MSc RESEARCH REPORT

SCHOOL OF MINING ENGINEERING

Review of techniques for identification of underground bord and pillar workings

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A research report submitted to the Faculty of Engineering and Built Environment, University of the Witwatersrand, Johannesburg, in the partial fulfilment of the requirements for the degree of Master of Science in Engineering.

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DECLARATION

I, Ganasen Loganathan Govender, Student Number 0515803W, declare that this research report is my own work except as indicated in the references, research carried out with suppliers and acknowledgements. It is submitted in partial fulfilment of the requirements for the degree of Master of Science in Engineering (Mining) at the University of the Witwatersrand, Johannesburg. It has not been submitted before for any degree or examination in this or any other university.

Ganasen Loganthan Govender

Signed at Witbank

On the 26th day of January 2018

ABSTRACT

The higher quality virgin coal resources in the Witbank Coalfield are near completion, hence new methods of mining the underground coal pillars that have been left insitu as primary support becomes attractive to mine using opencast methods. Up until 2006 more than three million pillars have been created (van der Merwe, 2006) and have been growing since. There are various challenges associated with pillar extraction via opencast mining method. These challenges relate to spontaneous combustion, underground water and the exact spatial location of underground pillars that have been mined in the early to mid-1900. The reliability of old underground mine plans pre-1960, before the Coalbrook disaster, saw underground pillars not being offset which resulted in unreliable survey plans (van der Merwe, 2006). This report focuses on possible techniques that can be used to identify underground pillars where no water and no spontaneous combustion are evident. The following two methods have been tested: Ground Penetrating Radar (GPR) technique which is based on geophysics and a down the hole 3D laser method using the Cavity, Auto-scanning, Laser System (CALS Tool) which uses reflectorless principles to measure the geometries of the underground pillars. The GPR did not provide any conclusive data, whilst the CALS Tool provides detailed information of the workings. The CALS Tool is not practical to identify every single pillar in a reserve but can be used on a larger extent as a short term mine planning mechanism. The CALS Tool proved to have the ability to identify the spatial location of the underground workings as confirmed by the test done at TOC.

DEDICATION

I dedicate this to my loving wife, Pamela, and my son, Aiden, in supporting me through this journey.

ACKNOWLEDGEMENTS

Firstly, I would like to thank God for giving me the strength and courage in pursuing this research.

Thanks to the TOC Management, Mining, Mine Planning and Survey disciplines for venturing on this journey.

A special thank you to my supervisor Kelello Chabedi in guiding me in this research and CSIR and other suppliers who opted to assist with the research on their available equipment and interest in the challenges.

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NOMENCLATURE

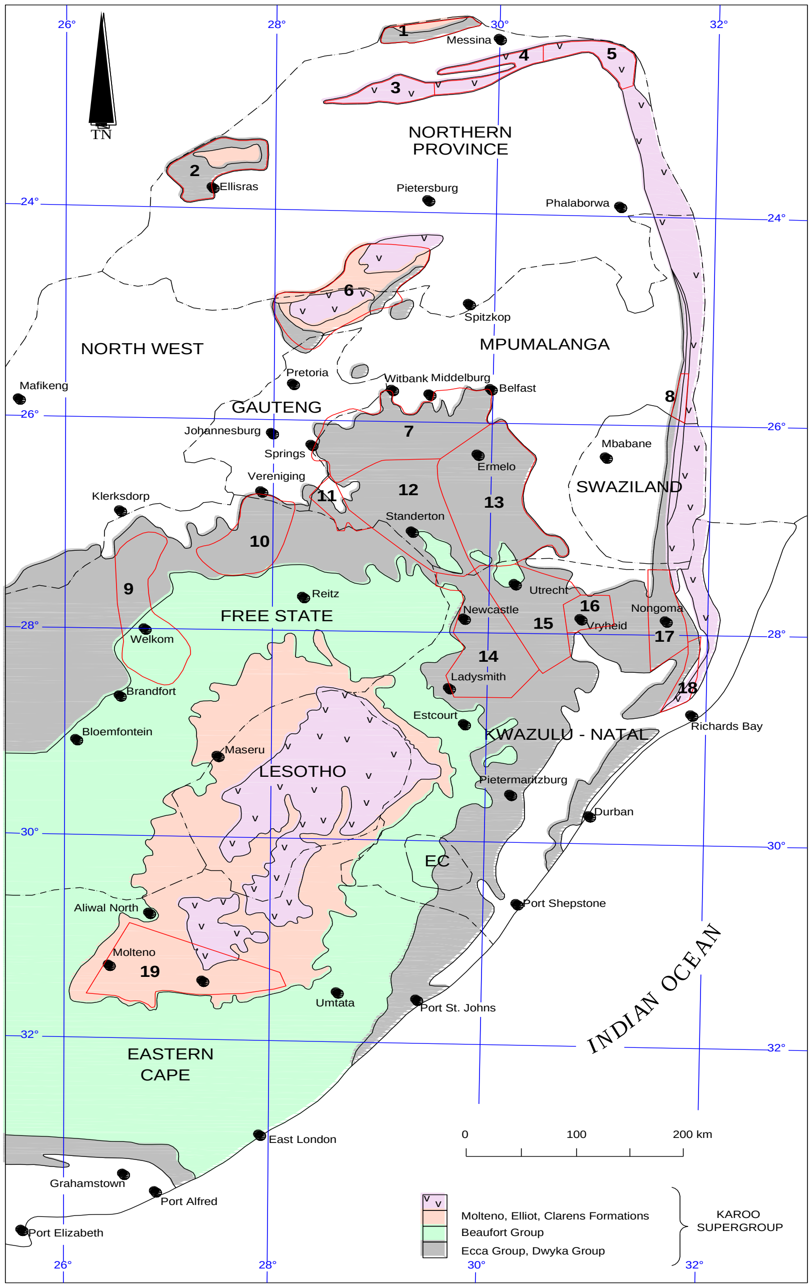
3D	Three dimensional
CALS Tool	Cavity, Auto-scanning, Laser System
GGV	Goedgevonden Complex
GPR	Ground pentrating radar
GCSA	Glencore Coal South Africa
iMpunzi	IMpunzi Complex
LOM	Life of Mine
MHz	Mega Hertz
MJ/Kg	Mega Joules per kilogram
Mt	Million tonnes
Mtpa	Million tonnes per annum
ROM	Run of mine
TOC	Tweefontein Opencast
t	Tonnes
Tweefontein	Tweefontein Complex
WISH	Windows Interpretation System for Hydrologist

1 INTRODUCTION

1.1. General

There has been no clear evidence on when the first coal was mined in the Witbank Coalfields (shown as No. 7 in **Figure 1-1**) in the Mpumalanga Province (Hancox & G¨otz, 2014). However, underground mining using bord and pillar method started in 1889 and has been the predominant method used for mining coal due to lack of suitable technology (King & Min, 1980). Small-scale opencast mining also started in 1889 with the first large opencast introduced in 1971 at Optimum Colliery using a dragline machine (Falconer, 1990). The Witbank Coalfield has practiced both underground and opencast mining for over 125 years. The average extraction for mining underground coal using bord and pillar is roughly 60% (van der Merwe & Mathey, 2013), meaning that for every 60t of coal extracted 40t are still left in the form of pillars.

