, including the sequence and the rate of mining, may also affect the overall seismic activity on a mine. It is important to note that the seismic recording system also plays a vital part in accurately tracking the seismicity recorded.

Seismic hazard for geological structures at 8 shaft

Ventersspost Dyke	M>1.5 (30 events) Mmax observed = 2.6 Mmax expected = 3.9
Running Dyke	M>1.5 (102 events) Mmax observed = 3.0 Mmax expected = 4.2
Libanon Dyke	M>1.5 (2 events)

Table III

Magnitude distribution from January 2000 to December 2004

Magnitude range	Number of events	Total energy (GJ)
-2.0–0.0	507	61.5
0.0–1.0	490	77.5
1.0–2.0	109	508
2.0–3.0	26	3790
3.0–4.0	1	8970

Table IV

Rates of seismicity

Magnitude range	Number of events MR	Number of events VCR
M<0	2	39
0 ≤ M < 1	11	44
1 ≤ M < 2	11	6
2 ≤ M < 3	3	3

From the above information it appears that the geological feature with the most seismic events is the Running Dyke with a total of 102 seismic events.

Figure 19 portrays the seismic events that took place from May 1996 to December 2004 on the VCR. The colour coding on the spheres represents the time in years while the size of the spheres represents the magnitude of these events. The largest event occurred in 2000 with a magnitude of 3.5 at 8 shaft and is shown in green at the centre of the figure. Figures 20 also illustrate these events.

Seismic hazards can be described by various seismic parameters, and a brief explanation is given below. Figure 21 presents data on the Gutenberg-Richter frequency –magnitude distribution. Seismicity can be described in terms of the Gutenberg-Richter relationship using the equation

$$Log\ N = a–bM$$

where (N), the cumulative frequency, indicates the number of events with magnitude equal to or larger than (M), the magnitude in a given time interval. The parameter (a) is a measure of the level of seismicity, whereas (b) is the slope of the cumulative frequency vs. magnitude graph. The *b* value describes the ratio between small and large events; in other words the *b* value describes the relative likelihood of large events taking place. A lower *b* value indicates a greater hazard since there are more large events in the data-set.

Figure 21 shows the magnitude on the x-axis and the frequency on the y-axis where the cut-off for sensitivity is at a magnitude of 0.0. The x intercept of the graph represents the maximum expected magnitude. The expected maximum magnitude at 8 shaft is estimated to be 4.0. The frequency is also indicated on the graph and indicates that an event of magnitude 3.5 did occur.

Figure 22 indicates the cumulative radiated energy and the cumulative seismic moment. In July 2000 a large event occurred that radiated a lot of energy and indicated the most seismic moment.

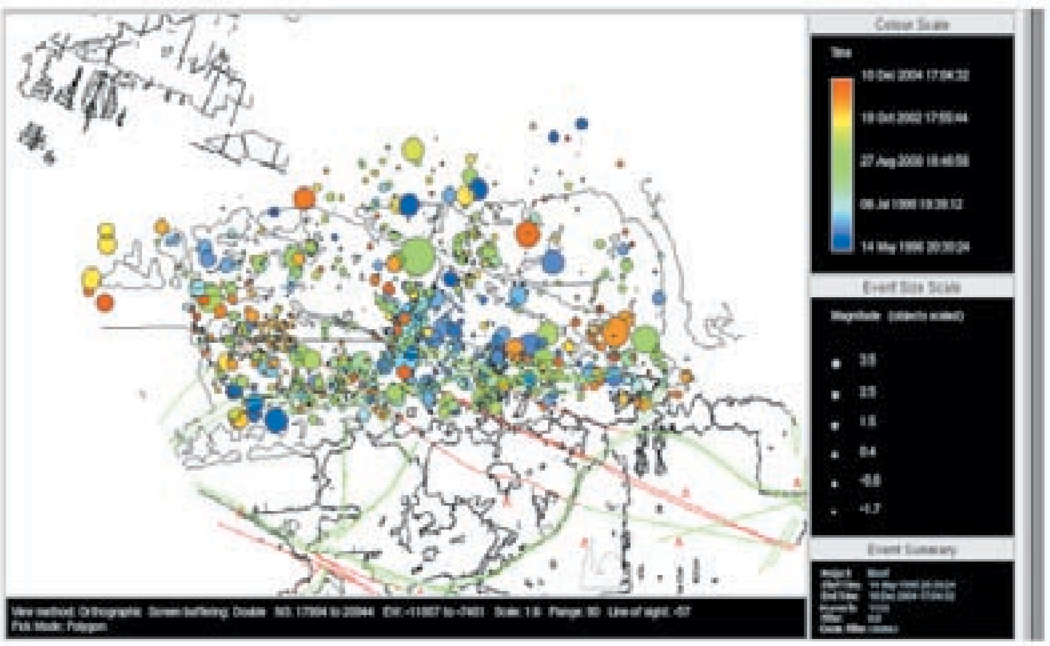

Figure 19—Distribution of all seismic events at 8 shaft from May 1996 to December 2004 on the VCR

