THE LOCATION, HAZARD ASSESSMENT AND SEALING OF UNSAFE MINE OPENINGS IN THE CENTRAL WITWATERSRAND GOLD MINING BASIN

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A dissertation submitted to the Faculty of Engineering and the Built Environment, University of the Witwatersrand, in fulfilment of the requirements for the degree of Master of Science in Engineering by research only

Johannesburg, 2009

DECLARATION

I declare that this dissertation is my own, unaided work. It is being submitted for the Degree of Master of Science in Engineering in the University of the Witwatersrand, Johannesburg. It has not been submitted before for any degree or examination in any other University.

G. Heath

9th day of November 2008

ABSTRACT

One of the most unfortunate legacies of more than 100 years of mining in the Central Witwatersrand Mining Basin is the presence of many unsafe mine related openings such as shafts and subsidences that are present in the southern part of the city of Johannesburg. Using available mine plans and knowledge of the manner in which these holes were formed, a search was undertaken and a total of 244 openings were located.

A literature survey revealed that perimeter walls, concrete seals and plugs have most often been used to prevent human access to these unsafe mine openings. Locally mine openings have most often been backfilled with available materials though concrete plugs or seals, walls and fences have also commonly been used. In order to assess which holes should be considered for sealing, a simple "hole risk rating system" was developed, which considered the depth of the hole and its proximity to settlements or thoroughfares. During a Department of Minerals and Energy project led by the author, it was concluded that concrete plugs were probably the most effective method of sealing such unsafe mine openings. Eighty holes were thus sealed using unreinforced, concrete plugs. Polyurethane Foam (PUF) has been used as an alternative method to seal mine openings in the United States for nearly 25 years and was used here to seal two abandoned mine openings. This method requires minimal design, engineering supervision and offers a quick, simple, cost effective and environmentally friendly method of sealing such openings.

The documentation of the mine openings, the openings plugged, the methods of plugging and the locations of the plugged holes ia a valuable practical and historical record. The plugging of many holes is a significant contribution to public safety.

Dedicated to my wife Lindy and children Jessica, Rachel and Jonathan

ACKNOWLEDGEMENTS

The Department of Minerals and Energy is hereby acknowledged for their foresight in identifying the risk that unsafe mine openings pose to the inhabitants of southern Johannesburg and allowing the author this opportunity to document this problem. Additionally, my project assistant, Mr. Donald Molapo, is thanked for his tireless assistance in locating these mine openings.

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1 INTRODUCTION

The extraction of gold from the Witwatersrand gold reefs has been carried out more or less continuously since the 1880's to produce a 100km elongated mining belt situated south of the Johannesburg central business district, South Africa.

Initially the outcropping reefs were exploited at surface and as techniques improved, extraction of deeper reserves was targeted. Openings, such as shafts, raizes, winzes and other excavations were created for the various underground activities associated with mining. Available records show that some 43 500t of gold have been produced to date from the area south of central Johannesburg (Wilson and Annhaeusser, 1998) which has resulted in the development of large, east west striking, tabular underground mining voids that intersect the surface in this area. As the attention of the various mining houses turned to deeper mining opportunities, scant thought was given to, nor required for rehabilitating the disturbance caused by the efforts of the previous mining. This resulted in a highly disturbed landscape consisting of dangerous, abandoned mine openings of various sizes, depths and origins. The collapse at surface of the near surface mining void also produced numerous mine related openings.

Figure 1.1 shows a young boy blissfully unaware of the danger posed by two deep, abandoned shafts in the Tudor area, Johannesburg, whose depths have been estimated at nearly 500m. Additionally, these two openings appear to have been initially sealed (with concrete) by the original mine owner, but have been subsequently opened by persons wanting to illegally access the shaft, and materials therein, below. Their actions have created a substantial risk for persons, such as this young boy, living nearby. The risk posed by such openings was further, dramatically illustrated during the course of this study when a young woman, who was inspecting a pipeline, fell 20m down a narrow (0,5m) subsidence (Makause Informal Settlement, Germiston) that had developed above an old stope (Appendix A).

1.1 Scope of the mine openings study

The Witwatersrand 'Mining' Basin, has developed as a result of exploitation of the gold rich horizons deposited in the Witwatersrand 'Geological' Basin (Figure 1.2), a former sedimentary basin that existed 2750 million years ago (Viljoen and Reimold, 1999). This elongated mining belt can be subdivided into three goldfields (Figure 1.3), namely the Central, Eastern and Western goldfields, though the latter is also typically subdivided, from a mining point of view, into the Western and Far Western goldfield. From a mining perspective, each of these areas, is referred to as a mining basin and each of which is:

a. Geologically separate (Scott, 1996) i.e the reefs are not continuous, but can be broken into sections by either tectonic breaks or regions of lower payability, which are referred to as "Gaps" and which separate these basins (Johnson, 2006).

b. Geohydrologically separate (Scott, 1996) i.e the water levels in the mine voids of each of the basins are independent with no natural connections.

For the purposes of the current research only the Central Mining Basin is considered here.

Figure 1.1 Local inhabitant dangerously close to two abandoned mine shafts, Johannesburg. Each of these openings is believed to be approximately 500m deep.

This study of the Central Witwatersrand Mining Basin was undertaken to:

1. form a comprehensive record of the openings that are present within this Mining Basin

2. consider various methods that have been previously used to seal such mine openings

3. determine the safety risk that each hole presents to local inhabitants

4. document existing methods used to seal these openings

5. investigate the merits of using Polyurethane Foam (PUF) to seal a number of these openings

6. document the use of concrete plugs to seal a substantial number of these openings. Particular reference is made to a Council for Geoscience (CGS) project, led by the author, to seal a number of mine openings on behalf of the Department of Minerals and Energy (DME) during the period 2006-2007.

The Central Mining Basin of the Witwatersrand Goldfield is defined:

a. by the lateral extent of the strike, as well as the dip, of the gold bearing reefs of the Central Rand Group (Witwatersrand Supergroup). These rocks form an east - west 'belt' that runs for approximately 38km through southern, central Johannesburg. The surface outcrops of these reefs lie immediately south of Main Reef Road, also known as the R29, and form the northern boundary of the study area.

b. by an unmined strip of land that forms the eastern boundary which is known as the 'Boksburg Gap' (Scott, 1996), separates the Eastern Mining Basin from the Central Mining Basin. It was not mined because of (apparently) very poor gold grades.

c. on its western side by the 'Witpoortjie Gap' (Antrobus, 1986), where a series of major faults (Roodepoort Fault and Doornkop Fault) have produced a horst block which separates the gold reefs of the Western Mining Basin from the Central Mining Basin, situated immediately east of Randfontein.

d. by the southern extent of the nine original farms on which the first gold mines were established, approximately 9 km south of the outcrop of the northernmost reefs.

The Central Mining Basin lies across three municipal boundaries namely; Ekurhuleni (Germiston/ Boksburg/ Springs), Johannesburg and Mogale City (Randfontein).

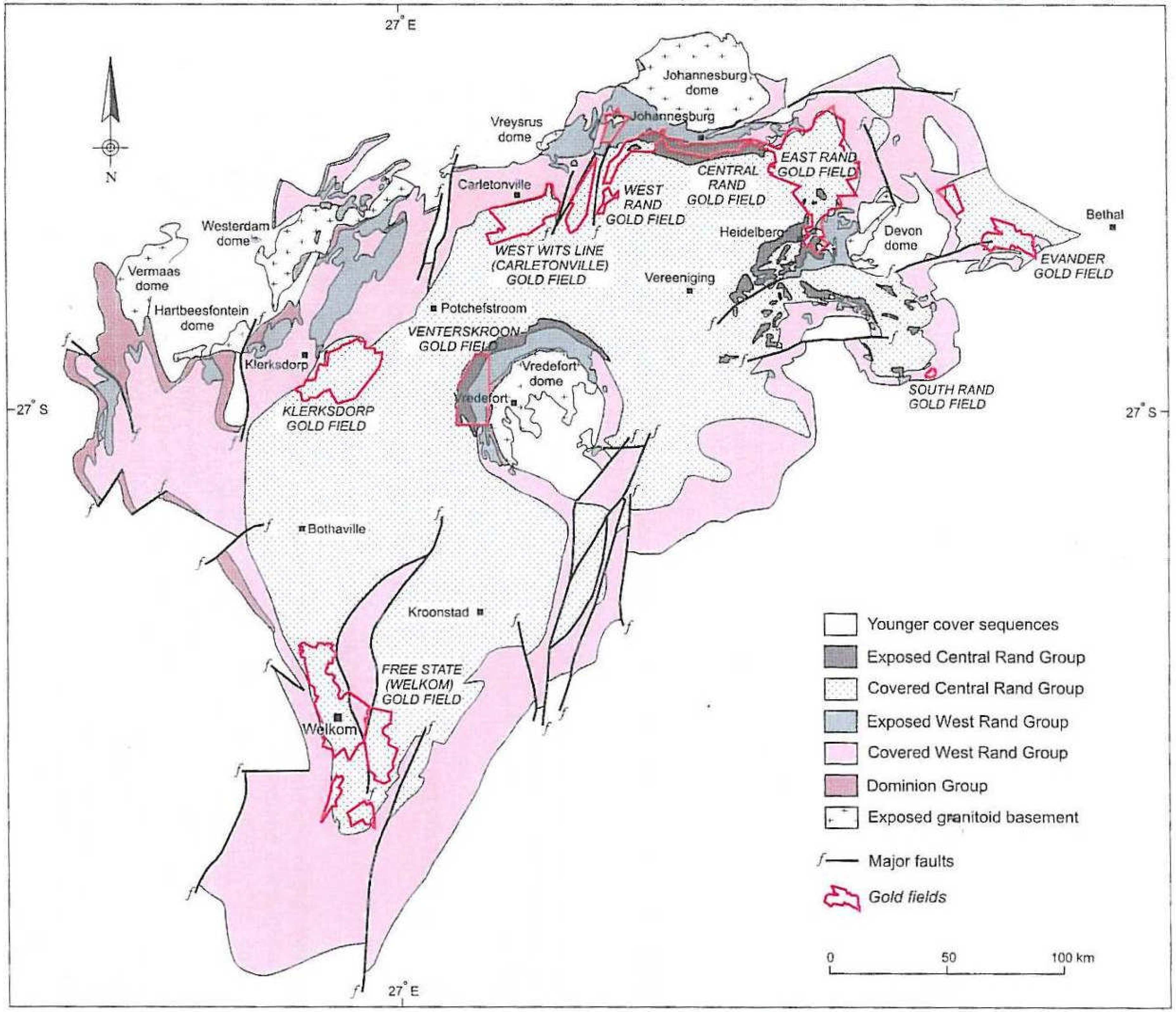

Figure 1.2 Map showing the Witwatersrand Geological Basin (Pretorious, 1986)

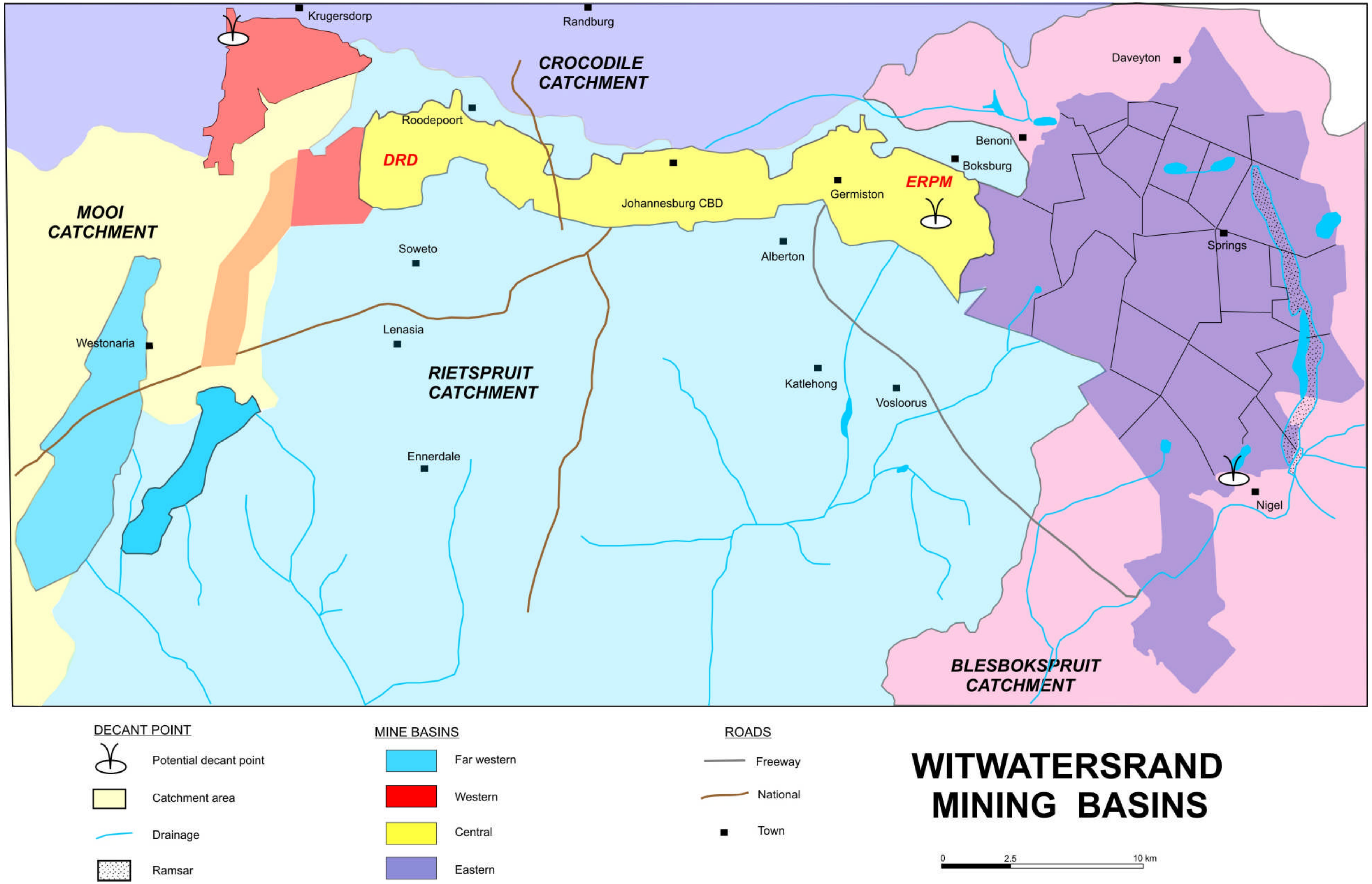

Figure 1.3 Witwatersrand Mining Basins (Council for Geoscience, 2004)

The location of unsafe, mine related holes is largely related to the exploitation of gold bearing reefs in the Central Mining Basin. These reefs consist essentially of thin (<2m thick) layers of gold bearing conglomerate. While many reefs are known in the Witwatersrand Supergroup in this area only the reefs in the Central Rand Group have proven to be gold bearing and hence of exploitable interest (Norman and Whitfield, 2006). At least 10 gold bearing reefs have been mined in the Central Basin with the Main Reef (including the Main Reef Leader and South Reefs), Bird and Kimberley reefs (which consists of four reefs) being the most important, Figure 1.4.

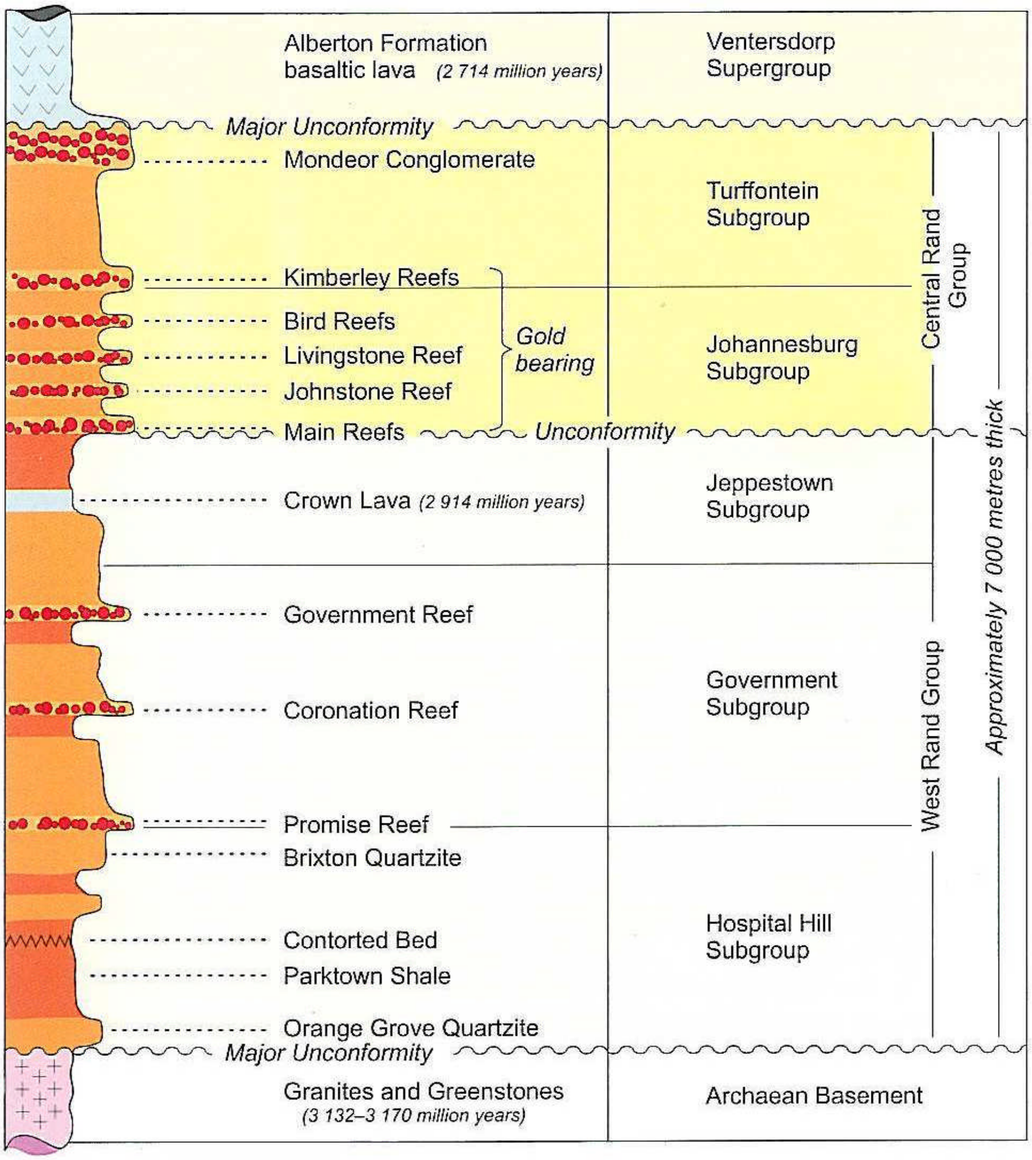

Figure 1.4 . Stratigraphic Column of the Witwatersarnd Supergroup showing the position of the reefs, Norman and Whitfield (2006)

The prime aim of this project was to identify as many as possible surface openings related to 'mining' activities (Figure 1.5). Openings produced by construction, building activities or dolomite related sinkholes are not related to mining activities and hence are not considered here.

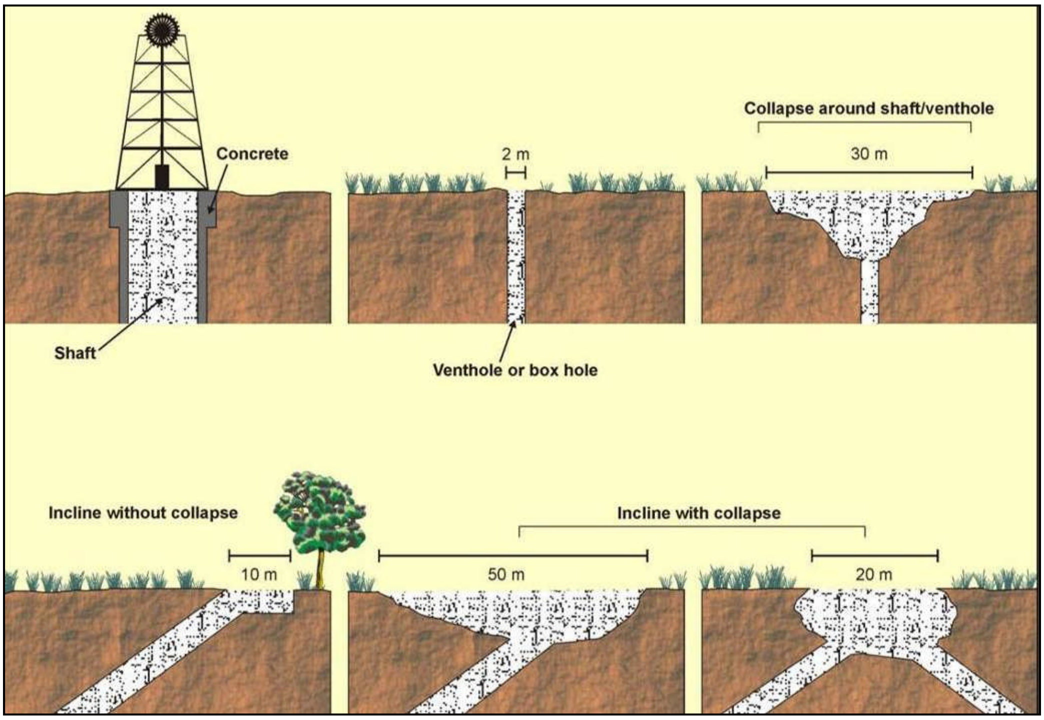

Figure 1.5 Typical examples of types of openings found in the study area

(Council for Geoscience, 2004)

In essence, for the purposes of this project, the mine openings i.e holes that were identified during this study, were produced by:

1. The sinking of a shaft (Figure 1.6), which is defined as a hole excavated to conduct underground mining operations. Typically shafts are used to provide access for mining personnel and equipment, ore extraction and/ or for ventilation. They vary greatly in shape (square, rectangular or circular) and extend to great depths (>2000m). They may be supported with some type of framework (wood or steel) and a form of headgear, for lifting purposes is typically placed over the shaft. In most cases they are vertical although inclined shafts are also common (Figure 1.7), into which access by foot, rail or vehicle is possible. Some of these incline shafts were also commonly used for ventilation purposes to allow air to enter or exit the mine workings below. 'Shaft' is used here to describe all of the above types of structures.

Figure 1.6 Steel framework within an abandoned, vertical mine shaft (Rand Leases Mine, Roodepoort)

Figure 1.7 Typical example of an abandoned inclined mine shaft, Ekurhuleni

2. Collapse at surface caused by the subsurface mining void i.e. a subsidence. In some areas linear type failures, along strike, are present which have been caused by the failure of underlying stopes. Hill (1981) has stated that during the 1970's collapse

into old mine workings was 'not uncommon' with at least 12 such events having being recorded. He is of the opinion that this type of collapsing of the backfilled void could continue indefinitely as the underlying support weakens. Additionally the records of subsidence have often not been kept and as stated by Bell *et* al (2000) there is no confidence as to whether, or to what degree, settlement has taken place. Brink (1983) has recognized four categories of this type of mine related subsidence in the Central Witwatersrand, namely:

a. Sinkholes (Figure 1.8). In these cases, material i.e backfill that has been deliberately placed in the near surface outcrop of shallow stopes to seal these voids is progressively washed downwards by infiltrating surface water. By a process of backward erosion a sinkhole develops at surface. This form of subsidence can also be exacerbated by a) the removal of pillars b) the removal of adjacent reefs c) the deterioration of timber props and waste packs (Bell *et al*, 2000) etc. Bell *et al* (2000) report that the sides of outcropping stopes can also collapse into the workings below leading to, in some cases in the Johannesburg area, huge subsidences Figure 1.9.

   Sinkholes, in terms of karstic or dolomitic origin, were not considered in this study.

b. Subsidence accompanying cavern development.

c. Tension fracture related subsidences. From 1903 to 1930 the Government Mining Engineer reported numerous surface cracks in this area due to undermining (Hill, 1981). Hill (1981) states that surface cracks produced as a result of the northwards and downwards settling of the rock mass overlying shallow undermining is a feature of the pre-1920 era. At the time of the writing of his article, Hill concluded that, with very few cracks visible (most would have probably been backfilled with soil) there was no expectation of their development today and hence they are discussed no further in this document.

d. "Normal" stope closure related subsidence. Such openings are found along strike of the outcropping reefs and if large enough may be rectangular in shape. This is a process that is related to the forces of gravity, percolating waters, rotting of timber supports etc. It thus is a process that has little or no time limit.

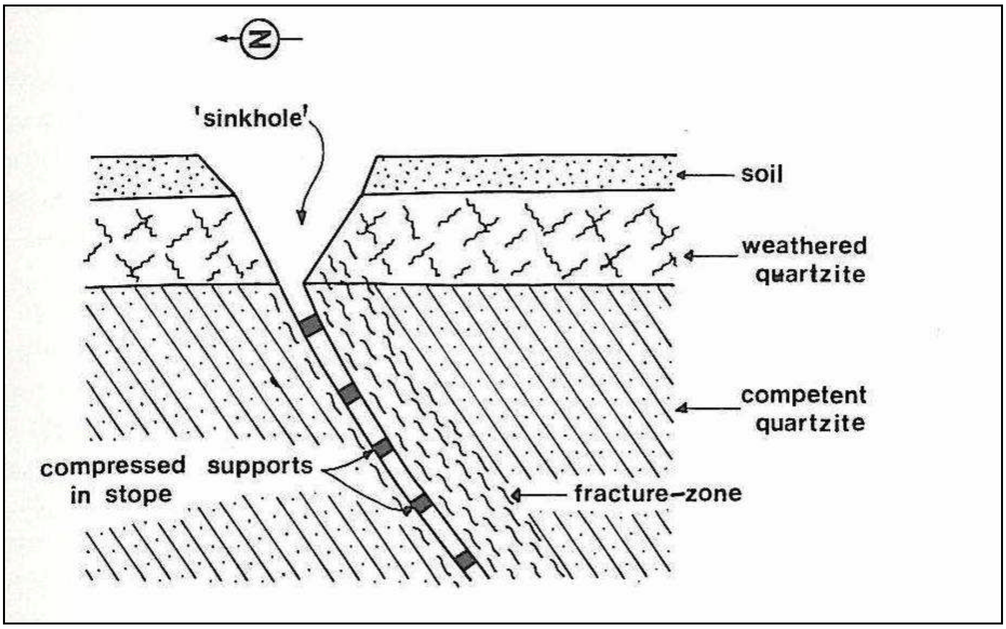

Figure 1.8. Surface 'sinkhole' development above an abandoned stope (Brink, 1983)

Where a 'hole' has been created at surface, "subsidence" is used here to describe any or all of the above type of features.

Bell *et al* (1989) have also defined the causes of mining related subsidence as being typically caused by:

a) Collapse between pillars.

b) The collapsing of the pillars themselves. They record that where the strength of the pillars is exceeded large subsidence zones may result.

c) Failure of the pillar roof or floor.

3. A mining related surface excavation such as a pit, quarry, borrow pit or trench.

Stacey and Bakker (1992) have identified a number of factors that may have an influence on the stability of the surface overlying shallow underground mine workings, which are listed below:

- Dip of reefs
- Stoping width
- Extent of mining
- Number of reefs mined

- Separation of reef
- Competence of rocks
- Support
- Time elapsed since mining

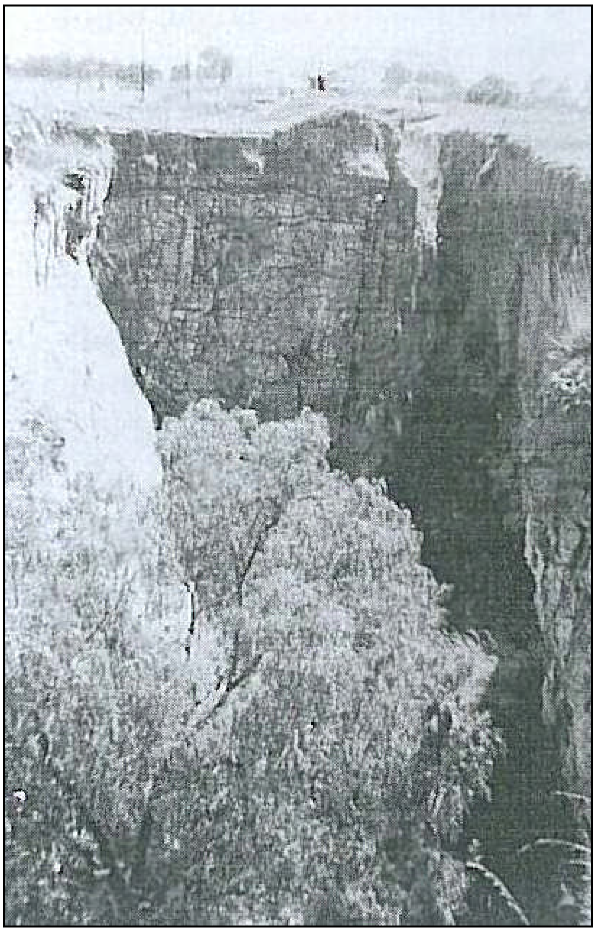

Figure 1.9 Collapse into stope in central Johannesburg (Bell *et al*, 2000)

While this dissertation is essentially concerned with existing mine openings, cognisance has to be taken of areas that are considered susceptible to subsidence formation. Barker (1993) has utilised mine plans of mined out areas in the central Johannesburg area and the dip of the ore body to develop a subsidence risk analysis. He has defined five levels of subsidence risk of which Level V is the highest and refers to the "near surface zone (<50 to 0mBS), including the outcrop zone (Figure 1.10), where sinkhole failures that extend to the surface may occur" (Barker, 1993). The northern edges of the undermined areas (Appendix B), where the stopes intersect the surface, are defined as the most susceptible to subsidence formation. Colouring has been added, by the author, in order to differentiate these zones. Bell *et al* (1989) however do caution that such thematic maps which attempt to depict varying levels of risk 'cannot be interpreted too literally' as they only represent information available at the time of compilation i.e they are almost immediately out of date especially if mining is still continuing.

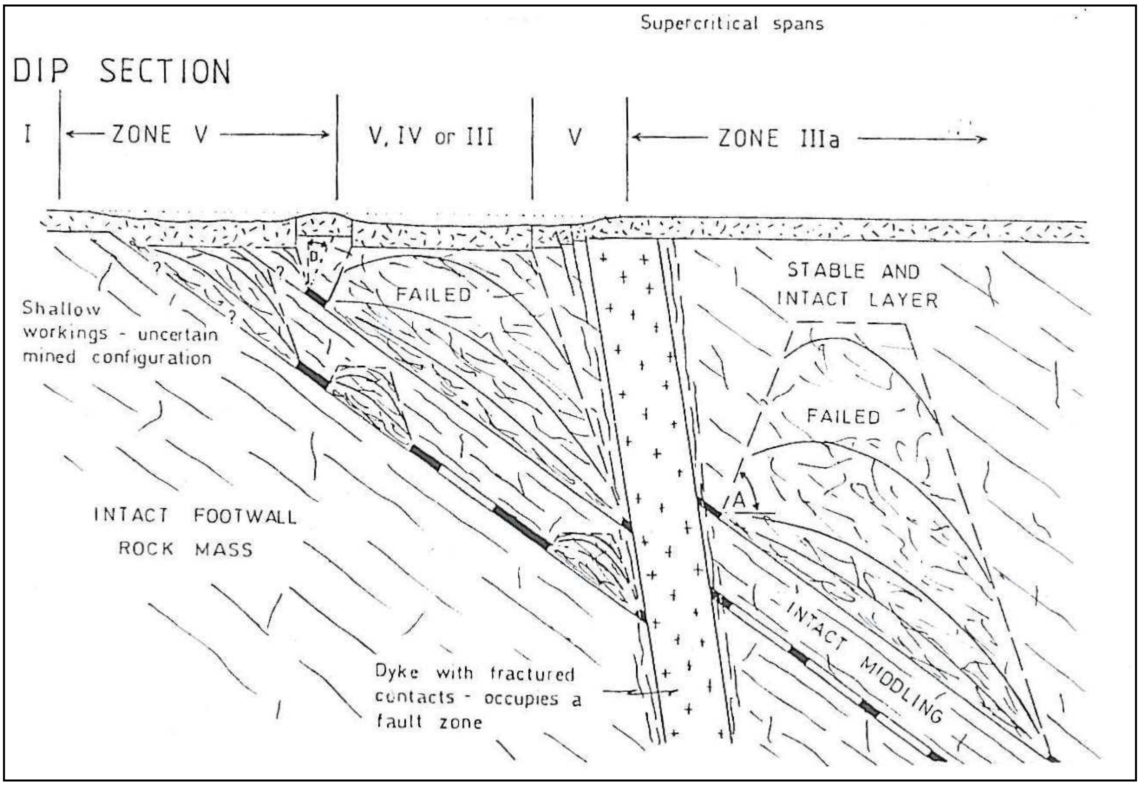

Figure 1.10. Dip section showing High risk zone (Zone V) in the stope outcrop region (Barker, 1998)

1.2 Possible closure methods

Mining, by definition, involves the excavation of the earth to extract water, ores or minerals. The resultant effect is almost always a hole in the ground. However, historically, when the purpose of the mining had come to an end, the mine and its shafts and other associated openings were typically abandoned by the mine operators, with little effort put into rehabilitation. This has been common practice throughout the world. In the United States for example, 9 934 mine openings have been reported (U.S National Parks, 1992).

Closure of these holes has obviously not been a major priority for mine operators and guidelines were not available for a long time in many countries for this to be undertaken to a suitable, uniform standard. Gallagher *et al* (1978) report that historically in the United Kingdom, the most common practice to close an old shaft involved a) jamming a large tree against the shaft sides and backfilling

b) building a wooden platform 3-15m below surface and backfilling. This often failed as the platform rotted away. In most instances, any readily available materials are typically used for closure, normally to complete the task as quickly and cheaply as possible, in a weak attempt to address issues of safety. Local examples exist, where materials such as builders' rubble and or waste rock have typically been dumped into these holes in a random uncontrolled fashion (Figure 1.11).

In some circumstances, authorities (Nova Scotia, 1997) have recommended the use of blasting to seal an opening with broken rock.

The 'Best Practices in Mine Reclamation' issued by the Colorado Division of Minerals and Geology (2002) recommend, when considering the best approach to safeguarding a mine opening, that the following factors be considered:

1. The life span. Is a temporary or a permanent solution required?
2. The degree of hazard elimination. Is total or partial elimination of the hazard required?
3. Maintenance requirements. Will the measure be subject to vandalism or environmental degradation?
4. Construction safety. What degree of risk will there be for construction workers? Obviously the longer time spent in a hole by the workers increases risks of accidents.
5. Environmental concerns. What fauna and flora will be disturbed when closing the hole? Can water enter (or exit) the hole?
6. Design concerns. The design is obviously dependant on the *in situ* conditions which may affect the feasibility of the design.
7. Cost. The measures to be considered are obviously dependent on the financial resources available to undertake the task.

In considering possible methods to close abandoned mine openings during this study the following assumptions have been made, namely that the measures :

i. form a permanent barrier to human access. 'Permanent' for the purposes of this study is taken as meaning >50 years.
ii. should not result in environmental deterioration i.e the materials used should be compatible with the local environment in which they are placed,

iii. be cost effective,
iv. be properly engineered solutions. Thus methods such as blasting to collapse the area around holes will not be considered, as the strength and stability of the material in the hole cannot be verified.

In the aforementioned DME project (Council for Geoscience, 2007) various options to seal unsafe mine openings in the Witwatersrand Mining Basin were considered before a preferred method was selected. This preferred method was used to seal the majority of the holes. The approaches used during that project are discussed below.

1.3 Context of Dissertation

The presence of many unsafe, abandoned mine openings in the Central Witwatersrand Mining Basin poses a significant risk to the residents of this area. Records of varying quality are scattered between the offices of various mining houses (whose ownership changes on a regular basis), mining institutions and the Department of Minerals and Energy. The persons with institutional knowledge of these mine openings are also disappearing due to retirement or resignation. Many of the records too, of which only single copies are available, have not been transferred to digital formats which poses a risk that such information could easily be lost forever. It is in this context that this dissertation aims to document, locate and produce a substantial, reliable and authoritative record of these unsafe, abandoned mine openings which will be of both technical and historical value. A review of local and international practices to seal such openings will also be undertaken.

Figure 1.11: Uncontrolled backfilling, Boksburg (circa 2004)

2 IDENTIFICATION OF MINE OPENINGS

2.1 Introduction and review of available information

The wide variety of activities associated with mining operations in the Witwatersrand Mining Basins has left behind a wide range of surface openings, as briefly defined above. The activities, use of the land and the responsibility surrounding these openings has also changed, resulting in a mixture of land-uses that often hide the presence of these holes. Similarly, the records of these holes have either been lost, as the mines ceased operating, or in the case of the very old mines, may never have been recorded. In many cases these openings are hidden by newer structures, vegetation or obscured by informal settlements. Only rarely are distinctive features such as a headgear left behind. Being essentially subsurface features, their location is thus a difficult task. Having experienced similar problems regarding locating abandoned shafts in the United Kingdom, the U.K. Department of the Environment (Anon, 1976) recommended that a four stage cyclical process be followed (Figure 2.1) that involves:

Stage I. The gathering of all available local information from old mine maps, air photos, published data etc. as well as field inspection

Stage II. The study of mining journals, local mining history and original documents

Stage III. The commissioning of specialized methods such as aerial photography in the area where the abandoned mine shafts are expected. In their approach geophysical surveys are also used to detect underground voids. Similarly geochemical surveys may detect chemical traces from the mined out areas. These exercises should be undertaken while simultaneously conducting field verification exercises.

Stage IV Field proving involving excavation, probing and drilling.

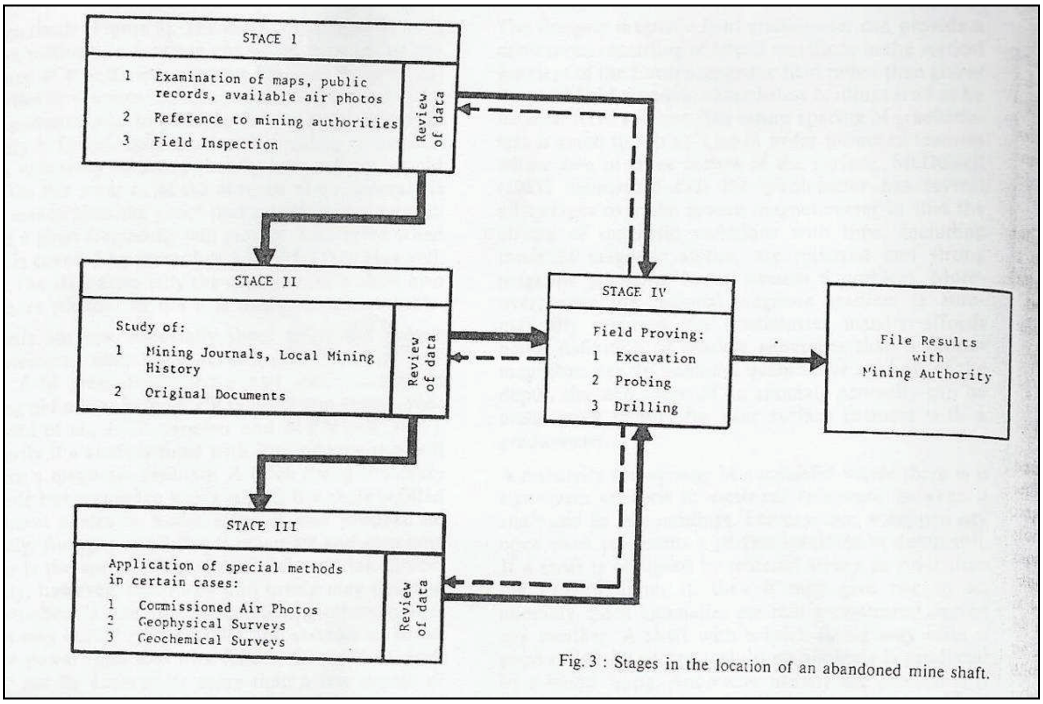

Figure 2.1: Stages in the location of abandoned mine shafts (Anon, 1976)

2.2 Literature Study

Prior to this study a number of studies had been carried out which are briefly summarized below:

- Scott, 1995. This report was commissioned by the Water Research Commission (WRC) to investigate the inflow rate and water quality if the gold mines of the Central and East Rand Basins were allowed to flood. Scott provides a thorough overview of the gold reefs that were extracted at surface.