Underground pillar extraction in South Africa was introduced in 1973 (Flint, 1984), with Glencore Coal South Africa (GCSA) still carrying out underground pillar extraction in two of their underground mines during 2009 to 2015. The total amount of coal left in coal pillars within South Africa is in the region of 600Mt (van der Merwe, 2006). It is not surprising that GCSA has considered underground pillar extraction in the recent years. GCSA mines approximately 36Mtpa from their underground and surface operations.



xstrata coal

xtrata coal south africa limited

COALFIELDS OF SOUTH AFRICA

1. Tuli, 2. Ellisras, 3. Mopane, 4. Tshipise, 5. Pafuri, 6. Springbok Flats, 7. Witbank, 8. Kangwane, 9. Free State, 10. Vereeniging-Sasolburg, 11. South Rand, 12. Highveld, 13. Ermelo (formely Eastern Transvaal), 14. Klip River, 15. Utrecht, 16. Vryheid, 17. Nongoma, 18. Somkele, 19. Molteno-Indwe

Figure 1-1: Coal fields of South Africa (Jeffrey, 2005)

GCSA has identified three (3) large opencast mines consisting of, iMpunzi Complex (iMpunzi), Goedgevonden Complex (GGV) and Tweefontein Complex (Tweefontein) as potential mines to improve on the Life of Mine (LOM) for the group. These mines were previously mined by underground bord and pillar methods and are now considered to be exploited using opencast methods.

Figure 1-2 shows the geographical locations of the three complexes and proximity to each other. The three large opencast mines are indicated by an inset in the rectangular block in the north-western portion of the map.

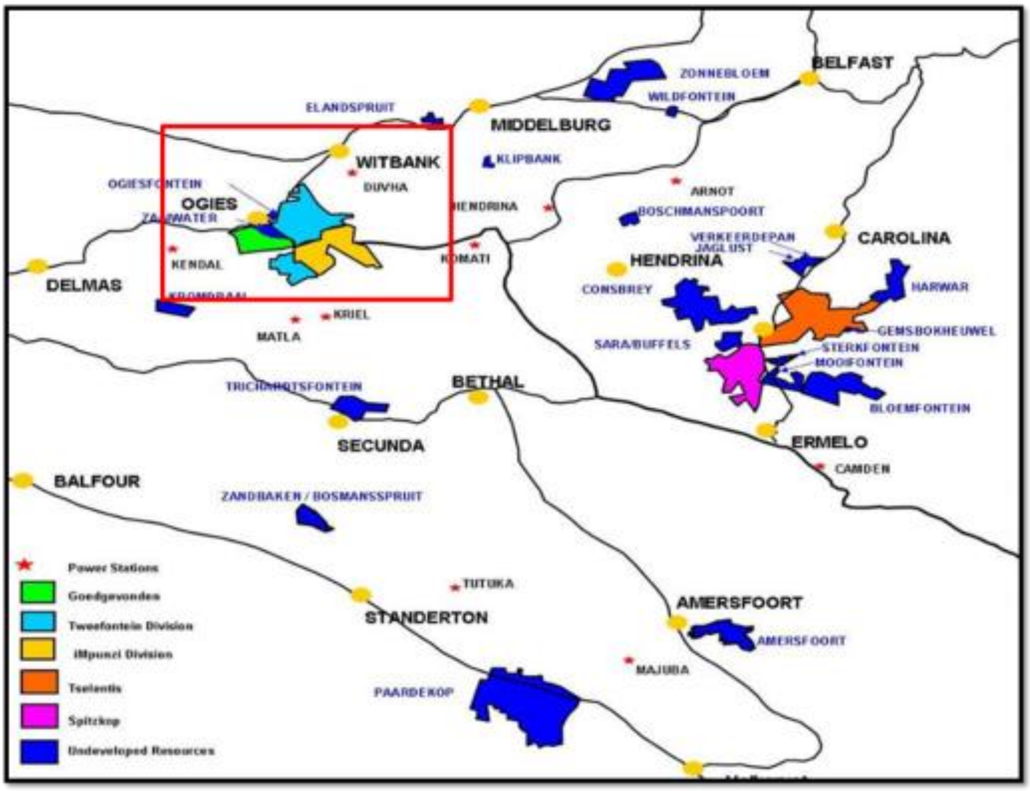


Figure 1-2: Geographically location of the 3 Glencore Complexes

(Tweefontein Opencast Colliery, 2015)

The purpose of this project report is to investigate how the underground pillars at GCSA opencast mines can be identified using ground penetrating radar (GPR) or down the hole technology such as cavity auto scanning laser system (CALS Tool) and later mined by opencast mining methods.

Table 1-1: Measured Resource and Extractable Reserves, adapted from (Glencore, 2014)

Complex	Measured Coal Resources (Mt)	Extractable Coal Reserves (Mt)
Impunzi	430	182
Goedgevonden	530	320
Tweefontein	730	210
Total	1690	712

Table 1-1 shows the total measured resources and extractable reserves for the three opencast operations. A measured resource is based on the information obtained from geological exploration drilling and infill geological drilling. The information obtained is then used to create a model of all the characteristics of the resource, coal in this case. The geological holes must be adequately spaced to ensure a high level of confidence in the geological model which will then be used to create a mine plan (SAMREC, 2009).

The extractable reserve is a mineable reserve that takes into account various modifying factors such as surface water bodies where no mining is allowed to take place unless approved, thin seams that are not economically viable to mine and various characteristic cut offs.

In 2014, GCSA produced 34.4 million tons per annum (Mtpa) Run of Mine (ROM) tonnes from all the mining operations in South Africa. The export coal produced was approximately 9.6Mtpa and the coal supplied to local domestic market was about 9.4Mtpa and the balance of the coal (15.4Mt) was discarded onto dumps (Glencore, 2014).

1.2. The problem and its setting

Figure 1-3 is a plan of mining at Tweefontein and it depicts the extent of underground mining at the Tweefontein Opencast (TOC) that has taken place from the 1930's.

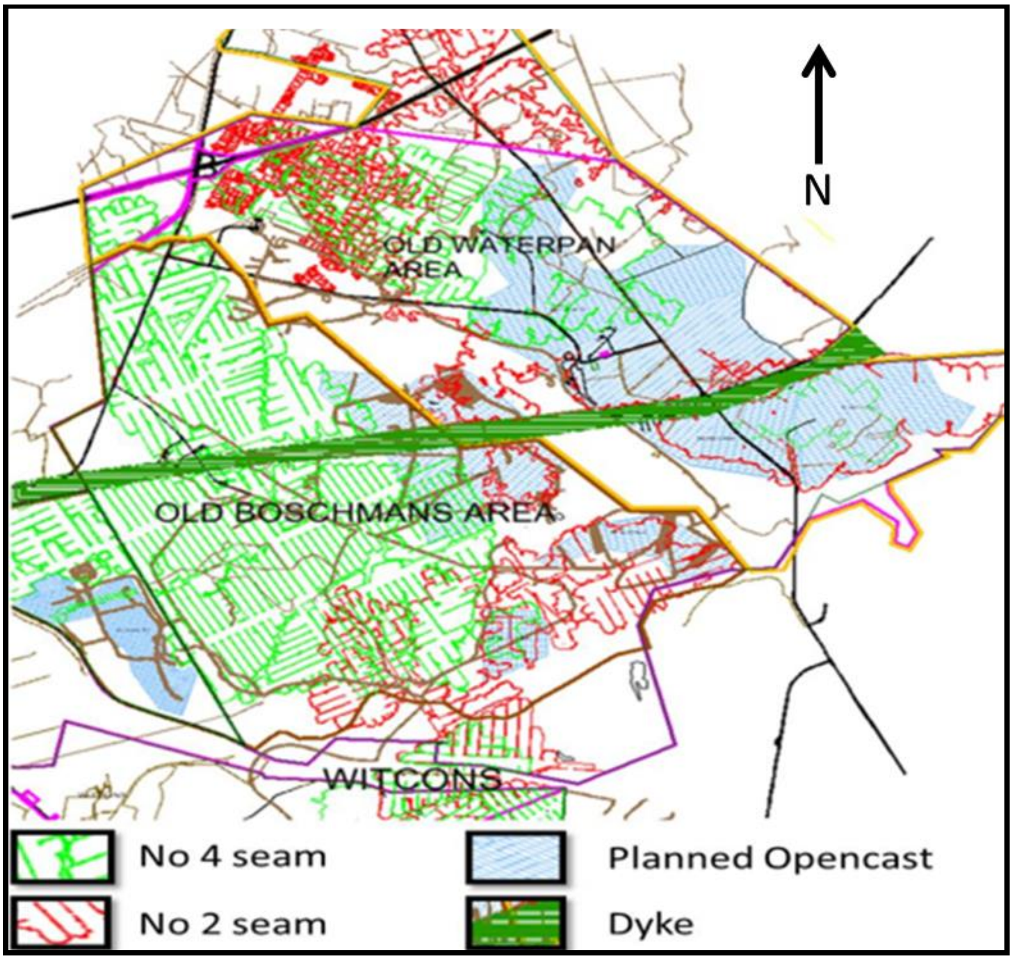


Figure 1-3: Mine Plan at TOC (Tweefontein Opencast Colliery, 2015)