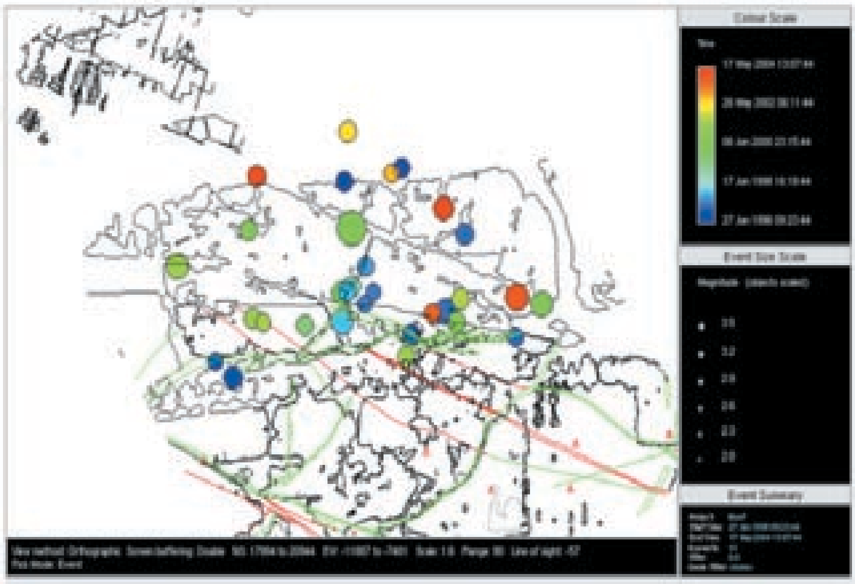

Figure 20—Distribution of the seismic events with magnitude greater than 0.5

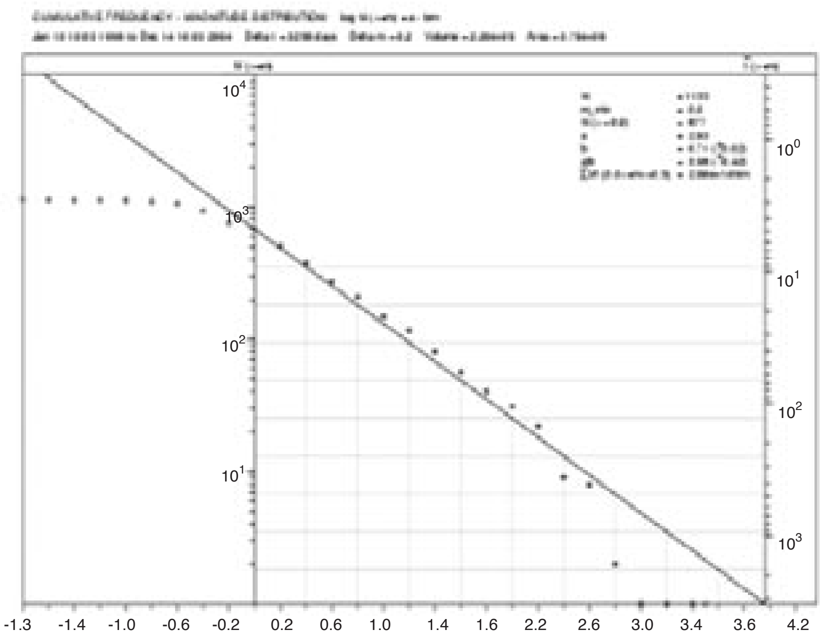

Figure 21—The Gutenberg- Richter relationship

Seismic activity near gold mining areas

Seismicity affects not only the mine underground workings, but also the residential areas close to the mine. Figure 23 serves as confirmation that areas near gold mines in the Far West Rand experience a significant amount of seismic activity. Westonaria, which is a residential town close to Kloof, seems to have experienced a considerable number of seismic events as a result of the mining, but other surrounding mines in the compartments could have contributed to this occurrence.

Conclusions on seismicity

From the information gathered at 8 shaft there is substantial evidence that structural features do act as sources for a high proportion of the larger seismic events. The Running Dyke was the most active, as a total of 102 seismic events was recorded from April 2003 to April 2004.