- Dept. Mineral and Energy Affairs, 1996. This report, an internal investigation by Frank Barradas, identified a number of openings (25) in the Far Eastern Mining Basin.

- Nemai, 2001. This investigation was carried out on behalf of East Rand Proprietary Mines (ERPM) and the Interdepartmental Committee of State Departments (IC) to identify openings in the central mining basin area. A total of 102 openings were identified by way of contacting interested and affected parties. No systematic ground or aerial surveys were undertaken. Openings were named according to the mine property on which they were found. Each hole was rated in terms of the safety hazard it presented. All the openings were plotted on a GIS system. Nemai also devised a system to rate the threat to human safety posed by these surface openings ('Hazard Level'), Table 2.1.

Table 2.1. Abandoned hole saftey rating (Nemai, 2001)

Hazard rating	**Safety condition**
Very little hazard	Typically fenced and hole covered
Slightly hazardous	Hole is typically not completely covered but is fenced
Hazardous	Site is typically not covered but is fenced
Very Hazardous	Site is typically not covered, is poorly fenced and is deep
Extremely Hazardous	Holing's safety should be attended to as the holing is neither covered nor fenced and is deep.

Using this rating system Nemai (2001) was able to determine the most hazardous holes. 'Thirty four' (Classes 4 and 5) holes (Figure 2.2) were considered to represent a 'considerable threat' to pedestrians in the area. It was recommended that the safety hazard presented by the openings be addressed as a matter of urgency. The defining criteria in this system were essentially based on whether the hole was covered or not (not defined) and the state of any surrounding fencing. Passing reference was given to the depth of the hole, though this was not defined.

- Dept. Minerals and Energyy, 2004. An openings database was compiled by A. Aukamp of the DME using the same openings collected in the Nemai report. No new openings were added.

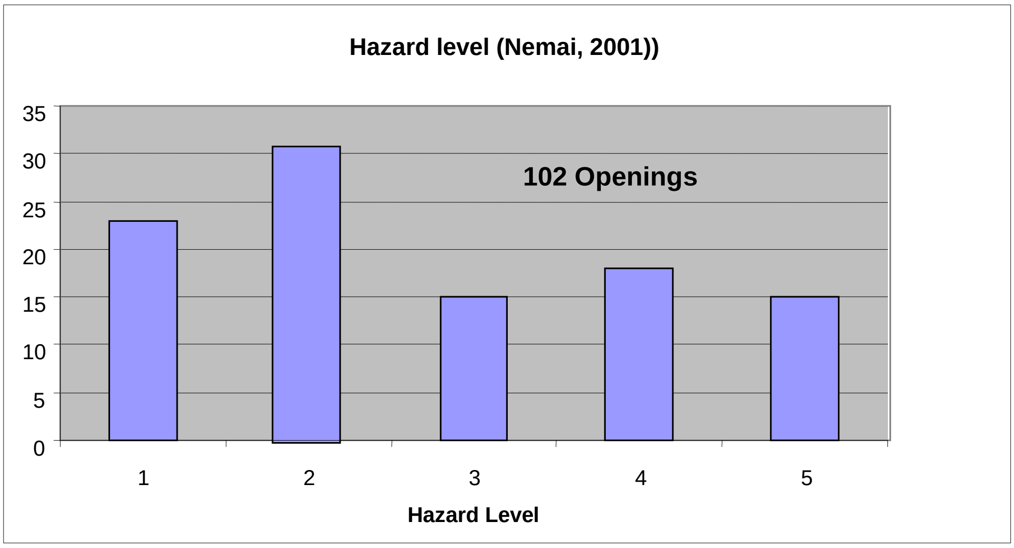

Figure 2.2: System to rate the hazard level of each opening (Nemai, 2001)

2.3 Review of mine plans

In order to locate the positions of the original mine shafts the original mine plans had to be located. Mine plans, believed to be probably the last remaining copies, were located in the DME (Pretoria) offices. These mine plans, belonging to 21 mine properties, show the position of officially excavated shafts in the Witwatersrand Central Mining Basin, Figure 2.3. According to Scott (1995) however a number of other mines also existed in this area, Figure 2.4. These mine boundaries have changed significantly over the 120 years of mining in this area, from the nine original mine properties to approximately 21 at the peak of mining (1950's), to four today. This of course has created some confusion in determining the number of mine shafts present due to the risk of double counting shafts recorded on different plans covering the same area. Barker (1992) also states that these mine plans often lacked essential near surface information leading to uncertainty as to whether near surface areas have been mined. From the available plans the positions of the mine shafts were extracted by scanning the mine plans into a digital format (JPEG) and then 'placing' (i.e geo-referencing) these images onto topographic maps within a Geographic Information System (Appendix B). The positions of the shafts could then be reasonably accurately determined from within the geographic co-ordinate system. In a parallel study, to locate shafts that could be used for measuring water table depths in this basin, Shango (2005) catalogued a total of 236 mine plans from 23 mines, Table 2.2.

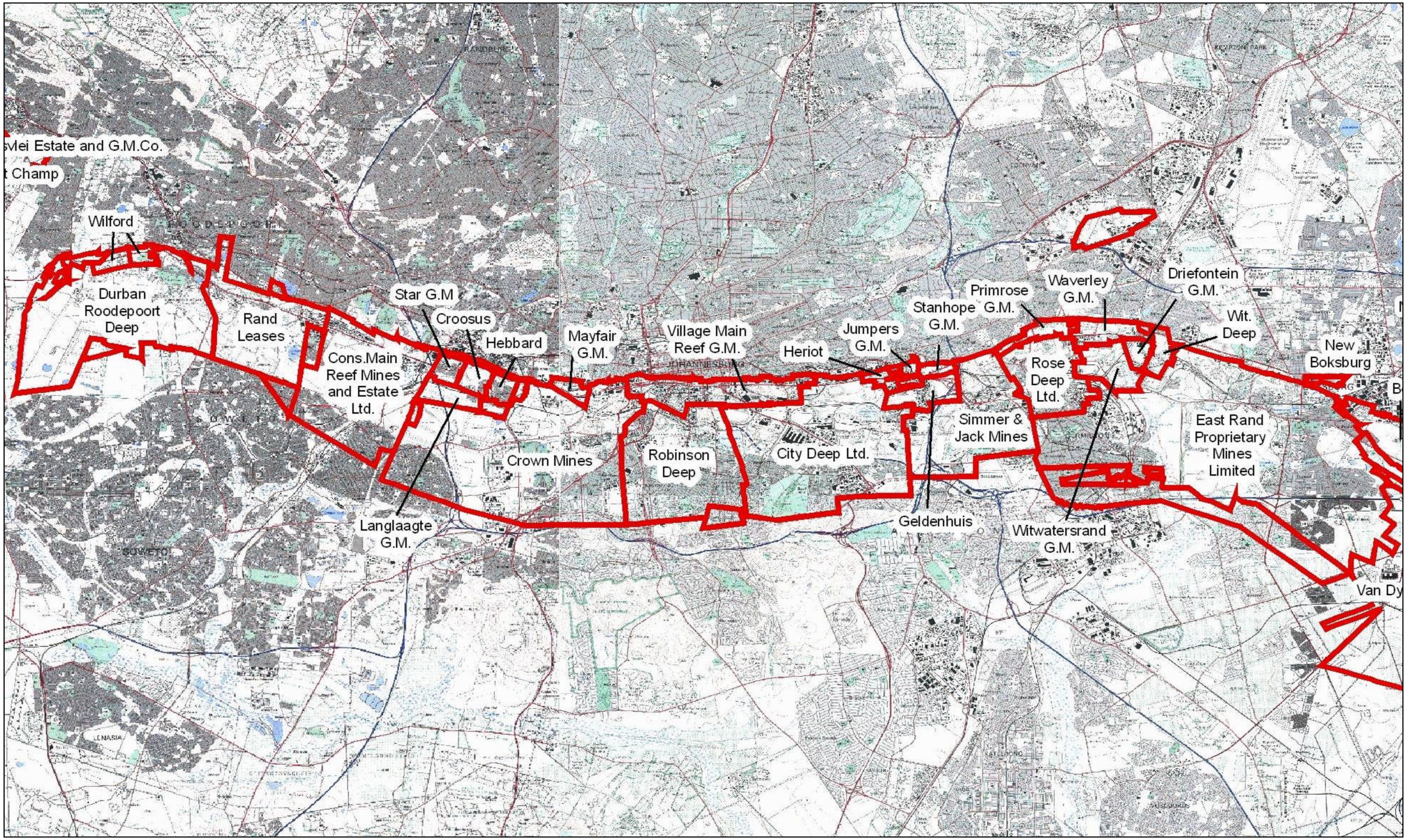

Figure 2.3. Mine properties with available mine plans, Central Mining Basin (DME, Pretoria)

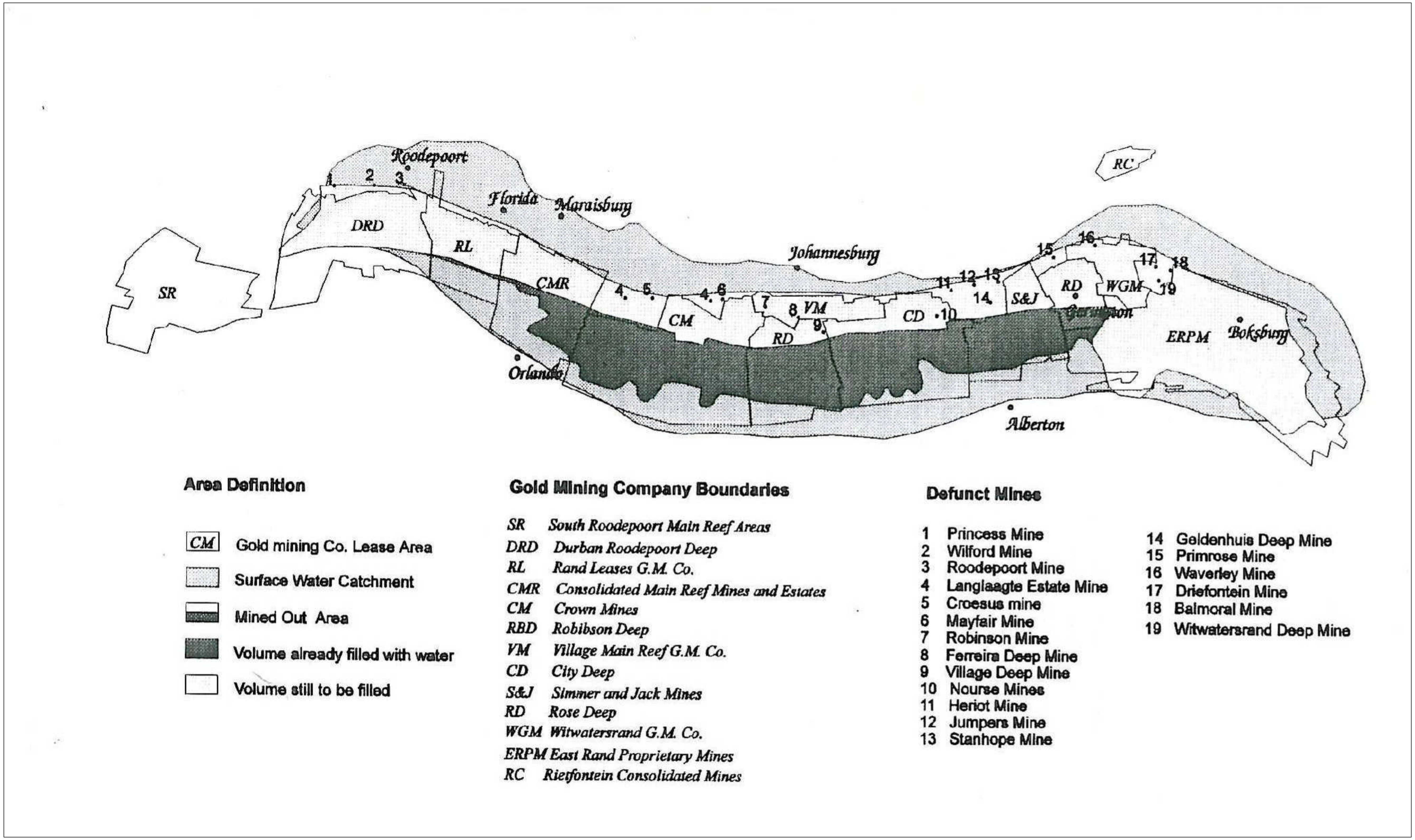

Figure 2.4. Original mine positions (Scott, 1995)

Table 2.2. Central Basin Mine plans (Council for Geoscience, 2005)

Mine	Abbreviations	DME Cubby Hole	Mine Plans Catalogued
Durban Roodepoort Deep	DRD	B7, D811, A143	3
Rand Leases	RL	D583	52
Consolidated Main Reef	CMR	B6	3
Langlaagte	LL	B117	21
Mayfair	MAY	C138	2
Crown Mines, Crown Deep and Norse Mines	CM	D699	25
Jumpers Consortium	JC	A141	1
Robinson Deep	RD	B135	33
Robinson Gold Mine	RGM	B69	1
Village Main Reef	VMR	B24	6
City Deep	CD	A60	11
Stanhope	SH	D305	16
Simmer and Jack and Simmer Deep	SJ	D637, B39, Back Storeroom Row 18 B39	38
Rose Deep	ROSED	D919, Back Storeroom Row 46 D627	10
Primrose	PR	No Plans	-
Waverley	WAV	D540 Row 43	1
Witwatersrand Gold Mine	WGM	A119 Back Storeroom	1
Witwatersrand Deep	WD	No Plans	-
Driefontein	DRIE	No Plans	-
Knights Central	KNC	B13	4
Knights Deep	KND	B14	3
East Rand Proprietary Mine	ERPM	C58, C92, D636	5
Total:			**236**

2.4 Background to exploitation of the gold reefs

In the Central Mining Basin the gold reefs strike east west from Boksburg to Randfontein over a distance of approximately 48km. Their southwards dip generally varies from steep near surface (50-90°) and becoming flatter at depth. These reefs outcrop south of the N12 Highway (Main Reef Road), also known as the R29. The early city of Johannesburg developed immediately north of these areas so that this major road did not have to cross these dangerous areas. All gold mining activities in this basin thus occurred south of this road except for the Rietfontein Mine. This mine developed in a small outlier (produced by faulting) of gold reefs that occurs approximately 10km north of the major reefs. This knowledge of the gold mining area guided the area in which the mine opening survey was conducted.

Perusal of the mine plans mentioned above helped to identify the positions of the original mine shafts i.e officially excavated holes. The position of other surface holes, such as subsidences, that also developed as a result of mining activities had to be undertaken via other means. Specific attention was given to searching the areas where they were most likely to develop, i.e at the surface or near surface intersection of the mined out gold reefs with the ground surface.

The initial exploitation of the gold reefs started in 1886 on the farm Langlaagte by the removal of the surface outcrop, Figure 2.5. These reefs could be traced for several kilometres which led to President Paul Kruger proclaiming nine farms in this area as public gold diggings (Wilson and Annhaeusser, 1998). Extraction began by open cutting of the reef which, with the use of simple equipment, was only feasible to a depth of 60ft (20m), Figure 2.6.

Figure 2.5. Original surface workings, Langlaagte, Southern Johannesburg

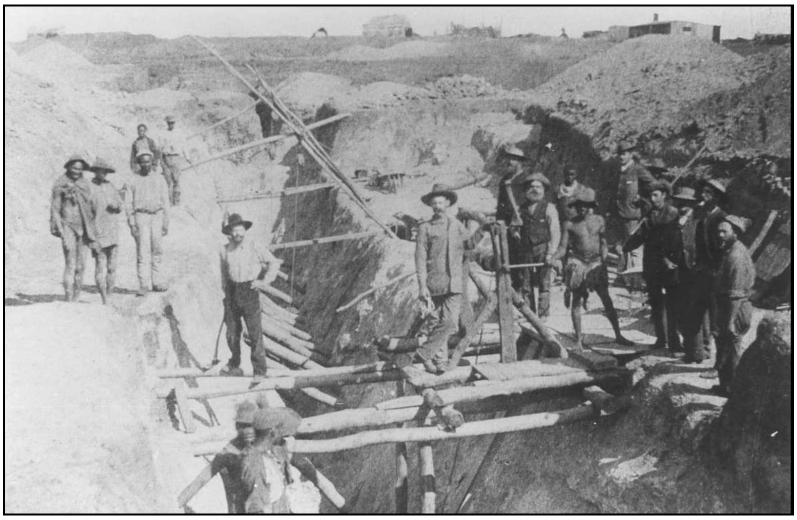

Figure 2.6. Exploitation of surface outcrop by early miners (Albrecht, 2006)

The specific nature of the reefs in this area had a major influence on the manner in which exploitation took place. Four major reefs running approximately parallel to each other are present in the study area, Figure 3.1, Figure 3.2. A number of other reefs in the immediate vicinity and parallel to these, which, with available information cannot be easily separated, are joined together to create three simple groups. These consist of:

1. The Main Reef group. Within this group the Main Reef varies from 1-6m thick and has been mined on DRD and ERPM Mines but was essentially barren in terms of gold (Scott, 1995). This reef is cut off in the eastern part of the basin by the South Reef. The Main Reef Leader was sought after for its high gold values, but being generally thin (0-2m thick) an adequate stope thickness required for access by miners was not possible and thus was often mined with the adjacent Main Reef. The South Reef is the third reef in this group and is generally more visible in the western portion of the Basin. It is 0,5-3m thick and is situated 15-60m stratigraphically above the Main Reef i.e. it outcrops a similar distance south of the Main Reef except in the central portion where they are only 10m apart and even in places cuts off the other reefs in this group.
2. Bird Reef. This reef is traceable across the whole Basin but is broken into at least six pieces in the central part of the Basin. These reefs are thin being less than 0,5m thick.
3. Kimberley Reef. Consists of four reefs that are laterally extensive across the middle part of the whole Basin.
4. Elsburg Reef. These reefs are upto 100m thick and can be located on the ridges from Mondeor to Elsburg in the southern, central portion of the Basin. Surface gold mining thus took place along these ridges.

As seen below, the exploitation of the reefs immediately south of Main Reef Road on the Simmer and Jack property eventually resulted in the creation of a large opencast mine, Figure 2.7. This was later followed by small incline shafts on the reef itself (Jeppe, 1943). More than 120 small mines were believed to have been in operation during this initial period (Wilson and Annhaeusser, 1998). In the Central Rand area these reefs were opened along a line of approximately 48km (Scott, 1995). Due to the variability of the reef and its gradient, these inclines were limited in their usefulness and small vertical shafts were soon sunk. As these mining areas were small, many of these inclines and small vertical shafts were excavated. By 1898 'deep level mining' (> 6000ft) had begun and deep shafts were installed. In the Central Mining Basin, the reefs typically have a steep dip near surface and then flatten out at depth, which resulted in the deep shafts being placed 300-520m south of the outcrop to intersect them at depth. A second line of shafts was later created, approximately 1100m south of the outcrop to intersect the reef at even greater depth, Figure 2.8. Due to economic considerations the larger shafts were typically placed 10 600 ft (approx. 3200m) apart, along strike. Ventilation shafts were typically placed in the centre of the mine property. Where the average dip was shallow the ventilation shafts were placed closer to the reefs and further apart where the dip was steeper (Jeppe, 1943).

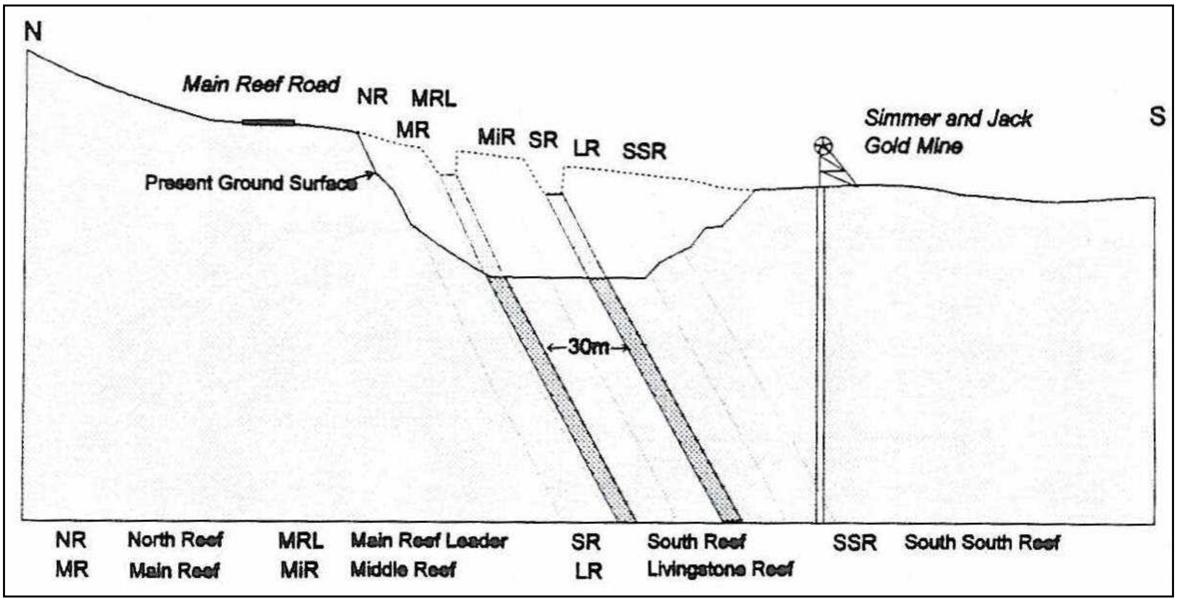

Figure 2.7. Cross section showing gold reefs that were exploited at Simmer and Jack Gold Mine (Scott, 1995)

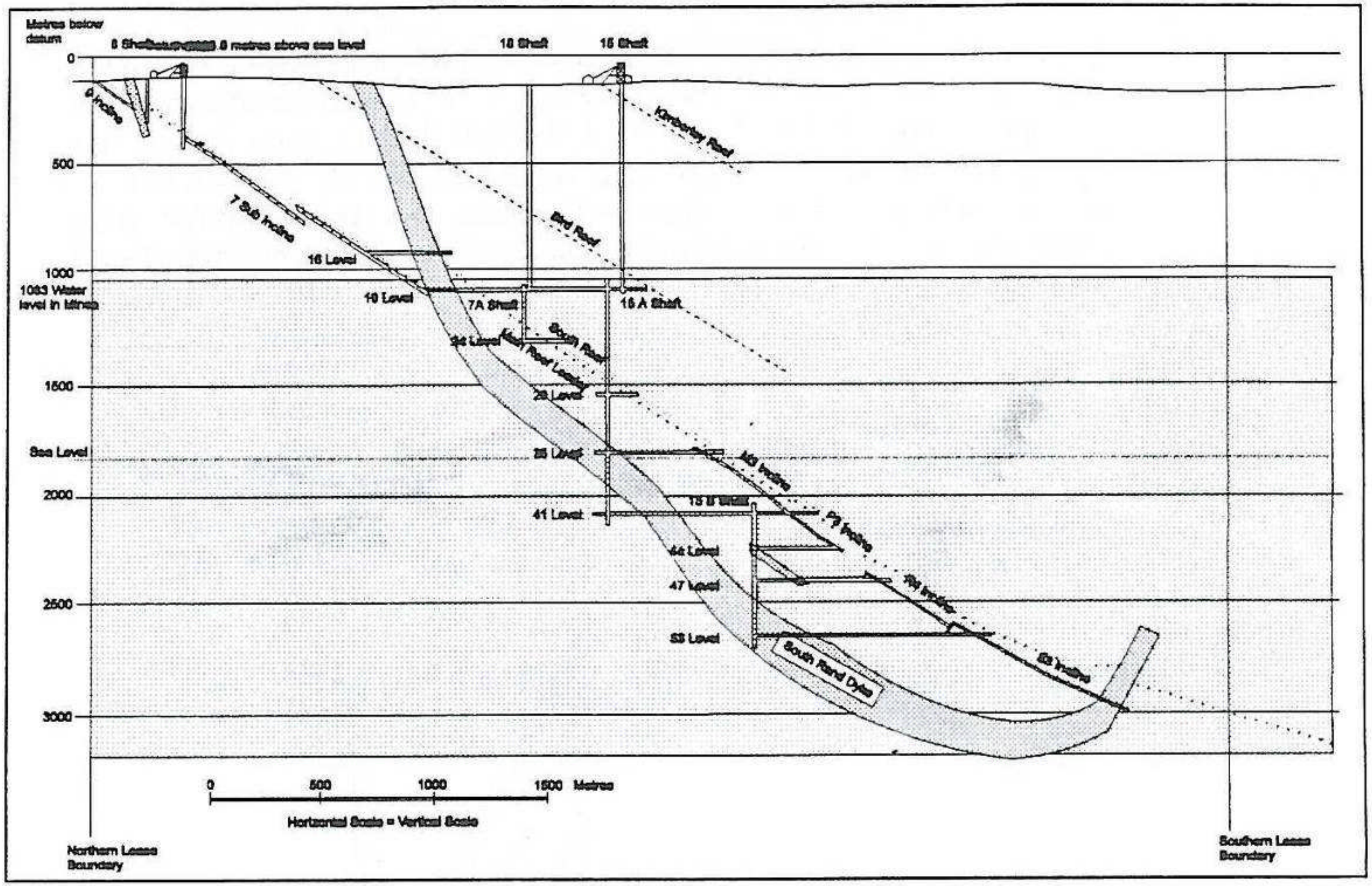

Figure 2.8. Cross section through Crown Mines property (Scott, 1995)

2.5 LIDAR Survey

The most obvious methods of locating holes in the ground are either by undertaking a survey on foot or by use of aerial photography. The former method is severely limited by the size of the terrain and access to it. Considering that the project area is approximately 150 000ha in extent it clearly was not an option to do a foot survey. The latter method, on the other hand, is limited by the availaibility of aerial photographs, and by the presence of vegetation and structures that prevent a clear line of sight of the ground surface. Additionally, reviewing of large scale photography requires a 'keen eye' and systematic approach to be able to locate these features amongst hundreds of aerial photogrpahs. A search, amongst local municipalities and survey companies, for suitable aerial photographs of the study was undertaken. Only 1: 30 000 imagery was available, which proved to be unsuitable for this purpose. In undertaking a similar exercise on the East Rand, Cameron Clarke (1986) found that similar aerial photography (1: 30 000 monochromatic) was useful for identifying open excavations, but could not be used for surface subsidences in the outcrop workings of the Witwatersrand strata.

As no aerial photographs of a suitable scale could be located, an attempt was made to use the LIDAR (Light Detection and Ranging) aerial photographic survey which had been conducted by the Council for Geoscience on behalf of the Department of Minerals and Energy during the period April to June 2005 (Council for Geoscience, 2005). In the process, imagery is produced utilizing laser and optical systems to produce a three dimensional picture of the ground surface. An infrared laserbeam is reflected off an optical dish and directed at the ground surface from an aerial platform such as an aircraft. The laser beam is able to penetrate through the covering vegetation to the ground surface below giving the ground height below the vegetation cover. To ensure accuracy, laser pulse readings are taken approximately every 0,25m along the flight path. The position of the aircraft is recorded via onboard Global Positioning Systems (GPS), which are linked with equivalent earth based GPS systems, Figure 2.9. The inertial movements of the aircraft are also recorded. Suitable cameras are also used to produce accompanying photographic imagery.

The laser data is then used to produce digital contour elevation maps which are superimposed onto the aerial photographs. The vertical accuracy is dependant on the height at which the aerial survey is flown, Figure 2.10, which in the case of the data supplied, was an altitude of 1000m giving a vertical accuracy of 0,1m and a scale of 1: 5000. The use of laser data allows 'depth' to be added to standard imagery as the laser beam penetrated to the shaft or subsidence cavity. Once the digital data have been downloaded a list of the mine 'features' is produced, and the features then verified in the field. At the scale at which the system operated, the results proved to be ineffective for the location of mine openings, and the method was not considered further.

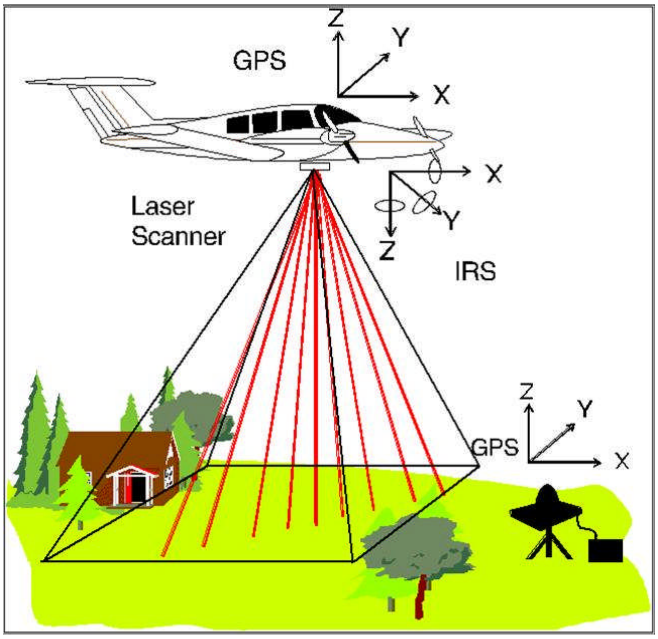

Figure 2.9: Production of LIDAR imagery (ALS, 2005)

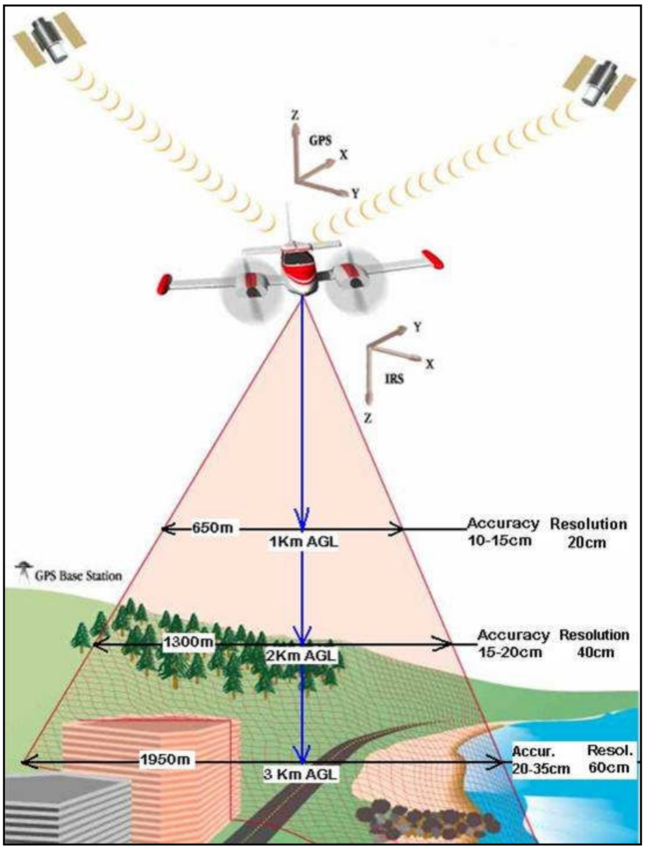

Figure 2.10. Resolution elevation relationship of LIDAR imagery (ALS, 2005)

2.6 Field Verification

Based on the information gained from available literature and mine plans field verification of the positions of identified holes was then undertaken.

Once an opening was located in the field its GPS co-ordinates (WGS 84 system) and characteristics were recorded, (Appendix C). A standard field sheet was used, Figure 2.11. The details that were recorded included:

- The location of the hole (x and y co-ordinates)
- The size of the hole
- The safety hazard rating

The header and locality information was transferred to a GIS system so that the positions of the openings could be plotted. The hole names used were derived from the earlier mentioned Nemai report (Nemai, 2001). These names are usually loosely linked to the original mine property names eg. ERPM (East Rand Proprietary Mine), S&J (Simmer and Jack Mine) etc. It was decided, for purposes of continuity (and to avoid confusion), to maintain and add to this system.

The photographs of each opening observed are stored in Appendix 2.

Each opening was classified into one of the following four simple categories of openings, namely:

a. Shaft
b. Subsidence
c. Mine related excavation
d. Underground mine related structure

Each opening was rated, using the system described below, in terms of the safety hazard it presented.

Holing Data

LOCATION :

Hole name	DRD 4	Logged by	D. Molapo
Longitude	27.87751	Datum	WGS
Latitude	-26.188897	Basin	C

SHAPE AND SIZE :

Length (m)	5	Hole Type	Shaft
Width (m)	5	Incline	yes
Depth (m)	100		
Area (m²)	25		
Volume (m³)	2500		

HAZARD :

Nearest settlement (m)	Nearby	CGS Hazard level	4C

CLOSURE METHOD :

Open or Closed?	Open	Volume and Materials	125
Method used		Size	Large
Probable Method	Concrete	Mining activity	Ceased.
Unit Cost	750	Responsibility	DRD
Probable Cost	93750	Mining Licence	ML 15/99

OWNER :

Holder	DRD
Telephone No	011-4824968(B Morton)

Photo:

Project Leader : Mr G.Heath
Private Bag X112, Pretoria, 0001
mailto:gheath@geoscience.org.za

COUNCIL FOR GEOSCIENCE

Figure 2.11: Example of information field sheet (Council for Geoscience, 2004)

2.6.1 Safety Rating criteria

In order to be able to assess which holes would require sealing the risk that each hole represented (in terms of safety) had to be determined. Two criteria were considered as being relevant in determining the risk posed by each hole:

- Depth of the hole i.e. the deeper the hole, the greater the likelihood of injury. Beyond a certain depth death is considered almost inevitable. The depths of two of the shafts, namely 1728,8m and 2105m at DRD and ERPM respectively, illustrate how deep some of these shafts are. This factor, which represents the hazard or danger posed by each hole, was given a score out of five (increasing score with depth). The size of the hole was considered to have an insignificant influence on the injury caused.
- Proximity of the hole to human settlements i.e the closer the hole to a local settlement or thoroughfare, the greater the risk that that hole creates i.e scale 1-5. A distance of 1000m was generally taken as the threshold distance about which this factor was considered relevant. Inclined holes required special consideration because, even though there was no danger posed in terms of falling from height, there were additional dangers posed because of easy access to the underground mine workings (refer Figure 1.7) which opened up other dangers, namely; falls of ground, gas, drowning and getting lost underground. These openings were treated as extremely hazardous.

These two factors were then added together, giving a score out of 10 (Table 2.3.

Table 2.3. Mine Opening Hazard Rating System

Hazard rating	**Description**	**Remarks**
1	Sealed Adequately	These openings had been sealed prior to this project and currently pose no danger.
2	Slightly hazardous	Small settlement or shallow surface opening or trench. Depth < 1,5m. Minor injuries possible.
3	Hazardous	Surface opening 1,5-3m deep. Minor injuries probable.
4	Very hazardous	Surface opening is 3-10m deep. Serious injuries probable though probably non fatal.
5	Extremely hazardous	Surface opening > 10m deep, serious injuries likely and probably fatal. Inclined holes: fatal injuries due to fall of ground, gas, drowning, getting lost.

Proximity Rating	**Description**
1	Opening is in a vacant field (> 1000m from any settlement or thoroughfare), area frequented by few people.
3	Opening is <1000m from a human settlement or thoroughfare. Area occasionally frequented by passers by.
5	Opening within or close to an urban settlement or where the holing threatens a road or walkway.

Overall Risk Rating		
Low	1-3	Hole shallow or far away from settlements i.e insignificant threat
	4-5	Hole either a) deep (>10m) and far away (>1000m) or b) close but shallow (<3m) or c) moderately deep (3-10m) and reasonably far away (>1000m)
Moderate	6-7	Hole either a) hole deep (>10m) but far away (>1000m) or b) moderately deep (3-10m) and reasonably close to settlements (<1000m)
High	8-10	Hole deep (>10m) and close to settlements (<1000m)

2.7 Summary

The location of unsafe mine openings in the Central Witwatersrand Mining Basin in this dissertation was based on a) a literature survey b) developing an understanding of the relationship between the gold reefs and the mine openings. Available LIDAR surveys were unfortunately not at a scale to be of any effective use. All holes were systematically documented and recorded on a GIS system. A simple safety risk rating system was developed to be able to assess the risk to local inhabitants that each hole poses.

3 THE UNSAFE MINE OPENINGS IN THE CENTRAL WITWATERSRAND MINING BASIN

Waltham *et* al (2005), state that where a hazard impinges upon human activity it involves a degree of risk. The hazard being considered in this study, namely deep mine openings, being situated in and adjacent to many residential communities in the southern Johannesburg area, pose a significant threat to the residents of these communities.

3.1 Introduction

The unsafe nature of these mine openings is illustrated by a number of historical as well as recent examples:

- A hole developed next to a building in the Motortown area, central Johannesburg, which swallowed three cars (Stacey and Bell, 1999)
- A Rand Water employee was seriously injured when she fell 20m down a 1m diameter hole (Appendix A) while inspecting a water pipeline in Germiston, February 2006
- the sudden development of a subsidence in Makause informal settlement (Germiston), above the reef outcrop which led to the death of a woman, circa October 2007.

3.2 The number and nature of the mine openings identified

The determination of the number of mine openings in the Central Witwatersrand Basin was based on the collation of:

- holes formally/ intentionally excavated and whose positions were officially recorded i.e mine shafts
- the holes formally/ intentionally excavated but whose positions were not officially recorded, i.e such as box holes and ventilation holes, and
- holes that developed as a result of collapse of the reef outcrop i.e subsidences.

In his survey of the available mine plans (236) for the Central Mining Basin, Shango (Council for Geoscience, 2005) initially identified 402 officially recorded shafts (Appendix E). However a number of factors place doubt on the accuracy of this total, namely:

- many of the mines were sold and resold over the years resulting in duplication of shafts on plans
- poor record keeping by the mine owners
- missing maps
- the use of shaft names that were not unique i.e No.1 Shaft, Shaft 1 etc.
- as underground plans were also reviewed, it is possible that subvertical shaft positions (which obviously do not daylight) were also recorded.

After a process of checking, verification (where possible) and elimination, a substantially lower total of mine plan shafts was arrived at, i.e 221. This total was then used as a guide i.e a theoretical total of what to expect in the field.

With the use of available mine plans and an understanding of the nature of the gold reefs in the central Johannesburg area, 244 mine openings were eventually located, Table 3.1, whose positions are shown in Figure 3.1 and 3.2. A larger version of these maps is shown in Appendix C where they have been plotted both on topographic maps and aerial photographs. The number of mine shafts located (170), represents 76,9% of the theoretical total (221). Most of the mine openings (69,6%) found in this basin were shafts, while a significant number were subsidences. Hill (1981) mentions the occurrence of a further 10 subsidence events in the Johannesburg city area. However as their positions could not be verified they are not included in this total. Only a few openings, defined as excavations and underground structures, were located and were hence not considered significant in this study.

Most of the mine openings (68%), were found along the strike of the northernmost group of reefs i.e the Main Reef Leader, Main Reef and South Reefs, Figure 3.3. A similar number of mine openings were scattered along each of the Bird Reef group and the Kimberley Reef group. No mine openings were along the Elsburg reefs during this study.

Table 3.1. Central Basin Mine Openings

Type of Openings	Number	Percentage
Shafts	170	69,6
Subsidence	60	24,5
Structure	7	2,8
Excavation	7	2,8
Total	244	100

The Main Reef group of reefs is dominated by shafts however a significant proportion (34%) of mine openings found here are subsidences, Table 3.2 . This is significantly higher than that found along the Bird Reef (7%) and Kimberley Reef (2,7%) groups situated further south. This high percentage of subsidences present along the Main Reef group can perhaps be attributed to the manner in which gold from the surface outcrop was initially exploited via many small claims. By the time the search for gold moved further south, primary mining groups had probably been established who would, by then, have realised that appropriately placed vertical shafts offered greater potential for the exploitation of gold, rather than down dip mining by winzes and incline shafts. Hill (1981) indicated that the down dip mining era largely came to an end by the late 1920's.