Figure 1-3 shows two areas that are likely to be mined to extend the LOM at Tweefontein by mining underground workings (Tweefontein Opencast Colliery, 2015). The two areas considered for mining are the Old Waterpan area towards the north and the Old Boschmans area towards the south separated by a dyke. The dyke is about 30m wide and is called the Ogies Dyke. Currently, there are three opencast pits that are in operation and three pits are in a ramp up phase. The red outlines indicate areas where the No 2 seam coal has been mined using bord and pillar methods. The majority of the No 2 seam was mined using drill and blast methods. The lighter green markings show the extent of No 4 seam coal which was mined by continuous miners in the Old Boschmans area as well as drill and blast methods in the Old Waterpan area. As described earlier all opencast mining within the TOC plan has encountered underground pillars left when bord and pillar was used.

TOC is a brownfield project that has currently completed the project phase and is currently in its ramp up phase. TOC is planning to produce 12Mtpa of ROM according to the company’s 5-year plan. TOC, during most of the LOM will be mining three pits at a time, two of which will be truck and shovel operations and the third a dragline operation.

Tweefontein has kept records of mining which has commenced as early as 1894 up until the merger with Glencore Xstrata in 2012, as presented in **Table 1-2**. The areas that are planned to be mined date back to the early 1930’s. Tweefontein has undergone various management changes and during the change of ownership plans got lost, mislaid and damaged. When management changed, in most cases, surveyors were also changed leading to changes in the survey system used as deduced from the old plans inspected at Tweefontein. van der Merwe & Mathey, (2013) noted that survey plans from the first half of the twentieth century were very unreliable and not correct. The unreliability of these plans resulted in underground pillars being either over or underestimated during mining and later on the mine planning phase of the opencast reserves.

Table 1-2: The Life of Mining within Tweefontein Complex (Tweefontein Opencast Colliery, 2015)

Year	Owner
1894	Henderson Transvaal Ltd Registered in London
1896	Henderson Consolidated Coal Registered in Pretoria
1896	Henderson Transvaal Estates took over management of Steenkoolspruit Colliery
1914	Premier Coal Estate acquired
1917	Ogies Colliery acquired (1907 – 1928)
1918	Amalgamated above 2 Collieries in Tweefontein United Collieries
1918	Tweefontein Colliery acquired (1907 – 1947)
1918	No.1 Area Colliery acquired (1907 – 1922)
1930	Waterpan Colliery commenced (1930)
1946	Witbank consolidated Coal Mine (Witcons) was started in 1946
1947	No.2 Area started (1947 – 1978)
1978	Boschmans Colliery started 1978
1999	Glencore purchased Duiker Exploration Ltd from Lonmin
1999	Xstrata South Africa Pty Ltd took over the Company
2012	Glencore – Xstrata merger

Figure 1-4 and **Figure 1-5** are areas within the planned opencast at TOC where the No 2 Seam was mined using bord and pillar. These two plans date back from 1930 and as indicated by van der Merwe & Mathey, (2013)

were found not to be reliable. The requirements of a survey plan are evident on these plans but the reliability of the characteristics of the pillars is not. Upon close inspection, the pillars are mostly square in nature as indicated on **Figure 1-4** and **Figure 1-5.** When underground bord and pillar methods were used, the pillars obtained will be irregular and not square because of blasting and offline mining. The square and rectangular shaped pillars shown in **Figure 1-4** are pillars that are drawn in during the mine planning phase to indicate how mining must have taken place. It is important that once pillars are created the surveyor should plot the true shape, size and location of these pillars to reflect the correct mining that has taken place.

Figure 1-4: Portion of an old underground working (Tweefontein Opencast Colliery, 2015)

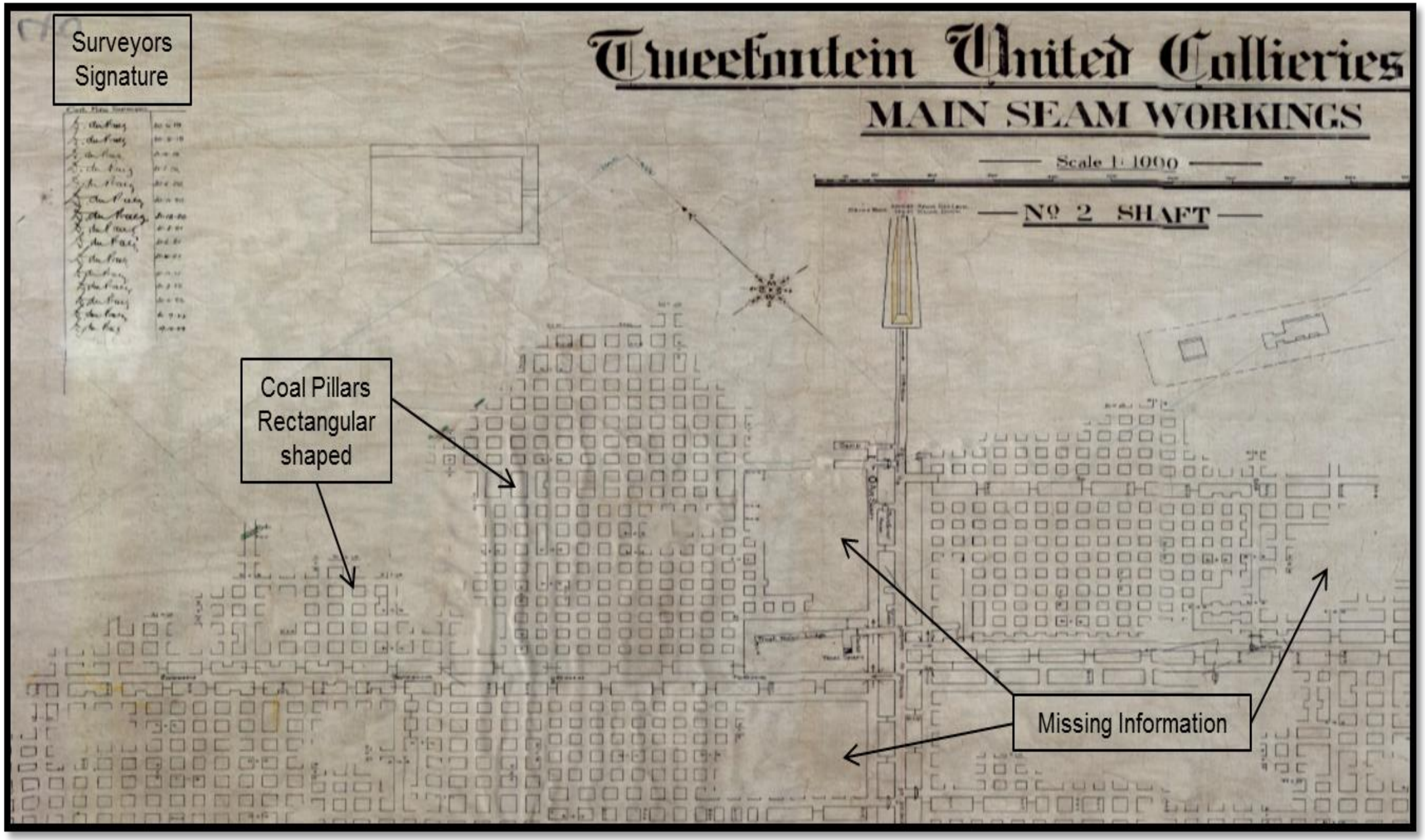


Figure 1-5: Typical underground plan in the earlier years of mining (Tweefontein Opencast Colliery, 2015)

In **Figure 1-4** within the red lines it is noticeable that information is missing where no pillars are indicated. The reason for this missing information is not known, but can only be deduced that there was possibly a dyke or some geological anomaly or surveying of pillars just not done.