According to a study carried out by McDonald in 1982 on seismicity of the Wits Basin, he suggested that a contributing factor to seismicity was linked to dewatering operations carried out in the compartments.

MacDonald (1982) also observed an apparent correlation between the level of seismicity and the rate of water pumping. Pumping of the water reduced the pressure due to the head of the water, and this in turn reduced seismicity. He also suggested that there might be some seasonal influence on the seismicity related to the rainfall, but as far as the author is aware, there has been no substantial evidence to prove this to be true at 8 shaft.

The seismicity at 8 shaft is of concern, especially after recording a magnitude of 3.5 at the shaft, the highest for Kloof. The expected magnitude at this shaft is 4.0 but the likelihood of it occurring is low.

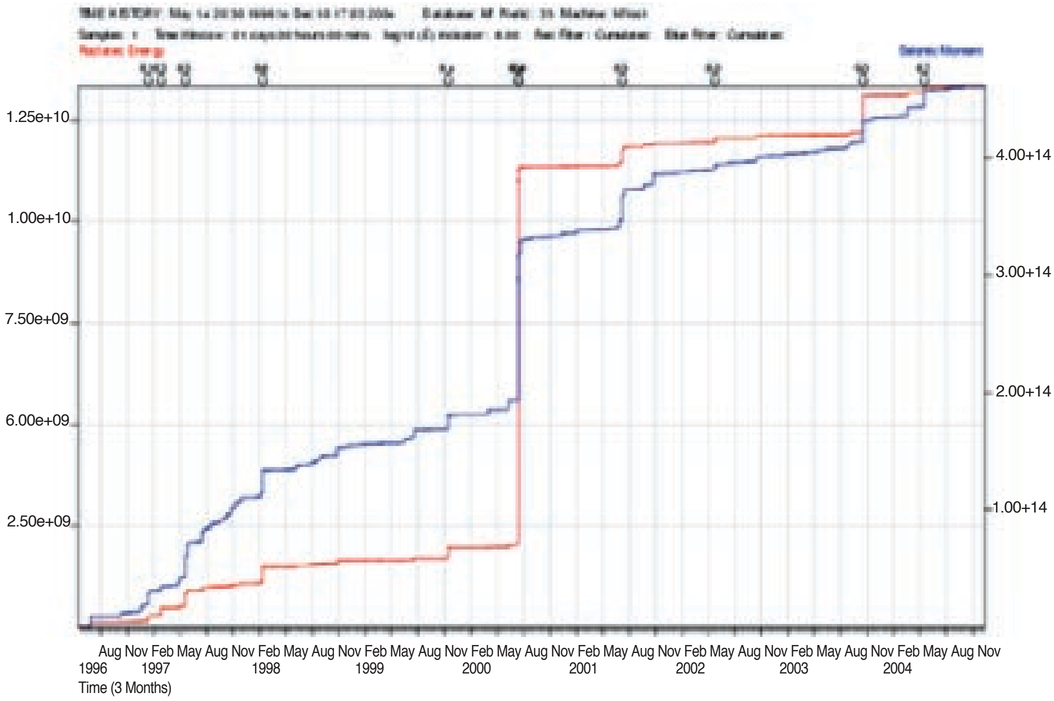

Figure 22—Cumulative radiated energy and cumulative seismic moment

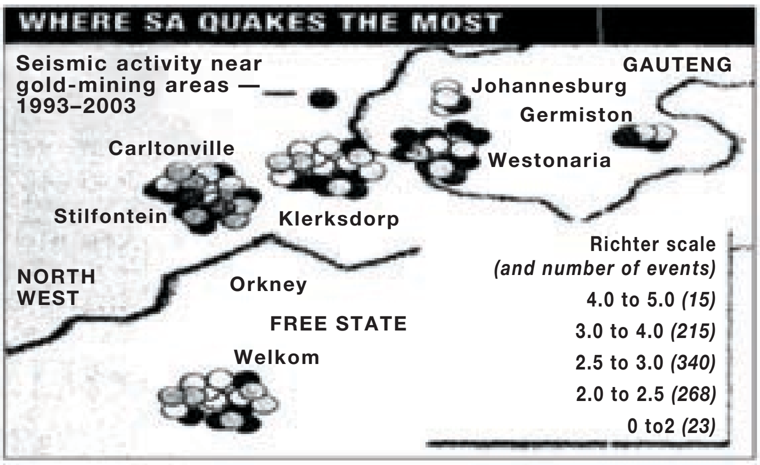

Figure 23—Location of seismic event (source: Business Day, May 2005)

Findings

The term dewatering tends to create a concept of completely dry mines. When a mine is being dewatered the mine still experiences a continuous inflow, and volumes of water must be pumped from the mine to prevent any inundations by water (WRC, 2001). The negative impacts of pumping the water are that the water table is lowered and ground instability results. Subsidence and sinkholes occur as a result of this instability.