Table 3.2. Type of mine openings and gold reefs

Mine Opening	Main Reef	Bird Reef	Kimberley Reef
Shafts	99	36	35
Subsidences	57	3	1
Structures	2	3	0
Excavations	8	0	0
Percentage Total Openings	68%	17.2%	14.7%

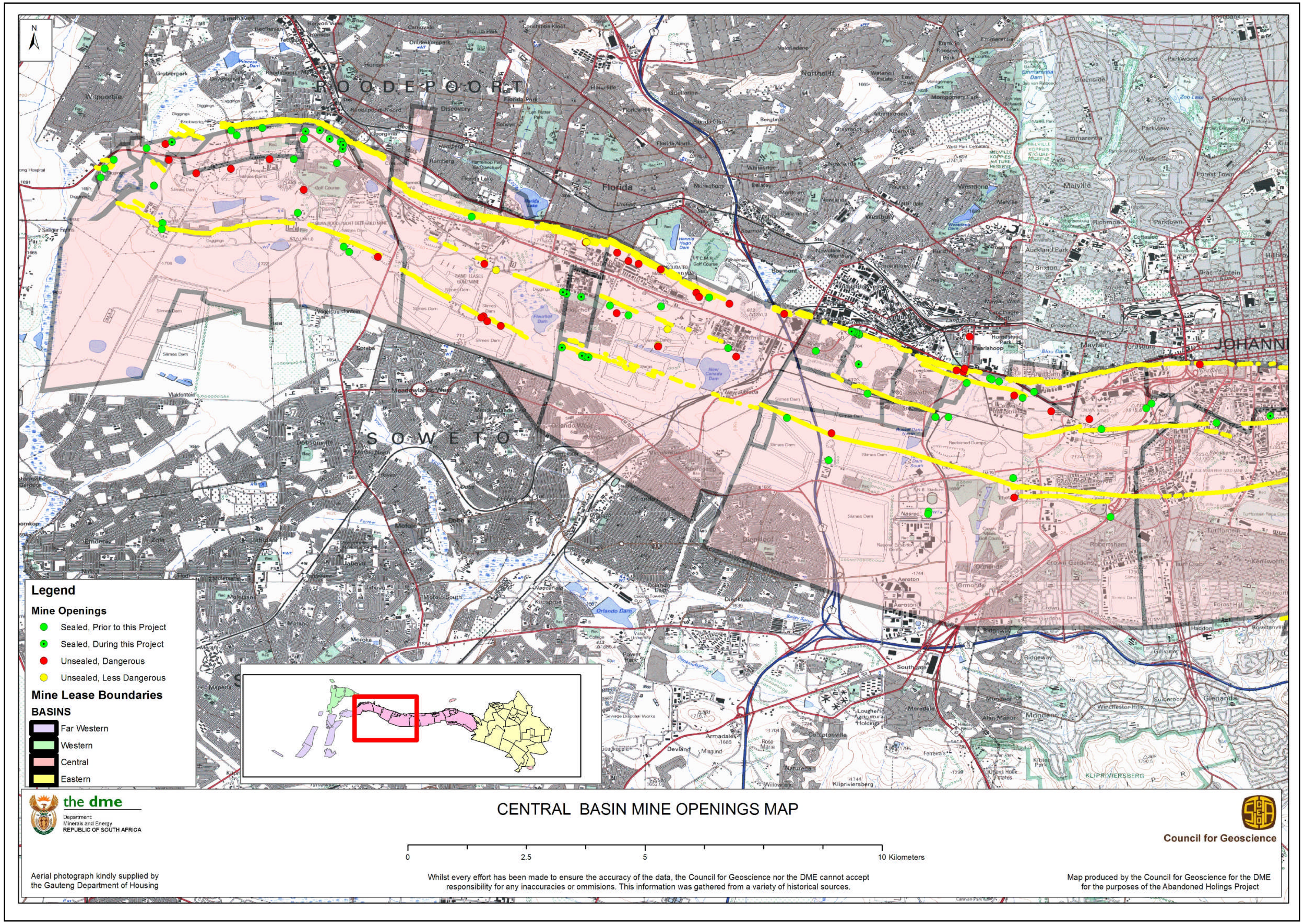

Figure 3.1. Central Basin Mine Openings

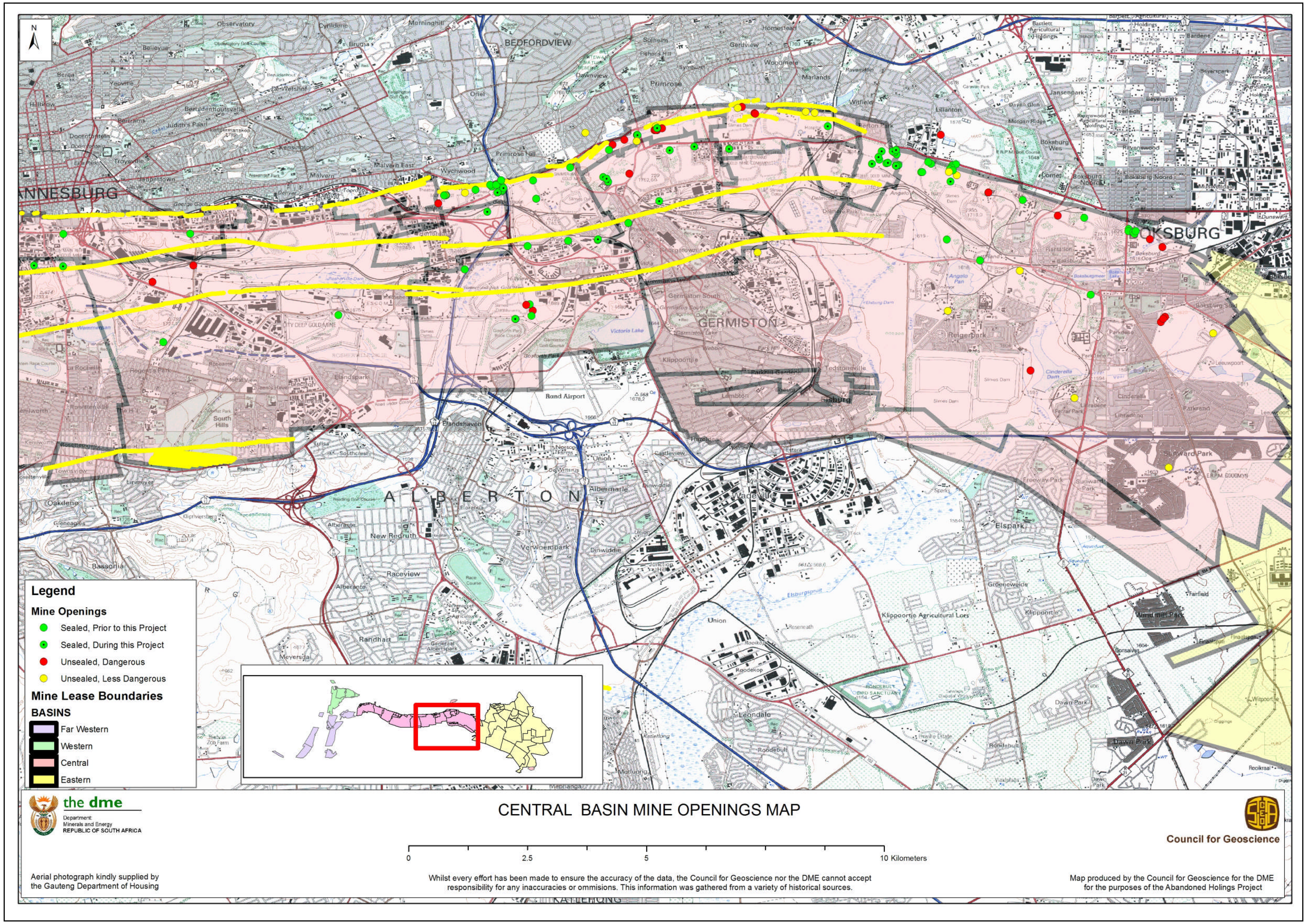

Figure 3.2. Central Basin Mine Openings

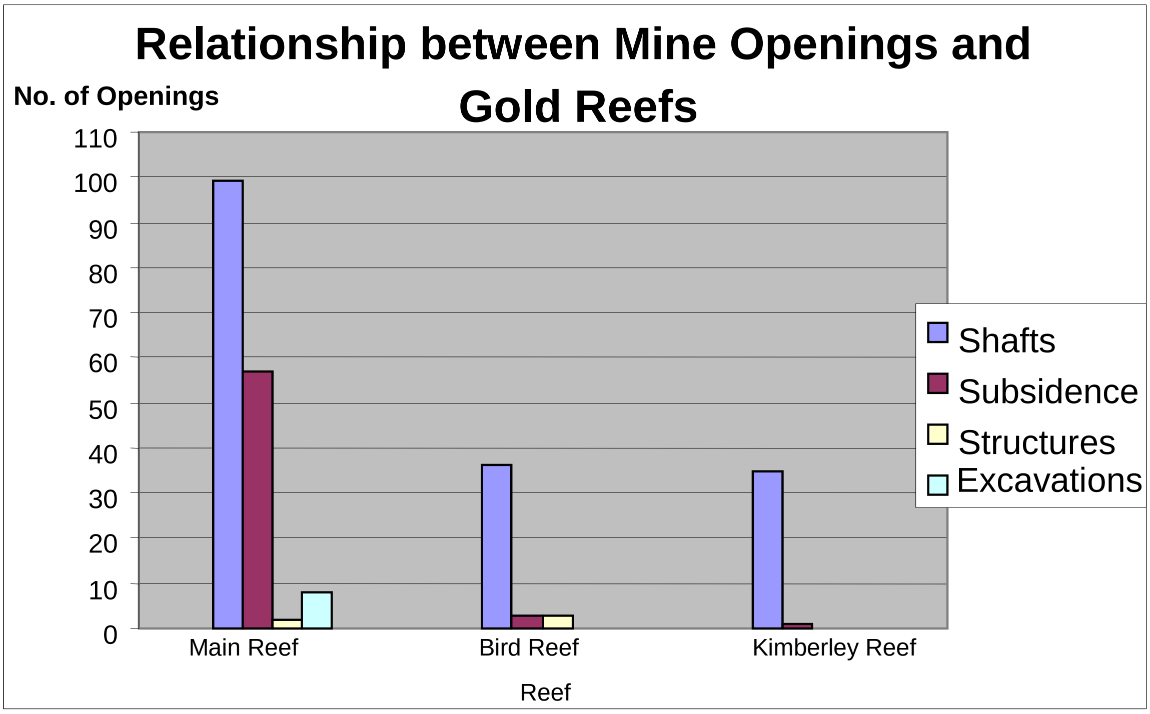

Figure 3.3. Relationship between mine openings and major reefs

The range of the largest dimension of the mine openings in the Central Witwatersrand Mining Basin varies from 1-85m with an average of 6,22m, Figure 3.4. For the most part the largest dimension of these openings is <10m which is typical of the shafts that make up the majority of the holes that were encountered.

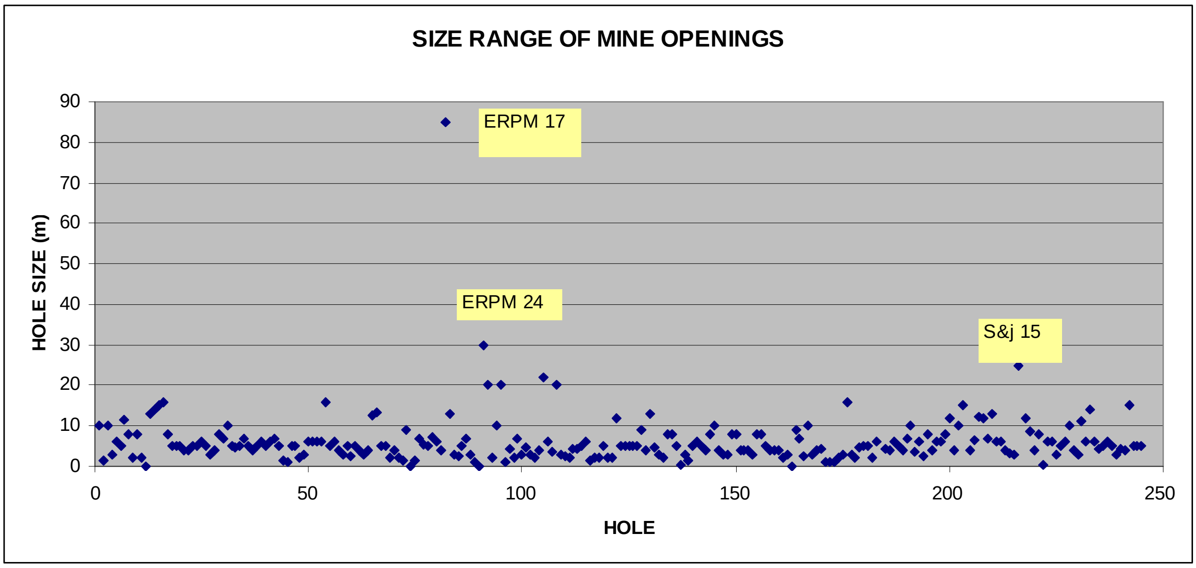

Figure 3.4. Size range of mine openings

The largest mine opening encountered in the study area was ERPM 17, Ekurhuleni (Figure 3.5), which is an old stope outcrop of the Main Reef into which substantial surface material has fallen, approximately 35 700m³. The initial dimensions of this hole would probably have been the intersection of the underground void i.e the stoping width (1-2m), with the surface. Continued collapse into the void below probably led to extension of this hole along strike. Subsequent transport of surface materials by water and gravity over a period of approximately 100 years have resulted in a hole 85m by 22m by 28m.

Similarly ERPM 24X (Figure 3.6) on the former Waverly Gold Mine, Ekurhuleni, visually provides a visible record of the volume of material that has collapsed into the void below. This hole is situated underneath a slimes dump into which the dump has fallen leaving a hole in the overlying material wth a circular dimension of approximately 20m i.e a volume of approximately 4000m³. This hole is situated on the Main Reef oucrop. During the course of this project the former mining rights holders, Centurion Gold, attempted to backfill an adjacent hole, < 10m away, using additional slimes. Within a year the volume of material used to fill this hole (approximately 1500m³) had already subsided leaving it exposed again.

Besides its size, approximately 27 000m³, S&J15 (Figure 3.7) on the former Primrose Gold Mine property also illustrates how quickly subsidence can occur. Up until 1999 this area was a working gold mine, with a working headgear positioned over an inclined shaft. Yet by 23 October 2002, the date of a site visit by L. Croukamp (pers. com), a massive subsidence was present which presumably had developed sometime within this period i.e three years. This appears to be indicative of the illegal removal of steel supports from the abandoned shaft which led to collapse of the hanging wall and eventually surface collapse, Figure 5.16.

Figure 3.5. Largest subsidence in study area, ERPM 17, Ekurhuleni

Figure 3.6. ERPM24x, collapse of a slimes dam into an underlying mine opening, Ekurhuleni

Figure 3.7: S & J 15, the old Primrose No.9 shaft, one of the largest known subsidences in the study area

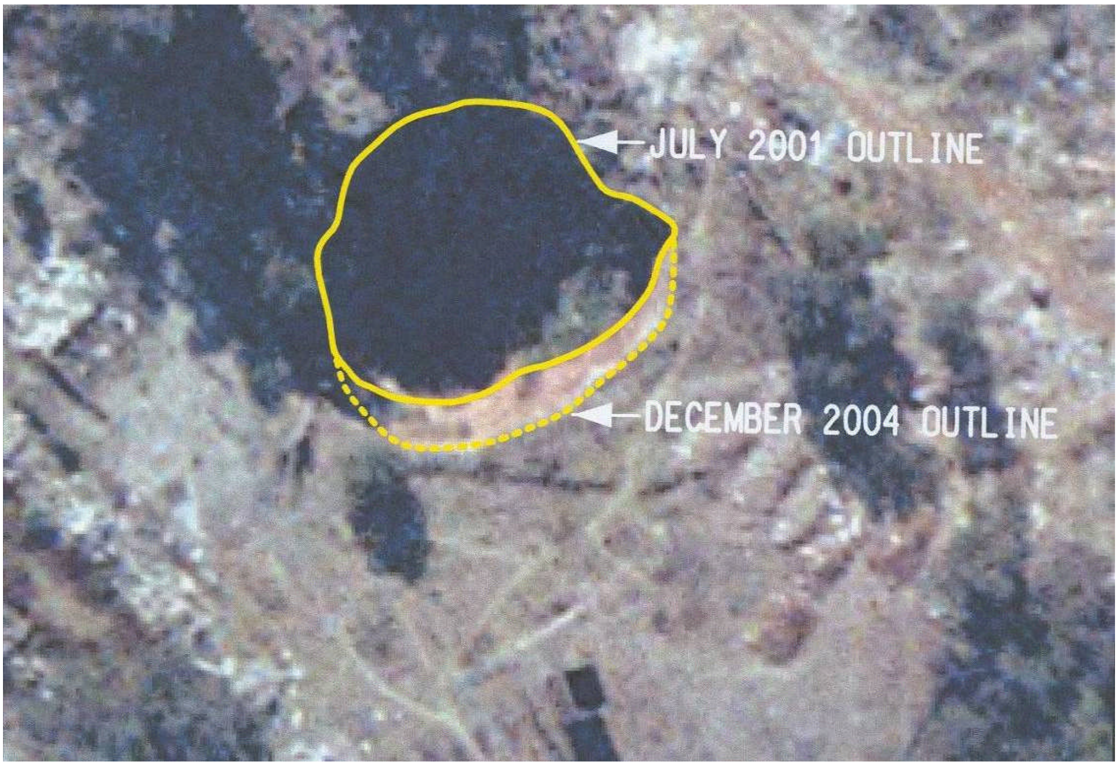

Figure 3.8. Aerial extent of growth of S&J 15

3.3 Hazardous nature of the mine openings

In order to prioritize which of these hazardous mine openings required closure, each hole was rated according to two simple criteria, namely a) depth and b) distance from settlements or thoroughfares, as explained in Chapter 2.

3.3.1 Depth factor

From their mine shaft survey of the mine plans stored in the Pretoria offices of DME, Shweitzer and Arnold (Council for Geoscience, 2006) recorded at least 34 shafts with depths >500m below the collar elevation (mbC), Appendix C . The deepest shaft depth recorded from this data source was the South Deep Shaft at the former Simmer and Jack Mine with a vertical depth of 1991mbc. This was not the "longest" shaft depth recorded, however, with the P8 Incline Shaft of Crown Mines having a length of 2066.88m. Not all these shafts could be located in the field. The depths of the shafts that were found and which could be related to the mine plans are shown in Table 3.3 which indicates a range of depths of up to 990.5mbc. The actual depths of these shafts could not be confirmed in the field due to obvious safety limitations. The deepest subsidence observed was that surrounding the Primrose No. 9 Shaft with a depth of approximately 35m, Figure 3.7.

During this study, the exact depth of each mine opening was considered to be only of limited interest, as anything deeper than 10m was considered to be extremely hazardous and certain to result in a fatality. Thus exact depths were not recorded. The percentage of these very deep holes compared to the shallower categories of holes (defined earlier in Table 2.3) is shown in Figure 3.9 with the majority of the holes (74,5%) being greater than 10m deep.

Table 3.3. Measured depths of some shafts in the Central Basin (Council for Geoscience, 2004)

No. of Shafts	CGS Shaft Names	DME Shaft Names	Depth (mbc)
1	Private 2	Langlaagte East Deep Shaft	457.2
2	Rudd Shaft	Rudd Shaft	448.6
3	S&J 15	Rose Deep 4	990.5
4	S&J 16A	Rose Deep 5	217.6
5	Knights Shaft	Rose Deep No. 1	438.9
6	Rose Deep no 2	Rose Deep no 2	517.2

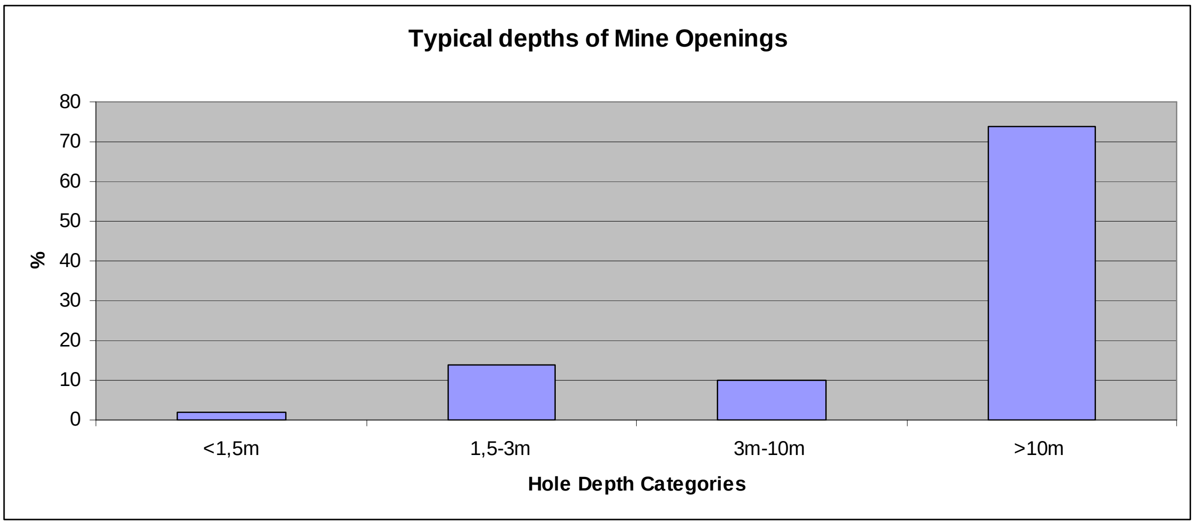

Figure 3.9. Typical depths of mine openings

3.3.2 Mine openings proximity factor

The distance between each hole and the nearest settlement, infrastructure, road or well used path was measured to determine what risk each hole poses to anyone living nearby.

In general the majority of the 244 holes in this basin were found within 100m (average 59,8m) of such settlements (Figure 3.10). At least 11% of the holes were found surrounded by such settlements i.e people were living around the collars of such openings (Figure 3.11). While some of these openings had been permanently sealed and hence posed little or no danger, others only had temporary barricades (such as barbed wire fences etc.), indicating that perhaps people were not aware of the danger posed by such mine openings. At least eight holes (ERPM 32-38, Appendix D) were found in the small loop of land that separates Main Reef Road and the N3 Highway, former Geldenhuys Mine (Figure 3.2). On a much smaller scale, Hole R61 was located within a metre of a major footpath that leads from the Meadowlands Men's Hostel (Soweto) to Main Reef Road, a thoroughfare that is more than likely used at night. The arbitrary 1000m which was initially chosen as being the dividing line between 'near' and 'far' proved to be too coarse when used in this Basin.

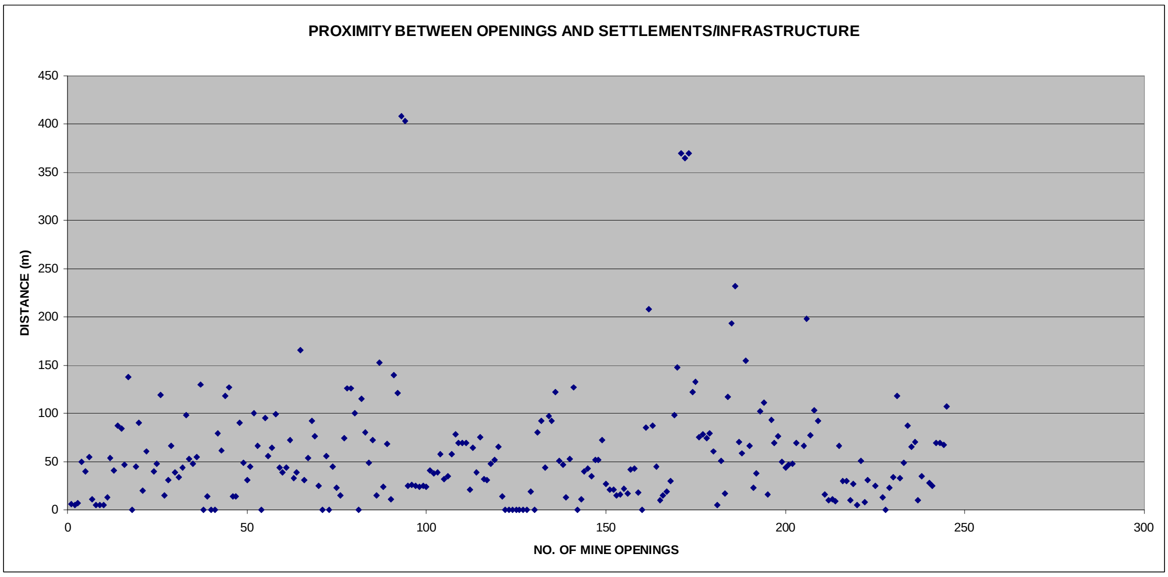

Figure 3.10. Proximity between mine openings and settlements/ infrastructure

Figure 3.11. Informal settlement situated close to dangerous mine opening (Balmoral Vertical), Balmoral Informal Settlement, Ekurhuleni

3.3.3 Results of the hole rating

Of the 244 mine openings located (Table 3.1), 151 were found to be open and unsafe (61,8%) while the remaining 93 had some type of access prevention (concrete slab, plug etc.) and hence were rated as not hazardous. These holes were classified as 'Sealed adequately', exampes of which are City Deep 4 and Crown Mine 8 (Appendix 8). Of these 151 open, unsafe openings, 97 (64,2%) were identified (Figure 3.12), as posing a 'high' risk i.e being deep and close to local settlements (Table 2.3). Such an example is shown in the Balmoral Informal Settlement (Ekurhuleni), which has developed within 10m of, and irrespective of, such a dangerous hole ('Balmoral Vertical') (Figure 3.11). A further 48 (31,7%) were considered to have a moderate risk i.e moderately deep and relatively close to settlements. The remaining 4% were considered to pose a 'low' risk i.e because they were shallow and/ or far from settlements and were not considered any further.

Using this system as a guideline, 49 high risk (50,5%) and 31 moderate risk holes (64,5%) were selected for closure, a total of 80. This resulted (Figure 3.12) in a reduction in risk due to the sealing of these medium and high risk openings. Prior to closure, the majority of the holes were considered to be a 'high' risk (64,2%) which after sealing reduced the number of high risk unsafe holes to 48 (29%). Similarly the holes with a medium risk (31,7%) were reduced to 18 i.e 11,9 %. Consequently the number of holes with a low risk risk increased because of the addition of the 80 newly sealed holes.

A number of 'high risk' mine openings could not be considered for closure during the DME Project because they were not 'abandoned' mine openings, i.e an existing mine owner had been identified whose legal responsibility it was to close those holes. Additionally, other high risk openings were identified later in the DME project, and were only then added to the high risk total, by which time construction tenders had already been issued. Hence it was too late to include closure of these holes in the DME project and they will more than likely be closed in the near future.

3.4 Summary

This dissertation has documented the position of 244 unsafe, abandoned mine openings in the central mining area of Johannesburg. The majority of these openings are <10m wide but being deep and close to local settlements they can be considered danagerous and pose a substantial danger to local inhabitants.

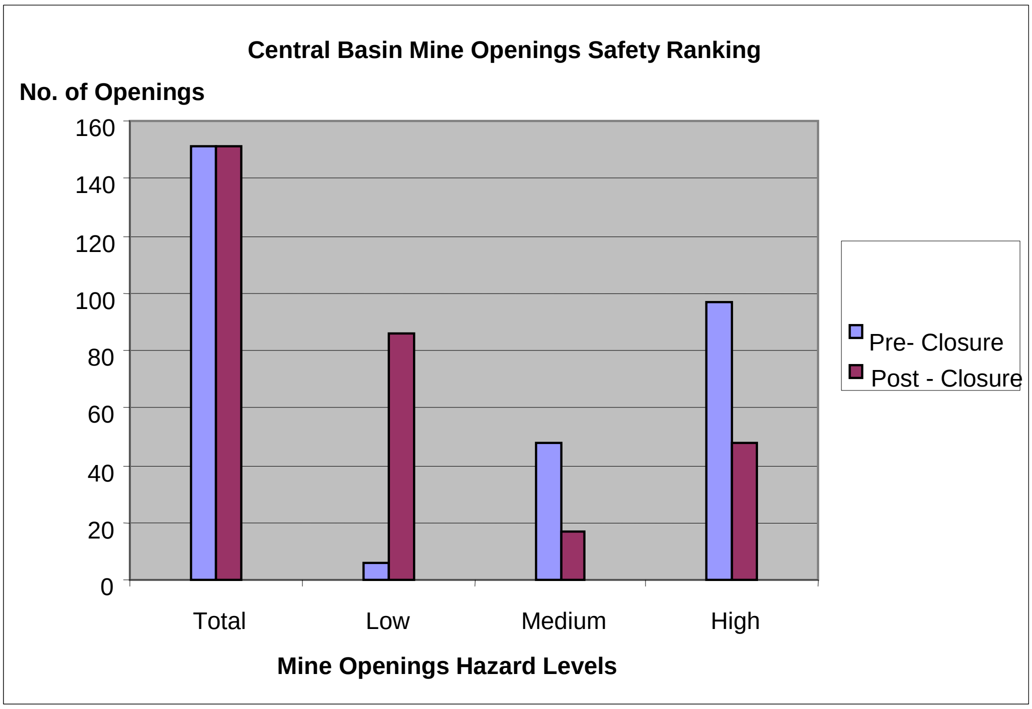

Figure 3.12: Simplified grouping of hazardous mine openings

4 COMMON METHODS OF CLOSING MINE OPENINGS

'Once a shaft has been sunk, it is impossible to restore the earth to its' original condition' (U.S Dept. Agriculture, 1981). While this comment probably refers to attempts to restore mine areas to their original, pristine conditions a survey of methods used internationally, and those observed locally in the Central Witwatersrand Mining Basin, to seal mine openings was undertaken.

4.1 Literature Survey

In their 'Best Practices in Abandoned Mine Reclamation' the Colorado Division of Minerals and Geology (2002) have noted that typically three types of closure methods are commonly used, namely:

i. Barriers - these methods are designed to discourage access and to keep persons away from the hazard. They are appropriate particularly when the opening is too large for other alternatives or when restricted access is required. Thus fences or grates are placed around or across the opening. These methods are necessary if access is required for various types of fauna (bats, birds, insects) or for ventilation purposes.

ii. Seals (or caps) - these methods prevent entry to the mine opening by placing panels or slabs across or on top of the opening. They should be of sufficient weight that substantial effort is required (such as heavy construction equipment) to remove them.

iii. Plugs - these methods eliminate the hazard altogether by filling all or part of the hole. The holes are thus backfilled completely with available materials or a concrete plug/ cap placed within a portion of the hole.

The Nova Scotia Department of Resources (1997), states that the effective life of the selected closure method must be considered. They consider methods such as fences, screens and grates to be of a temporary nature even though they may last up to 20 years (with suitable maintenance). The biggest failing with these methods is that they do not prevent deliberate or even accidental entry into mine openings. They define long term measures as being methods that 'seal and prevent entry….. but still preserve the general condition of the opening'. They define 'long term' as being methods that are expected to last for 30 to 50 years. Methods such as pre-cast or cast in place concrete caps, monolithic concrete caps and/ or native rock or concrete bulkheads are considered to fall into this category. Regular inspections and maintenance are still required. Permanent measures, such as backfilling and closure through blasting, are considered to be methods that permanently close off the opening and which will not require further inspection or maintenance.

Differences in definition are apparent above where the Nova Scotia Department considers backfilling to be a 'seal' and the Colorado Division of Minerals and Geology regarding this method as a 'plug'. For the purposes of definition during this study, measures such as the use of a monolithic mass of concrete (or other similar material) placed in or near the top of a hole will be termed a 'plug'.

As stated in Chapter 1 of this dissertation, only long term and permanent measures will be considered here and temporary methods are excluded. Similarly, only properly engineered methods are being considered where the surrounding conditions have been analysed, the method used has been properly calculated, and a reliable estimate of its effect can be determined.

4.1.1 Seals

Probably the most common form of seal used is the concrete cap where entry is prevented by the installation of concrete slabs or panels, precast or cast *in situ*, on top of the collar of the opening, (Figure 4.1).

The intention of this method is to create a long term to permanent method of preventing access that will require substantial effort, to remove. This is an efficient method, especially where numerous holes are located close to one another. Furthermore the panels can be designed and placed relatively easy without anyone having to enter the hole for any length of time, which has safety implications.

A number of sources[1] [2] [3] have shown that in general this method involves:

- o Excavating the top of the opening down to solid or competent bedrock to create solid footings for the panels.
- o Using either pre cast slabs or casting in situ slabs to cover the hole. Healy and Head (1984) specifically recommended that the dimensions of these slabs should be at least twice the diameter of the shaft and the slabs should not be less than 0,45m thick, (Table 4.1). The beam should be placed

[1] Healy and Head, 1984

[2] Nova Scotia, 1997

[3] Colorado National Park Service, 1992

symmetrically about the hole. These specifications are influenced by the nature of the local ground conditions. A minimum width of 6" (0,15m) for the steel beams has also been recommended (Colorado National Parks Service, 1992).

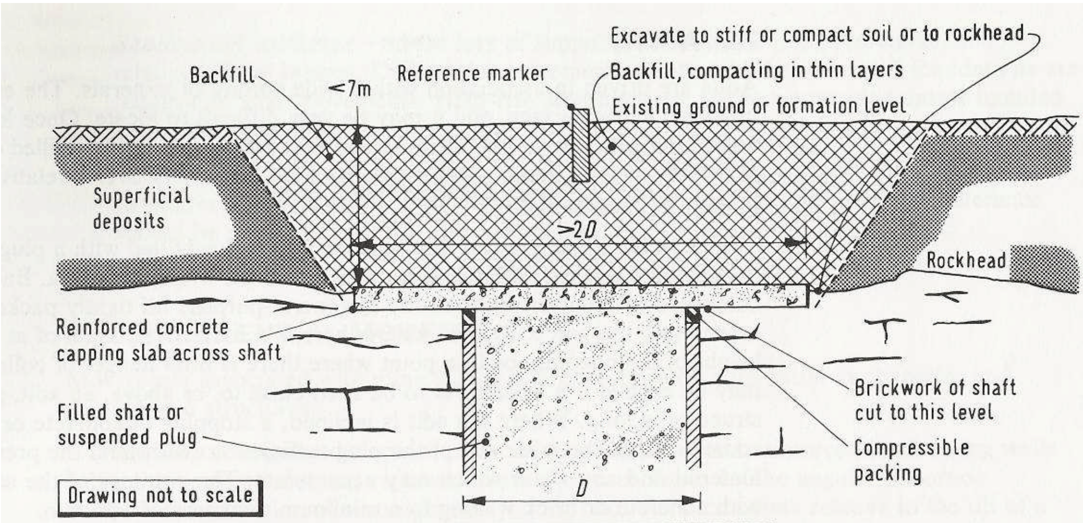

Figure 4.1: Typical concrete cap (Healy and Head, 1984)

- Placing steel beams to carry the panels or inserting reinforcing steel, along with the necessary formwork, if the concrete is cast in situ. These steel beams should be coated with epoxy resin or bituminous tar to prevent corrosion which could lead to failure. The steel beams should be placed perpendicular to the direction of the concrete panels.
- Placing backfill, generally unspecified, over the panels to prevent the ingress of water. However where the panels are < 2,5m from the surface, complete covering with backfill is not considered necessary (Colorado National Parks Service, 1992). Mounding of the backfill may assist the drainage of surface water away from the opening.
- If the cap is then covered by backfill the shaft position should be marked to indicate that there is a shaft below.

This method does require the use of a qualified structural engineer to oversee all aspects of the design.

The use of this method is limited by the hole diameter that panels are able to span. The delivery of materials or the precast panels may also be limited by road access. Concern has also been expressed by Healy and Head (1984) that water infiltration around the edges of the panels may in time lead to their subsidence and failure, Figure 4.2.

Table 4.1: Recommended design for concrete slabs (Healy and Head, 1984)

Shaft Diameter	**Slab Thickness**	**Slab Size**	**Minimum Reinforcement**
Up to 1,8m	Minimum 450mm	4,2m x x4,2m	200mm centres
1,8 - 2,7m		6,4m x 6,4m	
2,7 – 3,6m		8,2m x 8,2m	250mm centres

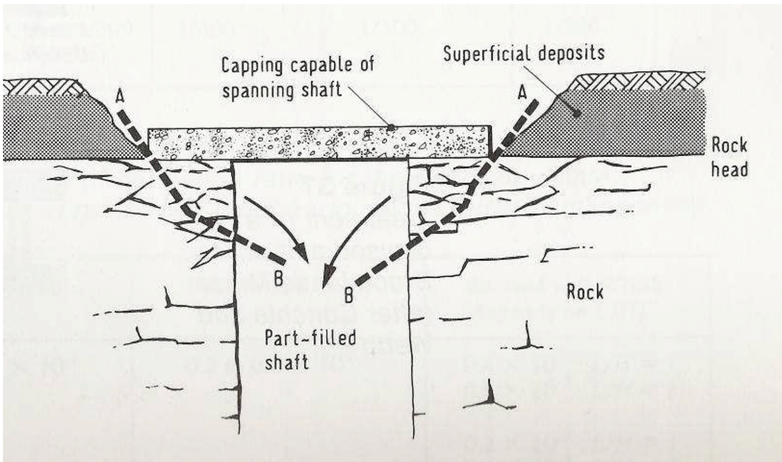

Figure 4.2: Potential mechanism of failure below a shaft covered by a cap (Healy and Head, 1984)

4.1.2 Plugs

Two types of plugs are reviewed below.

Concrete plugs

In the Isle of Man, the local authorities (Isle of Man, 1986) had identified 160 abandoned mine openings in their region. The preferred methods of treatment for abandoned shafts was to place an in situ reinforced concrete cap or plug over the shaft and then to cover it with soil and return it to its original condition. Where it was not possible to construct a shaft cap, such as limitations due to access, a suitable steel fence, with signage, was used.

A variation of the 'plug' method has been used in the south Limburg region of The Netherlands where 35 shafts had to be closed, circa 1971 (Schilp, 1971). The method chosen involved using two concrete plugs. The lower one was placed at the level of the highest underground station and supported by the floor. The shaft was then filled with clastic material, filler stones or debris. An upper concrete plug was placed at the surface.

Where mined out stopes intersect the surface, outcrops have been plugged using concrete before covering them with compacted backfill (Stacey, 1986). This approach involves excavating the stopes along strike until competent material in the stope walls is exposed. The concrete is then placed to form a base for the overlying backfill. The backfill layer is compacted between the stope walls, which results in a 'stabilising ground arch'. This method is probably only suitable for dipping (>30°) to vertically dipping stopes.

Polyurethane plugs

In dealing with the 9934 abandoned mine openings in the United States National Parks (U.S National Park Service, 1992) rigid Polyurethane Foams (PUF) have been used in some circumstances as an alternative method for the quick sealing of mine openings, (Figure 4.3). During the period 1987 to 1989 approximately 15% of abandoned mine openings holes closed in Colorado were sealed using this method (Rushworth *et al,* 1989). The advantages of creating PUF plugs, is that the PUF is highly portable, is easily and quickly applied with only minimal site preparation required. It also has low costs of design and implementation.

Essentially the foam is produced by the mixing of two components, an isocyanate (Component A) and a polyol resin (Component B) which is then pored or placed on top of a lightweight formwork (cardboard, plywood etc). A rapid exothermic reaction occurs within 15-45s, generating a rigid foam that expands to fill all voids and cracks and which bonds with the sidewall of the host rock. An expansion of 20-30 times typically occurs within 190-240s, Figure 4.4. Once this stage is reached the following layer of foam can be placed. The hole is then filled with successive layers to within 0,5m of the surface before covering with soil to prevent breakdown due to UV light and damage due to vandalsim. The soil layer also creates an arching layer that reduces the effective load by transferring it to the sidewalls.