The shape and location of pillars from old survey plans are affected by the following issues. The scales of the plans varied depending on responsible surveyor and legal requirement at the time. It was clearly evident on the old plans that different metrics units and datum planes have been used for survey purposes which make it difficult when converting to current systems especially when plans have to be joined or superimposed.

Survey plans are supposed to be kept for safe keeping in a fire proof room. These rooms in the past years were not properly ventilated resulting in plans shrinking, fading over the years, and disintegrating when exposed to moisture (Tweefontein Opencast Colliery, 2013). As discussed before, because of the various changes of ownership the original plans have gone missing and the only way to get the missing information is to do a resurvey. **Figure 1-4** gives an indication of missing information on plans and some of the pillars that have not been offsetted.

In the 1930's the pillars were not designed according to rock engineering principles as trial and error methods were preferred. This led to pillars being either over or under designed and thus resulting in either square or rectangular pillars. As a result of the inadequate surveying, the pillars were mostly small in size leading to the inability of pillars to carry the load above them. As a result safety factors were not used (Schalekamp, 2006). Safety factor is the load acting on a pillar divided by the strength of the pillar. Before 1967 the sizes of pillars were found to be much smaller, resulting in roof conditions that were not favourable. All of the above results in pillars not being offsetted and is worsened by areas that show no signs of offsetting.

1.3. Reserves within GCSA

The total extractable reserves currently planned within GCSA opencast is 712Mt as shown in **Table 1-3**, and about 10 percent of this reserve is coal in pillars. **Table 1-3** further indicates the coal left in pillars per coal seam in the three different complexes. This includes No 5, No 4, No 2 and No 1 seams. As part of the LOM at GCSA operations, all the seams shown in **Table 1-3** are planned to be mined by opencast mining because the seams are shallow occurring at depths less than 60m. The No 2 seam will provide 52Mt of the 72Mt to be mined. However, before mining the No 2 seam workings the No 5 seam and No 4 Seam will have to be mined.

Table 1-3: Detailed Reserve Tonnages of coal in pillars (Glencore, 2015)

Complex	Extractable Coal Reserves (Mt)	Coal in Pillars				
		5 Seam (Mt)	4 Seam (Mt)	2 Seam (Mt)	1Seam (Mt)	Total (Mt)
Impunzi	182			20	10	30
Goedgevonden	320	1		9		10
Tweefontein	210		9	23		32
Total	712	1	9	52	10	72

The No 5 seam is the upper most seam and No 1 seam is the lowest seam as indicated in the stratigraphic column shown in **Figure 1-6**. Between the three complexes the extractable coal from pillars is 72Mt, which is potentially 6 years of mining if 12 Mtpa is planned to be mined.

Figure 1-6 is a generalised stratigraphic column of the geology in the Tweefontein mining area. The Witbank Coalfields consists of five (5) coal seams, from Seam No. 1 to No. 5. Seams are numbered from the bottom upwards. The seams are commonly known as No. 1, No. 2, No. 3, No. 4 and No. 5 as shown in **Figure 1-6**. Except for seam No.3, all the other seam have been or are being mined economically either using underground or opencast mining methods.

The No 4 seam is on average 5.9m thick whilst the No 2 Seam is comprised of the upper portion which is on average 4.8m thick and the lower portion being an average of 3.0m thick. The No 2 Seam has the better coal qualities of raw calorific values between 21 and 25 Mega Joules per kilogram (MJ/Kg), whilst the No 4 Seam calorific values range between 19 to 24 MJ/Kg. The predominant seams mined at TOC are the No 4 and No 2 seams, where underground coal pillars are largely prevalent.

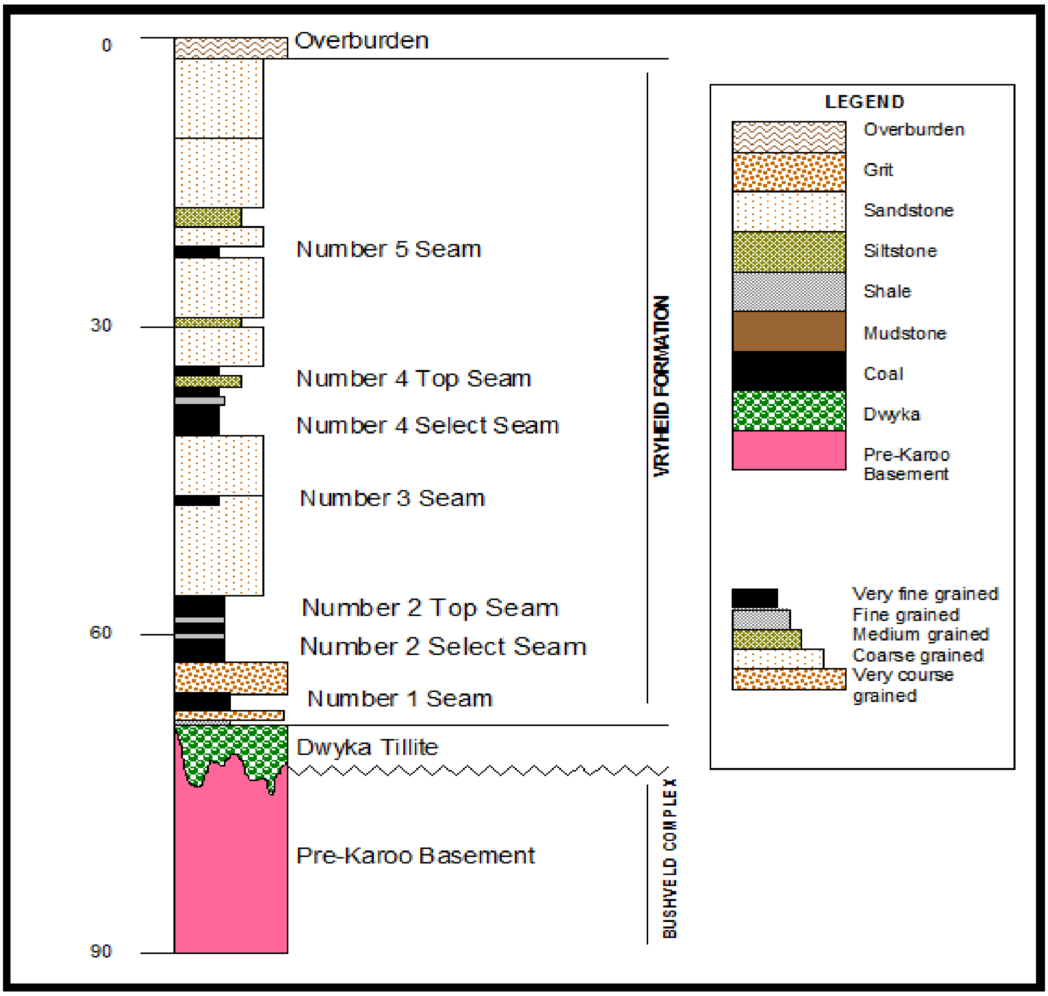


Figure 1-6: Generalised Stratigraphic column of the southern margin of the central portion of the Witbank Coalfield (Tweefontein Opencast Colliery, 2015)

1.4. Problem statement and research questions

The aim of the research is, to investigate how the underground pillars will be identified and as a result, increase confidence level of the reserve of TOC. The following questions will be addressed.

a. Will GPR or CALS Tool be the appropriate technology to identify underground pillars?

b. Underground coal mines are affected by two major contributors; underground workings that are flooded or having spontaneous combustion. Will GPR or CALS Tool be able be identify underground pillars in these environments.

c. Once the pillars are identified, how will it be used to interpret the underground workings?