The environmental impacts of dewatering

Dewatering affects the groundwater levels, which could result in the drying up of natural springs. Dewatering also has an impact on the farmers who depend on the groundwater for agriculture use.

The triggering of sinkhole development, particularly where the water table is close to the surface, is another risk. Sinkholes become a threat to infrastructure and property. The apartheid planning caused many low-cost suburbs to be developed on dolomite, and these people are therefore at risk.

The discharge of dewatering water

In the case of heavy rainfalls, excessive pumping could result (as was demonstrated by the data acquired from 8 shaft), and the dewatered water can increase the risk of flooding the stream, downstream of the discharge point.

Another risk that is posed by discharged water is that of dependency by informal settlements. There is a risk of encouraging these settlements, as they become attracted to the permanent source of water. Communities along Klein Rietspruit downstream of Randfontein 4 shaft, which has been discharging since 1986 (MINN429 course notes), prove this theory to be true.

The change in stream flow in the case of dry seasons when pumping is low, affects the flora and fauna. It should be noted that most impacts of dewatering are not permanent and will be slowly reversed once pumping stops.

Problems with sinkholes

A major risk that was found to be associated with sinkholes was that of the safety and security of people. As a result of the sinkholes that could arise, the following measures will have to be attended to at the mine's cost:

- Levelling of the area and a general stability analysis will need to be completed on a regular basis to ensure that the health and safety of people around the affected area is not compromised.
- The sinkholes will have to be secured for the safety of the structures in close proximity to the sinkholes, as well as for the animals.
- Attend to the illegal dumping of general or hazardous waste materials.
- Backfilling of the sinkholes with the appropriate material (not mine waste) will be expensive.
- The Potchestroom road north of Harvie Watt could be in great danger and commuters may not be able to utilize the road.

There is a pollution risk associated with sinkholes, as sinkholes act as pathways between the slimes dams and the groundwater. The backfilling of sinkholes with mine waste, tailings and waste rock, irrespective of how low their pollution risk actually is, is not in compliance with the law so other forms of material will need to be used.

Sinkholes have also been used as dumps for waste materials. The dumping of solid wastes, such as dead animals, garbage, and refuse, into sinkholes is a major hazard to groundwater resources.

Conclusions

Mining activities require the pumping of dolomitic water entering the mineworkings, which has resulted in surface instability. The risks associated with dewatering are real and relevant. From the background investigation conducted, it was evident that flooding of the workings in dolomitic compartments has occurred in the past, and lessons from these past experiences have taught the mining industry that 'prevention is indeed better than cure'. As a result, flooding disasters have not been recorded recently as the mines in the compartments have taken precautionary measures.

It was discovered that the dewatering of the dolomitic water formed sinkholes as a result of the lowering of the water table and accelerated ground movement. Sinkholes may be catastrophic, as they occur unexpectedly with little or no warning and may cause property damage or loss of lives, if they are sufficiently large.

When the water table data was compared with the pumping rates for the same time period (Table II), it was concluded that a relationship existed. The more the water was pumped, the lower the water table became.

Mining-induced seismic events were also evaluated, as these have serious consequences, and are unavoidable. Seismic events associated with geological structures were found to be major contributors to the problems associated with mines in dolomitic compartments. Seismic events are responsible for sudden ground movements, which can be hazardous when the ground is unstable.

The backfilling of sinkholes with gold mine tailings affects groundwater quality, which is an environmental problem. The environmental problems associated with dewatering were also investigated, but it was later concluded that most were not permanent and could be slowly reversed once dewatering stopped.

In conclusion, the analysis gave an indication of just some of the risks and challenges faced by the mines in the compartments, and the author strongly believes that the prime objective of mines in dolomitic compartments should be to reduce the incidence of large damaging events, thereby minimizing the risks to the workers.

Recommendations

The author recommends that other methods be implemented to aid with ground stability since dewatering cannot be stopped if the mines are to extract the gold safely.

- The rewatering of the dolomitic compartments to aid with ground stability is a concept that could be applied to alleviate instability problems.
- Finding other suitable methods to fill the sinkholes.
- The Seismic Department at Kloof Gold Mine should make better use of the seismic network.

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