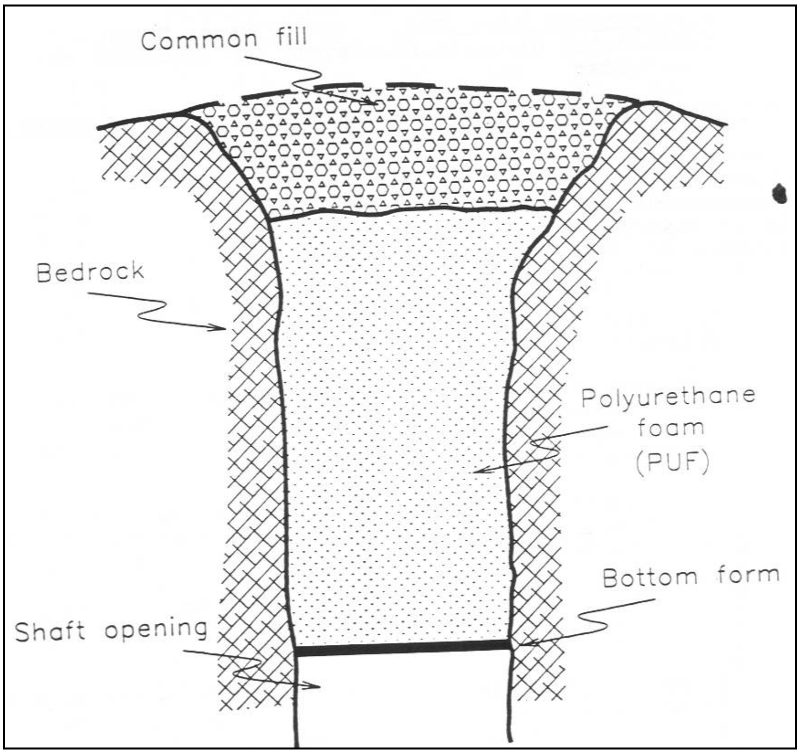

Figure 4.3: Polyurethane plug (U.S National Park Service, 1992)

Figure 4.4: Expanded, rigid PUF (Council for Geoscience, 2004)

The strengths of Polyurethane Foams are directly related to their density. They can be manufactured to produce densities that range from 12,81-961 kg/m^3 with a 400x increase in strength over this density range, Figure 4.5. While denser foams are able to produce plugs that are significantly stronger, perhaps similar to that of that of concrete they do though expand less, requiring more chemicals and hence cost more.The U.S National Park Service has thus chosen a foam density of 32 kg/m^3, which produces a compressive strength of approximately 240 kPa, as being the optimum, most cost effective density for the closing of mine openings. The density of this type of foam is approximately 1,3% that of concrete. This appears to have been accepted as the norm for this type of application. While higher foam densities can be achieved by varying the chemical nature of the two components used, the denser foams obviously expand less, require larger volumes of the raw materials and hence lead to increased costs.

PUF is tan-white to buff in colour, has no vesicles and forms a smooth bulbous surface on setting. It is a polyurethane, isocyanate based on a Polyol resin system. The typical product used is 4,4' – Diphenylmethane diisocyanate. It is water based with no chlorofluorocarbons. It has a 6-9 month shelf life if stored at > 60ºF. If the PUF darkens during production, becomes smooth and glassy, friable or brittle, the correct density has not been achieved and is probably caused by excess 'A' component. If however it lightens during production, becomes mottled, blowholes or pinholes develop, then excess 'B' component is present. If it is slow to rise and has a poor cell structure, if the equipment clogs and is slow in curing, then the materials have spoiled.

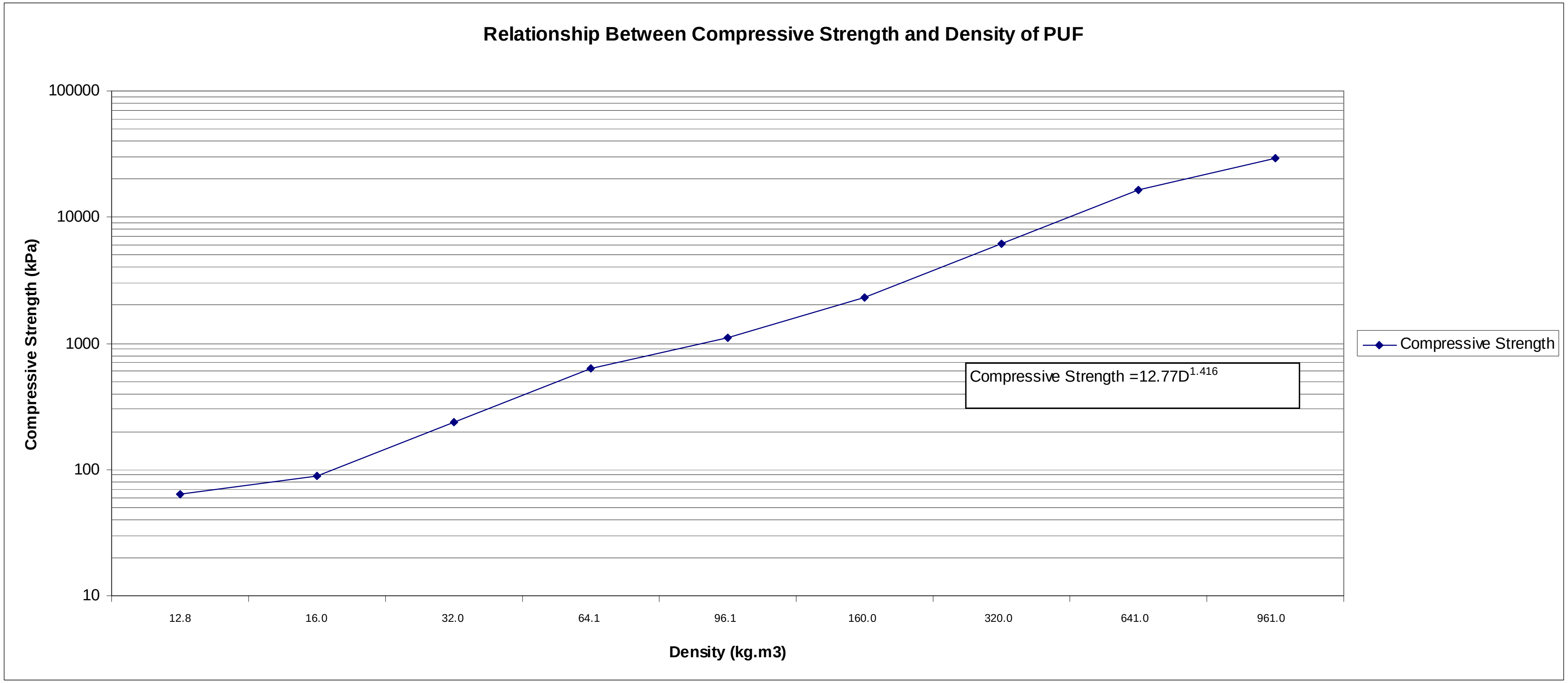

Figure 4.5 PUF, the effect of density on compressive strength (Dunham, 2004)[4]

[4] Graph converted from Imperial Units

A distinct property of Polyurethane Foams is that *closed* foam cells are produced during the chemical reaction process. This property inhibits the uptake of water which is particularly important when used in areas where subzero temperatures can be expected. If complete and proper mixing of the two components has taken place the product should contain almost 100% closed cells (Rushworth *et al*, 1989). Incomplete mixng however can lead to some open cells and hence 'weakening' of the final product. Generally this type of PUF has a compressive strength of 172-241kPa, and a tensile strength of 172-448kPa, Rushworth et al (1989).

The following standard tests were conducted on 32kg/m³ PUF samples by the U.S Bureau of Mines (1992),Table 4.2.

Table 4.2: List of standard tests conducted on PUF samples (U.S Bureau of Mines, 1992)

Test	ASTM standard	Specimen Size	Result
Density	ASTM D 1622	Variable	9,03-11,93 (kg.m^3)
Compressive Strength and modulus	ASTM D 1621	50,8mm x 50,8mm x 25.4	42,75-55,16 kPa 399,9-579,2 kpa
Tensile Strength and modulus	ASTM D 1623	50,8mm x 50,8mm x 25.4	42,75-114,5 kPa 1951-4709
Shear strength and modulus	ASTM C 273	304,8 x 50,8 x 25,4	59,98-63,43 kPa 806,7-992,8

Polyurethane Foams are best used in small to medium sized holes where the width of openings varies from 0,9-3m. The design plug thickness varies according to the length of the shortest dimension of the opening and the depth at which the plug is placed, Table 4.3, Figure 4.6.

Note:

- the larger the opening the thicker the plug required to span the opening. For example, using the same depth of formwork (eg. 7,0m), the PUF plug thickness varies from 2m for a 0,9m hole to 5,9m for a 3m hole.
- for any given shaft dimension the plug thickness increases with the depth of the formwork to carry the increased volume of backfill. Thus for a hole

dimension of 1,8m, the plug thickness varies from 2,1m if placed at 2,7m depth to 6,4m if placed at 12,8m depth.

- It appears that PUF plugs have to be at least as thick as they are wide, thus for a 0,9m wide opening a 0,8m thick plug is required while for a 3m wide opening a plug of at least 4,3m would be required.

The following general procedure for closing holes with PUF has been generally recommended:

i. a lightweight frame (consisting of re-bar, planks etc) is fixed across the hole opening, at a specified depth, and mesh/ tarp/ plastic placed across it. This forms a platform onto which the liquid PUF is poured.

ii. The two components are mixed at a 1:1 ratio and stirred in a container. The reaction then occurs resulting in creation and expansion of the foam.

iii. The mixture is then poured into the hole to create a layer. No foreign materials should be added to the PUF layer. For larger applications a spray pump can be used and the hoses attached to drums of chemicals mounted on a small truck. This system should be self-cleaning and adjustable to alter mixtures as necessary.

iv. Closure then takes place in lifts of 0,5m allowing suitable time for hardening of each layer. The foam should be tack free before applying the next lift. All voids must be filled. A standard table of foam thickness requirements is normally used (Table 4.3).

    To reduce the risk of fire during installation, a small fire extinguisher should be available. Lifts should not cut into pre-existing foam i.e the underlying layer should be relatively hard before applying the next layer. It is recommended that the process take place slow enough such that the exothermic reaction is controlled. Thermocouples may be used to monitor temperature.

    There should be no running water as PUF will react preferentially with water. It therefore should not be applied during rain unless protected by a cover. The foam therefore cannot be placed in wet conditions. The foam should not take on water as it could freeze and thaw and reduce the structural integrity.

Table 4.3: Polyurethane Foam Design Plug Thickness (Colorado Mined Land Reclamation Division, 1989)

Depth to Form (m)	Shortest Mine Opening Dimension (m)							
	0.9	1.2	1.5	1.8	2.1	2.4	2.7	3.0
1.5	0.8	not applicable						
1.8	0.9	1.1						
2.1	1.0	1.3	1.5					
2.4	1.0	1.4	1.7					
2.7	1.1	1.5	1.8	2.1				
3.0	1.2	1.6	2.0	2.3				
3.4	1.3	1.7	2.1	2.4	2.7			
3.7	1.3	1.9	2.3	2.6	2.9	3.0		
4.0	1.4	2.0	2.4	2.8	3.0	3.3		
4.3	1.5	2.0	2.5	2.9	3.2	3.5	3.7	
4.6	1.6	2.1	2.7	3.1	3.4	3.7	3.9	
4.9	1.6	2.2	2.8	3.2	3.6	3.9	4.1	4.3
5.2	1.7	2.3	2.9	3.4	3.8	4.1	4.3	4.5
5.5	1.7	2.4	3.0	3.5	3.9	4.3	4.5	4.7
5.8	1.8	2.5	3.1	3.7	4.1	4.5	4.8	5.0
6.1	1.8	2.6	3.2	3.8	4.3	4.7	4.9	5.2
6.4	1.9	2.7	3.4	4.0	4.5	4.8	5.2	5.4
6.7	2.0	2.7	3.4	4.1	4.6	5.0	5.4	5.6
7.0	2.0	2.8	3.6	4.2	4.8	5.2	5.6	5.9
7.3	2.0	2.9	3.7	4.4	4.9	5.4	5.8	6.1
7.6	2.1	3.0	3.8	4.5	5.1	5.6	6.0	6.3
7.9	2.1	3.0	3.9	4.6	5.2	5.7	6.2	6.5
8.2	2.2	3.1	4.0	4.7	5.4	5.9	6.3	6.7
8.5	2.2	3.2	4.1	4.8	5.5	6.1	6.6	6.9
8.8	2.3	3.2	4.1	5.0	5.7	6.2	6.7	7.1
9.1	2.3	3.3	4.2	5.1	5.8	6.4	6.9	7.3
9.4	2.4	3.4	4.3	5.2	5.9	6.6	7.1	7.5
9.8	2.4	3.4	4.4	5.3	6.1	6.7	7.3	7.7
10.1	2.5	3.5	4.5	5.4	6.2	6.9	7.5	7.9
10.4	2.5	3.6	4.6	5.5	6.4	7.1	7.7	8.1
10.7	2.5	3.6	4.7	5.6	6.5	7.2	7.8	8.3
11.0	2.6	3.7	4.8	5.8	6.6	7.4	8.0	8.5
11.3	2.6	3.7	4.8	5.9	6.8	7.5	8.2	8.7
11.6	2.7	3.8	4.9	6.0	6.9	7.7	8.4	8.9
11.9	2.7	3.9	5.0	6.1	7.0	7.8	8.5	9.1
12.2	2.7	3.9	5.1	6.2	7.1	8.0	8.7	9.3
12.5	2.8	4.0	5.2	6.3	7.3	8.1	8.8	9.4
12.8	2.8	4.1	5.3	6.4	7.4	8.3	9.0	9.6

REFERENCE: (CMLRD, 1989, P.43)
Note: Original values converted from feet to metres

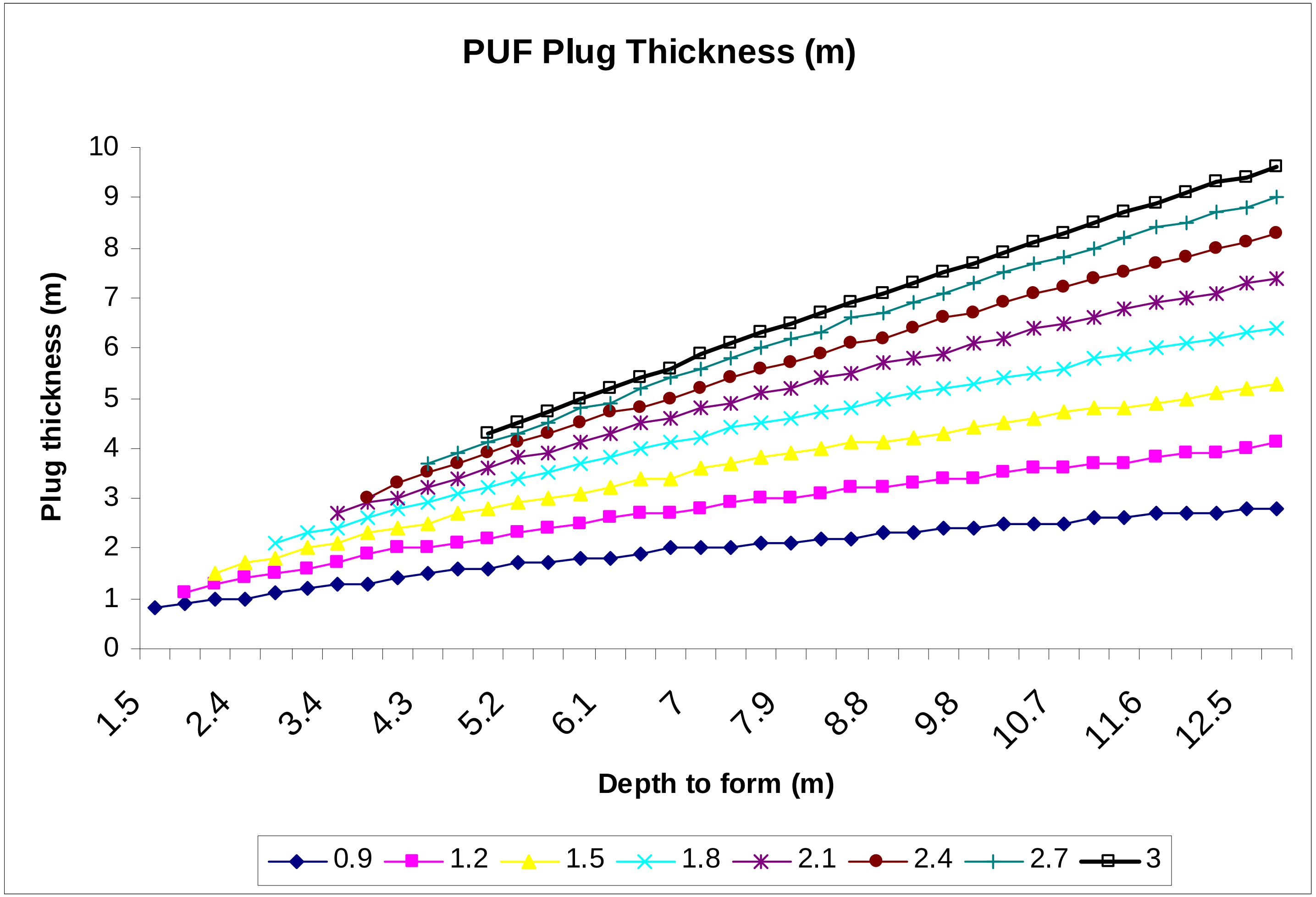

Figure 4.6 Graphical depiction showing variation in Polyurethane Foam plug thickness in relation to shortest mine dimension (Colorado Mined Land Reclamation Division, 1989)

v. Density tests can be taken at any time during application by filling a container. Typical density should be 32.0 kg/m³ ±8%, minimum of 29.63 kg/m³. If the results are not acceptable then corrective action must be initiated.

vi. Tensile strength tests using three samples (0,00163 m³) can be taken.

vii. An access pipe/ ventilation pipe or drainage pipe may be added if needed.

PUF, being inert, does not react to acids or acid mine drainage and is extremely resistant to chemical degradation (Rushworth *et al*, 1989). It is thus environmentally friendly and can be discarded in standard sanitary landfills. PUF however decays when exposed to Ultra Violet light (sunlight) and is flammable at > 398ºC, although a flame retardant can be added.

PUF plugs should not be used within 200ft (60m) of heavy vehicular traffic and no vehicular traffic should be allowed to drive over them.

The use of PUF as an alternative to conventional types of formwork (wood etc.) has been advocated by Dunham (2004), Figure 4.7, where a layer of PUF is inserted across the mine opening before successive layers of concrete are placed.

A procedure in South Africa developed by Parry-Davies (1992), but never implemented, was what he referred to as the "Balloon Technique" for the consolidation of old mine workings. He designed (and patented) this technique for the sealing of dangerous mine workings where man access was not possible. Essentially he recommended that:

i. boreholes be drilled to intercept an open stope (Figure 4.8),

ii. large (2,5m diameter), cubical polyethelene "balloons" be inserted into the stopes through these holes and then inflated.

iii. once these balloons had sealed the open slope, polyurethane foam could then be inserted into them to form a lightweight, stiff barrier. The role of the balloon was to provide a type of formwork onto which the foam could be placed. The expansion of the foam (typically 30 times) would then press against the stope walls to form a stronger barrier for the placing of concrete.

iv. Place successively a few layers of lightweight, fibrous concrete, in lifts of 0,5-1m, which would not load the polyurethane layer excessively. Once these layers had bonded to the stope sidewalls to form a strong plug, conventional concrete could be placed (and/or backfill) to fill the hole.

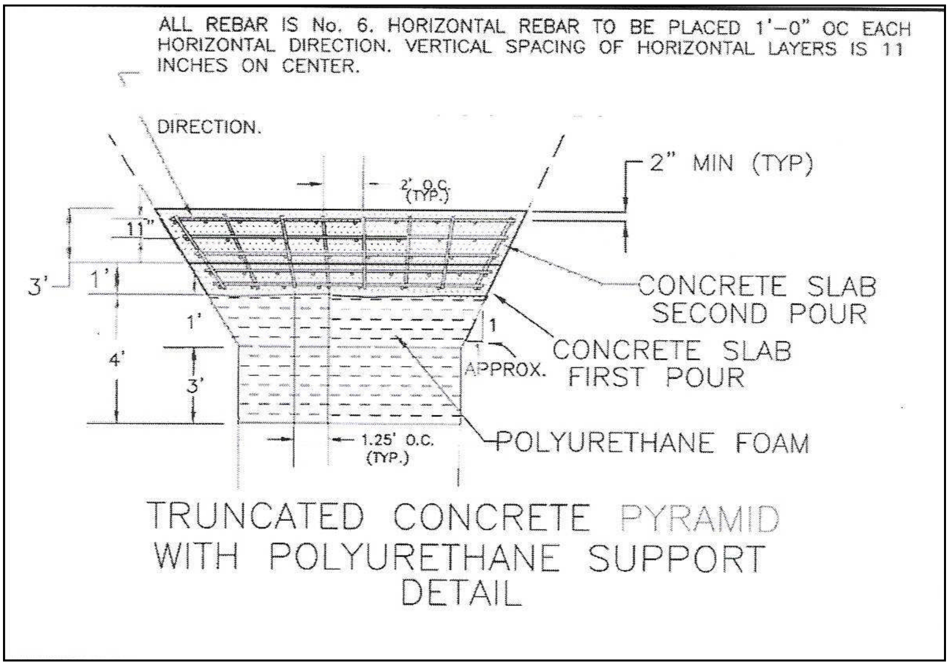

Figure 4.7: Truncated concrete pyramid with polyurethane support (Dunham, 2004)

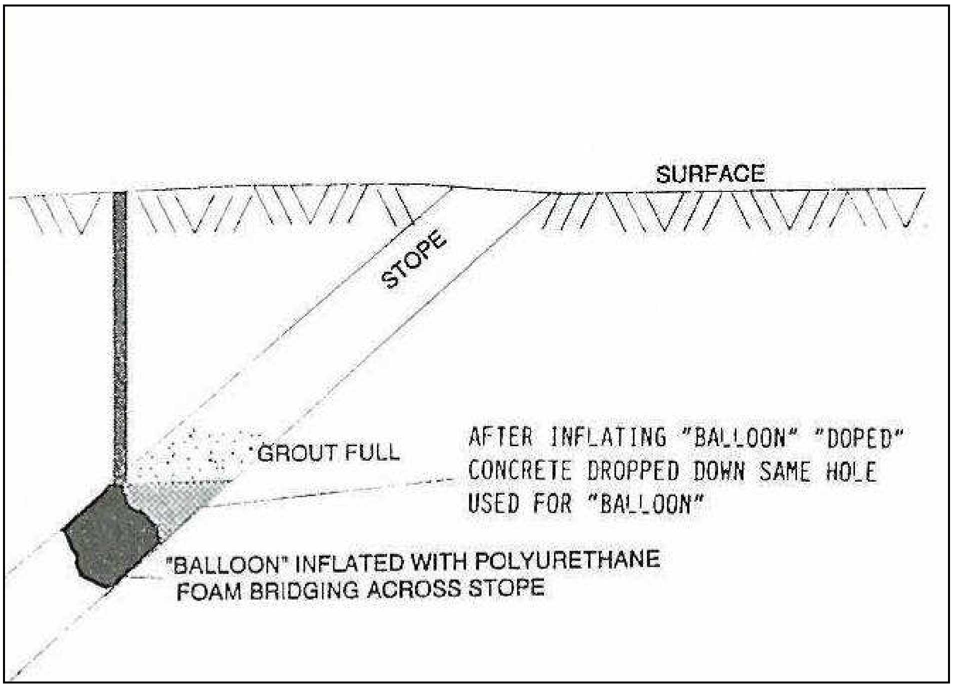

Figure 4.8. "Balloon" technique for consolidating old mine workings (Parry-Davies, 1992)

The Grand Junction office of the U.S Department of Energy reports (1998) that a similar technique has been used in that area where weather balloons are placed down abandoned mine shafts (maximum diameter of 3m) as the temporary formwork before PUF is placed in layers to form the permanent seal.

4.2 Legal requirements

The mining industry in South Africa has over the last 100 years made a significant contribution to the economy, but has also had a huge, often negative, impact on local communities and the environment. As a result of this laws have had to be enacted to ensure that this impact does not result in lasting damage, particularly to the environment. Parties responsible for such damage have had to be identified, standards set and recommendations made regarding prevention and rehabilitation.

Mining in South Africa is now governed by the Minerals and Petroleum Resources Development Act (MPRDA) which became operational on the 1 May 2004. This Act replaces the Mines and Works Act (1911) and the Minerals Act of 1991. In essence the primary purpose of the Act is to provide 'equitable access to and the sustainable development of the nation's mineral and petroleum resources' (Edward Nathan and Friedland, 2005). Section 1 of this Act defines a mining operation as "any operation relating to the act of mining and and matters directly incidental thereto".

Regulation 5.6.1 of this Act states that, "*If in the opinion of the Regional Director the conditions of or the circumstances,…., in undermined ground, and of dangerous slimes dams, waste dumps, ash dumps, shafts, holes, trenches or excavations of whatever nature, made in the course of prospecting or mining operations, whether abandoned or being worked, are dangerous to life or health of persons, property or public traffic, he may order that it be safeguarded to his satisfaction by the owner or manager of the mine or works".* In the more recent version of this Act (Section 46 of the MPRDA, 2004) if the owner (permit holder) cannot be traced, has died or is in liquidation, the liability then rests with the State to make these holes safe.

Prior to the issuing of the above Act, the Department of Minerals and Energy (DME) had already issued guidelines (Dept. Minerals and Energy, 1991) for the treatment and sealing of disused shafts and outcrops in the Gauteng region, namely Regulation 5.6.1 of the Minerals Act (1991). While these are general guidelines applicable for the closing of any shaft they "may with the permission of the Regional Director, be adapted to suit each individual shaft". Essentially these guidelines state that:

- the positions of these shafts have to be surveyed

- competent persons have to be appointed to take charge of the safety and health of the site workers
- if a mining title holder will retain responsibility for the shaft, security fences, steel grills, reinforced slabs or even backfilling (with permission from the Regional Director) may be used to seal the shaft
- if there will be no-one present to retain responsibility for the shaft, then a system consisting of two slabs can be used for near vertical shafts (dip >40°) and any appropriate *ad hoc* design for near horizontal shafts/ adits.

The 1991 DME Guidelines recommends the following method for closing of shafts:

- For near vertical shafts the insertion of lower and upper heavily reinforced slabs, using high strength concrete, are required.
- These slabs have to be attached to the surrounding rock by a hitch which must be excavated at least 1m into the solid rock of the side walls and pinned to the surrounding rock.
- After the lower slab is constructed, granular inorganic fill (such as mine sand, stone, rubble or similar materials) has to be placed to cover the shaft and compacted.
- The upper slab, has to be placed at least 3m above the lower slab and it may not receive any support from the underlying fill.
- The upper slab should be able to support a minimum pressure of 2000kg.m^{-2} from the overlying material.
- This upper slab has to exceed the diameter of the shaft in all directions and should have the name of the shaft inscribed on it.
- Suitable precautions are required to prevent water entering above the lower slab.
- Shafts still being used for ventilation purposes by other mines may be not be sealed.
- Both a plan and section, showing the design and method used have to be signed by an engineer.
- The concrete mixing and placing also have to be supervised by an engineer, with the concrete cubes having to be sent for testing.
- According to these regulations, once the shaft sealing has been completed to

the satisfaction of the DME the land may be used for commercial and light industrial uses providing no foundations are placed on such sealed shafts.

Besides the hazard posed by unsafe shafts the DME has also issued regulations regarding building on shallow undermined land which poses a risk of subsidence and settlement. Essentially these restrictions limit the height of the structure according to the depth of the undermined stope, Figure 4.9. Where undermining is less than 90m below surface no surface structures are allowed. As depth of mining increases successively more storeys are allowed. Where mining is deeper than 240m there are no building restrictions as mining is not believed to have any surface effects. This system was derived from observation of undermined areas by the Government Mining Engineer in the Witwatersrand areas who observed that substantial cracks had developed after mining where undermining was less than 800 feet below surface.

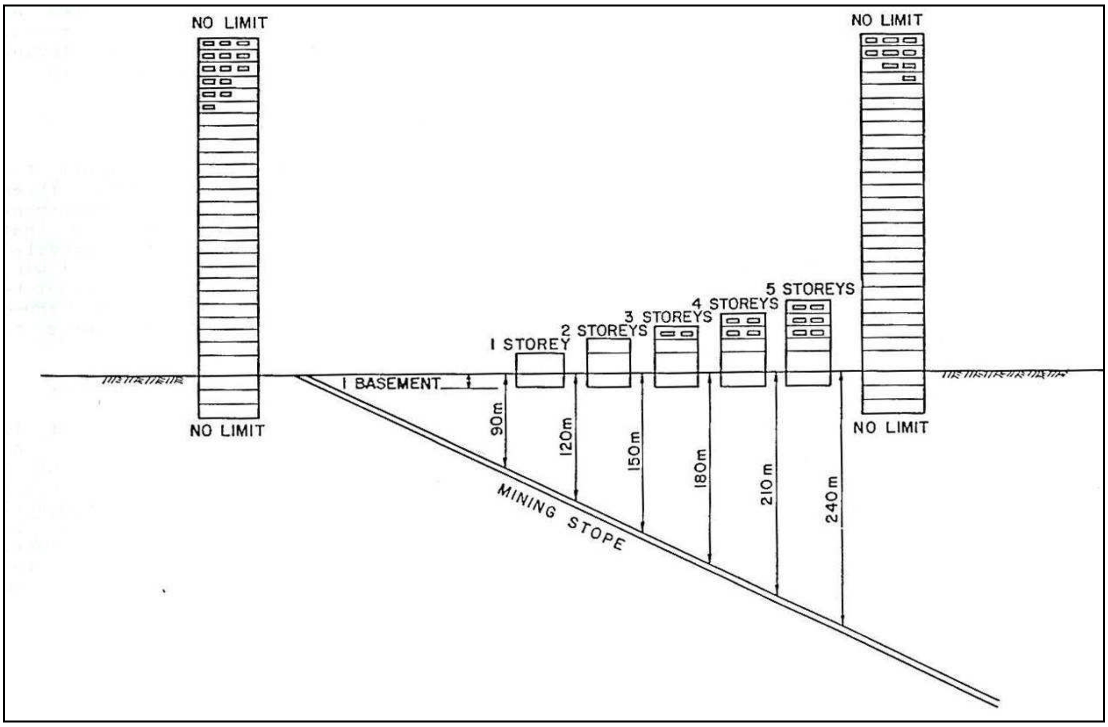

Figure 4.9. Building restrictions on undermined land (Government Mining Engineer, 1965)

4.3 Typical Methods Observed in the Central Witwatersrand Mining Basin

Various methods to close mine openings were observed in the study area. Typical methods used included:

i. Concrete slabs,

ii. steel grates,

iii. perimeter walls and fencing,

iv. corrugated iron sheets and

v. backfilling.

The methods used to seal existing sealed mine openings in the Central Basin are shown in Appendix H.

4.3.1 Seals

Steel gratings consisting of a lattice of steel mesh and/or closely spaced steel bars have been used to seal access to mine shafts in the study area. This steel however appears to be in great demand as scrap and was only rarely found in its original place, Figure 4.10. Similarly, corrugated iron sheets fixed to the top of the shaft have also been used. This system of sealing shafts apprears to have only been suitable for smaller holes unless a shaft frame was still present onto which the iron sheets could be attached. Occasionally these iron sheets were found to be corroded or bent, allowing human access into the shafts.

Concrete seals, where a layer of concrete was placed across the top of the shaft, were also commonly found, (Figure 4.11). No information could generally be found regarding the nature or age of such seals. However, in general, most observed seals seem not to have been tampered with. This can probably be ascribed the effort required to remove the reinforcing from the concrete matrix. There were exceptions however such as at the Kleinfontein Mine (outside the study area), Ekurhuleni, where evidence was seen (Figure 4.12) that the concrete layer covering the shaft was removed by force, the reinforcing bar cut and access to the shaft gained.

Figure 4.10: Mine opening (S & J 8) sealed with a metal grate and barbed wire fencing, Johannesburg

Figure 4.11: Typical shaft sealed with concrete seal (Crown Mine 8 Shaft A, Johannesburg)

Figure 4.12. Access attempt through reinforced concrete seal, Kleinfontein Mine (Ekurhuleni)

4.3.2 Fences and Walls

Brick walls have also been used to create perimeter walls to prevent access to many shafts (Figure 4.13). These are typically 1.8m to 3m high and most are still fully intact. A few have however deteriorated due to cracking etc of the structures and holes have also been found in some of these walls.

Fencing, like corrugated iron, was observed to be one of the least effective measures of preventing human access to unsafe holes. Several holes which were previously fenced are now largely accessible as the materials (wire, poles etc.) have been stolen.

4.3.3 Plugs

Concrete plugs have been the most common method observed for sealing mine shafts, which is what one would expect, as this would be in fulfilment of the Government Mining Engineer's recommended method of sealing shafts. These plugs have largely proven to be durable with most of them still intact. It was observed on occasions, that attempts had been made to remove the reinforcing steel from within the plugs, while elsewhere the steel was commonly removed from the side walls of the shafts. This practice is obviously highly dangerous considering the depths of these shafts. (>100m deep). No attempt was made by the author, by way of a drill etc., to determine the thickness of the plugs used and thus no information is at hand regarding the range of concrete thicknesses used for these plugs.

4.3.4 Backfilling

Backfilling of the mine openings has also been widely used in the study area. This method is probably the historical default method chosen by most persons faced with having to seal a mine opening, particularly if required to do so when the mine or shaft is at the end of its economic life cycle[5]. In its simplest form any hard rock and/ or soil material in the vicinity of the opening is utilized. Stacey (1983) reports finding loose, sandy gravel and ash fill in a backfilled reef outcrop in the Cleveland area, central Johannesburg. In some cases more effort using this method is attempted as in the mined out Main Reefs in the Cleveland area (central Johannesburg) where the archives of the Government Mining Engineer's Department show that waste rock was (hand?) packed into the empty stopes after mining to prevent collapse of the hangingwall (Stacey and Bell, 1999). Control over compaction during backfilling is generally difficult due to access difficulties for men and equipment. Great reliance is then placed on the roughness of the shaft and jamming effect obtained from dumping the material. Thus it is not clear, as no tests are possible, whether the material has collected at the bottom of the hole or somewhere higher in the shaft. A number of mine shafts were observed being sealed in this manner during the period of this study eg. Mine Opening R61, ERPM 1-6. On occasions the mine owner had to add material on a later occasion to these holes, particularly R61, because settlement had already taken place.

Figure 4.13. Access attempts through perimeter wall in Mine Opening Roode 5, Johannesburg

[5] Unofficial discussions, and personal observations, with at least two mine officials on two different active mines during the period of this dissertation, indicate that this is common practice in the Johannesburg area

The inefficacy of this method to cover (seal?) underlying mine voids was illustrated by two collapses that occurred during February 2005 and October 2006 which resulted in severe injuries for one woman and a fatality another. In the first instance a woman inspecting a water pipeline fell 20m through a small collapse (1m diameter), Mine Opening ERPM 57, that had developed in thick fill (approx. 20m) placed over shallow underlying stopes. It is understood that the fill material had been placed in this area some 50 years previously. This is seen in Figure 2.7 which illustrates a typical profile in this area in the former Simmer and Jack Mine property in the vicinity of this collapse. The depth of this vertical hole in the backfill was estimated at 20m before the underlying, steeply dipping stopes were encountered. In the second instance, sudden unexpected collapse in fill material placed in shallow underlying stopes in the Makuse Informal Settlement, Ekurhuleni, resulted in the death of a young woman [6].

Not only does backfilled material get eroded and deposited in the underlying stopes, the mine opening (shaft or subsidence) also frequently acts as a receptacle for surrounding materials which under the influence of gravity, and presumably aided by rainwater, transports the surficial materials into the underlying void. The ability of even a small opening (9-12m^2) to 'swallow' large volumes of surface material is illustrated by Mine Opening ERPM 17 which was on inspection identified as a backfilled stope. The collapse consisted of a 50m long by 20m wide subsidence into an opening approximately 15m below surface, Figure 3.5. The volume of material that had subsided into this void up until present (a 40-50 year period) is estimated at approximately 4500m^3.

On occasion dynamic compaction of the surface fill has also been undertaken to densify this fill material, as undertaken in the Cleveland area and reported by Stacey (1983). This stabilisation work was carried out to allow development of the site, and no deterioration of the surface has been reported to date.

4.3.5 Mine openings considered for sealing

Of the 80 mine openings in the Central Witwatersrand Mining Basin that were considered to be sufficiently dangerous to warrant sealing:

- 20 (25%) were vertical mine openings and 60 (75%) were inclined, Table 4.4.
- Of the vertical openings, 11 (55%) were found with pre-existing concrete linings while the remaining openings were unlined (45%).

[6] Mine opening ERPM 65

- In the inclined mine openings however, only 6 (10%) were lined while the overwhelming majority (90%) were unlined. This is probably a reflection that most of the inclined mine openings were instances where the gold reef outcrop intersected the surface, and access was possible for initial, small scale, informal mining via inclined holes. The larger, formal, high production mines would more than likely have installed concrete linings because of the large volumes of men and materials that would have used these access points.

Table 4.4**.** Table showing split between vertical and inclined mine openings

Vertical mine opening	20	Lined	11
		Unlined	9
Incline mine opening	60	Lined	6
		UnLined	54

4.3.6 Conclusions

Historically, as per the limited requirements of former times, cost effective methods were most commonly used to seal mine shafts when the use of that underground opening had come to an end. The most basic methods such as fences and walls have over time proved to be largely ineffective, with backfilling of shafts appearing to have been the most popular and most convenient method used (Table 4.5). Properly installed concrete plugs or seals were observed to be still fulfilling their function of preventing access to the underground workings. Only approximately 16% of the observed holes in the Central Mining Basin appear to have met the DME 1991 Guideline.

Table 4.5. Observed methods used to seal abandoned mine openings in the Central Mining Basin

Method Used	No. of holes	Percentage
Wall	7	7.5
Backfill	48	51.6
Slab	19	20.4
Fence	4	4.3
Plug[7] [8]	15	16.1
Total	**93**	**100**

[7] Information supplied by John Cruise, 2004, Ground Stabilization and Rhabilitation of Contracts Undertaken by John Cruise Mining (PTY) Ltd,

[8] Nemai, 2001

5 CASE STUDIES OF SELECTED METHODS OF CLOSING MINE OPENINGS IN THE CENTRAL WITWATERSRAND BASIN

5.1 Introduction

As stated in the Introduction to this dissertation, the author on behalf of the Council for Geoscience was requested by the Dept. Minerals and Energy to seal the most dangerous, abandoned mine openings identified in the Central Witwatersrand Mining Basin. While that is an ongoing program some of the methods used in that project to seal a number of those holes are discussed here.

As Polyurethane Foam has been widely used to seal mine openings in the United States it made sense to test its efficacy under South African conditions. In this application however it appears to be largely unknown in South Africa and therefore has not been used by local contractors. Mass concrete on the other hand, being a known quantity, with strength and relative ease of application, has proven to be a popular choice for the construction of plugs. In the abovementioned project, concrete plugs offered a 'permanent' solution to sealing mine openings in this area. They were thus proposed as the preferred method in that project.

The value of both of these methods is discussed below.

5.2 Case Study 1: Polyurethane Foam (PUF) Plugs

The effectiveness of Polyurethane Foam as a potential method to seal mine openings was tested on two abandoned mine openings in the Ekurhuleni area. The first consisted of a shallow abandoned soil lined ventilation hole (ERPM 19A) and the second consisted of a concrete lined mine shaft (ERPM 16A).

5.2.1 PUF Test Hole 1: ERPM 19A

This test was undertaken on the 19/5/2004 at a small abandoned ventilation shaft (Hole 19A) situated in the Balmoral informal settlement, Ekurhuleni, Figure 5.1 and Figure 5.2, as an urgent solution was required to eradicate this communuity hazard. PUF was considered because of its proven relaibaility in the United States where its efficacy, reliability and ease of installation had already been proven.