1.5. Limitations of the research

The research will concentrate on the underground areas within the TOC mining areas only. The areas that will be investigated will be the areas that have surveyed mine plans. The basis of this is to compare the technology being utilised in a known surveyed area. The study will be ahead of the current mining window where no coal has been extracted via opencast mining methods and will be corresponding to the mine plan shown in **Figure 1-7.**

1.6. Research objectives

The research objective is to investigate a practical method to determine satisfactory features of underground pillars for the TOC area using current technology, which is GPR or CALS Tool.

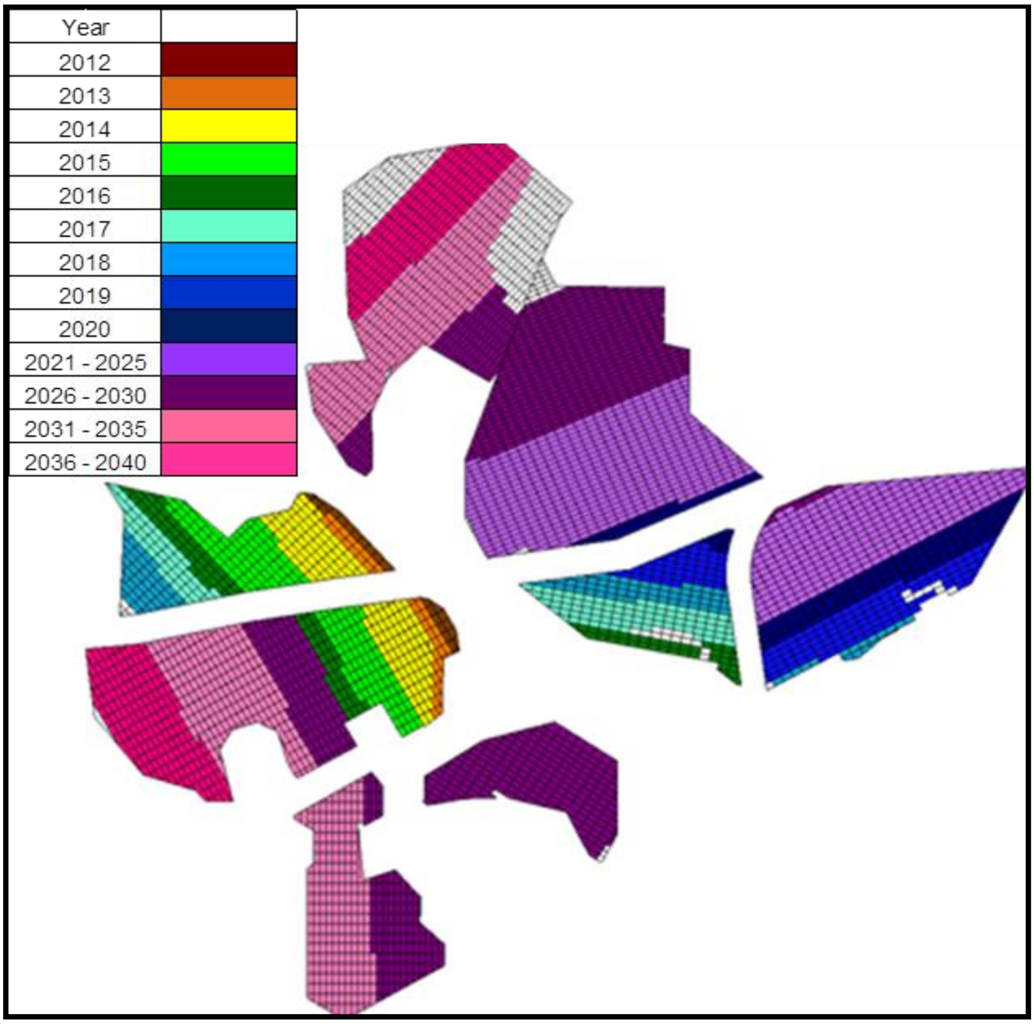


Figure 1-7: Progress plot of the LOM (Tweefontein Opencast Colliery, 2015)

1.7. Research methodology

The methodology followed in this research to identify pillars is to investigate the GPR technique and a down the hole instrument (CALS Tool). The two methods involve identifying underground areas that have surveyed information of underground pillars that the survey department is certain about their location and geometries and thereafter experimenting with the GPR and CALS Tool in the more uncertain areas.

The GPR and CALS units will not be purchased upfront but rather suppliers will be consulted to assist in the use of their instruments for this research. The GPR testing would require specialists in that field hence the specialist who supply the instruments will be consulted. In order to best compare the GPR and CALS Tool technique the same underground area will be trialled to determine the best method; however the latter will not limit the study should different areas be required to be tested. The results will be analysed and compared with the available scanned and digitised plans, which will be followed by how to interpret the results.

After the area has been scanned using GPR, the data will be examined and compiled offsite whilst the scanned data from the CALS Tool can be done on site with the expertise of the mine's survey department. All scanned data will then be compared to the actual position of the underground pillars on the survey plans. The choice of which technique is suitable would be based on information or data obtained during pillar identifying process, cost, ease of use, supplier support, which includes the willingness of the supplier to do the trials and any other criteria that will be beneficial to the mine.

1.8. Report structure

Chapter 1 is the introductory chapter.

Chapter 2 will focus on the literature review relating to previous identification of underground pillars, different types of technology available and mining methods during pillar mining.

Chapter 3 will discuss the application of GPR and CALS Tool.

Chapter 4 will discuss the analysis and interpretation of the different technologies.

Chapter 5 will be the conclusion and recommendations

2 LITERATURE REVIEW

2.1 Introduction

The coal mining industry in the Witbank area, located in Mpumalanga, has started surface mining of underground coal mining pillars which were previously mined using bord and pillar mining method. **Figure 2-1** is a diagram depicting the extraction of the pillars using opencast techniques. Large mining companies such as Anglo American Thermal Coal, BHP Billiton Energy Coal South Africa now South 32, Glencore-Xstrata and Exxaro are mining pillars from old underground coal mines. Mining of underground pillars using opencast techniques involves stripping of the overburden using either a dragline or truck and shovel or a combination of both and exposing the coal as shown in **Figure 2-1**. The aim of the project is to identify a practical method to pinpoint pillar positions of old underground workings. The identification of pillars left by previously mined bord and pillar workings will optimise the mine planning process in current opencast pillar mining operations.

The mining of underground coal pillars is associated with spontaneous combustion and vast areas are filled with water. Every mine extracting underground coal pillars is using one of the six basic methods discussed in this chapter.

The review of the identification of underground pillars in this chapter will include geophysical techniques and down the hole technology.

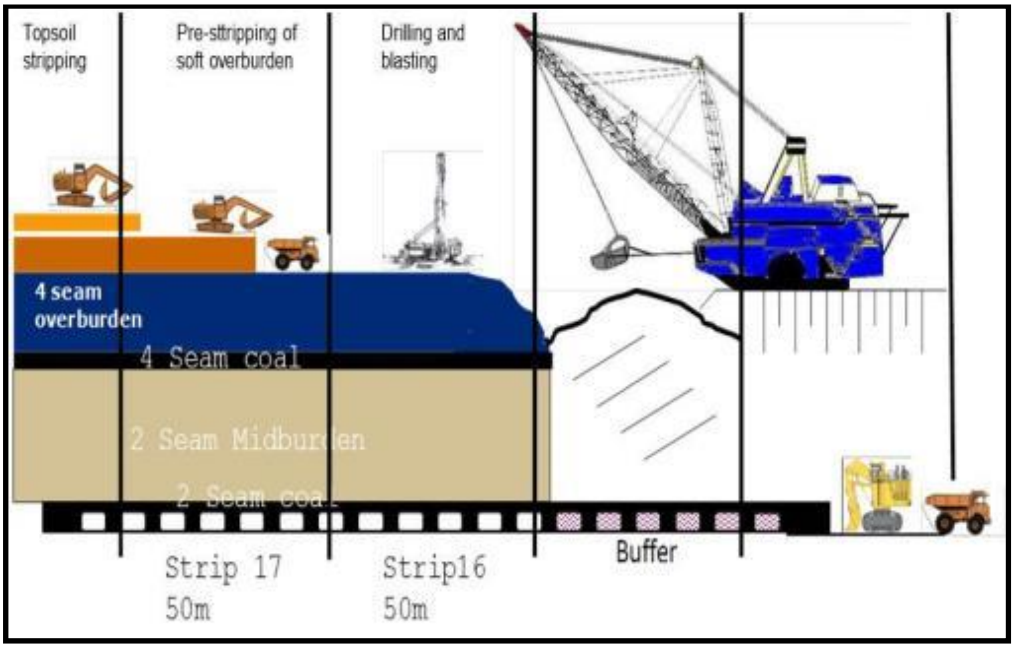


Figure 2-1: Typical Mining Sequence practiced at Impunzi Complex in Witbank (Impunzi, 2015)

2.2 Geology

Figure 1-6 is a typical borehole intersection derived from boreholes drilled in the TOC mine plan. All coal seams are evident in this mining area and it is clearly identified that the seams are not continuous throughout the mining plan as shown in **Figure 2-2**. The method that is used to mine a particular seam is based on various criteria which are analysed by the mine planning department. The mine planning department derives the most suitable method that will be used to mine the reserve.

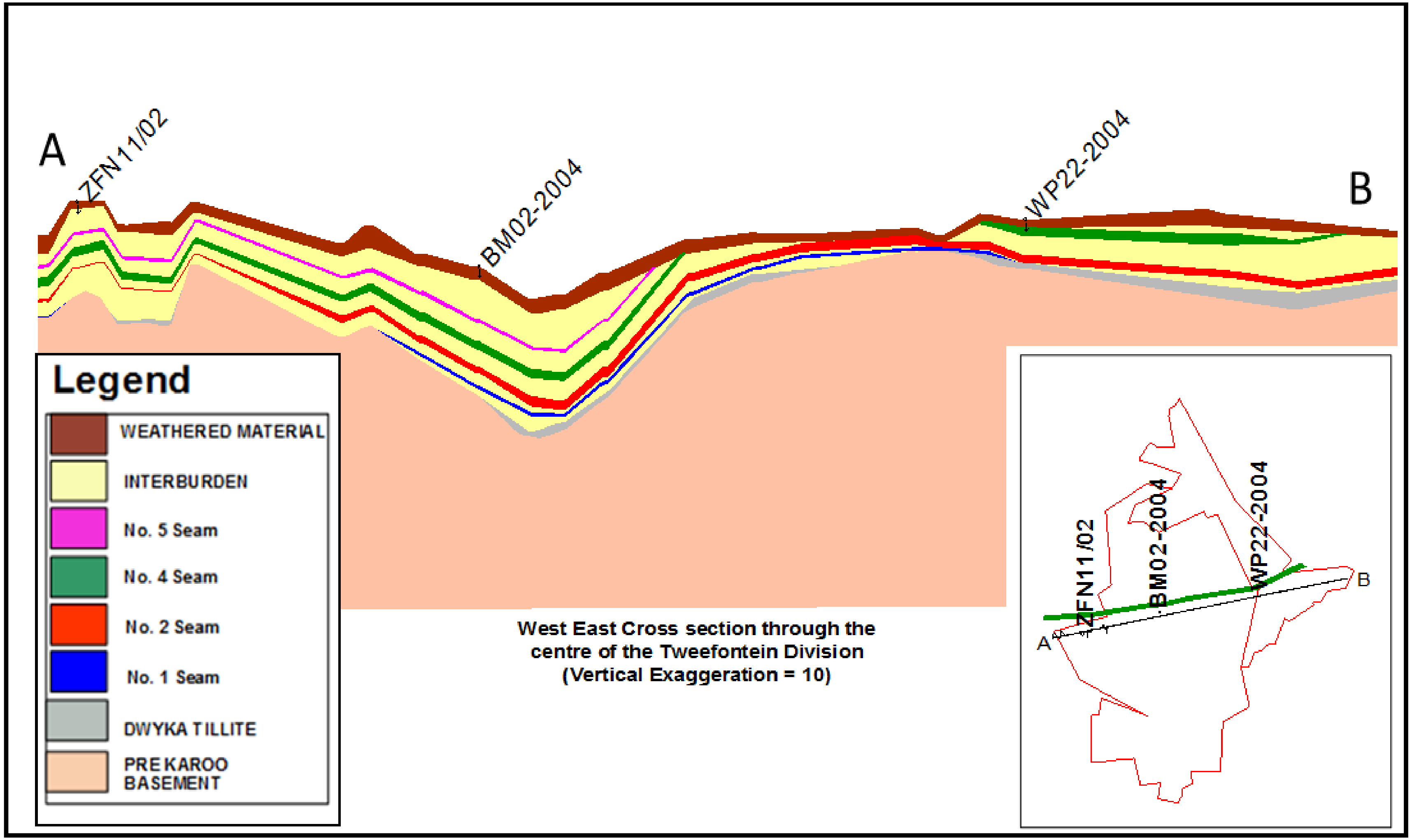


Figure 2-2: Cross section of the geology in the TOC mine plan (Tweefontein Opencast Colliery, 2015)

Table 2-1: Average thicknesses of the coal seams in the Witbank Coalfields (Jeffrey, 2005)

SEAM	SEAM THICKNESS (m)
5	0m to 2.0m
4	2.5m to 6.5m
3	0.3m on average
2	4.5m to 20m
1	0m to 3.0m

Table 2-1 and **Table 2-2** is a comparison of the TOC mining plan to the typical seams mined in the Witbank Coalfields.

Table 2-2: Average thickness intersected in the TOC mine plan (Glencore, SA, 2010)

SEAM	SEAM THICKNESS (m)
5	0.3m to 5.8m
4	0m to 10.1m
3	0.4m on average
2	0m to 11.6m
1	0m to 2.0m

The seam thicknesses are comparable, hence ensuring that reserve estimation is as accurate as possible. Not all seams will be mined in a perfect cross section through each pit; however, each seam will be mined during the LOM. **Figure 2-2** shows how some seams are not evident in parts of the cross section and therefore indicating that coal seams are not consistent throughout the TOC reserve.

The total extractable reserves (SAMREC, 2009) for the coal in TOC mining plan are 210Mt and 101Mt of marketable reserves, of which 32Mt is in underground pillars as highlighted in **Table 1-3**. The LOM for TOC is 20 years which makes it a 10Mtpa operation. This reserve has considered all the coal that has been mined out previously by underground mining (Tweefontein Opencast Colliery, 2015). The geology of the coal has no indication of any major complexity except for the Ogies dyke.