This shaft is rectangular in shape being 2,6m (long), 1,7m (wide) and 11m (deep),Figure 5.3. It has the following profile consisting of an overlying layer of loose to moderately dense fill (3,2m deep), followed by a 2,4m thick layer of moderately hard, weathered quartzite before slightly weathered, hard rock quartzite is encountered at a depth of 5,6m.

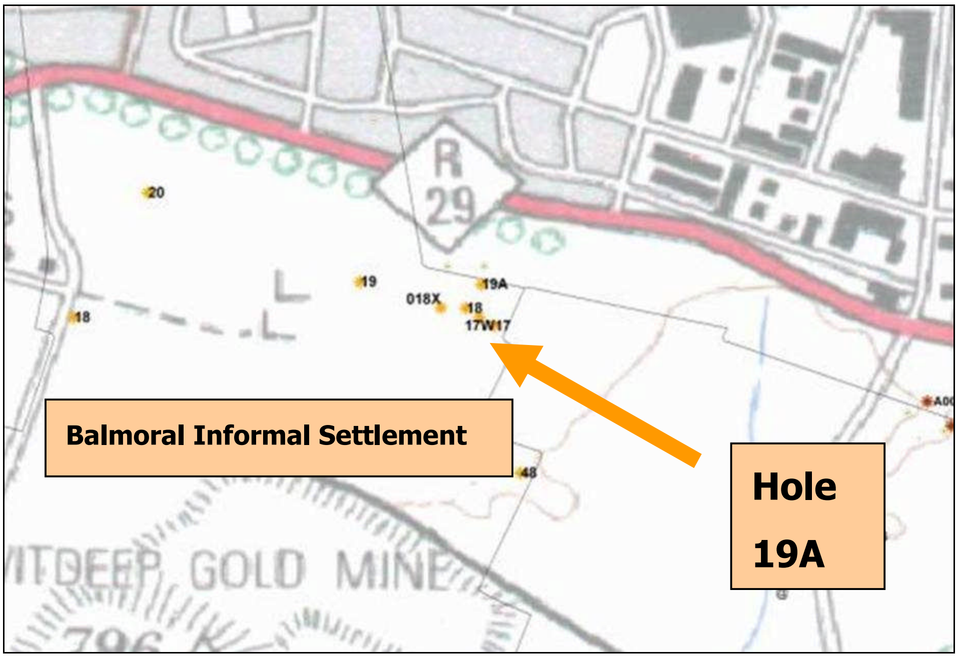

Figure 5.1: Locality plan of Holes sealed with PUF, Ekurhuleni

Figure 5.2 Hole 19A, Ekurhuleni

Methodology

The depth of the base of the plug and hence the required foam thickness, was chosen according to prescribed standards used in the United States (CMRLD, 1989) which was then adapted from imperial to metric units, Table 4.3. While the recommendations of this standard are independent of the nature of the sidewalls it was decided that the relatively hard, moderately weathered quartzite layer (depth 5,6m) would provide suitably good bonding characteristics in which to place the foam plug for this first field trial. Accordingly, with the hole having a shortest dimension (of the opening) of 1,7m and the base of the plug being placed at 5,6m, a vertical height of foam of 3,53m was required. This standard is not recommended for openings having a shortest dimension of larger than 3,5m and where the plug has to be placed at a depth of greater than approximately 14m.

A layer of wire mesh (5mm thick strands), covered by a sheet of thin (20 micron) plastic was lowered by ropes to the appropriate depth to form the base of the plug (Figure 5.4). PUF was then produced on surface using a mechanical mixer with an applicator nozzle system which was supplied by the contractor (McArthur's Packaging). As far as could be ascertained this was the only known portable system available for hire in the Witwatersrand area This system was chosen so that the foam could be mixed consistently, delivered quickly and placed accurately.

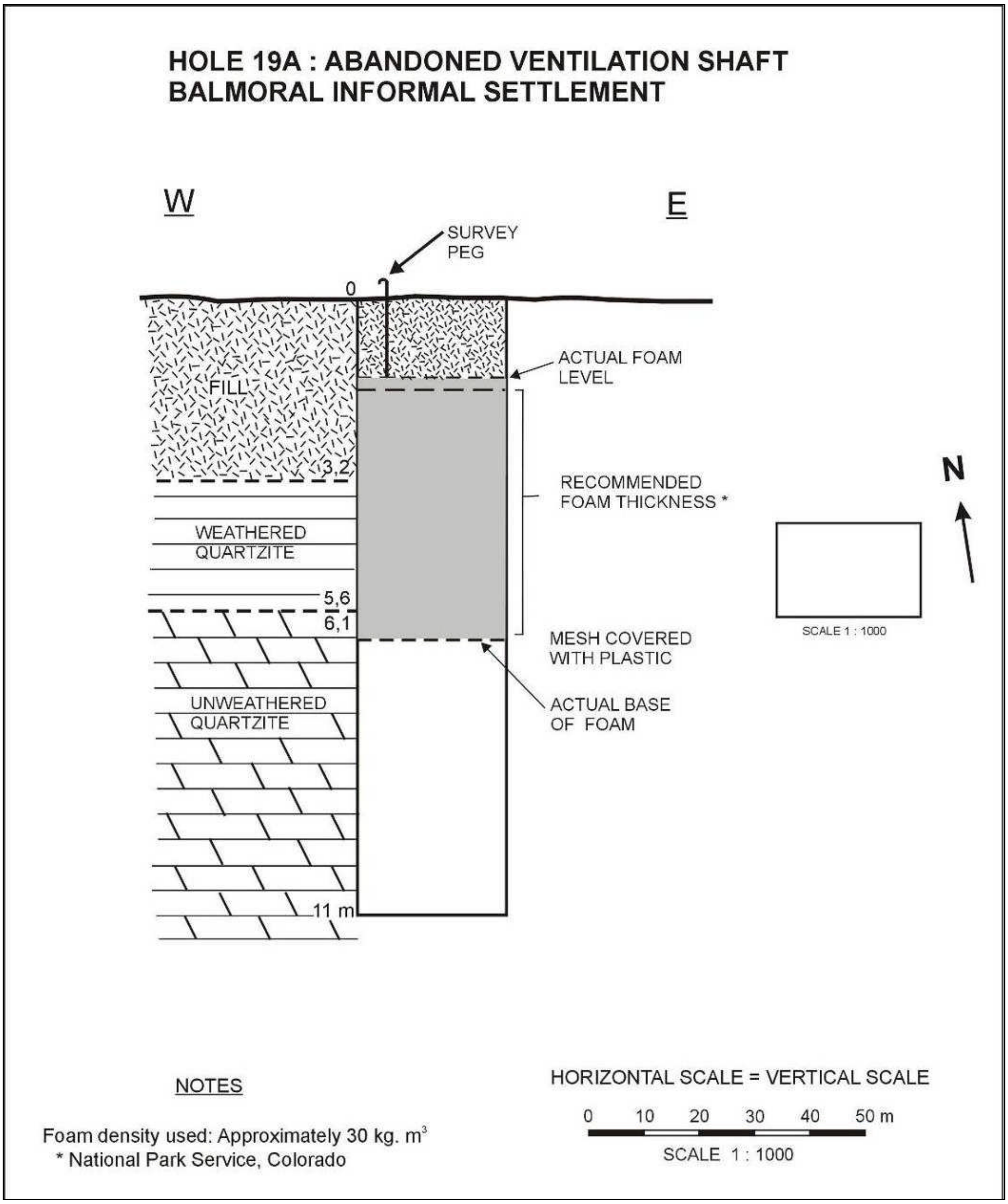

Figure 5.3: Geological cross section of Hole 19A (Council for Geoscience, 2005)

Figure 5.4: Base of plug being lowered into position

The two components (the isocyanate and polyol resin) were mixed at a ratio of 1:1 respectively using an initial mix temperature of 60º C. This resulted in a 'cream time' of 15-20s at which point it was then discharged through the applicator nozzle, at a delivery rate of 3,2kg/min, into the hole, Figure 5.5. 'Cream time' is taken as the reaction time of the two components which results in the mixture changing from a clear liquid to an opaque, creamy or viscous mixture.

The foam mixture was initially sprayed on to the formwork, close to the sidewalls, so that a rigid bond would form and the platform could become self supporting. Approximately 45-50s after mixing, the 'creamy' mixture expanded (30-32 times) and hardened to form a rigid, impermeable foam. The foam was applied in layers with each layer bonding with the sidewall (Figure 5.6) until the required thickness of foam plug was attained. The hole was then backfilled with an overlying protective layer of soil and a survey peg installed. According to the foam manufacturer, who observed this hole being filled with PUF, the foam attains its maximum strength after 24 hours.

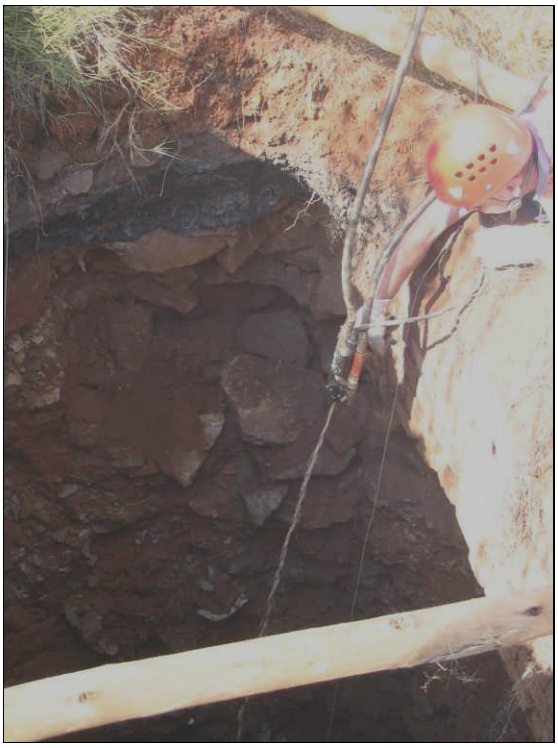

Figure 5.5: Thin stream of foam mixture being delivered from the applicator nozzle

Results

Before the initial foam layer could bond with the sidewalls, the base of the formwork slipped 0,5m to a depth of 6,1m. According to the foam thickness required as stated in the U.S specifications (Table 4.3), the plug thickness required had to be adjusted to 4,7m for a hole of these dimensions. A theoretical volume 20,77 m^3 of PUF was thus required to create a plug of this thickness at this depth. According to the contractor's records however, 800 kg of chemicals (components A and B) were used which should theoretically have generated 26,6 m^3 of rigid foam, at a density of 30 kg/m^3 which indicates that the PUF did not foam to the expected volume.

Once the upper layer of the foam had set reasonably hard in the hole/ shaft it was then backfilled with soil (Figure 5.7) so that it could be protected from potentially damaging sunlight and from curious residents who may have wanted to take samples of the foam. The time taken for this whole process was approximately 6 hours. A survey peg was also installed, so that any settlement could be monitored which to date (3 years) indicates that no noticeable settlement nor deterioration of the foam has taken place.

Figure 5.6: Layers of expanding foam

Figure 5.7: Placing covering material over PUF filled shaft

Analysis

During the process of placing the foam it soon became apparent that:

- the rate of the delivery by this mechanical system was low. As this equipment did not allow for adjustment of the flow rate it was then decided to use a simple manual mixing system whereby equal amounts of each component were decanted into a mixing bucket and the reaction allowed to take place. Buckets of this mixture (approx. 10 l) were then poured into the hole. This resulted in a rapid increase in the rate of foam being placed.

- the expected rate of foam expansion was not being achieved with the mechanical mixer. This, the contractor believed[9] was due to the foam mixture cooling excessively after being discharged from the nozzle but before landing on the plug floor (4-6m below). Thus an incomplete reaction was taking place and hence the foam was not expanding as expected and hence more chemicals were required. The contractor attempted to adjust the temperature of the reaction, to produce a longer 'creaming time', however this seemed to have little effect.

Substantially more chemicals were used during this trial due to:

i. the foam mixture falling between the formwork base and the sidewalls and hence being lost. It was quickly realised that a base with a larger degree of overlap with the sidewalls would probably eliminate any future gaps through which the foam mixture could fall.

ii. the mixture from the mechanical mixer cooling excessively before being placed, hence expanding insufficiently and thus requiring greater volumes of mixture.

iii. the plug being placed at a lower depth than theoretically required. According to the recommended standards for an opening of these dimensions (Table 4.3) the base of the plug could theoretically have been placed at a depth of 2,59m with a plug thickness of 1,95m, the volume required being 8,62 m³. This would have resulted in the entire plug being placed in the moderately loose fill layer. However, this was the first such use of this foam and thus a conservative approach was taken and the plug placed deeper down so that there would be solid wall rock onto which the

[9] C. McArthur, pers.comm.

foam could bind. This obviously resulted in a far greater amount of foam being required, and consequently greater cost. While no specific recommendations are stipulated in the U.S standard it is presumed that selection of the depth to place the plug is based on an evaluation of the wall rock conditions. It is quite likely that further testing would show that the foam is suitable for a range of wall rock conditions.

While a direct comparison with other methods (backfilling with available materials or inserting a concrete plug) to fill this shaft has not been undertaken, the following should be borne in mind when compared with traditional methods:

i. no detailed engineering designs were necessary, which resulted in time and cost savings.

ii. no large volumes of fill materials were necessary, which would have required heavy equipment to transport and place these materials, if available. Backfilling would have required the whole shaft (11m) to be filled, which could be substantial if deep shafts are present.

iii. no person was required to enter the opening which would be necessary if a concrete plug had to be fixed at some depth below surface.

iv. concrete plugs and the bringing in of materials would require substantial site preparations.

v. traditional methods would take days per hole as opposed to hours, which was demonstrated here.

5.2.2 PUF Test Hole 2: Mine Opening S&J 15B

Mine Opening S&J 15B is an abandoned, vertical, rectangular, concrete lined shaft, whose dimensions measure 3,5m long by 1,5m wide. The shaft is estimated at >1000m deep. It is situated on the former Rose Deep Mine property, Ekurhuleni (Figure 5.8).

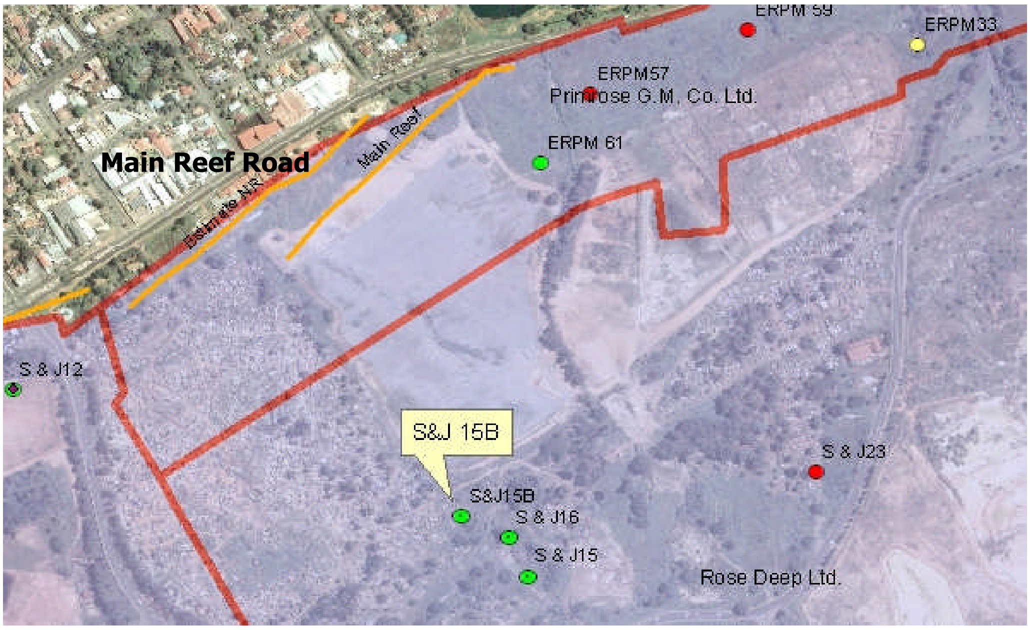

Figure 5.8. Location of S & J 15 B, Ekurhuleni

This site was selected to test whether the Polyurethane Foam could be used as a mine plug, that;

- would be a cost effective alternative to concrete plugs
- forms an effective bond with the concrete lining of the mine shaft
- could be placed by relatively unskilled labour
- could be placed without a formal plug design normally produced by an engineer
- could be placed quicker than that of concrete plugs.

The previous users of this shaft had placed a 2,5m concrete wall around its perimeter and presumably a seal on top of this wall. At the time that the author found the shaft in the field (circa mid 2006) however, no surface seal was present leaving the shaft vulnerable to entry and hence a major hazard. Thus, despite the shaft entrance not being level with the ground surface this shaft was taken as being typical of many such similar shafts which when sealed and covered, tend to be forgotten about. This raises the possibility that someone may unknowingly build on top of such a plug. The load thus chosen to test the plug's capabilities was taken as needing to be able to carry at least the load of a portion of a house.

Methodology

The test was carried out as follows:

1. Wire mesh was mounted onto a light timber frame, covered with thin, standard, plastic sheeting and lowered into the concrete lined shaft. It was suspended 9m below the top of the shaft by nylon ropes tied to the four corners.

2. The PUF was produced on site by mixing the two components, namely the Polyol and the Resin, in standard 20l buckets. This was undertaken at a 1:1 ratio as per the manufacturer's specifications to produce a foam with a density of approximately 30 kg/m³. As the reaction began to take place (after approximately 40s) this mixture was then poured onto the suspended plastic sheet and timber frame. The recommended plug thickness to seal a shaft, Table 4.3, having a minimum dimension of 1,5m, is 4,2m. The actual plug thickness created, for testing purposes, was 2m.

3. The first PUF pours did not expand as expected i.e did not achieve a theoretical 30x expansion. It was then observed that the PUF chemicals being used had significantly exceeded their expiry date, by more than 12 months. According to specifications published by a PUF manufacturer in the United States, PUF chemicals have a limited shelf life (Foamconcepts.com). New chemicals were then purchased, which when mixed produced the expected expansion and a plug 2m thick was achieved.

4. It was initially hoped to use water to load the foam plug but a watertight seal could not be achieved so concrete gravel (19mm) was used instead. A front end loader was used to place the stone in the shaft (Figure 5.10). Care had to be taken when placing the gravel with the front end loader not to drop it from height and cause damage to the foam which is vulnerable too puncturing. A thin layer of gravel was thus initially hand placed before using the front end loader.

5. Measured amounts of gravel were then continually added to induce failure. However even after the loading of a total of 36m³ of gravel i.e a layer 2,8m thick and weighing 80tonnes, it was decided that the test be halted as failure had still not taken place.

6. As the PUF was only being used here on a test basis, the Consulting Engineer felt it prudent to seal this shaft with a 1,5m thick concrete plug which was placed in the upper portion of the shaft.

Figure 5.9. S & J 15B: PUF plug being created in mine shaft

Figure 5.10. S & J 15B: Gravel load being placed on PUF plug

Results and conclusions

The initial intention of this field test of the bearing strength of the PUF was to test various thicknesses of PUF plugs to failure. An initial plug thickness of 2m (Figure 5.11) was thus chosen which was based on the dimensions of the hole. Such a plug thickness is substantially thinner than the Colorado Division of Mines and Geology (2002) recommended PUF plug thickness (5,5m) for a shaft of these dimensions (3,5m x 1,5m). After loading the plug with 57 tonnes of gravel however, failure was not achieved. Therefore it would appear, that even such a PUF plug is able to carry a significant load perhaps equivalent to that of a house.

Plug dimensions: 3,5m (L1) x 1,5m (W1)

Plug area: 5.25m^2

Load Mass: 5,25 x 5,5m x 2000kN/m^3 = 577,50 kN

Overburden Pressure = 577,5/5.25m^2 = 110 kPa

5.3 Case Study 2: Concrete Plugs

While reinforced concrete perimeter walls and concrete seals were considered as acceptable measures to seal mine openings, the former do not eliminate the hazard entirely and the latter are limited by the size of hole that they are able to span. Concrete plugs were thus considered as being the most suitable method that would eliminate the hazard altogether, irrespective of the size of the hole, as well as provide a 'permanent' i.e a 50 year design life, solution.

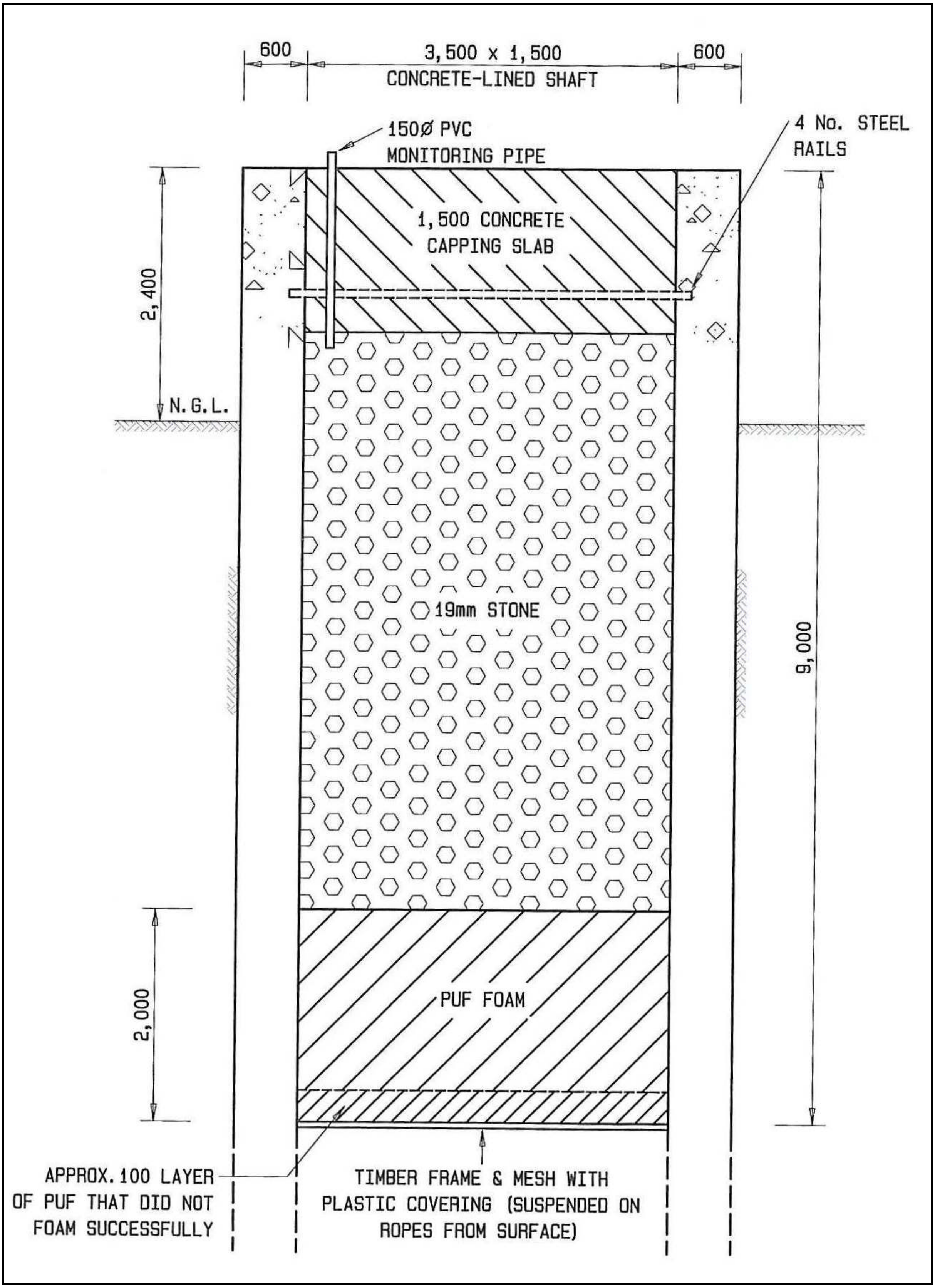

Figure 5.11. Field test: Hole S & J 15B, Ekurhuleni (Council for Geoscience, 2008)

5.3.1 Methodology

A generic plug design, with only three slight variations, was produced by SRK Consulting (Dept. Minerals & Energy, 2007) that could be used in any hole irrespective of its shape (Figures 1-3, Appendix I). The bearing capacity of this plug design was based on the shear strength of the bond between the sidewalls and the concrete plug. There was thus no need to excavate slots in the sidewalls nor attach steel dowels which are susceptible to chemical attack in the long term. The thickness of the concrete plugs was determined as at least 1x the minimum width of the shaft though the contractor frequently used a thickness of 2x the minimum shaft width. SRK Consulting indicate that, in their experience, such designs are capable of bearing 15MPa of water pressure. They assume that unlined shafts would have a lower unconfined compressive strength (in soils) of 1MPa and obviously higher in unlined rock sided tunnels. A typical example using their assumptions indicates that the expected load on the plugs will be well within this limit:

Typical plug dimensions:	5m (L1) x 2m (W1)
Assume Overburden thickness:	10m (H1)
Overburden volume =	$100m^3$
Overburden Mass = 100 m^3 x 1600kg/ m^3 =	160 000kg
Overburden Force = 160 000kg x $10m.s^{-2}$ =	1 600 000 N
Overburden Pressure = 1 600 000N/$10m^2$ =	$160\,000 N.m^{-2} \sim 0{,}2$ MPa

Slight variations in the plug design were produced to allow for the inclination of the shaft i.e. vertical or inclined. Where a concrete lining was present, the lining of the shaft was scabbled to increase the roughness so that a firmer bond between the plug and lining could be produced. The roughness recommended by SRK was to create undulations 20mm deep and a spacing of 200mm. An important factor to be considered was whether the shaft lining had sufficient strength to carry the load imposed by the concrete plug.

Where a lining was absent the base of the plug was set well within competent bedrock, which in most of this basin is quartzite. These sides too were barred to remove any loose blocks and to increase the shear resistance of the sidewalls. For inclined shafts, whose inclination usually varied between 30º and 45º, a single design could be used irrespective of the presence of a lining, with the base of the plug being placed in competent rock.

This general design consisted of a plug of 20MPa concrete that was placed on a sacrificial formwork at depth. This formwork consisited of a wooden platform that was suspended via steel cables from steel girders placed across the top of the opening. A 300mm primary, reinforced (10mm diameter steel at 200mm centres with two layers of Ref.617 mesh), slab was then cast onto the suspended formwork, Figure 5.12 , to provide a safe platform for the workers. Once this had achieved adequate strength (typically 24 hours), a secondary, thicker (600mm), similarly reinforced slab was then cast and allowed to cure for 48 hours. The insertion of these two reinforced slabs allowed for the creation of sufficient bearing capacity to carry the load of the successive layers (up to 3m) as they too in turn were allowed to cure. The wet concrete was delivered to the work surface via a chute. The main plug was then placed in 1m lifts until the design thickness had been achieved. A similar design was used for inclined shafts, Figure 5.13.

Available backfill material was then placed on top of the plug to fill each hole as well as to provide secondary protection for the concrete plug. The top of the backfill was domed to lead water away from the hole. Ingress water, which could erode the contact between the plug and the shaft wall, is probably the single biggest agent that could threaten the integrity of the plug.

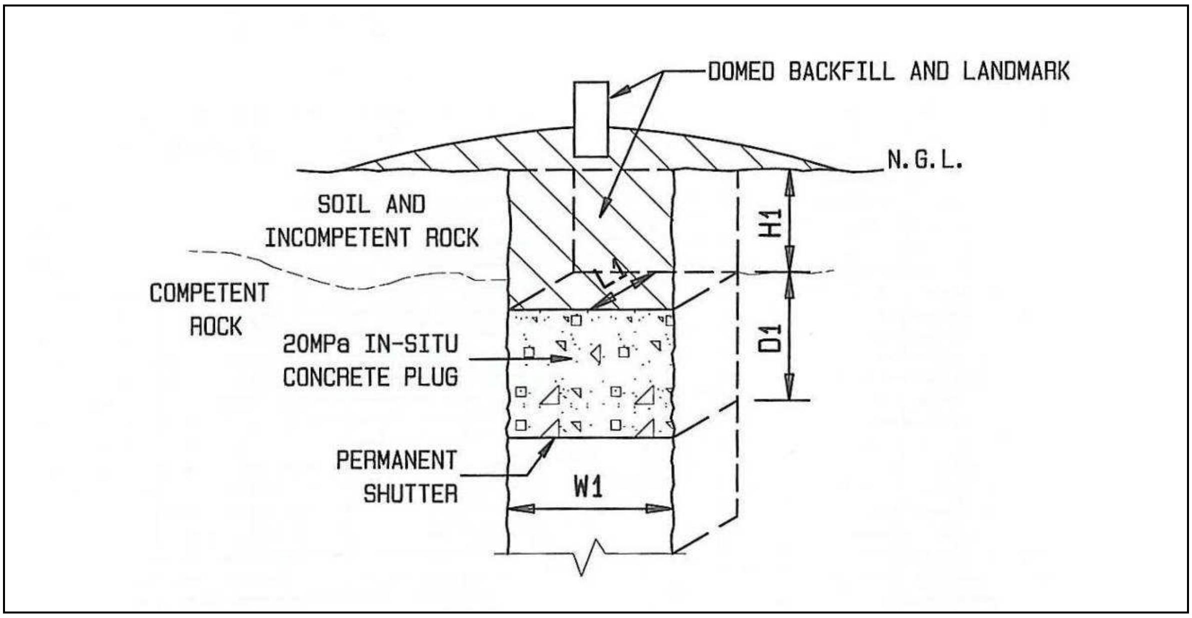

Figure 5.12 Determination of plug thickness for a vertical shaft (Council for Geoscience 2007)

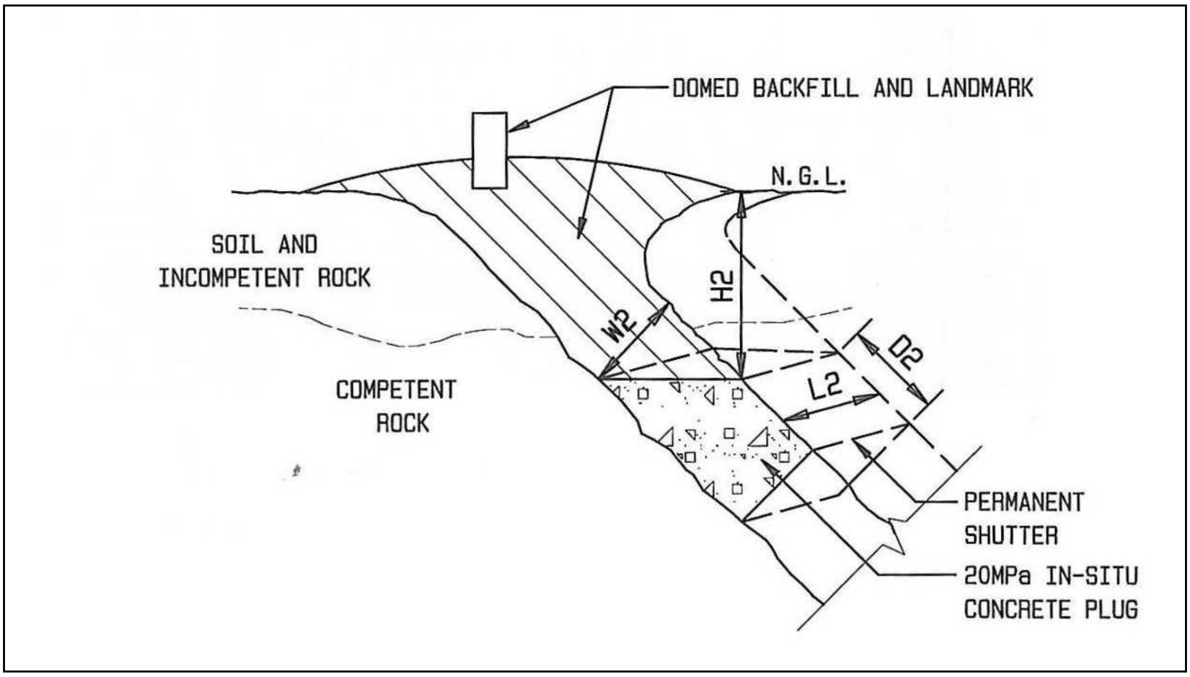

Figure 5.13. Determination of plug thicknesses for an inclined shaft (Council for Geoscience, 2007)

Figure 5.14. Sacrificial formwork, suspended by steel cables from steel girders, prior to the casting of the primary slab

5.3.2 Results

In general the dimensions of the holes, whether vertical or inclined, that were considered for sealing were of a similar size, Table 5.1, with an overall range of the smallest dimension (W1 or W2) being from 4.1m to 3.15m. The average plug size, in both vertical and inclined holes, was therefore also similar i.e 2,9m long. The plug thickness was not affected by; a) the presence of a lining or b) the hole inclination. The only factor affecting plug thickness was the smaller dimension i.e L1 or W1.

The effect of the presence of a lining is reflected in the depth at which the plugs were placed. While the average depth, for both vertical and inclined openings, at which the plugs were placed is largely similar i.e 3.01m compared to 5.59m, the vertical openings (Table 5.2) show that those unlined had to be placed at greater depth, 4.09m compared to 2.72m, in order to find competent rock. In the inclined shafts however this relationship is not so obvious largely because two of the openings S&J 15 and S&J15A, were placed significantly deeper than the average i.e 32 and 33m respectively. The former hole was the largest hole encountered in the project area into which a substantial amount of overburden material had drained. The throat was thus found at considerable depth below surface i.e 32m. The latter hole represents an access shaft to S&J15 and the contractor decided to place the plug at a similar depth.

Table 5.1. Concrete plug dimensions

Vertical mine openings				
Average shortest dimension (L1), m	Average widest dimension (W1), m	Average backfill thickness (H1), m	Average plug thickness (D1), m	Average plug volume, m^3
2.44	4.43	3.01	2.9	53.1
Range of shortest dimension (L1), m	Range of longest dimension (W1), m	Range of backfill thickness (H1), m	Range in plug thickness (D1), m	Range of concrete volume (m^3)
1.4-10.2	1-4.7	0-6.3	1.8-5.2	9-144
Inclined Mine openings				
Average shortest dimension (L2), m	Average widest dimension (W2), m	Average backfill thickness (H2), m	Average plug thickness (D2), m	Average plug volume, m^3
3.15	4.1	5.59	2.9	42.27
Range of shortest dimension (L2), m	Range of longest dimnsion (W2), m	Range of backfill thickness (H2), m	Range in plug thickness (D2), m	Range of concrete volume (m^3)
1.5-12	1.8-9	1.5-33	0.5-6.3	4-110

Table 5.2. Typical depths of concrete plugs

Type of Opening	Total Overburden thickness (m)	No. Openings	Average Overburden (m)
Vertical Lined	29.9	11	2.72
Vertical UnLined	36.8	9	4.09
Inclined Lined	78.5	6	13.08
Inclined Unlined	182.65	54	3.38

The average time taken to close each hole, was typically 12 calendar days. The activities making up this period of time consisted of:

- prepare hole. Loose soils and other materials (tree trunks etc.) were removed from the perimeter of the hole collar. In cases such as ERPM 60, a crane with a grab bucket had to be used to remove waste that had been dumped in the hole and which covered the throat. Initial cleaning of the sides of the hole had to be undertaken to establish the competent bedrock contact. Typical duration 1-2 days.
- install formwork. Two steel girders (such as railway tracks) were placed across the hole with at least four steel cables attached. Workers suitably attached to safety harnesses were then lowered to the level where the first slab could be installed. Scabbling of the concrete or rock sides, depending on the presence of a lining, was then undertaken. The wooden, sacrificial formwork was then lowered to this level.
- install slabs. A grid of rebar steel was then created, a chute lowered to pour the concrete (25MPa) and the first slab, 200mm thick, left to set. After 48 hours, once the first slab had hardened sufficiently, the rebar grid for the second slab was placed. The concrete for this slab, 600mm thick, was then poured and allowed to set. Typical duration 2-4 days. On all the vertical shafts a vertical pipe to surface was installed so that future monitoring of water levels in the shafts could take place.
- install mass concrete plug. Once the second slab had set sufficiently and was able to provide sufficient carrying capacity the mass concrete was poured in 1m lifts with 24 hours curing time between lifts. This process took between 1 and 6 days.
- Backfill remainder of hole. During the DME project the Conractor chose to complete the plug creation process for all the holes requiring closure before backfilling all of the holes together. The time taken for this process therefore could not be included in the collective time taken to close these holes.
- place landmark. Similarly the placing of the landmarks was undertaken long after the creation of the plugs and the backfilling operations.

This methodology was used for the closing of all these holes. Two holes, ERPM 17 and S & J 15/15A require special mention however, largely because of the size of the holes that were closed.

ERPM 17

As stated earlier (Section 4.3.3) and shown in Figure 3.5, ERPM 17 developed into a very large hole by virtue of the overlying materials subsiding into the shallow outcrop of the gold reefs. Locating the throat so that the plug could be inserted proved to be difficult due to a layer of unknown thickness of overlying materials which had fallen from the sidewalls of this large elongate subsidence. This created a safety risk for the labourers who were tasked with finding the throat which was situated somewhere below their feet at the base of this 28m deep hole.

After many futile attempts the Contractor then used a portable soil auger at the base of this hole to drill eight 6m long probe holes. The intention of this approach was to find either an empty stope or a stope filled with backfilled materials. Even after considerable effort these abandoned stopes could not be located and hence the concrete plugs could not be placed.

As the throats of the subsidence were somewhere in the approximately 1700m^2 floor, a change to the plug design was required. Three soilcrete plugs, covering areas of up to 150m^2, each 2m thick, were placed at the base of the subsidence. The soilcrete was produced using a dry mix consisting of cement (3%) and non plastic soils. As this mix was placed it was wetted to a moisture content (optimum) of 15%.

Five layers, each 2m thick, were then placed over the soilcrete consisting of alternating sheets of Grade 5 Bidim and compacted soil. This was undertaken to create a 10m thick impermeable layer that covered the whole base of the subsidence. The top 18m of the subsidence was then backfilled and compacted, using a heavy duty drum roller, before a landmark was placed on top.

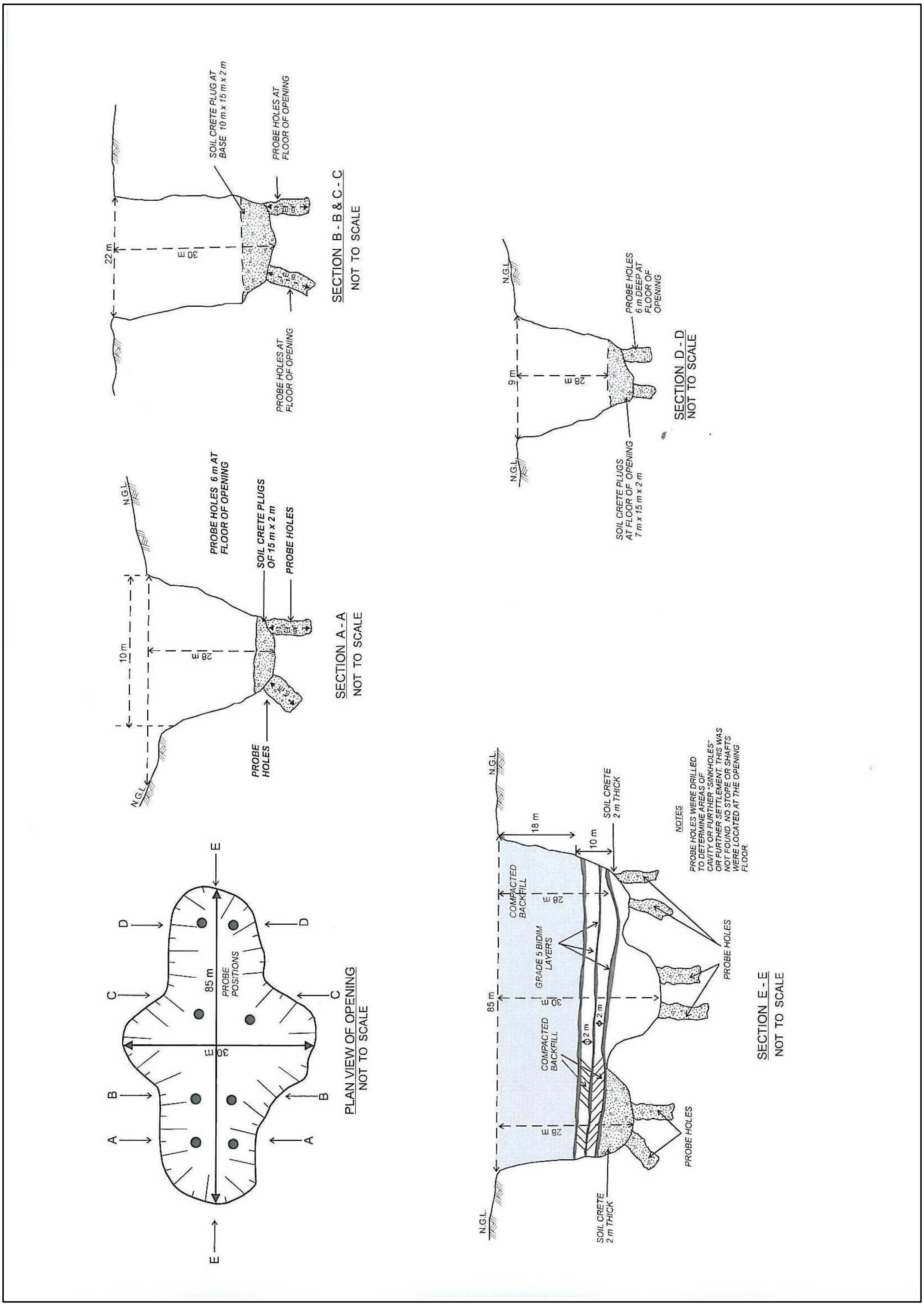

Figure 5.15. Investigation and sealing solution for ERPM 17, Ekurhuleni

S & J 15 and 15A

As described earlier S & J 15 (Section 3.2) was one of the largest holes located in the study area (Figure 3.7) with an estimated volume of 27000m³ and a depth of 30m. During preparation of a sealing solution an adjacent incline hole, S&J 15A, was discovered. It was then realised that S&J 15 was draining into a break in the Armco lining of S&J 15A.

A concrete plug was then placed in competent rock of S & J 15A to seal this shaft, which had a volume of 36 m³, at a depth of 35m below surface, Figure 5.16. S&J15 was then entered from the surface and a further plug of 108 m³ placed at its base. The shaft and hole were then both backfilled to surface.

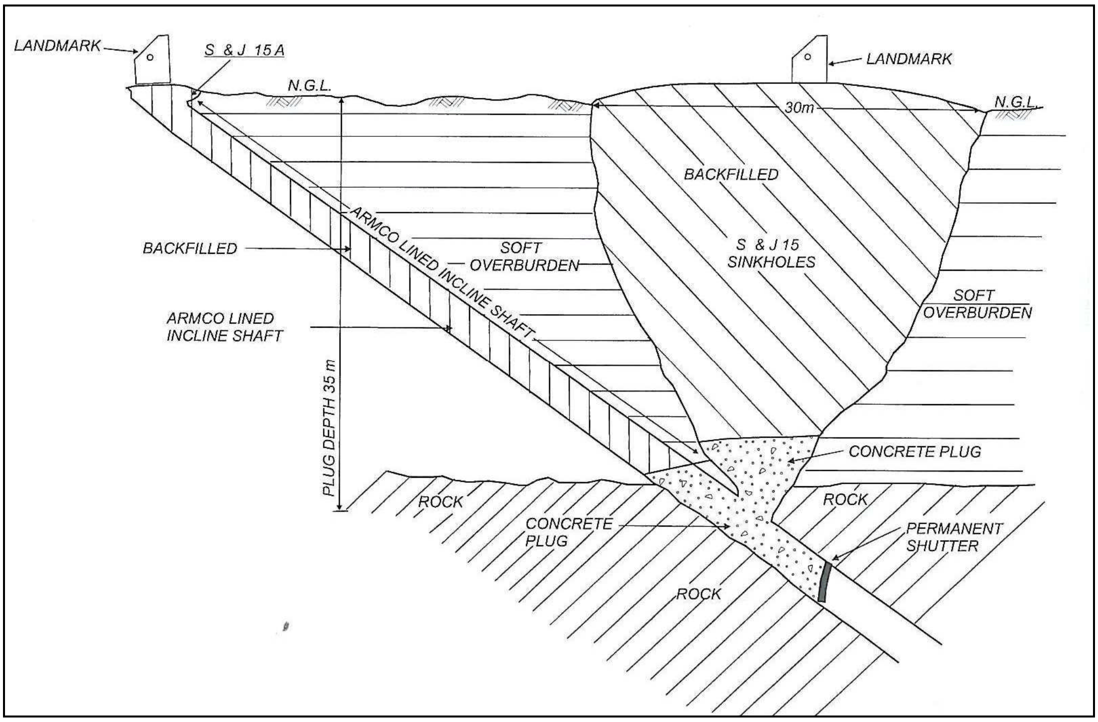

Figure 5.16. Concrete plugs installed in S&J 15 and S&J 15A, Ekurhuleni

5.4 Comparison between PUF and concrete plugs

The casting of concrete plugs is probably the most conventional method of permanently sealing mine openings in South Africa today. Steel grids and fences are generally not considered because of the risk of theft, and walls are easily broken. In order to conform with mining regulations however this method requires that a number of onerous conditions be adhered to. The use of PUF plugs however offers the ability to close these openings in a much simpler manner, with a minimal time of persons entering the mine opening, or even no requirement for entry.

Advantages of PUF:

- No detailed design or engineers needed. This proven technology from the United States has accompanying tables of required foam thicknesses, based on readily available 32kgm^{-3} density PUF, that guide the creation of PUF plugs to the required standard. The recommendations in these tables appear to be conservative, based on the the two tests conducted.
- Cost effective: PUF cost is R1200/m^3 (2007 prices). No cleaning of wall sides is needed so minimal labour is required. Components of foam can be hand mixed. Only additional materials required are rope, plastic sheeting and standard chicken mesh to create the formwork on which to cast the PUF.
- Environmentally friendly; being inert it has no deleterious impact on the environment
- Short and easy installation time with minimal equipment needed. Typically one day needed per hole, though accessibility for transporting chemical components, and cleaning away of vegetation may lead to delays. In many instances labourers would not need to enter the mine opening, which reduces the risk of injury or fatality.
- Ideal for remote locations, as components of the foam can be carried to site by local labour.
- Limited quality control needed.
- The PUF could also be considered as a base for a concrete plug which would avoid the insertion of the two lower concrete slabs in the concrete plug method, and hence speed up construction. A hybrid approach could thus be considered.

Disadvantages of PUF:

- Technology not familiar to local contractors
- If not covered by soil is susceptible to UV deterioration.
- As it is not very hard it is susceptible to being damaged by vandals but this can be overcome by covering it with an overburden layer.
- Based on the U.S specifications the size of the hole is limited to 3,3m

(shortest dimension) for this density of PUF though with a greater density it could be considered for closing larger holes.

Advantages of Concrete Plugs

- Plugs are proven technology which can be designed to whatever design criteria are required.
- Engineer certified
- Has more than adequate hardness which prevents most vandalism.
- Cost effective materials in urban environments where readymix concete is readily available. Can also be produced on site even in remote locations. Typical cost is R650/m^3, 2007 average prices.

Disadvantages of Concrete Plugs

- Needs to be engineer designed and certified
- Needs certified contractors
- Substantial preparation of site needed to ensure that the concrete keys into the sidewalls. This creates a substantial safety risk as labourers are in the hole for a number of days. Compliance with safety regulations requires monitoring.
- Total cost per cubic meter of plug cast includes:
    - Concrete
    - Labour
    - Hole preparation
    - Engineers design
    - Engineer's supervision
    - Use of safety officer
    - Checking engineer's monitoring

5.5 Insertion of landmarks

Once an unsafe mine opening has been sealed and covered with soil, its position is easily and quickly and inevitably forgotten about. This could pose a risk for current and future users of this land. The insertion of an immovable, concrete landmark was thus proposed by the author to permanently mark the position of such openings. Servitudes showing the positions of these landmarks were then created and submitted to the Surveyor General of South Africa for recording on the Title Deeds of these sites.

This landmark consists of a 2,5ton, 30MPa strength concrete block, approximately 1,85mm high and 0,9mm wide which is placed on top of the domed surface of the newly sealed mine opening, Figure 5.17. It thus is sufficiently hard and heavy to ensure that criminal attempts to remove it or deface it will be very difficult. It is hoped that this will ensure longevity. A graphical depiction of a mining headgear is recessed onto the side of the landmark to indicate to all persons, irrespective of their reading capabilities, that some sort of mine hole is beneath this monument. The official hole number is also enscribed as well as reference to the Dept. Minerals and Energy. Thus should any person require further details regarding this hole it can be traced to the Department.

Figure 5.17. Typical landmark placed on sealing of a mine opening

5.6 Summary

The use of concrete plugs as seen in case studies used in this dissertation shows the efficacy of using this method to permanently seal unsafe mine openings. Polyurethane Foam plugs, widely used in the United States, were used for the first time in South Africa and were shown to offer a cost effective, 'low technology' approach to sealing such openings.

6 CONCLUSIONS

1. The legacy of more than 100 years of mining in the Central Witwatersrand Mining Basin is the presence of many unsafe, abandoned mine related openings such as shafts and subsidences.

2. Using available mine plans and knowledge of the manner in which these holes were created a total of 244 openings was located, Table 6.1. The majority of these openings located were shafts (69,6%) and subsidences (24,5%).

3. The majority of these openings were found along the Main Reef/ South Reef/ Main Reef Leader group of reefs (68%).

4. Typically the openings found range in size from 1-72m with an average of 6,22m. Two of the largest holes were found to to be growing in size, with surface material being transported into the mining void below.

5. A literature survey of methods used elsewhere in the world was conducted which revealed that perimeter walls, concrete seals and plugs were often used. A survey of methods used in the study area revealed that most often holes were merely backfilled with available materials. Concrete plugs or seals were also commonly used and occasionally walls and fences were found (which were often in disrepair).

6. In order to assess which holes should be considered for sealing a simple hole risk rating system was developed which considered the depth of the hole and its proximity to settlements or thoroughfares. Of these open unsafe holes 64,2% were considered to pose a high risk and a further 31,7% to pose a moderate risk. This system was used as a guideline for planning the sealing of a number of these holes.

7. During a Department of Minerals and Energy project led by the author it was concluded that concrete plugs were probably the most effective method of sealing such unsafe mine openings as they offered complete sealing of the hole for a design life of at least 50 years.

8. Eighty holes were thus sealed using unreinforced, concrete plugs. The average plug size was 2,9m thick, using a guideline of one to two times the thickness of the minimum dimension of the hole. A total of 3544,5 m^3 of 20MPa concrete was used to seal these holes.

9. Once the plug had been placed and the hole backfilled with soil, a 2,5ton concrete landmark was used to mark the position of the shaft.

10. Polyurethane Foam (PUF) has been used as an alternative method to seal mine openings in the United States for nearly 25 years. After some simple laboratory tests the PUF was used to seal two abandoned mine openings. To date (nearly 3 years) these PUF holes have proved to be as effective as the concrete plugs. Furthermore, sealing of such holes using PUF requires minimal design and engineering supervision and as a result offers a quick, simple cost effective and environmentally friendly method of sealing such openings.

11. The documentation of the mine openings, the openings plugged, the methods of plugging and the locations of the plugged holes in this dissertation represents a valuable record for future reference.

Table 6.1. Summary of mine openings (Council for Geoscience, 2007)

Number of Openings	**244**
All sealed	**173**
Previously sealed	*93*
Sealed by CGS	*80*
Unsealed Openings	**71**
Dangerous	*46*
Less dangerous	*25*

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APPENDIX A:
RAND WATER PIPELINE ACCIDENT

INITIAL REPORT
ON ABANDONED MINE OPENING ACCIDENT
G.HEATH, 18/3/2005

BACKGROUND

A woman, Patricia Nzimande was reported, in the local media, to be seriously injured after falling down an abandoned mine 'shaft' (Figure 1) situated in Ekurhuleni. This incident took place at approximately 10am on the 17/3/05. This woman was undertaking pipeline inspection duties on behalf of Rand Water.

Figure 1: Ekurhuleni, small subsidence into which a woman fell on the 17/3/2005.

SITE REPORT

This hole is situated in the proclaimed mine lands 100m south of Main Reef Road (R29), Ekurhuleni (Figure 2). It is approximately 0,5m x 0,5m wide and 20m deep and is hidden in long grass in this open piece of veld. This hole is a few metres from a well worn footpath.

While the hole is narrow at the surface (0,5m) it widens immediately underground. At a depth of 20m the hole inclination changes from vertical to steeply inclined where, the original stopes are encountered, and continues for at least another 50m.

This area was a former open cast mining operation, overlying mining stopes, that has been backfilled with a variety of materials. It appears that it was formed by the loosening and collapse into the underlying void of these unconsolidated materials. This process appears to have occurred by a process of backwards collapse until the void reached the surface. It is thus by definition a 'subsidence' and not a 'shaft'.

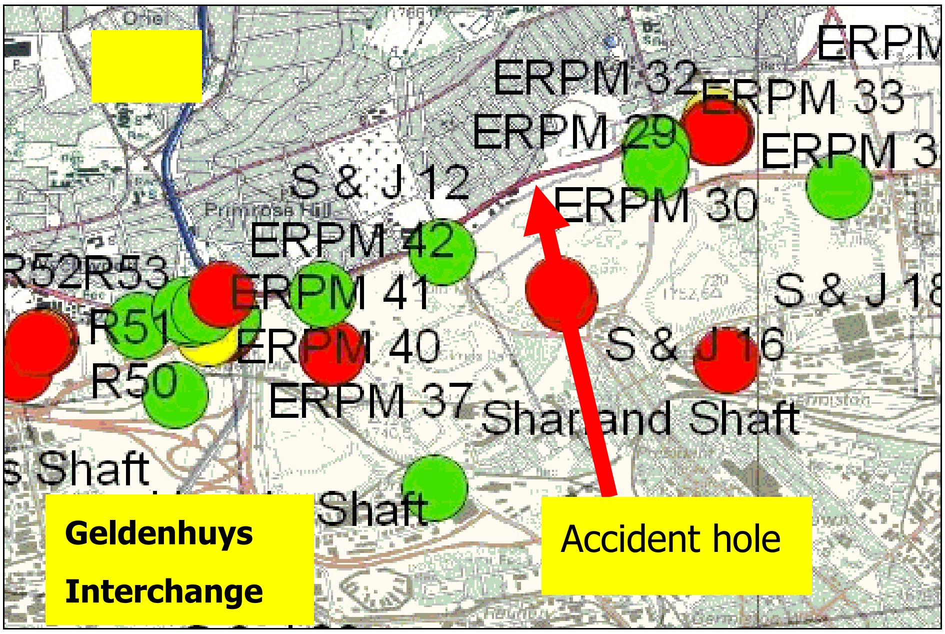


Figure 2: Location of accident hole plus location of other known abandoned mining holesholes.

APPENDIX B:

CENTRAL WITWATERSRAND MINING LANDS STUDY RISK ANALYSIS MAPS

(BARKER, 1993)

See attached CD

APPENDIX C:
MAPS SHOWING UNSAFE MINE OPENINGS

See attached CD

APPENDIX D:
MINE PLANS REVIEWED

No. of Mines	Names of Mines	No. of plans scanned	Names/ Description of plans
1	City Deep	2	i). General Surface Plan, ii). General Underground plan
2	Consolidated Main Reef Mines and Estate Ltd	3	i). General Surface Plan, ii). General Underground plan (Main Reef and Main Reef Leader), iiii). General Underground plan (South Reef)
3	Croesus Gold mining Co. 1959 Ltd	2	i). 2 Surface Plans
4	Crown Gold Mines	1	
5	Durban Roodepoort Deep Ltd	6	i). General Surface Plan, ii). 4 Underground plans of the south reef and iii). Block No.2 of South Leader
6	East Rand Proprietary Mines	6	i). General Surface Plan, ii). Surface plan and iii). 4 Underground plans
7	Herbbard Gold Mining Co. Ltd	1	i). Reclamation Plan (South Reef)
8	Jumpers Gold Mining Co. Ltd	2	i). Plan of Underground Workings and ii). Underground plan
9	Knights Deep Ltd	3	i). Surface plan - Section between West and Glenluce, ii). General Underground plan of Simmer and Jack East Ltd and iii). Underground plan
10	Langlaagte Estate and Gold Mining Co. Ltd	6	i).Two Surface plans ii). Four Underground plans
11	Mayfair Gold Mining Co. Ltd	5	i). Five Underground Plans (Farm Langlaagte No. 224 IQ)

No. of Mines	Names of Mines	No. of plans scanned	Names/ Description of plans
12	New Boksburg Gold Mine	1	
13	Rand Leases Gold Mining Co. Ltd	8	i). Surface Plan (South Reef, Main Reef Leader, Main Reef), ii). Surface plan, iii). Government Surface plan, iv). Underground Plan- Vogelsfontein 231 IQ, v). Undgerground Plan - Rand Leases D3 Hall OR, vi). Underground Plan - RL MA D3, vii). Underground Plan of the Kimberly Reef, viii). Underground Plan of the Main Reef
14	Robinson Deep Ltd	5	i). 2 General Surface Plans (Turfontein Nos. 100&96.IR. Booysen Estate No. 98 .IR. and Klipriversberg No. 106 IR. and Birkenruth No.95 – IR. District of Johannesburg), ii). General Surface Plan, iii). General Surface plan of Turfontein No. 21 and Booysen No. 20 Estate and iv). General surface plan of the Turf Mines
15	Rose Deep Ltd	1	
16	Simmer and Jack	12	i). 7 General Surface Plans (Sheets D3,C3,D4,C4,B6,B4,F3, ii). Simmer Deep Ltd General surface plan and iii). 2 Underground plans of Simmer Deep Ltd
17	South Roodepoort MR	1	
18	Stanhope Gold Mining Co. Ltd	5	i). General surface plan, ii). 2 Surface plans, iii). Surface plan of the South Reef Plan and iv). Surface plan of the Main Reef leader
19	Star Gold Mining Co. Ltd	4	i). 3 Surface Plans and ii). Reclamation plan of the Main Reef Leader and Main Reef

No. of Mines	Names of Mines	No. of plans scanned	Names/ Description of plans
20	Village Main Reef Gold Mining Co. Ltd	4	i). Surface plan- Anti-pollution plan, ii). 2 General surface plans and iii). General Underground plan
21	Wilford Pty Ltd	1	

APPENDIX E:

MINE OPENINGS DERIVED FROM MINE PLANS

Mine	No. of shafts per mine	Shaft Name	Y-Coord	X-Coord
City Deep	1	No.2 Shaft	-26.21070285540	28.09415643040
	2	No. 4 Shaft	-26.23274432960	28.06782308850
	3	No.2 A Incline Shaft	-26.22020648000	28.09997138970
	4	East Shaft (Henry Nourse)	-26.20894892300	28.09929616400
	5	Central Shaft (Henry Nourse)	-26.20933478850	28.09434393620
	6	Henry Nourse West Shaft	-26.20983721750	28.08909814630
	7	No.3 Shaft (Nourse Shaft)	-26.21103285510	28.09228641750
	8	No.2 Shaft (Nourse Decline)	-26.21172764270	28.09612153020
	9	West Incline Shaft	-26.21323335070	28.08855810690
	10	No.4A Incline Shaft	-26.21216421760	28.08250596300
	11	No.2 Shaft	-26.22090683170	28.07065629660
	12	No.1 Shaft (N)	-26.21666907350	28.10103510670
	13	No.3 Shaft (N)	-26.21686590410	28.09688114910
	14	No.3A Incline Shaft	-26.22101043600	28.09104830960
	15	East Incline Shaft	-26.21141009230	28.10199874500
	16	Mo. 1A Incline Shaft	-26.21733996100	28.10745483400
	17	No.4 Incline Shaft	-26.21415185950	28.09936454150
Consolidated Main Reef Mines and Estate Ltd	1	A Shaft	-26.19722190100	27.91529053650
	2	5 Shaft Vertical	-26.19992153550	27.92216753020
	3	Aurora Vertical Shaft	-26.19081254280	27.92463136260
	4	Aurora Shaft Incline	-26.19021956340	27.92510467080
	5	4 Compound Shaft	-26.19874437100	27.93157409340
	6	New Unified Incline	-26.19323997130	27.93375569390
	7	Old West Incline Shaft)	-26.19644181400	27.93943188690
	8	No.2 Incline Shaft	-26.19693703460	27.94052049590
	9	No.3 Vertical Shaft	-26.20751284460	27.94278624010
	10	Central Incline Shaf	-26.19812863200	27.94770776940
	11	East Incline Shaft	-26.20000214380	27.95461544040
	12	Incline Shaft	-26.20404547190	27.92864408370
	13	No.2A Incline Shaft	-26.20559323510	27.93607157650
	14	No.3A Incline Shaft	-26.20769724870	27.94226631800
	15	3BW Incline Shaft	-26.22059152410	27.93773650240
	16	3BE Incline Shaft	-26.22072167740	27.93808868170
	17	3C Incline Shaft	-26.22869892270	27.93405010320

Mine	No. of shafts per mine	Shaft Name	Y-Coord	X-Coord
Croesus Gold ining Co. 1959 Ltd	1	Croesus Shaft	-26.20464811900	27.97058431890
	2	West Shaft	-26.20660150670	27.97382854950
	3	Air Shaft	-26.20736066850	27.97136605660
	4	Central Shaft	-26.20770313320	27.97696678830
	5	Main Shaft	-26.20916444320	27.97474593390
	6	Bird Winze	-26.21223667620	27.96508766580
	7	Est Deep	-26.20886501000	27.96965825870
Crown Gold Mines	1	No.17 Shaft	-26.22382296700	27.96404441390
	2	N0.16 Shaft	-26.23423684530	27.98101599250
	3	Shaft	-26.22789553730	27.99839499720
	4	No.15 Shaft	-26.23082021420	27.99738065840
	5	N0.2 Shaft	-26.21889259780	28.02854774020
	6	No.5 Shaft	-26.22088469730	28.01608605110
	7	No.7 Shaft	-26.21692263280	28.00168981210
	8	No.14 Shaft	-26.23823367050	28.01185394640
Durban Roodepoort Deep Ltd	1	N0.2A Shaft	-26.16657774420	27.86364169760
	2	N0.4 Shaft	-26.17355448880	27.84348097150
	3	No.5 Shaft	-26.18035875760	27.86019217970
	4	Shaft	-26.17666284560	27.86318681610
	5	N0. 8 Shaft	-26.18265211830	27.85410814000
	6	No.6 Shaft	-26.18286598790	27.83502010650
	7	No.3 W. Incline Shaft	-26.18558523570	27.83460044470
	8	No.6A Shaft	-26.18615444610	27.83744549040
	9	2 W. Incline	-26.18117557680	27.84701092200
	10	A. Shaft	-26.16901393240	27.87768015460
	11	Evelyn Shaft	-26.16432447330	27.85810966530
	12	Wilford No.2 Shaft	-26.16452925320	27.85512419030
	13	No.2 Shaft	-26.16441069640	27.86300282660
	14	No.1 Wilford	-26.16502503600	27.84986350310
	15	Princess Shaft	-26.16545615160	27.84784803800
	16	No.3 Shaft	-26.16704050110	27.84397123170
	17	N0.4 Shaft	-26.16756861760	27.84274255240
	18	No.6 Shaft	-26.16602737960	27.84064086420
	19	No.7 Shaft	-26.16685727700	27.83817272780
	20	Shafta	-26.17254692420	27.82642914090
	21	Shaftb	-26.17303192910	27.82569624450
	22	Shaftc	-26.17308581860	27.82337899850
	23	Shaftd	-26.17339837730	27.82455378840
	24	Shafte	-26.17601740420	27.82357300050
	25	Shaftf	-26.17375404760	27.82531901840
	26	Shaftg	-26.17167391520	27.82498490390
	27	Monza Liza Adit	-26.17504739420	27.83510318530
	28	Circular Shaft	-26.17603895990	27.86292630360
	29	Shafth	-26.17055301490	27.86972068420
	30	5 Shaft	-26.18029514800	27.86244453200

Mine	No. of shafts per mine	Shaft Name	Y-Coord	X-Coord
	31	8 Shaft	-26.18191183120	27.85694996460
	32	9 Shaft	-26.18495119570	27.83602900590
	33	Bird Reef Adit	-26.17744978550	27.82373359110
	34	7 Shaft	-26.18612490770	27.87284196070
	35	5A Shaft	-26.18408936610	27.86273424070
East Rand Proprietary Mines	1	West Vertical Shaft	-26.21316556010	28.21841390680
	2	Angelo Shaft	-26.20486539870	28.22964807870
	3	Central Vertical Shaft	-26.22588217940	28.21537180110
	4	Commet Deep Shaft	-26.21679060730	28.22378777870
	5	Hercules Shaft	-26.22204094200	28.23377499620
	6	Cinderella Shaft	-26.22433796340	28.24262528450
	7	South East Shaft	-26.24322758650	28.24304222290
	8	Cinderella East Shaft	-26.22839920750	28.26239269610
	9	Ventilation Shaft	-26.23383887970	28.26914359790
	10	No.2 Shaft	-26.24419776160	28.29158056680
	11	Shaft	-26.20842287270	28.23959058220
	12	Agnes Shaft	-26.20840451580	28.24036157060
	13	Shaft	-26.20905802030	28.24133081320
	14	Shaft	-26.20865233350	28.24053779650
	15	Shaft	-26.20924342470	28.24110685940
	16	Shaft	-26.20966563260	28.23990264890
	17	Shaft	-26.20961203050	28.24193512120
	18	Shaft	-26.20948353250	28.24305489010
	19	Cason Shaft	-26.20975521410	28.24506129560
	20	Shaft	-26.21057760170	28.24573682830
	21	Shaft	-26.21070242840	28.24567441500
	22	Shaft	-26.21233178390	28.25386598320
	23	Shaft	-26.21282374790	28.25357961610
	24	Shaft	-26.21302567350	28.25440200370
	25	No.1 Incline Shaft	-26.21280539110	28.25498575210
	26	Shaft	-26.21361676460	28.25581915380
	27	Blue Sky Incline	-26.21416783770	28.25768678140
	28	Shaft	-26.21291957080	28.25645320000
	29	No.3 Incline	-26.21611807120	28.26127591600
	30	Shaft	-26.21622821240	28.26137137170
	31	Shaft	-26.21623555520	28.26070318180
	32	No.4 Incline Shaft	-26.21777900050	28.26367589280
	33	Shaft	-26.21568081070	28.26193162330
	34	Shaft	-26.21523290310	28.26190225230
	35	Shaft	-26.21795963210	28.26700803120
	36	No.5 Shaft	-26.21890317510	28.26539262690
	37	Shaft	-26.22023808640	28.26756497850
	38	No.1 South Shaft	-26.21301475830	28.25505250340
	39	Blue Sky Main Inclin	-26.21435340840	28.25778751240
	40	South West Ventilati	-26.21451975850	28.18777696730

Mine	No. of shafts per mine	Shaft Name	Y-Coord	X-Coord
Hebbard Gold Mining Co. Ltd	1	Herbbard Shaft	-26.21140442970	27.97979853090
	2	Herbbard Junior Shaft	-26.21048446220	27.98344308630
Jumpers Gold Mining Co. Ltd	1	West Vertical Shaft	-26.20601472970	28.11450489140
	2	East Vertical Shaft	-26.20477321660	28.11912906400
	3	East Incline Shaft	-26.20344874360	28.12080554170
Knights Deep Ltd	The Knights mine plans could not be geo-referenced. The boundaries on the plans do not fit anywhere on the Lease boundary map.			
Langlaagte Estate and Gold Mining Co. Ltd	1	East Shaft	-26.20526004590	27.97497075900
	2	West Deep	-26.20761076770	27.96045661850
	3	West Incline Shaft	-26.20382634940	27.96721266340
	4	Old Incline	-26.20518420830	27.97171264240
	5	East Deep	-26.20999206050	27.96826785860
	6	Star Shaft	-26.20437491260	27.96207263770
Mayfair Gold Mining Co. Ltd	1	Estate Shaft	-26.21285013800	28.00653402430
	2	Vernon Shaft	-26.21383127420	28.00905929770
	3	Marcus Shaft	-26.21420638870	28.00171482370
	4	Robinson Shaft	-26.21427991910	28.00660711560
	5	New Main Shaft	-26.21506768150	28.00676317550
	6	Shaft	-26.21327898900	28.00314412800
	7	Shaft	-26.21328436660	28.00346239370
	8	Shaft	-26.21327887930	28.00356665310
	9	Shaft	-26.21296752760	27.99779726490
	10	Shaft	-26.21260536330	27.99737693470
New Boksburg Gold Mine	1	Shaft	-26.22387729530	28.27476691170
	2	Shaft	-26.22446554210	28.27556104490
	3	Shaft	-26.22225961640	28.27263451680
	4	Ventilation Shaft	-26.23306658050	28.28910753060
	5	No.2 Shaft	-26.23110225450	28.30023535380
Rand Leases Gold Mining Co. Ltd	1	No 6 Shaft	-26.18390453960	27.91100168750
	2	No 7 Shaft	-26.18584318720	27.91736882520
	3	No 1 Shaft	-26.17556202510	27.88107283380
	4	No 2 Shaft	-26.17813246390	27.88441020690
	5	No 3 Shaft	-26.17980257890	27.88813522250
	6	No 5 Shaft	-26.18292400170	27.90452430970
	7	No 9 Shaft	-26.18532921480	27.89076996300
	8	No 10 Shaft	-26.18541751570	27.89636628180
	9	KR.2 Shaft	-26.20027464340	27.89754362800
	10	Aurora West Shaft	-26.17872402400	27.92438846290
	11	Rast Shaft	-26.19164745160	27.95414390370
	12	RL 11 Shaft	-26.18994028010	27.89830256580

Mine	No. of shafts per mine	Shaft Name	Y-Coord	X-Coord
Robinson Deep Ltd	1	No.1 Shaft	-26.22115031060	28.03798586490
	2	Chris Shaft	-26.22942416380	28.03278869870
	3	Turf Shaft	-26.22765340870	28.05071095380
Rose Deep Ltd	1	No.5 Shaft	-26.20362506190	28.15605690550
	2	No.4 Shaft	-26.20366436080	28.15647322790
	3	No.3 Shaft	-26.19886281490	28.15833983690
	4	No.1 Shaft Rose Deep	-26.19659419170	28.17144988790
	5	Hammond Shaft	-26.20407398800	28.16515003400
Simmer and Jack	1	North vertical Shaft	-26.20628162020	28.13782695070
	2	No.1 Shaft	-26.20784277160	28.13938810210
	3	No.3 Shaft	-26.20590991750	28.14615309160
	4	No.2 Shaft	-26.21037035010	28.13708354520
	5	Rhodes Shaft	-26.21572286920	28.14001999670
	6	Catlin Shaft	-26.22074085590	28.12162071220
	7	Milner Shaft	-26.21416171780	28.14778858350
	8	Rudd Shaft	-26.21367850430	28.15403318920
	9	South Deep Shat	-26.22850944270	28.18770573850
	10	West Sub-Vert Shaft	-26.23594349710	28.16841808440
	11	Milner Shaft	-26.21393766810	28.14190958210
	12	Howard Shaft	-26.21920344490	28.13011563180
	13	South Deep Shaft	-26.22812129270	28.14194818750
	14	Incline Shaft	-26.20035615830	28.14833394130
South Roodepoort MR	1	Ventilation Shaft	-26.21718967080	27.75777993440
	2	No.2 Shaft	-26.21831671400	27.76898274290
	3	No.1 Shaft	-26.21793351930	27.77682696290
Stanhope Gold Mining Co. Ltd	1	No 6 Shaft	-26.20530514640	28.12612851550
	2	No 5 Shaft	-26.20515439140	28.12906823830
	3	Diagonal Shaft	-26.20476114070	28.13296381280
	4	Geldenhuis Shaft	-26.20848190280	28.13126647860
	5	West Shaft	-26.20912768580	28.12459691420
	6	Main Shaft	-26.20732880920	28.12713299390
	7	East Shaft	-26.20748585920	28.13207329250
	8	Vertical Shaft	-26.20601035440	28.12261467840
Star Gold Mining Co. Ltd	These plans could not be geo-referenced because the boundaries on the plans do not fit to the Lease boundaries.			

Mine	No. of shafts per mine	Shaft Name	Y-Coord	X-Coord
Village Main Reef Gold Mining Co. Ltd	1	N0.4 B. Incline Shaft	-26.21203107900	28.08310106590
	2	No.1 Shaft	-26.21475345770	28.05242858630
	3	Worcester no.2	-26.20984241510	28.03262654260
	4	Mynpacht Shaft	-26.21014944330	28.06835659060
	5	West Shaft	-26.21013927550	28.07078635850
	6	No.3 Shaft	-26.20966138840	28.08288910380
	7	No.4 Shaft	-26.21175900780	28.08285182180
	8	No.2 Vertical	-26.21241991550	28.05243583240
	9	Ferreira East	-26.21372749600	28.04009414350
	10	Wolhuter East	-26.21350380410	28.07605599590
	11	No.2 Shaft Chris	-26.21835012170	28.03273230950
	12	No.1 Shaft Turf	-26.21926827500	28.05225586210
	13	No.2 Shaft Turf	-26.21923777160	28.04674389180
	14	No.1 Shaft Chris	-26.22031555960	28.03658489310
	15	Charlton Incline	-26.20999989800	28.06332621600
	16	Ferreira Shaft	-26.21346780140	28.04030159240
Wilford Pty Ltd	1	No.5 Incline	-26.16526388450	27.84824208830
	2	Incline Shaft	-26.16774101210	27.83722188760
	3	N0.7 Incline	-26.16743670550	27.83854141270
	4	Wilford No.1 Shaft	-26.16570312920	27.84993898900
	5	Shaft	-26.16580996020	27.84790272480
	6	Shaft	-26.16481287060	27.85502544120
	7	Evel.. Shaft	-26.16481287060	27.85876485110
	8	No.4 Vertical shaft	-26.16877727310	27.83290785620
	9	Shaft	-26.17088411060	27.83780557350
	10	Pars Shaft	-26.19781991290	28.20579573120

APPENDIX F:
TOTAL LIST OF MINE OPENINGS

No.of holes	CGS Hole Name	Original Shaft Name	Area	Municipality	Latitude	Longitude	Date logged	Length (m)	Width (m)	Depth (m)	Area (m²)	Hole Type	Incline	Safety Report	Hazard	Proximity	Priority Rating	Risk
1	A006		ERPM	Ekhurleni	-26.20146	28.2146		10	9	30	90	Shaft		Old shaft closed by municipality (according to old mineworkers) + big sinkhole closed	1	5	6	Low
2	Wilford No.1 Shaft	No. 1 Wilford	DRD	Johannesburg	-26.16582	27.85073	7/7/2006	5	5	100	25	Shaft		Shaft closed	0	5	5	Low
3	A002	No original opening name	ERPM	Ekhurleni	-26.20015	28.22045		1.5	1.5	0.5	2.25	Subsidence		Shaft backfilled. Method of closure unknown.	1	5	6	Low
4	A004	No original opening name	ERPM	Ekhurleni	-26.19998	28.22118		10	6	30	60	Subsidence		Big sinkhole closed. Shack on top of it; identified by local people. Probably closed by Chestnut Projects	1	5	6	Low
5	A010	No original opening name	ERPM	Ekhurleni	-26.19434	28.2183		3	2	2	6	Subsidence		Disturbed land with holes. Mine related ruins on hill.	1	5	6	Low
6	Angelo Deep Shaft	Angelo Deep Shaft	ERPM	Ekurhuleni	-26.21819	28.22573	14/6/2006	6	3	100	18	Shaft		Shaft closed on 13/6/7 according to scrab metal collector in the area. Method of closure unknown	0	5	5	Low

No.of holes	CGS Hole Name	Original Shaft Name	Area	Municipality	Latitude	Longitude	Date logged	Length (m)	Width (m)	Depth (m)	Area (m²)	Hole Type	Incline	Safety Report	Hazard	Proximity	Priority Rating	Risk
7	Angelo Ventilation Shaft	Angelo Ventilation shaft	ERPM	Ekurhuleni	-26.21419	28.21943	14/6/2006	5	2	100	10	Shaft	Ventilation	Shaft closed on 13/6/7 according to scrab metal collector in the area. Method of closure unknown	0	5	5	Low
8	B54 Shaft	Cinderella West Saft	ERPM	Ekhurleni	-26.22465	28.24666		11.5	5.8	100	66.7	Shaft		Shaft enclosed in a wall. Steel grate on top of the wall	5	5	10	High
9	Balmoral Hole no.1		ERPM	Ekhurleni	-26.19964	28.20828	20/3/2006	8	8	0	64	Subsidence	Hole	Shaft closed by CGS. Shaft plugged and backfilled	0	5	5	Low
10	Balmoral no.2 Verical Shaft		ERPM	Ekhurleni	-26.19975	28.20801	20/3/2006	2	2	0	4	shaft	vertical	Shaft closed by CGS. Shaft plugged and backfilled	0	5	5	Low
11	Balmoral Verical Shaft		ERPM	Ekhurleni	-26.19987	28.20528	20/3/2006	8	3	0	24	shaft	vertical	Shaft closed by CGS. Shaft plugged and backfilled	0	5	5	Low
12	Benrose Shaft	Worhuter Shaft	City Deep	Johannesburg	-26.21313	28.07632	######	2	2	100	4	shaft		Shaft enclosed in a wall. Shaft completely inaccessible	0	5	5	Low
13	Chris Shaft	Chris Shaft	Village Main	Johannesburg	-26.22045	28.03654	1/8/2006	0	0	100	0	shaft	vertical	Shaft closed	0	5	5	Low
14	City Deep no.1 Shaft	City Deep No.3 Vertical	City Deep	Johannesburg	-26.21909	28.07692		13	8	100	104	shaft		Shaft enclosed in a large brick structure.	5	5	10	High
15	City Deep no.2 Shaft	City Deep No.4 Shaft	City Deep	Johannesburg	-26.23366	28.07122		14	9	100	126	shaft		Shaft closed. Closure method unknown. Headgear has not been removed	0	5	5	Low
16	City Deep no.3 Shaft	City Deep No.2 Shaft	City Deep	Johannesburg	-26.22225	28.06918		15	10	100	150	shaft		Shaft lie open in factories' area. A lot of human traffic in the area.	5	5	10	High
17	City Deep no.4 Shaft	City Deep No.5 Shaft	City Deep	Johannesburg	-26.2285	28.10435		16	11	100	176	shaft		shaft sealed with a concrete slab	0	5	5	Low

No.of holes	CGS Hole Name	Original Shaft Name	Area	Municipality	Latitude	Longitude	Date logged	Length (m)	Width (m)	Depth (m)	Area (m^2)	Hole Type	Incline	Safety Report	Hazard	Proximity	Priority Rating	Risk
18	City Deep no.5 Shaft	Worcester N0.1 Shaft	City Deep	Johannesburg	-26.21315	28.05231	27/9/2006	8	6	100	48	shaft	vertical	Shaft closed. Closure method unknown. Headgear has not been removed.	0	5	5	Low
19	Clement Shaft	Clement Shaft	Simmer and Jack	Ekhurleni	-26.21111	28.15917	22/11/2005	5	4	100	20	shaft		Shaft closed. Closure method unknown.	0	5	5	Low
20	CMR - R 67B		CMR	Johannesburg	-26.1897	27.925	2/8/2006	5	4	100	20	shaft	Incline	Shaft had been backfilled. Shaft opening again	5	5	10	High
21	CMR - R67	Aurora Vertical	Consolidated Main Reef	Johannesburg	-26.18814	27.9229	25/10/2005	5	2	100	10	shaft	vertical	Shaft enclosed in a concrete wall	5	5	10	High
22	CMR Central Shaft	CMR Central shaft	CMR	Johannesburg	-26.19784	27.94419	2/8/2006	4	4	100	16	shaft	Incline	Shaft had been closed, but is re-opening. Shaft by a busy dirt road.	5	5	10	High
23	CMR East Shaft	East Incline Shaft	Consolidated Main Reef	Johannesburg	-26.19975	27.95457	25/10/2005	4	2	100	8	shaft	Incline	No safety measures. Shaft behind shopping mall	5	5	10	High
24	CMR no.10 Shaft	CMR No.10 shaft	Consolidated Main Reef	Johannesburg	-26.20623	27.94393	25/10/2005	5	4.5	100	22.5	shaft		Shaft backfilled by Iprop.	0	5	5	Low
25	CMR no.2 Shaft	CMR No. 2 shaft	Consolidated Main Reef	Johannesburg	-26.19663	27.94033	2/8/2006	5	4	100	20	shaft	Incline	Shaft sealed with a concrete slab	0	5	5	Low
26	CMR no.4 Shaft	No.4 Compound Shaft	Consolidated Main Reef	Johannesburg	-26.1983	27.93119	25/10/2005	6	4	100	24	shaft		Shaft backfilled by Iprop.	0	5	5	Low
27	CMR no.8 Shaft	CMR No. 8 shaft	Consolidated Main Reef	Johannesburg	-26.19819	27.9215	25/10/2005	5	5	100	25	shaft		Shaft backfilled by Iprop.	0	5	5	Low