2.3 Coal pillars

The mining height is the vertical measurement of the seam that was mined out, measured from the floor of the coal to the roof of the coal. The bord width is the perpendicular horizontal measurement across the area that has been mined out from pillar to pillar. The pillar width is the coal left insitu after the bords have been mined which is measured along the sides of the pillar left insitu. **Table 2-3** shows the underground mining widths for the coal mines in South Africa, including the Witbank Coalfields (van der Merwe & Mathey, 2013).

Table 2-3: Underground mining widths (van der Merwe & Mathey, 2013)

Criteria	Min	Max	Witbank Coal Field Average
Average Mining Height	3.0m	3.5m	2.8m
Bord Width	6.0m	6.5m	6.1m
Pillar Width	5.9m	10.5m	8.2m

The mined-out seam mining height was based on the method used during that time. This resulted in areas that have coal in the roof. As mentioned earlier, there is approximately 600Mt of coal left in underground pillars. The tonnage trapped in each pillar is about 301t, when assumed that the pillars are square and the mining height is 2.8m and the average relative density of coal 1.6t/m^3. The table below shows opportunistic revenue per pillar.

Table 2-4: Potential revenue per pillar

Area (m^2)	67.2
Seam Height (m)	2.8
Density t/m^3	1.6
Total tonnes	301.0
Saleable Coal (t) @ 50% Yield	150.5
Coal Price R/t	R 630.00
Revenue	R 94 811

The export coal price on the 1st March 2016 was R630 per tonne (Infomine, 2016), which results in an opportunistic revenue of R189 billion based on a 50% yield of the ROM coal, which is the 600Mt of coal left in underground pillars. Unfortunately, not all these pillars will be economical mineable through pillar extraction or opencast mining methods. In 2011 there were 8 large mines that were mining underground pillars through opencast mining methods (Department of Mineral Resources, 2011). Mining of underground pillars using opencast mining methods started as early as 1983, at New Vaal Colliery (Phillips, et al., 2011) and then in 1985 at Landau Colliery (Laybourne & Watts, 1990), whilst Glencore started such mining in the early 1990's at Impunzi.

2.4 Challenges associated with the mining of underground coal pillars

The challenges associated with opencast mining of previously mined underground workings are geometries and spatial location of pillars, underground water and spontaneous combustion. The accuracies of the mine plans were noted in a report on the updating of coal pillars of old underground mines, especially post 1960 (van der Merwe & Mathey, 2013).

Spontaneous combustion is managed through the following two techniques which are commonly practiced, namely buffer blasting and cladding.

Buffer blasting is an area which is blasted between the current mining area and the unblasted area to be mined, as illustrated in **Figure 2-3**.

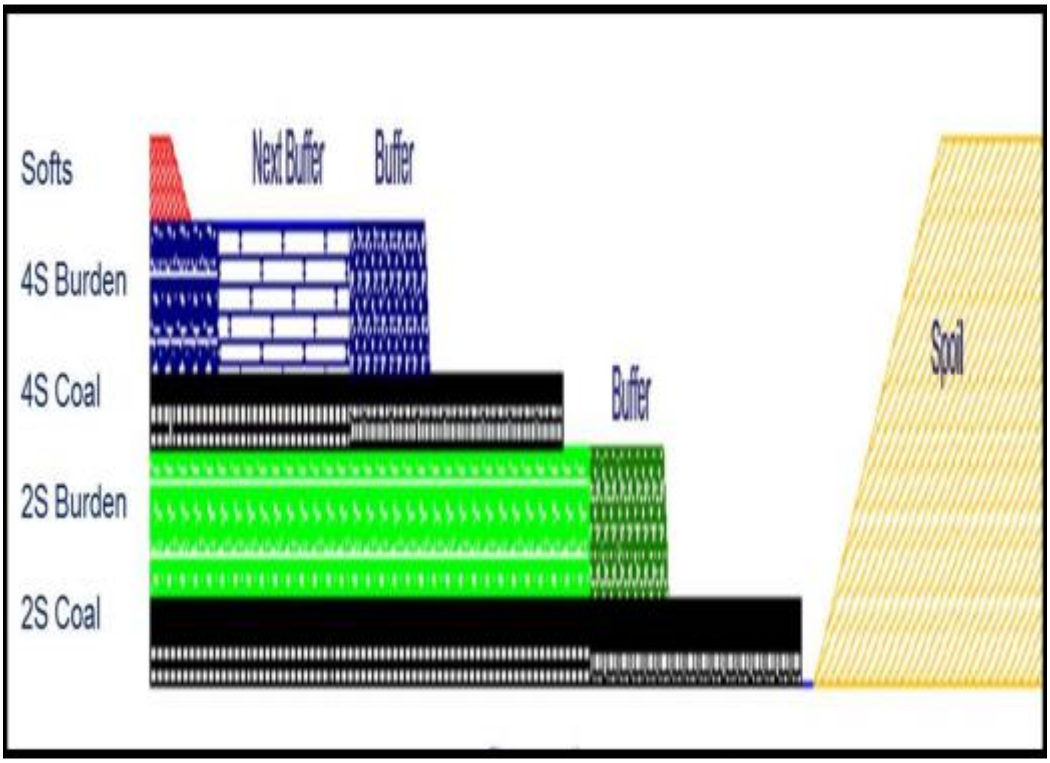


Figure 2-3: Planned buffer blasting method at TOC (Tweefontein Opencast Colliery, 2015)

The aim of buffer blasting is to:

- Create a safe working platform when equipment and people work on top of previously mined underground workings.
- Assist in overburden material or coal to be blasted and thereby falling into voids of the old underground workings which reduces the risk of spontaneous combustion (Schalekamp, 2006).

Buffer blasting is achieved by blasting the roof above the mined out coal, be it coal or overburden, which fills the voids of the underground workings or by blasting of the underground pillars causing both the pillars and roof which is blasted to fill the underground voids (Clough & Morris, 1985). Buffer blasting minimises air from entering the voids through the highwall and thus reduces spontaneous combustion. The voids are closed when the pillars or waste material after blasting assists this material to fill the void. **Figure 2-3** indicates where a buffer blast is required and **Figure 2-5** the position of cladding which takes place after the No 2 seam coal is removed during the mining process.

Cladding with soft overburden is the smothering or covering of burning material or material that has the potential to burn using fine material to cover the flames which results in oxygen suffocation. The aim of buffer blasting is to eventually cause the fire to be stopped and to prevent areas that have the potential to burn. This method is practiced when the underground pillars are not blasted, which leaves visible underground voids that allow oxygen to enter, potentially assisting in spontaneous combustion, as shown in **Figure 2-4**. The highwall is cladded as shown in **Figure 2-5**, which assist with the prevention of spontaneous combustion.