No.of holes	CGS Hole Name	Original Shaft Name	Area	Municipality	Latitude	Longitude	Date logged	Length (m)	Width (m)	Depth (m)	Area (m²)	Hole Type	Incline	Safety Report	Hazard	Proximity	Priority Rating	Risk
28	CMR Old West Shaft	Old West Shaft	CMR	Johannesburg	-26.19574	27.93787	2/8/2006	3	3	100	9	shaft	vertical	Shaft enclosed in a wall structure appears to have been pluged at 10m below surface	5	5	10	High
29	CMR Old West Shaft B		CMR	Johannesburg	-26.19654	27.93844	2/8/2006	4	4	100	16	shaft	vertical	Shaft enclosed in a concrete wall.	5	5	10	High
30	CMR- R66	Randleases No.7 Incline	DRD	Johannesburg	-26.18621	27.9169	5/9/2005	8	8	100	64	shaft	Incline	No safety measures.	5	5	10	High
31	Crown Mine 12 Ventilation	Crown Mine 12 Ventilation	Crown Gold Mines	Johannesburg	-26.21938	27.98324	######	7	6	100	42	shaft	Ventilation	Shaft enclosed in a large brick structure.	0	5	5	Low
32	Crown Mine no.1 Shaft	Crown Mine No. 6 shaft	Crown Gold Mines	Johannesburg	-26.21828	28.00522	23/11/2004	10	3	100	30	shaft	vertical	Shaft enclosed in a brick wall. Wall is no longer intact.	5	5	10	High
33	Crown Mine no.10 Shaft	Crown Mine No. 18 West shaft	Crown Gold Mines	Johannesburg	-26.21952	27.95508	######	5	3.5	100	1750	shaft		Shaft sealed with a concrete slab.	0	5	5	Low
34	Crown Mine no.11 Shaft	Crown Mine No.16 Ventilation shaft	Crown Gold Mines	Johannesburg	-26.23772	27.98187	######	4.8	2.6	100	12.48	shaft	Ventilation	Shaft sealed with a slab.	0	5	5	Low
35	Crown Mine no.12		Crown Gold Mines	Johannesburg	-26.134638	27.581388	30/11/2004	5	3.5	100	17.5	shaft	Incline	No safety measures. Water in shaft	5	5	10	High
36	Crown Mine no.12 Incline Shaft	Crown Mine 12 Incline	Crown Gold Mines	Johannesburg	-26.21934	27.98571		7	4	3	28	shaft	Incline	Shaft backfilled. Shaft not completely closed though. Drums in shaft.	3	5	8	Low
37	Crown Mine no.13 Shaft	Crown Mine No. 8 shaft	Crown Gold Mines	Johannesburg	-26.21525	27.99817	######	5	5	100	25	shaft	vertical	Shaft enclosed in a wall. Wall no longer intact	5	5	10	High
38	Crown Mine no.14 Shaft	Crown Mine No. 10 Incline shaft	Crown Gold Mines	Johannesburg	-26.21256	27.9953	######	4	4	100	16	shaft	Incline	Shaft backfilled. White drum with shaft name on shaft	0	5	5	Low

No.of holes	CGS Hole Name	Original Shaft Name	Area	Municipality	Latitude	Longitude	Date logged	Length (m)	Width (m)	Depth (m)	Area (m²)	Hole Type	Incline	Safety Report	Hazard	Proximity	Priority Rating	Risk
														position				
39	Crown Mine no.15 Shaft	Crown Mine no.7 shaft	Crown Gold Mines	Johannesburg	-26.21568	27.99978	######	5	4	100	20	shaft		Shaft area developed. The exact position of shaft could not be determined.	0	5	5	Low
40	Crown Mine no.16 Shaft		Crown Gold Mines	Johannesburg	-26.21768	28.02324	######	6	5	100	30	shaft		Grating ontop of shaft. Shaft headgear not removed	0	5	5	Low
41	Crown Mine no.17 Shaft	Crown Mine no. 14 shaft	Crown Gold Mines	Johannesburg	-26.23829	28.01644	25/10/2005	5	4	100	20	shaft	vertical	Shaft most probably safe. Shaft is being used by Gold Reef City.	0	5	5	Low
42	Crown Mine no.17 Ventilation Shaft	Crown Mine 17Ventilation	Crown Gold Mines	Johannesburg	-26.21938	27.98324	25/10/2006	6	5	100	30	shaft	Ventilation	Shaft sealed. Building in which shaft is enclosed is being used for educational purposes	0	5	5	Low
43	Crown Mine no.17 Vertical Shaft	Crown Mine 17Vertical	Crown Gold Mines	Johannesburg	-26.22751	27.96301	25/10/2005	7	5	100	35	shaft	vertical	Shaft sealed. Water monitoring shaft.	0	5	5	Low
44	Crown Mine no.2 Shaft	Crown Mine No. 18 Ventilation shaft	Crown Gold Mines	Johannesburg	-26.23088	27.998	23/11/2004	5	5	100	25	shaft		Enclosed in a large brick structure.	0	5	5	Low
45	Crown Mine no.3 Shaft		Crown Gold Mines	Johannesburg	-26.21200	27.9936	######	1.5	1	50	1.5	shaft		Opening backfilled. Exact closure method unknown.	0	5	5	Low
46	Crown Mine no.4		Crown Gold Mines	Johannesburg	-26.21216	27.99395	E4:F5	1	1	20	1	Subsidence		Opening backfilled. Exact closure method unknown.	0	5	5	Low

No.of holes	CGS Hole Name	Original Shaft Name	Area	Municipality	Latitude	Longitude	Date logged	Length (m)	Width (m)	Depth (m)	Area (m^2)	Hole Type	Incline	Safety Report	Hazard	Proximity	Priority Rating	Risk
47	Crown Mine no.5 Shaft	Crown Mine No. 1 shaft	Crown Gold Mines	Johannesburg	-26.21678	28.02422	23/11/2004	5	4	100	20	Shaft		Grating ontop of shaft. Shaft headgear not removed	0	5	5	Low
48	Crown Mine no.6 Shaft	Crown Mine No. 5 shaft	Crown Gold Mines	Johannesburg	-26.22164	28.01472	23/11/2004	5	5	100	25	Shaft		Shaft capped.	0	5	5	Low
49	Crown Mine no.7 Shaft	Crown Mine No.3 shaft	Crown Gold Mines	Johannesburg	-26.21973	28.01247	23/11/2004	2	1	6	2	Shaft	vertical	Trench, partly filled.	3	5	8	Medium
50	Crown Mine no.8 Shaft	Crown Mine No. 16 Vertical shaft	Crown Gold Mines	Johannesburg	-26.237223	27.981945	30/11/2004	3	2	100	6	Shaft		Shaft sealed with a concrete slab	0	5	5	Low
51	DRD 3 Vertical	DRD No.3 Vertical shaft	DRD	Johannesburg	-26.17041	27.85696	7/7/2006	6	3	100	18	Shaft	vertical	Shaft enclosed in a wall	5	5	10	High
52	DRD Bitcom Incline Shaft	DRD Bitcom Incline shaft	DRD	Johannesburg	-26.17386	27.82492	13/7/2006	6	4	100	24	Shaft	Incline	Shaft backfilled by DRD	0	5	5	Low
53	DRD Bitcom Shaft	DRD Bitcom Shaft	DRD	Johannesburg	-26.16753	27.83722	29/5/2006	6	3	100	18	Shaft	Incline	No safety measures	5	5	10	High
54	DRD Bitcom Ventilation Shaft	DRD Bitcom Ventilation shaft	DRD	Johannesburg	-26.17216	27.82568	13/7/2006	6	5	100	30	Shaft	Ventilation	Shaft backfilled by DRD	0	5	5	Low
55	DRD Hole		DRD	Johannesburg	-26.17221	27.84963	2/9/2005	16	16	8	256	Shaft	vertical	No safety measures.	3	5	8	Medium
56	DRD Hope Shaft	DRD Hope shaft	DRD	Mogale	-26.17052	27.82738	13/7/2006	5	4	100	20	Shaft	Incline	Shaft backfilled by DRD	0	5	5	Low
57	DRD Monaliza Shaft	DRD Monaliza shaft	DRD	Mogale	-26.17542	27.83504	13/7/2006	6	4	100	24	Shaft	Incline	Shaft backfilled by DRD	0	5	5	Low
58	DRD no.1 Shaft	DRD Greatbrittan incline shaft	DRD	Johannesburg	-26.18696	27.871	######	4	4	100	16	Shaft		Shaft backfilled by DRD.	0	5	5	Low
59	DRD no.1 Vertical Shaft	DRD No. 1 Vertical shaft	DRD	Johannesburg	-26.17112	27.86973		3	2	100	6	Shaft	vertical	Shaft backfilled by DRD.	0	5	5	Low

No.of holes	CGS Hole Name	Original Shaft Name	Area	Municipality	Latitude	Longitude	Date logged	Length (m)	Width (m)	Depth (m)	Area (m²)	Hole Type	Incline	Safety Report	Hazard	Proximity	Priority Rating	Risk
60	DRD no.2 Vertical Shaft	DRD No. 2 Vertical shaft	DRD	Johannesburg	-26.17041	27.86156	7/7/2006	5	4	100	20	Shaft	vertical	Shaft backfilled by DRD.	0	5	5	Low
61	DRD no.3 Shaft	DRD No. 07 Shaft	DRD	Johannesburg	-26.18796	27.87208	######	2.5	0.9	20	2.25	Shaft		Shaft backfilled. Exact closure method unknown	0	5	5	Low
62	DRD no.4	DRD Open pit shaft	DRD	Johannesburg	-26.188897	27.87751	######	5	5	100	25	Shaft	Incline	No safety measures.	5	5	10	High
63	DRD no.4 Ventilation Shaft	DRD No.04 Ventilation shaft	DRD	Johannesburg	-26.17054	27.83786	2/8/2005	4	2	100	8	Shaft		Shaft enclosed in a wall. Shaft is, however, accessible.	5	5	10	High
64	DRD no.4 Vertical Shaft	Princess Ventilation Shaft	DRD	Johannesburg	-26.17309	27.84303	2/9/2005	3	2	100	6	Shaft	Incline	Shaft enclosed in a wall. Shaft wall can be seen from R41 (in the south)	5	5	10	High
65	DRD no.5 Shaft	DRD N0.5 shaft	DRD	Johannesburg	-26.18056	27.86229	5/7/2006	4	4	100	16	Shaft	vertical	Shaft sealed. Shaft breather pipe can be seeing on shaft position.	0	5	5	Low
66	DRD no.7	DRD No. 6 shaft	DRD	Johannesburg	-26.18247	27.83665	######	12.6	4.3	100	54.18	Shaft		Shaft sealed with a concrete slab.	0	5	5	Low
67	DRD no.8	DRD No. 9 shaft	DRD	Johannesburg	-26.18368	27.83652	######	13.3	5	100	66.5	Shaft	Incline	No. 9 shaft, Steel grate., headgear removed	0	5	5	Low
68	DRD no.9	Circular Shaft	DRD	Johannesburg	-26.17618	27.86343	26/11/2004	5	5	100	25	Shaft	Incline	Shaft safe. Security guard on site at all times.headgear still on shaft. Alarm shaft	5	5	10	High
69	DRD Tinkla Shaft	DRD Tinkla shaft	DRD	Johannesburg	-26.16661	27.86349	5/7/2006	5	4	100	20	Shaft	vertical	Shaft backfilled by DRD	0	5	5	Low
70	DRD2		DRD	Johannesburg	-26.18696	dd	######	2	1	20	2	Subsidence		No safaety measures - mine air exits here	3	5	8	Medium

No.of holes	CGS Hole Name	Original Shaft Name	Area	Municipality	Latitude	Longitude	Date logged	Length (m)	Width (m)	Depth (m)	Area (m²)	Hole Type	Incline	Safety Report	Hazard	Proximity	Priority Rating	Risk
71	East Memorials Shaft	LL Proprietry Incline shaft	Lanlaagte	Johannesburg	-26.21289	27.98916	######	4	4	100	16	Shaft	Incline	Shaft closed with slab. Slab chipped open.	5	5	10	Low
72	ERPM 58		Centurion	Ekhurleni	-26.19312	28.16559	######	2	1	80	2	Subsidence		Fenced off. Opening on shallow undermined land. Woman fell into this opening and died	0	5	5	Low
73	ERPM 59		Centurion Gold Mines	Ekhurleni	-26.19532	28.15842	18/7/2007	1.5	5	5		Excavation	vertical	No safety measures in place around the opening	0	5	5	Low
74	ERPM 60		ERPM	Ekhurleni	-26.2014	28.21982	13/11/2006	9	9	1	81	Subsidence		Opening occurred beneath a shack. The shack was damaged, but there were not casualties. Opening on shallow undermined land.	1	5	6	Low
75	ERPM 63		Centurion	Ekhurleni	-26.19304	28.16464	######	0	0	0	0	Subsidence		Subsidence occuring. Shack built on this subsiding ground. Small opening developed in one of the Shack rooms. Subsidence occuring on shallow undermined land	0	5	5	Low
76	ERPM.32X		Centurion	Ekhurleni	-26.19439	28.16088	######	1.5	1.5	0	2.25	Subsidence		Subsidence occurring on shallow undermined land	1	5	6	Low

No.of holes	CGS Hole Name	Original Shaft Name	Area	Municipality	Latitude	Longitude	Date logged	Length (m)	Width (m)	Depth (m)	Area (m²)	Hole Type	Incline	Safety Report	Hazard	Proximity	Priority Rating	Risk
77	ERPM1	Shaft	ERPM	Ekhurleni	-26.21223	28.25382	######	7	4	10	28	Shaft		Shafts backfilled by ERPM after discussions with CGS	0	5	5	Low
78	ERPM12		ERPM	Ekhurleni	-26.20674	28.23377	######	5.5	5.5	100	30.25	Shaft		Wire mesh over shaft opening.	5	5	10	High
79	ERPM13		ERPM	Ekhurleni	-26.2053	28.22732	######	5	5	100	25	Shaft		Shaft enclosed in a wall. Wall still intact	5	5	10	High
80	ERPM14		ERPM	Ekhurleni	-26.2053	28.22732	######	7.1	5.7	100	40.47	Shaft		Shaft enclosed in a wall. Wall no longer intact	5	5	10	High
81	ERPM15	Angelo Shaft	ERPM	Ekhurleni	-26.2053	28.22732	######	6.3	4.3	100	27.09	Shaft		Shaft partly covered with logs	5	5	10	High
82	ERPM16		ERPM	Ekhurleni	-26.2032	28.22013	######	4	3	50	12	Shaft		Shaft closed by CGS. Shaft plugged and backfilled	0	5	5	Low
83	ERPM17		ERPM	Ekhurleni	-26.19809	28.20993	16/11/2004	72	26	17	1872	Subsidence		Shaft closed by CGS. Shaft plugged and backfilled	0	5	5	Low
84	ERPM18		ERPM	Ekhurleni	-26.19769	28.2095	16/11/2004	13	10	40	130	Subsidence		Shaft closed by CGS. Shaft plugged and backfilled	0	5	5	Low
85	ERPM18A		ERPM	Ekhurleni	-26.1975	28.20918	27/3/2006	3	3	50	9	Subsidence		Shaft closed by CGS. Shaft plugged and backfilled	0	5	5	Low
86	ERPM19A		ERPM	Ekhurleni	-26.19725	28.20983	16/11/2004	2.5	1.7	11	4.25	Shaft		Shaft closed by CGS. Shaft plugged with a PUF plug and backfilled	0	5	5	Low
87	ERPM2	Shaft	ERPM	Ekhurleni	-26.21262	28.25377	######	5	5	10	25	Shaft		Shafts backfilled by ERPM after discussions with CGS	0	5	5	Low
88	ERPM20		ERPM	Ekhurleni	-26.19747	28.20712	14/1/2005	7	5	6	35	Subsidence		Shaft closed by CGS. Shaft plugged and backfilled	0	5	5	Low

No.of holes	CGS Hole Name	Original Shaft Name	Area	Municipality	Latitude	Longitude	Date logged	Length (m)	Width (m)	Depth (m)	Area (m²)	Hole Type	Incline	Safety Report	Hazard	Proximity	Priority Rating	Risk
89	ERPM21 Shaft		ERPM	Ekhurleni	-26.19272	28.1969	######	3	3	5	9	Shaft		Shaft closed by CGS. Shaft plugged and backfilled	0	5	5	Low
90	ERPM22		ERPM	Ekhurleni	-26.19015	28.19442	######	1	2	1	2	Subsidence		Subsidence backfilled. Exact closure method unknown	0	5	5	Low
91	ERPM23		ERPM	Ekhurleni	-26.18995	28.19274	######	0,5	0.5	2	0.5	Subsidence		Subsidence backfilled. small openings developing.	0	5	5	Low
92	ERPM24		Centurion	Ekhurleni	-26.19025	28.18303	######	30	20	6	600	Subsidence		No safety measures. An open hole at Cedar Dump. A water ingress point	3	5	8	Medium
93	ERPM24X		Centurion	Ekhurleni	-26.19034	28.18321	######	20	30	30	600	Subsidence		No safety measures. An open hole at Cedar Dump. A water ingress point	5	5	10	High
94	ERPM25		Centurion	Ekhurleni	-26.18906	28.18069	######	2	2	4	4	Subsidence		No safety measures. An open hole at Cedar Dump. A water ingress point	3	5	8	Medium
95	ERPM26		Centurion	Ekhurleni	-26.18928	28.17985	######	10	10	1	100	Subsidence		No safety measures. An open hole at Cedar Dump. A water ingress point. Opening very shallow	1	5	6	Low
96	ERPM27		ERPM	Ekhurleni	-26.19276	28.16437	######	20	10	3	200	Subsidence		Subsidence backfilled. Small openings developing, however. Shallow undermined land	0	5	5	Low

No.of holes	CGS Hole Name	Original Shaft Name	Area	Municipality	Latitude	Longitude	Date logged	Length (m)	Width (m)	Depth (m)	Area (m²)	Hole Type	Incline	Safety Report	Hazard	Proximity	Priority Rating	Risk
97	ERPM28		ERPM	Ekhurleni	-26.19348	28.16414	######	1	1	2	1	Subsidence		It appears that opening was backfiiled and re-opened.	3	5	8	Medium
98	ERPM29		ERPM	Ekhurleni	-26.19345	28.16465	######	4.5	4.5	1.5	20.25	Subsidence		Opening was backfilled.	3	5	8	Medium
99	ERPM3	Shaft	ERPM	Ekhurleni	-26.21288	28.25465	######	2	2	5	4	Excavation		Shafts backfilled by ERPM after discussions with CGS	0	5	5	Low
100	ERPM30		ERPM	Ekhurleni	-26.19346	28.16438	######	7	7	10	49	Subsidence		It appears that opening was backfiiled and re-opened.	3	5	8	Medium
101	ERPM31		ERPM	Ekhurleni	-26.19347	28.16436	######	3	3	2.5	9	Subsidence		Trenches backfilled	3	5	8	Medium
102	ERPM32		Centurio n	Ekhurleni	-26.19434	28.1608	######	4.7	4.5	2.6	21.15	Subsidence		Subsidence occurring on shallow undermined land	0	5	5	Low
103	ERPM32Y		Centurio n	Ekhurleni	-26.19442	28.1609	######	3	2	0	6	Subsidence		Subsidence occurring on shallow undermined land	1	5	6	Low
104	ERPM32Z		Centurio n	Ekhurleni	-26.114036	28.93858	######	2	2	4	4	Subsidence		Subsidence occurring on shallow undermined land	3	5	8	Low
105	ERPM33		Centurio n	Ekhurleni	-26.19553	28.16078	######	4	1.3	1.5	5.2	Structure		An old mine-related structure	1	5	6	Low
106	ERPM34		Centurio n	Ekhurleni	-26.204166	28.13495	26/10/2004	22	12	7.5	264	Subsidence		No safety measures. Water ingress point	3	5	8	Low
107	ERPM34X		Centurio n	Ekhurleni	-26.20472	28.13529	26/10/2004	6	5	5.6	30	Subsidence		No safety measures. Water ingress point	3	5	8	Low
108	ERPM35		Centurio n	Ekhurleni	-26.20442	28.13533	26/10/2004	3.5	3	2.5	10.5	Subsidence		No safety measures. Water ingress point	1	5	6	Low

No.of holes	CGS Hole Name	Original Shaft Name	Area	Municipality	Latitude	Longitude	Date logged	Length (m)	Width (m)	Depth (m)	Area (m²)	Hole Type	Incline	Safety Report	Hazard	Proximity	Priority Rating	Risk
109	ERPM36		Centurion	Ekhurleni	-26.20411	28.13527	17/12/2004	20	8	3	160	Shaft	Incline	No safety measures. Water ingress point	1	5	6	Low
110	ERPM36X		Centurion	Ekhurleni	-26.20465	28.13549	17/12/2004	3	2	2	6	Shaft		No safety measures. Water ingress point	3	5	8	Low
111	ERPM36Y		Centurion	Ekhurleni	-26.2045	28.13551	17/12/2004	2.5	2	2	5	Structure		No safety measures. Water ingress point	1	5	6	Low
112	ERPM37		Centurion	Ekhurleni	-26.20508	28.13527	26/10/2004	2	1.5	7	3	Shaft		No safety measures. Water ingress point	5	5	10	Low
113	ERPM37X		Centurion	Ekhurleni	-26.20441	28.13495	26/10/2004	4.5	4	3	18	Subsidence		No safety measures. Water ingress point	3	5	8	Low
114	ERPM37Y		Centurion	Ekhurleni	-26.20485	28.13539	26/10/2004	4.5	3.5	6	15.75	Subsidence		No safety measures. Water ingress point	5	5	10	Low
115	ERPM37Z		Centurion	Ekhurleni	-26.20531	28.13447	26/10/2004	5	5	7	25	Subsidence		No safety measures. Water ingress point	3	5	8	Low
116	ERPM38		Centurion	Ekhurleni	-26.204445	28.135555	17/12/2004	6	2	1	12	Structure		No safety measures. Water ingress point	1	5	6	Low
117	ERPM38X		Centurion	Ekhurleni	-26.20528	28.13441	17/12/2004	1.5	1	1.9	1.5	Subsidence		No safety measures. Water ingress point	3	5	8	Low
118	ERPM39		Centurion	Ekhurleni	-26.20482	28.13026	25/11/2005	2	1	10	2	Subsidence		Opening backfilled. Exact closure method unknown.	0	5	5	Low
119	ERPM4	No.1 South Shaft	ERPM	Ekhurleni	-26.2131	28.2549	######	2	1.5	5	3	Excavation		Shafts backfilled by ERPM after discussions with CGS	0	5	5	Low

No.of holes	CGS Hole Name	Original Shaft Name	Area	Municipality	Latitude	Longitude	Date logged	Length (m)	Width (m)	Depth (m)	Area (m²)	Hole Type	Incline	Safety Report	Hazard	Proximity	Priority Rating	Risk
120	ERPM40		Centurio n	Ekhurleni	-26.204166	28.133333	16/11/2004	5	1	10	5	Subsidence		Opening backfilled. Exact closure method unknown.	0	5	5	Low
121	ERPM41		ERPM	Ekhurleni	-26.203888	28.133055	16/11/2004	2	2	5	4	Subsidence		Opening backfilled. Exact closure method unknown.	0	5	5	Low
122	ERPM42		ERPM	Ekhurleni	-26.203888	28.134167	16/11/2004	2	2	5	4	Subsidence		Opening backfilled. Exact closure method unknown.	0	5	5	Low
123	ERPM43		ERPM	Ekhurleni	-26.20206	28.2213	16/11/2004	12	10	3	120	Shaft		Plugged and backfilled by Chestnut Projects.	0	5	5	Low
124	ERPM44		ERPM	Ekhurleni	-26.20117	28.22009	16/11/2004	5	5	5	25	Subsidence		Suspected to have been closed by Chestnut Projects. Exact closure method unknown.	0	5	5	Low
125	ERPM45		ERPM	Ekhurleni	-26.200556	28.220278	16/11/2004	5	5	0	25	Shaft		Suspected to have been closed by Chestnut Projects. Exact closure method unknown.	0	5	5	Low
126	ERPM46		ERPM	Ekhurleni	-26.200834	28.219999	16/11/2004	5	4	0	20	Shaft		Suspected to have been closed by Chestnut Projects. Exact closure method unknown.	0	5	5	Low
127	ERPM47		ERPM	Ekhurleni	-26.20146	28.21478	16/11/2004	5	5	20	25	Shaft		Suspected to have been closed by Chestnut Projects. Exact closure method unknown.	0	5	5	Low

No.of holes	CGS Hole Name	Original Shaft Name	Area	Municipality	Latitude	Longitude	Date logged	Length (m)	Width (m)	Depth (m)	Area (m²)	Hole Type	Incline	Safety Report	Hazard	Proximity	Priority Rating	Risk
128	ERPM48		ERPM	Ekhurleni	-26.19988	28.21644	16/11/2004	5	5	20	25	Subsidence		Suspected to have been closed by Chestnut Projects. Exact closure method unknown.	0	5	5	Low
129	ERPM49		ERPM	Ekhurleni	-26.201111	28.220556	16/11/2004	9	8	30	72	Subsidence		Suspected to have been closed by Chestnut Projects. Exact closure method unknown.	0	5	5	Low
130	ERPM5	No.1 Incline Shaft	ERPM	Ekhurleni	-26.21265	28.25518	######	4	4	10	16	Shaft	Incline	Shafts backfilled by ERPM after discussions with CGS	0	5	5	Low
131	ERPM50		ERPM	Ekhurleni	-26.19952	28.21592	16/11/2004	13	9	30	117	Subsidence		Suspected to have been closed by Chestnut Projects. Exact closure method unknown.	0	5	5	Low
132	ERPM51		ERPM	Ekhurleni	-26.19906	28.20664	14/1/2005	4.7	4.7	10	22.09	Shaft	Incline	Shaft closed by CGS. Shaft plugged and backfilled	0	5	5	Low
133	ERPM52		ERPM	Ekhurleni	-26.19857	28.2065	14/1/2005	3	3	100	9	Shaft	Incline	Shaft closed by CGS. Shaft plugged and backfilled	0	5	5	Low
134	ERPM53	Ventilation Shaft	ERPM	Ekhurleni	-26.22988	28.25993	1/3/2005	2	2	10	4	Shaft	vertical	Shaft enclosed in a fence.	5	5	10	High
135	ERPM54		ERPM	Ekhurleni	-26.232	28.26981	1/3/2005	8	8	0	64	Shaft	Incline	Shaft closed. Closure method unknown.	1	5	6	Low
136	ERPM55		ERPM	Ekhurleni	-26.20011	28.21025	1/3/2005	8	8	10	64	Shaft	Incline	Shaft closed by CGS. Shaft plugged and backfilled	0	5	5	Low
137	ERPM56		ERPM	Ekhurleni	-26.20016	28.21006	1/3/2005	5	5	7	25	Subsidence		Shaft closed by CGS. Shaft plugged and backfilled	0	5	5	Low

No.of holes	CGS Hole Name	Original Shaft Name	Area	Municipality	Latitude	Longitude	Date logged	Length (m)	Width (m)	Depth (m)	Area (m²)	Hole Type	Incline	Safety Report	Hazard	Proximity	Priority Rating	Risk
138	ERPM57		ERPM	Ekhurleni	-26.19625	28.15622	18/3/2005	0.5	0.5	50	0.25	Subsidence		No safety measures. Opening on shallow undermined. Woman working for Rand Water fell into this opening. She survived	5	5	10	Low
139	ERPM6	Blue Sky Main shaft	ERPM	Ekhurleni	-26.21418	28.25783	######	3	3	35	9	Shaft		Shaft lie open in a vacant land. Wire-mesh placed over shaft.	5	5	10	High
140	ERPM61		Centurion Gold Mines	Ekhurleni	-26.19725	28.15554	18/7/2007	1.5	2	15		Excavation	vertical	Opening closed. Closure method unknown	5	0	5	Low
141	ERPM7	Cason Shaft	ERPM	Ekhurleni	-26.21009	28.24544	######	5	5	100	25	Shaft		Fenced and walled.	0	5	5	Low
142	ERPM9	Shaft	ERPM	Ekhurleni	-26.20969	28.24041	######	6	4	100	24	Shaft		No safety measures	5	5	10	High
	ERPM 64		Centurion	Ekhurleni			16/11/2007	5	1.5	100	7.5	shaft	Incline	Community erected fence	5	5	10	High
143	F004 Shaft		Rand Leases	Ekhurleni	-26.19145	27.89992		4	3	10	12	Shaft	Incline	Possibly entrance to shaft. Opening covered with landfill	0	5	5	Low
144	F008 Shaft		Rand Leases	Ekhurleni	-26.18608	27.91704	28/9/2005	8	5	100	40	Shaft	Incline	Shaft closed by DRD.	0	5	5	Low
145	Geldenhuis Shaft	S&J Rudd Shaft	Simmer & Jack	Ekurhuleni	-26.21432	28.15341	######	10	4	100	40	Shaft	vertical	Shaft closed by CGS. Shaft plugged and backfilled	0	5	5	Low
146	Geldenhuis Shaft B		Simmer & Jack	Ekurhuleni	-26.21418	28.15342	5/9/2006	4	3	30	12	Structure	vertical	Structure dangerous and open	5	5	10	Low
147	Gosforth Hole		Simmer and Jack	Ekhurleni	-26.22925	28.13783	14/1/2005	3	2	10	6	Shaft		No safety measures.	5	5	10	Low
148	Gosforth Incline Shaft		Simmer and Jack	Ekhurleni	-26.22924	28.13782	14/1/2005	3	2	20	6	Shaft	Incline	Open shaft. No safety measures	5	5	10	Low

No.of holes	CGS Hole Name	Original Shaft Name	Area	Municipality	Latitude	Longitude	Date logged	Length (m)	Width (m)	Depth (m)	Area (m²)	Hole Type	Incline	Safety Report	Hazard	Proximity	Priority Rating	Risk
149	Haggie Shaft	Howard shaft	Nourse Mines	Ekhurleni	-26.21985	28.12825	25/11/2004	8	3	30	24	Shaft		Shaft sealed with concrete slab	0	5	5	Low
150	Knights Shaft	Rose Deep No.1 Shaft	Primrose	Ekhurleni	-26.19659	28.17168	30/11/2004	8	4	100	32	Shaft		Shaft closed by CGS. Shaft plugged and backfilled	0	5	5	Low
151	Langlaagte Main 2		Langlaagte	Johannesburg	-26.2035	27.9687	5/9/2006	4	4	100	16	Subsidence		No safety measures	5	5	10	Low
152	Langlaagte Main 3		Langlaagte	Johannesburg	-26.20341	27.9683	5/9/2006	4	2	100	8	Subsidence		No safety measures	5	5	10	Low
153	Langlaagte Main 4		Langlaagte	Johannesburg	-26.20331	27.96818	5/9/2006	4	4	100	16	Subsidence		No safety measures	5	5	10	Low
154	Langlaagte Main 5		Langlaagte	Johannesburg	-26.20316	27.96779	5/9/2006	3	3	100	9	Subsidence		No safety measures	5	5	10	Low
155	Langlaagte Main 6		Langlaagte	Johannesburg	-26.20321	27.96767	5/9/2006	8	8	100	64	Subsidence		No safety measures	5	5	10	Low
156	Langlaagte Main 7		Langlaagte	Johannesburg	-26.20306	27.96737	5/9/2006	8	6	100	48	Shaft		Wall surrounding shaft vandalised. Shaft accessible	5	5	10	Low
157	Langlaagte Main B		Langlaagte	Johannesburg	-26.20372	27.96878	21/8/2006	5	2	100	10	Subsidence		Shaft closed by CGS. Shaft plugged and backfilled	0	5	5	Low
158	Langlaagte Main Shaft	Langlaagte Main Shaft	Langlaagte	Johannesburg	-26.20372	27.96878		4	4	100	16	Shaft	Incline	Shaft closed by CGS. Shaft plugged and backfilled	0	5	5	Low
159	Langlaagte West Deep Shaft	LL West Deep	Lanlaagte	Johannesburg	-26.20678	27.96055	22/6/2002	4	3	100	12	Shaft		Shaft closed. Closure method unknown	0	5	5	Low
160	Macro Shaft		Crown Gold Mines	Johannesburg	-26.21455	28.00197	######	4	3.5	15	14	Shaft		Shaft closure in progress	5	5	10	Low
161	Memorial 1	Langlaagte Outcrop (LLPI)	Langlaagte	Ekhurleni	-26.21075	27.98853	18/11/2004	2	2	100	4	Excavation		No safety measures. Opening along the reef outcrop	5	5	10	High
162	Memorial 2		Langlaagte	Ekhurleni	-26.21051	27.98727	18/11/2004	3	2	5	6	Excavation		No safety measures. Opening along the reef outcrop	3	5	8	Medium

No.of holes	CGS Hole Name	Original Shaft Name	Area	Municipality	Latitude	Longitude	Date logged	Length (m)	Width (m)	Depth (m)	Area (m²)	Hole Type	Incline	Safety Report	Hazard	Proximity	Priority Rating	Risk
163	Memorial 3		Langlaagte	Ekhurleni	-26.21017	27.98876	18/11/2004	0	0	5	0	Excavation	Incline	No safety measures. Opening along the reef outcrop	3	5	8	Medium
164	Old Wits Vertical shaft		Wits Gold Mine	Ekhurleni	-26.19702	28.17823	24/8/2006	9	5	15	45	Shaft	vertical	Shaft within industrial area. No safety measures	5	5	10	Low
165	Pencil Park Shaft	Geldenhuis Shaft	Centurion Gold Mines	Ekhurleni	-26.20896	28.1325	25/11/2004	7	2.7	100	18.9	Shaft		Shaft closed by CGS. Shaft plugged and backfilled	0	5	5	Low
166	Private no.1 Shaft		Langlaagte	Johannesburg	-26.21489	27.97038	18/11/2004	2.5	2.5		6.25	Shaft	Incline	No safety measures.	0	5	5	Low
167	Private no.2 Shaft	East Deep Vertical	Langlaagte	Johannesburg	-26.20929	27.9687	18/11/2004	10	3	100	30	Shaft	vertical	No safety measures.	0	5	5	Low
168	R39	Crown Mine No.17 shaft	Rholes	Johannesburg	-26.22242	27.96353	######	4	3	5	12	Shaft		Trenches to the south and east of the shaft.	5	5	10	High
169	R41	Crown Mine No.15 shaft	Crown Gold Mines	Johannesburg	-26.23458	27.99817	######	4.3	2	>100	8.6	Shaft	vertical	No safety measures. Shaft cache still in the shaft	5	5	10	High
170	R42		ERPM	Johannesburg	-26.20592	27.9306	######	1	1	10	1	Structure		Hole is cemented on sides.	5	2	7	Medium
171	R43		ERPM	Johannesburg	-26.2057	27.93066	######	1	1	3	1	Structure		Hole is well cemented inside.	3	2	5	Medium
172	R44		ERPM	Johannesburg	-26.20595	27.93069	######	1	1	6	1	Structure		It looks like a shaft but is just a hole.	5	2	7	Medium
173	R45		ERPM	Johannesburg	-26.20265	27.93245	######	2	2	3	4	Subsidence		There is a rock on the northern side of the hole	3	2	5	Medium
174	R49	Cleaveland Shaft	Centurion Gold Mines	Ekhurleni	-26.20736	28.12326	######	2.9	2	>100	5.8	Shaft	vertical	Shaft closed by CGS. Shaft plugged and backfilled	5	5	10	High
175	R50		Centurion Gold Mines	Ekhurleni	-26.2058	28.12474	######	16	5	5	80	Subsidence	Incline	Shaft closed by CGS. Shaft plugged and backfilled	0	5	5	Low

No.of holes	CGS Hole Name	Original Shaft Name	Area	Municipality	Latitude	Longitude	Date logged	Length (m)	Width (m)	Depth (m)	Area (m²)	Hole Type	Incline	Safety Report	Hazard	Proximity	Priority Rating	Risk
176	R51		Centurion Gold Mines	Ekhurleni	-26.20583	28.12461	######	3	3	>10	9	Subsidence	Incline	Shaft closed by CGS. Shaft plugged and backfilled	0	5	5	Low
177	R52		Centurion Gold Mines	Ekhurleni	-26.20582	28.12447	######	2	1.5	1.2	3	Subsidence	Incline	No safety measures	0	5	5	Low
178	R53		Centurion Gold Mines	Ekhurleni	-26.20585	28.12433	######	4.7	3.9	>10	18.33	Shaft	Incline	Shaft closed by CGS. Shaft plugged and backfilled	0	5	5	Low
179	R56	KR No. 2 Incline	Rand Leases	Ekhurleni	-26.20021	27.89754	######	5	4	100	20	Shaft	Incline	No safety measures. Shaft close to thoroughfares in the area.	5	5	10	High
180	R58		CMR	Johannesburg	-26.20614	27.91239	######	5	3	30	15	Shaft	Incline	Shaft closed by CGS. Shaft plugged and backfilled	0	5	5	Low
181	R58A		CMR	Johannesburg	-26.2079	27.91678	28/5/2006	2	2.5		5	Subsidence		opening closed by CGS	5	0	5	Low
182	R59	KR No. 19 Shaft	CMR	Johannesburg	-26.20767	27.91621	######	6	6	35	36	Shaft	Incline	Shaft closed by CGS. Shaft plugged and backfilled	0	5	5	Low
183	R59A		CMR	Johannesburg	-26.20795	27.91745	30/8/2006					Shaft		Shaft closed by CGS. Shaft plugged and backfilled	0	5	5	Low
184	R60		Consolidated Main Reef	Johannesburg	-26.20002	27.92502	######	4.5	4.5	100	20.25	Shaft	Incline	Shaft closed. Closure method unknown.	0	5	5	Low
185	R61	CMR No.5 vertical	Consolidated Main Reef	Johannesburg	-26.19961	27.92281	######	4	4	100	16	Shaft	vertical	No safety measures. 400m from school	5	5	10	High
186	R62	Randleases 4 or A Shaft	Rand Leases	Johannesburg	-26.19592	27.91327	######	6	2	35	12	Shaft	Incline	Shaft closed by CGS. Shaft plugged and backfilled	0	5	5	Low
187	R62 East		Rand Leases	Johannesburg	-26.1965	27.91604	21/8/2006	5	4	100	20	Shaft	Incline	Shaft closed by CGS. Shaft plugged and backfilled	0	5	5	Low

No.of holes	CGS Hole Name	Original Shaft Name	Area	Municipality	Latitude	Longitude	Date logged	Length (m)	Width (m)	Depth (m)	Area (m²)	Hole Type	Incline	Safety Report	Hazard	Proximity	Priority Rating	Risk
188	R62 West		Rand Leases	Johannesburg	-26.19561	27.91259	21/8/2006	4	4	20	16	Subsidence	vertical	Shaft closed by CGS. Shaft plugged and backfilled	0	5	5	Low
189	R63	CMR No.3 Verical	Consolidated Main Reef	Johannesburg	-26.20786	27.94545	######	7	5	150	35	Shaft	Incline	Razor-wire erected around shaft, otherwise no stringent safety measures.	5	5	10	High
190	R64	Shaft	Rand Leases	Johannesburg	-26.20202	27.90082	######	10	8	60	80	Shaft	Incline	No safety measures. Shaft close to thoroughfares in the area.	5	5	10	High
191	R65	KR No. 2 Ventilation shaft	Rand Leases	Johannesburg	-26.20046	27.89709	######	3.7	3	100	11.1	Shaft	Ventilation	No safety measures. Shaft close to thoroughfares in the area.	5	5	10	High
192	R68		CMR	Johannesburg	-26.19025	27.92696	27/6/2007	6	5	100	30	Shaft	vertical	shaft enclosed in a wall. The wall is falling apart	5	5	10	High
193	R69		CMR	Johannesburg	-26.19131	27.93114	27/6/2007	2.5	2	100	5	Shaft	vertical	shaft enclosed in a wall.	5	5	10	High
194	Rand Leases Adit		Rand Leases	Johannesburg	-26.20113	27.89825	20/6/2006	8	8	100	64	Shaft		No safety measures	5	5	10	High
195	Rand Leases no.1 Shaft	Randleases 11 Vertical	Rand Leases	Johannesburg	-26.19026	27.89768	######	4	7	100	28	Shaft		No safety measures	5	5	10	High
196	Rand Leases no.4 Incline Shaft	Rand Leases No.7 Shaft	Rand Leases	Johannesburg	-26.18127	27.89526	5/9/2005	6	3	100	18	Shaft	Incline	Shaft sealed with a concrete slab	0	5	5	Low
197	RD01E	RD01E	Village Main	Johannesburg	-26.21924	28.05225	22/6/2006	6	2.5	100	15	Shaft	vertical	Shaft enclosed in a wall. Wall no longer intact	0	5	5	Low
198	RD02E	RD 02E	Village Main	Johannesburg	-26.21911	28.04677	22/6/2006	8	3	100	24	Shaft	vertical	Shaft enclosed in a wall. Steel grate on top of the wall	0	5	5	Low

No.of holes	CGS Hole Name	Original Shaft Name	Area	Municipality	Latitude	Longitude	Date logged	Length (m)	Width (m)	Depth (m)	Area (m²)	Hole Type	Incline	Safety Report	Hazard	Proximity	Priority Rating	Risk
199	Roodepoort 5A		Roodepoort	Johannesburg	-26.16714	27.87061	6/3/2007	12	7	100	84	Subsidence		Opening to be closed by Chestnut during II Phase	0	5	5	Low
200	Roodepoort 5B		Roodepoort	Johannesburg	-26.16705	27.87053	6/4/2007	4	3	100	12	Shaft	Incline	Opening to be closed by Chestnut during II Phase	0	5	5	Low
201	Roodepoort 5C		Roodepoort	Johannesburg	-26.16714	27.87044	6/5/2007	10	6	100	60	Subsidence		Opening to be closed by Chestnut during II Phase	0	5	5	Low
202	Roodepoort 5D		Roodepoort	Johannesburg	-26.16769	27.8709	6/6/2007	15	6	100	90	Shaft	Incline	Opening to be closed by Chestnut during II Phase	0	5	5	Low
203	Roodepoort 7		Roodepoort	Johannesburg							0	Shaft	vertical		5	5	10	High
204	Roodepoort no.1	Roode01	DRD	Johannesburg	-26.16512	27.86381	######	4	2	100	8	Shaft	vertical	Shaft enclosed in a wall. Shaft accessible	5	0	5	Low
205	Roodepoort no.2	Roode02	DRD	Johannesburg	-26.16492	27.86652	######	6.5	6.5	100	42.25	Shaft	vertical	Shaft enclosed in a wall	5	0	5	Low
206	Roodepoort no.3	Roode03	DRD	Johannesburg	-26.16653	27.86835	######	12.2	12.2	100	148.84	Shaft	vertical	Shaft enclosed in a wall. Shaft accessible	5	0	5	Low
207	Roodepoort no.4	Roode04	DRD	Johannesburg	-26.16849	27.87084	######	12	12	100	144	Shaft	vertical	Shaft enclosed in a wall. Shaft accessible	5	0	5	Low
208	Roodepoort No.4 Original Shaft	No. 4 Roodepoort	DRD	Johannesburg	-26.16834	27.83362		7	5	100	35	Shaft	vertical	Shaft closed. Closure method unknown	0	5	5	Low
209	Roodepoort no.6	Wilford No. 7 incline shaft	DRD	Johannesburg	-26.16715	27.83845	29/05/2006	13	12	100	156	Shaft	Incline	No safety measures	5	0	5	Low
210	Rose Deep no.2		Simmer & Jack	Ekhurleni	-26.19726	28.16702	28/9/2005	6	3	100	18	Shaft	vertical	Shaft closed by CGS. Shaft plugged and backfilled	0	0	0	Low
211	S & J Rhodes Shaft	S&J Rhodes shaft	Simmer & Jack	Ekurhuleni	-26.21543	28.14012	14/6/2006	6	5	100	30	Shaft	vertical	Shaft closed. Headgear remains visible on rock dump	0	5	5	Low

No.of holes	CGS Hole Name	Original Shaft Name	Area	Municipality	Latitude	Longitude	Date logged	Length (m)	Width (m)	Depth (m)	Area (m²)	Hole Type	Incline	Safety Report	Hazard	Proximity	Priority Rating	Risk
212	S & J11		Simmer & Jack	Ekhurleni	-26.20302	28.14115	25/11/2004	4	3.5		14	Shaft	Incline	Barbed fencing and conctrete slab	5	5	10	Low
213	S & J12	S&J Incline Shaft	Simmer & Jack	Ekhurleni	-26.20053	28.1482	25/11/2004	3.2	2.8		8.96	Shaft	Incline	Shaft sealed with a concrete slab. Slab vandalised	5	5	10	Low
214	S & J15	Primrose No.4 Shaft	Simmer & Jack	Ekhurleni	-26.20325	28.15537	24/11/2004	3	3	12	9	Shaft	Incline	Shaft closed by CGS. Shaft plugged and backfilled	0	5	5	Low
215	S & J16		Simmer & Jack	Ekhurleni	-26.20269	28.15509	24/11/2004	25	25	20	625	Shaft	Incline	Shaft closed by CGS. Shaft plugged and backfilled	0	5	5	Low
216	S & J16A		Simmer & Jack	Ekhurleni								Shaft		Shaft closed by CGS. Shaft plugged and backfilled	0	5	5	Low
217	S & J17		Simmer & Jack	Ekhurleni	-26.20297	28.13514	24/11/2004	12	7	15	84	Shaft	Incline	Shaft closed. Closure method unknown	0	5	5	Low
218	S & J18	Hammoned Shaft	Simmer & Jack	Ekhurleni	-26.20692	28.16501	25/11/2004	8.7	2.6	100	22.62	Shaft	vertical	Shaft closed by CGS. Shaft plugged and backfilled	0	5	5	Low
219	S & J20	S&JKIMI	Simmer & Jack	Ekhurleni	-26.22768	28.14109	24/11/2004	4	3	100	12	Shaft	Incline	Razor-wire erected around shaft, otherwise no stringent safety measures.	5	5	10	High
220	S & J21	South Deep Shaft	Simmer & Jack	Ekhurleni	-26.22869	28.14085	24/11/2004	8	4	100	32	Shaft	vertical	Shaft sealed with a concrete slab	0	5	5	Low
221	S & J23		Simmer & Jack	Ekhurleni	-26.20172	28.15936	27/9/2005	0.5	0.5	100	0.25	Shaft		Shack built on old mine structures	3	2	5	Low
222	S & J24	Stanhope N0.5 Shaft	Simmer & Jack	Ekhurleni	-26.20533	28.12828	27/9/2006	6	5	100	30	Shaft	Incline	Shaft probably still active	0	5	5	Low
223	S & J25	Incline East Shaft	Simmer & Jack	Ekhurleni	-26.19395	28.15108		6	5	100	30	Shaft	Incline	Shaft enclosed in a wall. Security personnel on site	0	5	5	Low

No.of holes	CGS Hole Name	Original Shaft Name	Area	Municipality	Latitude	Longitude	Date logged	Length (m)	Width (m)	Depth (m)	Area (m^2)	Hole Type	Incline	Safety Report	Hazard	Proximity	Priority Rating	Risk
224	S & J8	North Vertical Shaft	Simmer & Jack	Ekhurleni	-26.20651	28.14174	24/11/2004	3	2		6	Shaft	vertical	Shaft enclosed in a fence.	5	0	5	Low
225	S & J9	No.1 Shaft	Simmer & Jack	Ekhurleni	-26.20651	28.14174	24/11/2004	5	2		10	Shaft	vertical	Shaft closed. Closure method unknown	0	5	5	Low
226	S&J15B		Simmer & Jack	Ekurhuleni	-26.20238	28.15443	29/6/2006	6	4	100	24	Shaft	vertical	Shaft enclosed in a wall	5	0	5	Low
227	Sharland Shaft	Milner Shaft		Johannesburg	-26.21445	28.14779	######	10	3	100	30	Shaft	vertical	Shaft sealed with a concrete slab	0	5	5	Low
228	South Deep Shaft		Simmer & Jack	Johannesburg	-26.22651	28.14052	24/11/2004	4	4	20	16	Shaft	vertical	No safety measures.	0	5	5	Low
229	Start of Kimberley Reef Shaft	S&J No.1 Incline	Simmer & Jack	Ekhurleni	-26.2266	28.13986	24/11/2004	3	1.5	3	4.5	Shaft	Incline	Razor-wire erected around shaft, otherwise no stringent safety measures.	5	5	10	High
230	TD21	Hercules South	ERPM	Ekhurleni	-26.23904	28.23528	7/1/2005	11.3	11.3	100	127.69	Shaft	vertical	No safety measures	5	5	10	High
231	TD22	South East Shaft	ERPM	Ekhurleni	-26.24428	28.24360	6/1/2005	6	5	100	30	Shaft	vertical	Shaft still active	0	5	5	Low
232	TD25	Cinderella North East Shaft	ERPM	Ekhurleni	-26.14364	28.16092	6/1/2005	14	2.3	100	32.2	Shaft	vertical	Shaft still active	5	5	10	High
233	TD26	Hercules Shaft	ERPM	Ekhurleni	-26.22011	28.23326	6/1/2005	6	5	100	30	Shaft	vertical	Shaft still active	0	5	5	Low
234	TD28		ERPM	Ekhurleni	-26.13472	28.15388	6/1/2005	4.5	2.8	100	12.6	Subsidence			2	5	7	Medium
235	TD31	Central Vertical	ERPM	Ekhurleni	-26.22774	28.21965	6/1/2005	5	4	100	20	Shaft	vertical	Shaft still active	0	5	5	Low
236	TD35	Far East Vertical	ERPM	Ekhurleni	-26.25745	28.26141	6/1/2005	6	5	100	30	Shaft	vertical	Shaft still active	0	5	5	Low
237	TD40	South West Ventilation	ERPM	Ekhurleni	-26.21663	28.18363	6/1/2005	5	5	100	25	Shaft	vertical	Shaft still active	0	5	5	Low
238	TD41		ERPM	Ekhurleni	26.13199	28.16557	7/1/2005	2.8	2.2	100	6.16	Shaft	vertical	Shaft sealed with a concrete slab	0	5	5	Low
239	TD45	Cinderella East Shaft	ERPM	Ekhurleni	-26.13415	28.15559	7/1/2005	4.3	4.3	100	18.49	Shaft	vertical	Opening closed. Closure method	2	5	7	Medium

No.of holes	CGS Hole Name	Original Shaft Name	Area	Municipality	Latitude	Longitude	Date logged	Length (m)	Width (m)	Depth (m)	Area (m^2)	Hole Type	Incline	Safety Report	Hazard	Proximity	Priority Rating	Risk
														unknown				
240	West Gate Shaft	Worcester No.2 Shaft	Johannesburg	Johannesburg	-26.20934	28.03341	######	4	3	100	12	Shaft	vertical	Shaft enlosed in a wall	5	5	10	High
241	West Shaft		ERPM	Ekhurleni	-26.20021	28.20979	16/11/2004	15	15	17	225	Shaft		No safety measures	0	5	5	Low
242	West Shaft Incline Shaft		ERPM	Ekhurleni	-26.20023	28.20982	16/11/2004	5	5	17	25	Shaft	Incline	No safety measures	0	5	5	Low
243	Wilford Incline Shaft	Wilford Incline	DRD	Johannesburg	-26.16496	27.84966	7/7/2006	5	4	100	20	Shaft	Incline	Shaft closed	0	5	5	Low
244	Wilford Shaft		DRD	Johannesburg	-26.09832	27.51522	3/3/2006	5	5	100	25	Shaft		shaft closed	0	5	5	Low

APPENDIX G:

PHOTOGRAPHIC RECORD OF MINE OPENINGS


1.A006


2.A002


3.A004


4.A010a


5.Angelo Deep


6.Angelo Vent Shaft


7.B54a


8. Balmoral Hole


9.Balmoral 2 Vertical


10.Balmoral Ve


11.Benrose Shaft a


12. Chris Shaft


13.City Deep 1


14.City Deep 2


15.City Deep


16.City Deep 4


17.City Deep 5


18.Clement Shafta


19.CMR-R67B


20.CMR R6


21.CMR Central Shaft a


22.CMR East Shaft 23.CMR


23.CMR 10 Shafta 23.CMR

24.CMR 2 Shaft 24.C


25.CMR 4 Shafta 25.CM


26.CMR 8 shafta


27.CMR Old West shaft 27.CMR Old


28.CMR Old West shaft 28.CMR Old


29.CMR-R30 b


30.Crown Mine 12 Ventilation shaft b


31.Crown Mine Shaft b 31.Crown


32.Crown Mine 10 shaft a 32.Crown Mine


33.Crown Mine 11 shaft a 33.Crown Mine


34.Crown Mine 12 shaft b


35. Crown Mine 12 Incline

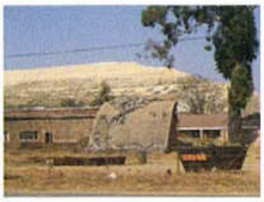

36.Crown Mine 13 Vertical shaft a


37.Crown Mine 14 Incline shaft b


38.Crown Mine 15 shaft a


39.Crown Mine 16 shaft b


40.Crown Mine 17


41.Crown Mine 17 Ventilation


42.Crown Mine 17 Vertical shaft a


43.Crowr Mine 2 shaftine 2 shaft


44.Crown Mine 3 shaft


45.Crown Mine 4


46.Crown Mine 5 shaft a


47.Crown Mine 6 shaft


48.Crown Mine 7 shaft


49.Crown Mine 8 shaft


50.drd 3


51.DRD Bitcom incline shaft a


52.DRD Bitcom Shaft


53.DRD Bitcom ventilation shaft a


54.DRD Hole,a


55.DRD Hope


56.DRD Monaliza shaft


57.DRD 1a


58.DRD 1 vertical shaft a


59.DRD 2 vertical shaft


60.DRD 3 vertic


61.drd 4


62.DRD 4 incline shaft incline shaft a


63.DRD 4 vertical shaft a


64.DRD 5 shafte


65.drd 7


66.drd 8


67.DRD 9 vertical shaftrtical shaft


68.DRD ... nkla Shaft


69.drd 2


70.East


71.ERPM58


72. ERPM 59


73.ERPM60


74.ERPM 63


75.ERPM32


76.erpm1


77.ERPM12b


78.erpm13


79.ERPM14b


80.ERPM15


81.ERPM16b


82.erpm17


83. ERPM18


84.ERPM18A


85.ERPM19


86.erpm2


87.erpm20


88.erpm21


89.erpm22


90.erpm23


91.erpm24

92.ERPM24xa


93.ERPM25A


94.ERPM26b


95.erpm27


96.ERPM28A


97.erpm29


98.ERPM3A


99.erpm30


100.erpm3


101.erpm32


102.ERPM32Ya


103.ERPM32Za


104.ERPM33a


105.ERPM3

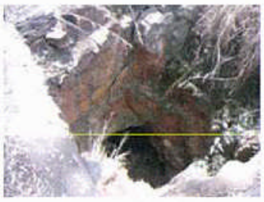

106.ERPM34X


107.erpm35


108.erpm36


109.ERPM36X


110.ERPM3


111.ERPM37a


112.ERPM37X


113.ERPM37Y


114.ERPM37Z


115.erpm3


116.ERPM38X


117.erpm39


118.ERPM4A


119.erpm40


120.erpm4


121.erpm42


122.erpm43


123.erpm44


124.erpm45


125.erpm4


126.erpm47


127.erpm48


128.erpm49


129.ERPM5A


130.erpm5


131.ERPM51a


132.ERPM52d


133.ERPM53a


134.ERPM54a


135.ERPM5


136.ERPM56a


137.ERPM57a


138.ERPM6b


139.ERPM 61


140.Erpm7


141.ERPM9b


142.ERPM 64


143.F004 Shaft


144.F008 Shaft


145.geldenhuis


146.Geldenhuis 2


147. Gosforth Hole


148.Gosforth Incline Shaft


149. Haggie Shaft


150.Knights S


151.LL Main 2


152.LL Main 3


153.LL Main 4


154.LL Main 5


155.LL Main


156.LL Main 7


157.LL Main Shaft B


158.Langlaagte shaft d


159.LL West Deep


160.Macro Sl


161. Memorial 1


162. Memorial 2


163. Memorial 3


164. Old Wits Vertical Shaft


165.Pencil P


166. Private no.1 shaft


167. Private no.2 shaft


168. R39


169. R41


170. R42


171. R43


172. R44


173. R45


174. R49


175. R50


176. R51


177. R52


178. R53


179.R56


180. R58


181. R 58A


182. R59


183. R59A


184. R60


185. R61


186. R62


187. R 62 East


188. R 62 West


189. R63


190. R64


191. R65


192.R68


193.R69


194. Rand Leases Adit


195. Rand leases n


196. Rand Leases 4 Incline


197. RD01E


198. RD02E


199.Roode5A


200.Roode5


201.Roode5C


202. Roode5D


204. Roodepoort no.1


205 Roodepoort no.2


206. Roodepoor


207. Roodepoort no.4


208. poort no.4
Roodepoort shaft


209.Roodepoort no. 6


210. Rose Deep no.2


211. Roode


212. S&J11


213. S&J12


214. S&J 15


215. S&J16


216.S&J 16 Ir


217. S&J 17


218. S&J 18


219. S&J 20


220. S&J 21


221. S&J 2


222. S&J 24


223. S&J 25


224.S&J 8


225. S&J 9


226. S&J 1


227. [illegible]land Shaft


228. South Deep Shaft


229. Start of Kimberly Reef Shaft


230. TD21


231. TD2


232. TD25


233. TD26


234. TD28


235. TD31


236. TD3


237. TD40


238. TD41


239. TD45


240. WestGate Shaft


241. West s

APPENDIX H:

HISTORICAL METHODS USED TO SEAL MINE OPENINGS

Closure Methods of 'Previously Closed' Mine Openings			
Central Basin			
No.of holes	**CGS Hole Name**	**Original Shaft Name**	**Closure Method**
1	A006		Backfill
2	A002	No original opening name	Backfill
3	A004	No original opening name	Backfill
4	Angelo Deep Shaft	Angelo Deep Shaft	Backfill
5	Angelo Ventilation Shaft	Angelo Ventilation shaft	Backfill
6	Benrose Shaft	Worhuter Shaft	Wall
7	Chris Shaft	Chris Shaft	Backfill
8	City Deep no.1 Shaft	City Deep No.3 Vertical	
9	City Deep no.2 Shaft	City Deep No.4 Shaft	Wall
10	City Deep no.4 Shaft	City Deep No.5 Shaft	Wall
11	City Deep no.5 Shaft	Worcester N0.1 Shaft	slab
12	Clement Shaft	Clement Shaft	Backfill
13	CMR - R 67B		
14	CMR Central Shaft	CMR Central shaft	
15	CMR no.10 Shaft	CMR No.10 shaft	Backfill
16	CMR no.2 Shaft	CMR No. 2 shaft	slab
17	CMR no.4 Shaft	No.4 Compound Shaft	Backfill
18	CMR no.8 Shaft	CMR No. 8 shaft	Backfill
19	Crown Mine 12 Ventilation	Crown Mine 12 Ventilation	Wall
20	Crown Mine no.10 Shaft	Crown Mine No. 18 West shaft	slab
21	Crown Mine no.11 Shaft	Crown Mine No.16 Ventilation shaft	Wall
22	Crown Mine no.12		
23	Crown Mine no.12 Incline Shaft	Crown Mine 12 Incline	Backfill
24	Crown Mine no.14 Shaft	Crown Mine No. 10 Incline	Backfill

Closure Methods of 'Previously Closed' Mine Openings			
Central Basin			
No.of holes	**CGS Hole Name**	**Original Shaft Name**	**Closure Method**
		shaft	
25	Crown Mine no.15 Shaft	Crown Mine no.7 shaft	Plug
26	Crown Mine no.16 Shaft		slab
27	Crown Mine no.17 Shaft	Crown Mine no. 14 shaft	Plug
28	Crown Mine no.17 Ventilation Shaft	Crown Mine 17Ventilation	slab
29	Crown Mine no.17 Vertical Shaft	Crown Mine 17Vertical	slab
30	Crown Mine no.2 Shaft	Crown Mine No. 18 Ventilation shaft	Wall
31	Crown Mine no.3 Shaft		Backfill
32	Crown Mine no.4		Backfill
33	Crown Mine no.5 Shaft	Crown Mine No. 1 shaft	slab
34	Crown Mine no.6 Shaft	Crown Mine No. 5 shaft	slab
35	Crown Mine no.7 Shaft	Crown Mine No.3 shaft	
36	Crown Mine no.8 Shaft	Crown Mine No. 16 Vertical shaft	slab
37	DRD 3 Vertical	DRD No.3 Vertical shaft	
38	DRD Bitcom Incline Shaft	DRD Bitcom Incline shaft	Plug
39	DRD Bitcom Shaft	DRD Bitcom Shaft	Backfill
40	DRD Bitcom Ventilation Shaft	DRD Bitcom Ventilation shaft	Backfill
41	DRD Hole		
42	DRD Hope Shaft	DRD Hope shaft	Backfill
43	DRD Monaliza Shaft	DRD Monaliza shaft	Backfill
44	DRD no.1 Shaft	DRD Greatbrittan incline shaft	Backfill
45	DRD no.1 Vertical Shaft	DRD No. 1 Vertical shaft	Backfill
46	DRD no.2 Vertical Shaft	DRD No. 2 Vertical shaft	Backfill

Closure Methods of 'Previously Closed' Mine Openings			
Central Basin			
No.of holes	**CGS Hole Name**	**Original Shaft Name**	**Closure Method**
47	DRD no.3 Shaft	DRD No. 07 Shaft	Wall
48	DRD no.5 Shaft	DRD N0.5 shaft	Backfill
49	DRD no.7	DRD No. 6 shaft	slab
50	DRD no.8	DRD No. 9 shaft	Backfill
51	DRD Tinkla Shaft	DRD Tinkla shaft	Backfill
52	East Memorials Shaft	LL Proprietry Incline shaft	
53	ERPM 58		fence
54	ERPM 59		Plug
55	ERPM 60		fence
56	ERPM 63		fence
57	ERPM1	Shaft	Backfill
58	ERPM2	Shaft	Backfill
59	ERPM22		Backfill
60	ERPM23		Backfill
61	ERPM26		Backfill
62	ERPM27		Backfill
63	ERPM29		
64	ERPM3	Shaft	Backfill
65	ERPM30		
66	ERPM31		
67	ERPM33		Backfill
68	ERPM39		Backfill
69	ERPM4	No.1 South Shaft	Backfill
70	ERPM40		Backfill
71	ERPM41		Backfill
72	ERPM42		Backfill
73	ERPM43		Plug
74	ERPM44		Plug
75	ERPM45		Plug
76	ERPM46		Plug
77	ERPM47		Plug
78	ERPM48		Plug
79	ERPM49		Plug
80	ERPM5	No.1 Incline Shaft	Backfill
81	ERPM50		Plug
82	ERPM54		Backfill
83	ERPM61		Plug
84	ERPM7	Cason Shaft	Fence
85	F004 Shaft		Backfill
86	F008 Shaft		Backfill
87	Haggie Shaft	Howard shaft	slab

Closure Methods of 'Previously Closed' Mine Openings			
Central Basin			
No.of holes	**CGS Hole Name**	**Original Shaft Name**	**Closure Method**
88	Langlaagte West Deep Shaft	LL West Deep	Backfill
89	Macro Shaft		Plug
90	Private no.1 Shaft		slab
91	R53		Plug
92	R60		Backfill
93	Rand Leases no.4 Incline Shaft	Rand Leases No.7 Shaft	slab

APPENDIX I:
SRK CONCRETE PLUG DESIGN
(COUNCIL FOR GEOSCIENCE, 2007)

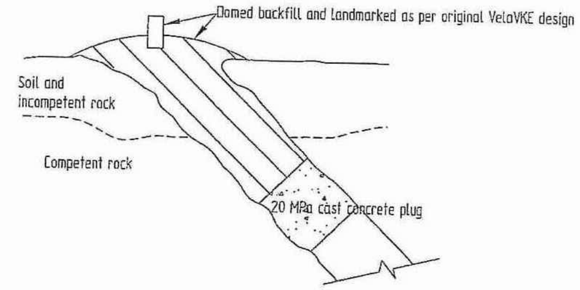


Figure 1: **Decline shaft plug configuration.**

1.2 Vertical shafts

The proposed alternative entails the in-situ construction of a monolithic parallel sided concrete plug in the shaft (Figure 2). The plug will consist of un-reinforced 20 MPa in-situ cast concrete. The plug will be located in competent rock and will be constructed as follows. The rock sidewalls will be barred down and cleaned at the plug site. Shuttering will be suspended from surface onto which a 300 mm thick concrete slab will be cast. This slab will be allowed to cure until a cube strength of no less than 25MPa is reached where after a 600 mm thick slab will be cast onto it and allowed to cure until a cube strength of 25MPa is reached. A mass concrete plug will be cast onto the hardened concrete slabs. These slabs will be able to carry up to 3 m of wet plug mass concrete. The shaft will then be backfilled above the plug to surface with soil.

Both the 300 mm and 600 mm slabs will be reinforced to ensure strength during subsequent construction phases

In cases where the vertical shaft has been fitted with a shaft lining, the plug will be keyed into the original shaft lining provided that the shaft liner is able to transfer the self weight of the plug and imposed loads to the surrounding rock or soil (Figure 3).

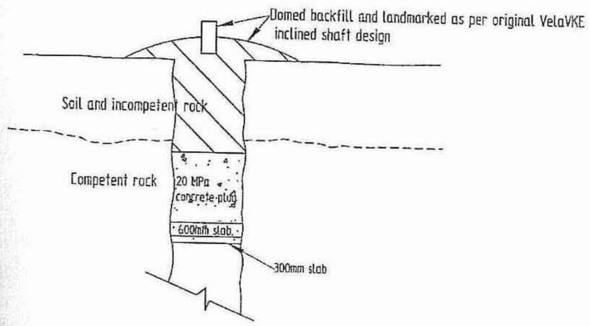


Figure 2: **Plug configuration in vertical shaft without shaft lining.**

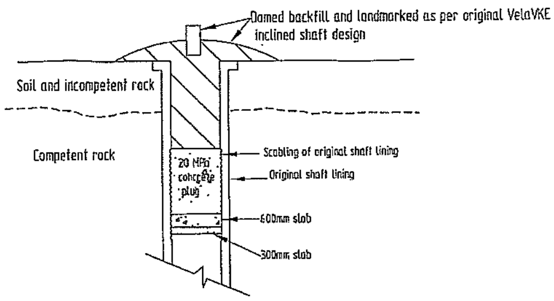


Figure 3: **Plug configuration in vertical shaft with shaft lining.**

2 Assessment of the proposed alternatives

The proposed alternative plug construction method is robust and easily executable. Parallel sided plugs have proven successful in the past under extreme conditions. Recently, parallel sided plugs have been constructed at South Deep and have been designed to withstand 15 MPa of water pressure.

The original proposal makes use of a 0.5 m deep slot in the rock to provide bearing resistance for the slab type plug which is expected to be adequate. The excavation of a slot is, however, considered not to be practical. The plugs being monolithic mass concrete structures, utilise the shear strength of the concrete and surrounding rock. In-situ roughness of mined openings are sufficient to prdvide necessary shearing resistance.

An estimate of the shearing resistance of the concrete rock interface can be evaluated using the work on the shaft resistance of rock socketed piles by Williams et al. (1980) (Figure 4). Assuming a conservative lower bound unconfined compressive strength of the rock at 1MPa, provides a side resistance reduction factor of approximately 0.45, resulting in a shear strength of 0.45 MPa. For a 2 m x2 m tunnel, this will result in a resistance of 3.6 MPa per meter length of the plug.

APPENDIX J:

MATERIAL QUANTITIES

FOR INSTALLING CONCRETE PLUGS IN CENTRAL BASIN MINE OPENINGS

COUNCIL FOR GEOSCIENCE (2007)

No.	Contract Ref. No.	Start Date	Finish Date	Method Used	Lined Shaft	Unlined Shaft	Conc. Qty m3	H1(m)	L2(m)	L1(m)	D1(m)	W1(m)	H2(m)	D2(m)	W2(m)	H1+D1	h2+d2
1	BAL1	6/20/2006	7/27/2006	Vertical Plug		X	54	5	3	4	4.5					**9.5**	**0**
2	BALVert	6/20/2006	7/15/2006	Vertical Plug		X	30	5	3	3	3.5					**8.5**	**0**
3	Cons Mod	31/7/2007	16/9/2007	Vertical Plug	X		159	3	5.5	3.5	7					**10**	**0**
4	DRD BC (Bit Com)	12/3/2007	3/4/2007	Inclined Unlined		X	28					2.5	3	3.1	3	**0**	**6.1**
5	ERMP-21	5/15/2006	5/19/2006	Incline Plug		X	18			3			3	2	2	**0**	**5**
6	ERPM 57 (Cent. 1)	14/7/2007	22/7/2007	Inclined Lined		X	38					1.8	3.75	2.75	3	**0**	**6.5**
7	ERPM 59 (Cent. 2)	14/7/2007	22/7/2007	Inclined Lined		X	37					1.9	3.3	3.7	3.3	**0**	**7**
8	ERPM16	5/24/2006	6/6/2006	Incline Plug		X	24		6				3	2	2	**0**	**5**
9	ERPM-17	4/6/2006	9/19/2006	See Note 1												**0**	**0**
10	ERPM-18	4/6/2006	6/24/2006	Incline Plug		X	108		8				31	2	6.75	**0**	**33**
11	ERPM-18 A	4/6/2006	6/24/2006	Incline Plug		X	72		6				3	2	6	**0**	**5**
12	ERPM-20	5/15/2006	5/19/2006	Incline Plug		X	32		5.3				3	2	3	**0**	**5**
13	ERPM32	5/25/2006	5/6/2006	Incline Plug		X	24		6				2	2	2	**0**	**4**
14	ERPM32A	5/25/2006	5/6/2006	Incline Plug		X	29		7				2	2.1	2	**0**	**4.1**
15	ERPM32B	5/25/2006	5/6/2006	Incline Plug		X	32		5.3				2	3	3	**0**	**5**
16	ERPM-51	4/6/2006	4/21/2006	Incline Plug	X		24			4			3	2	3	**0**	**5**
17	ERPM-52	4/6/2006	4/21/2006	Incline Plug		X	26			4.3			3	2	3	**0**	**5**
18	ERPM-55	4/6/2006	5/4/2006	Conc.Slab			102	0		17				0.5	12	**0**	**0.5**
19	ERPM-56	4/6/2006	4/21/2006	Incline Plug		X	43			4			3	3	3.5	**0**	**6**
20	Geld 2	2/7/2007	19/7/2007	Vertical Plug	X		90	2.5	2.4	10	2.4					**4.9**	**0**
21	Geld A	10/4/2007	17/6/2007	Vertical Plug		X	55	2	2.8	4.8	3					**5**	**0**
22	Geld B	10/4/2007	17/6/2007	Inclined Unlined		X	100					2	5.3	6.3	3	**0**	**11.6**
23	Geld C	10/4/2007	17/6/2007	Inclined Unlined		X	145					2	5.3	5.5	5	**0**	**10.8**
24	Geld D	10/4/2007	17/6/2007	Inclined Unlined		X	9					2	2	2.4	2	**0**	**4.4**
25	Geld E	10/4/2007	17/6/2007	Inclined Unlined		X	287					2	9.9	5.8	5	**0**	**15.7**
26	Geld F	10/4/2007	17/6/2007	Inclined Unlined		X	34					2	3.8	3	3	**0**	**6.8**
27	Geld G	10/4/2007	17/6/2007	Inclined Unlined		X	51					2	4.5	3.8	3	**0**	**8.3**
28	Geld H	10/4/2007	17/6/2007	Inclined Unlined		X	110					1.8	5.5	4.8	4.1	**0**	**10.3**
29	Geld I	10/4/2007	17/6/2007	Inclined Unlined		X	4					1	1.5	1.5	1.5	**0**	**3**
30	Geldenhuys	6/26/2006	23-Jul-06	Vertical Plug	X		56	5.1		8.75	2	3.2				**7.1**	**0**
31	Gos Inc.	16/4/2007	25/6/2007	Inclined Lined	X		27					2.5	3	3	3	**0**	**6**
32	Gos Inc. 1	16/4/2007	25/6/2007	Inclined Lined	X		27					2.4	2.5	2.5	4.3	**0**	**5**
33	Knights	5/18/2006	5/23/2006	Vertical Plug	X		36	4		4.4	1.8	4.5				**5.8**	**0**
34	Langlaagte Main	8/15/2006	9/2/2006	Incline Plug		X	18		3				3	3	2	**0**	**6**
35	Langlaagte Main 1	8/21/2006	9/2/2006	Incline Plug		X	18		3				3	3	2	**0**	**6**
36	LL 4	20/3/207	3/4/2007	Inclined Unlined		X	31	3	3.4	3	3					**6**	**0**
37	LL2	20/3/207	3/4/2007	Inclined Unlined		X	23	2	3.2	2.4	3					**5**	**0**
38	LL2A	20/3/207	3/4/2007	Inclined Unlined		X	28	1.9	2.9	2.9	3.3					**5.2**	**0**
39	LL3	20/3/207	3/4/2007	Inclined Unlined		X	8	2	2	2	2					**4**	**0**
40	LL3 B	20/3/207	3/4/2007	Inclined Unlined		X	14	3.7	1.8	2.1	3					**6.7**	**0**
41	LL3A	20/3/207	3/4/2007	Inclined Unlined		X	32	2	2.5	5	2.6					**4.6**	**0**
42	LL5	20/3/207	3/4/2007	Inclined Unlined		X	17	2	4	1.8	2.4					**4.4**	**0**
43	LL6	20/3/207	3/4/2007	Inclined Unlined		X	44	3	4	3.7	3					**6**	**0**
44	LL7	20/3/207	3/4/2007	Inclined Unlined		X	44	3	4.2	3.5	3					**6**	**0**
45	OWS	27/7/2007	28/8/2007	Vertical Plug		X	144	4	9	4	4					**8**	**0**
46	Pencil Park	7/15/2006	9/5/2006	Vertical Plug		X	42	5.8		7	2	3				**7.8**	**0**

No.	Contract Ref. No.	Start Date	Finish Date	Method Used	Lined Shaft	Unlined Shaft	Conc. Qty m3	H1(m)	L2(m)	L1(m)	D1(m)	W1(m)	H2(m)	D2(m)	W2(m)	H1+D1	h2+d2
47	Private 2	7/17/2006	9/5/2006	Vertical Plug	X		65	6		8.1	2	4				**8**	**0**
48	Pvt 2 A	20/3/207	3/4/2007	Inclined Unlined		X	11	2	3	1.9	2					**4**	**0**
49	R50	5/24/2006	6/7/2006	Incline Plug		X	18		4.1			2		2.4	1.8	**0**	**2.4**
50	R51	5/24/2006	6/7/2006	Incline Plug		X	18		4.1			2		2.4	1.8	**0**	**2.4**
51	R55 / R55A	5/24/2006	6/7/2006	Incline Plug		X	18		4.1			2		2.4	1.8	**0**	**2.4**
52	R58	6/7/2006	5/25/2006	Incline Plug		X	24		4				2	3	2	**0**	**5**
53	R58 A	5/28/2006	6/28/2006	Incline Plug		X	24		4				2	3	2	**0**	**5**
54	R59	6/7/2006	7/10/2006	Incline Plug		X	24		4				2	3	2	**0**	**5**
55	R59A	7/17/2006	7/20/2006	Incline Plug		X	18		4.5				2	2	2	**0**	**4**
56	R62	7/3/2006	7/25/2006	Incline Plug		X	42		3.5				3	3	4	**0**	**6**
57	R62E	7/3/2006	7/26/2006	Incline Plug		X	24		4				3	3	2	**0**	**6**
58	R62W	7/3/2006	7/26/2006	Incline Plug		X	24		4				3	3	2	**0**	**6**
59	RO 1	19/2/2007	9/3/2007	Vertical Plug	X		30	2	3.6	1.6	5.2					**7.2**	**0**
60	RO 2	19/2/2007	9/3/2007	Vertical Plug	X		16	1.8	1.8	2.8	3.2					**5**	**0**
61	RO 3	19/2/2007	9/3/2007	Vertical Plug		X	78	2	8	3	3.1					**5.1**	**0**
62	RO 4	19/2/2007	9/3/2007	Vertical Plug	X		24	2	2	5	2.4					**4.4**	**0**
63	RO 5	19/2/2007	9/3/2007	Inclined Unlined		X		63	2.6	8	3.1					**66.1**	**0**
64	RO 5 A	19/2/2007	9/3/2007	Inclined Unlined		X	12	2	2.5	2	4.8					**6.8**	**0**
65	RO 5 B	19/2/2007	9/3/2007	Inclined Unlined		X	19	2	3.3	2.4	2.4					**4.4**	**0**
66	RO 5 C	19/2/2007	9/3/2007	Inclined Unlined		X	36	2	3	4	3					**5**	**0**
67	RO 5 D	19/2/2007	9/3/2007	Inclined Unlined		X	169	3	6	9.4	3					**6**	**0**
68	RO 5 E	19/2/2007	9/3/2007	Inclined Unlined		X	86	3	5.4	4	4					**7**	**0**
69	Roode 6	12/3/2007	3/4/2007	Inclined Unlined		X	58.5					2.7	5	3.9	3	**0**	**8.9**
70	Roode 6 A	23/7/2007	21/8/2007	Unlined Incline		X	46					1.6	3.4	3.5	4	**0**	**6.9**
71	Rose Deep 2	5/29/2006	6/10/2006	Vertical Plug		X	30	4		4.4	1.8	3.8				**5.8**	**0**
72	SJ 11	10/4/2007	17/5/2007	Inclined Lined	X		20					1.8	5	2	2	**0**	**7**
73	SJ 15 B	25/6/2007	25/7/2007	Vertical Plug	X		9	1.5	3	1.4	2.1					**3.6**	**0**
74	SJ 8	10/4/2007	17/5/2007	Vertical Plug	X		20	2	4.9	2	2					**4**	**0**
75	SJ-15	5/4/2006	6/24/2006	Incline Plug	X		108	2		10.2			32	3.5	3	**2**	**35.5**
76	SJ-15A	4/6/2006	4/16/2006	Incline Plug	X		36		2				33	4	4	**0**	**37**
77	SJ-16	5/4/2006	6/24/2006	Incline Plug		X	42									**0**	**0**
78	SJ-18	7/12/2006	8/23/2006	Vertical Plug		X	68	3.5		9.7	3.5				2	**7**	**0**
79	WEST	4/6/2006	5/4/2006	Vert .Plug		X	51	5.5		6	1.8	4.7				**7.3**	**0**
80	WEST INCL	4/6/2006	5/4/2006	Incline Plug		X	53			6.4			5.5	2	4.1	**0**	**7.5**
																0	**0**
																0	**0**
																0	**0**