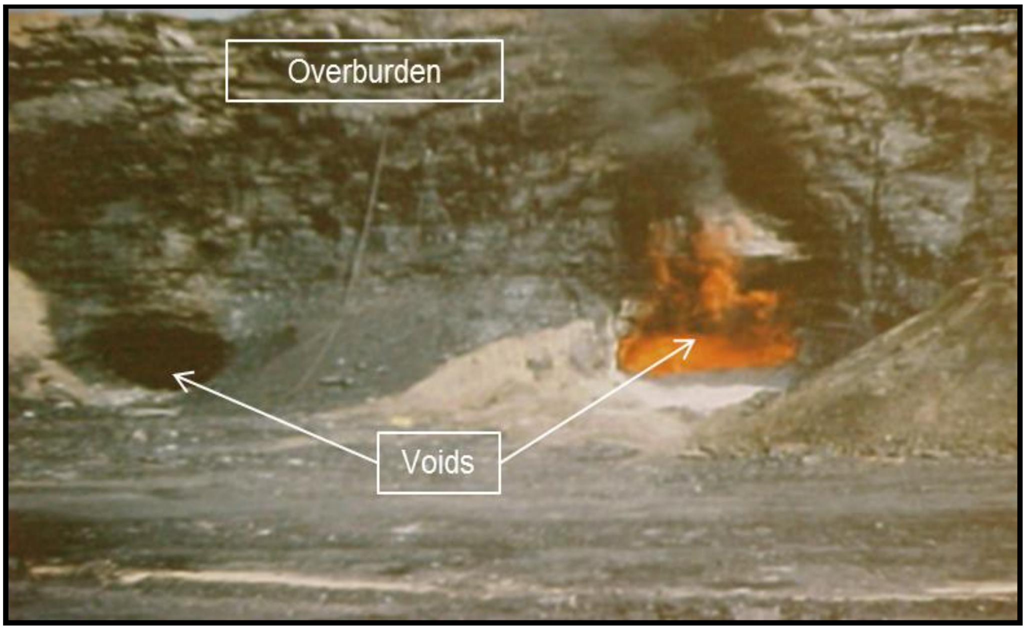


Figure 2-4: When voids are left open (Phillips, et al., 2011)

Figure 2-5: Cladding of open voids (Rogans, 2008)

At TOC, the underground water is planned to be used for coal processing purposes, whilst the balance of the water is planned to be pumped into other old underground workings which is later planned to be recycled through a water purification plant for potable use (Glencore, SA, 2010). The understanding of the underground water is managed through a water management system known as the Windows Interpretation System for Hydrologist (WISH) model. The water in the underground workings serve as a barrier preventing excess oxygen from causing possible spontaneous combustion, hence dewatering will be planned strategically in this regard. Furthermore, excess water underground might impact on the results achieved with identifying underground pillars. The CALS Tool cannot be submersed into water hence areas that are flooded will not be measured or will have to be dewatered.

The off-setting of underground pillars only became a requirement after the Coalbrook disaster which led to the development of the safety factor formula (van der Merwe & Mathey, 2013). Furthermore, the accuracy of the geometries of the underground pillars in the first half of the 20th century was not reliable based on a study during the updating of the coal database (van der Merwe & Mathey, 2013). This is evident in **Figure 1-4** and **Figure 1-5** where spatial information of underground pillars is missing or not offsetted and supports the evidence by van der Merwe and Mathey, (2013) that the spatial characteristics of pillars in the first half on the 20th century are not reliable. The reason for understanding the geometries and spatial location of pillars is to have an accurate amount of coal tons to determine the size of the potential resource which relates to whether the reserve can be economically mined and to assist with a suitable mining method in terms of productivity and safety. The mining methods discussed below will highlight the various options available when mining underground coal pillars. The reserves within GCSA vary in characteristics, hence the understanding of the underground workings will aid in the method to be used. The different mining methods not only consider thickness of the coal seam but provides guidance in how to achieve improved coal qualities as well as the choice of equipment. Since the early introduction of mining underground pillars with opencast methods the following methods have been experimented and some still in use;

- **Method 1**: Collapsing of bords
- **Method 2**: Variation of method 1 to gain better quality of saleable coal
- **Method 3**: Preservation of the workings
- **Method 4**: Collapsing of the bords and excavation of the un-blasted coal
- **Method 5**: Preservation of the workings and excavation of un-blasted coal
- **Method 6**: Collapsing of the pillars (Clough & Morris, 1985).

The methods are explained in the section that follows. The description of the activities in **Table 2-5** below shows a summary all the activities encountered in the various mining methods.

Activity 1 is the drilling and blasting of the overburden or interburden material which will be removed using suitable equipment to remove this waste, (Activity 2). Activity 3 is dozer clean-up of which is either clean-up of coal or waste just above the coal. The drilling and blasting of the coal pillars is Activity 4 whilst loading of the coal is Activity 5. The coal left in the floor is ripped using a dozer and thereafter loaded as indicated by Activity 6. The naming of the mining activity might differ from method to method; however, the general process of the activity remains the same in the field.

Table 2-5 Activities practiced in the various mining methods, adapted from (Clough & Morris, 1985)

		Mining Method					
Activity		**1**	**2**	**3**	**4**	**5**	**6**
1	Interburden / Overburden Drilling	✓	✓	✓	✓	✓	✓
2	Waste removal	✓	✓	✓	✓	✓	✓
3	Dozer cleanup of coal or waste	✓	✗	✓	✓	✓	✗
4	Drilling coal pillar	✓	✓	✓	✗	✗	✗
5	Coaling	✓	✓	✓	✓	✓	✓
6	Ripping floor coal	✓	✓	✓	✗	✗	✓

✗ Indicates corresponding activity not practiced

✓ Indicates corresponding activity practiced

2.4.1 Method 1: Collapsing of voids

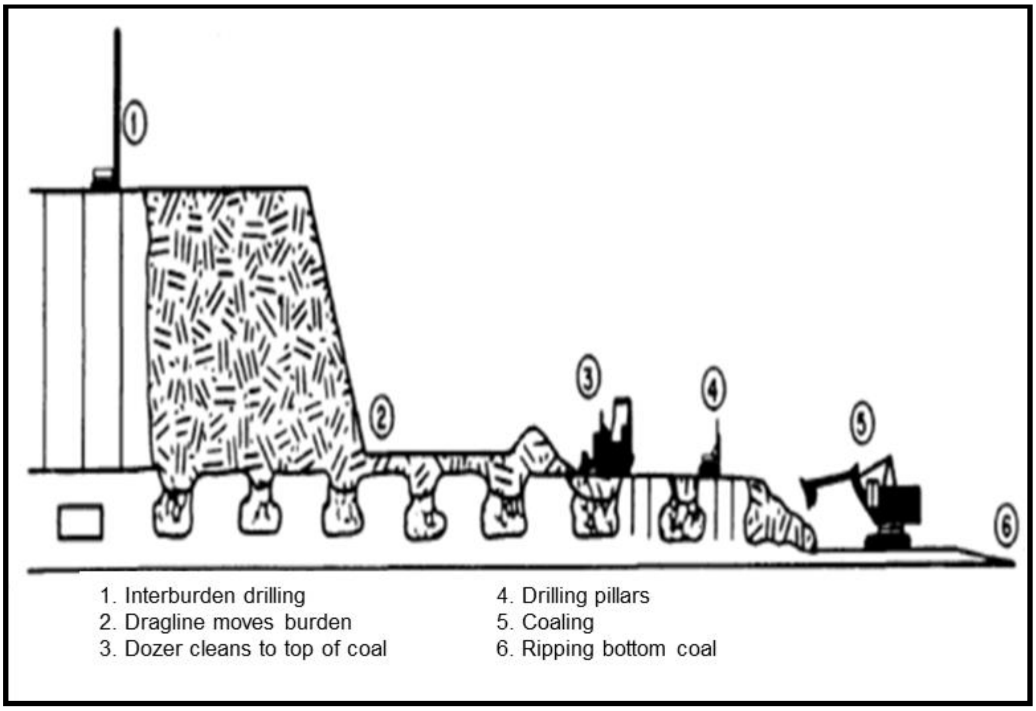


Figure 2-6: Method 1 (Clough & Morris, 1985)

Method 1 requires collapsing of the bords where the overburden will be mined by either a dragline or truck and shovel fleet. The theory is that the load of the blasted overburden should cause the top coal above the bords to fail, where mined height is lower than seam thickness.

Figure 2-6 shows how method 1 is managed with the sequence of activities. The interburden activity, indicated as 1 in **Figure 2-6**, can be extracted using a dragline or truck and shovel.

2.4.2 Method 2: Variation of method 1 to improve the quality of saleable coal

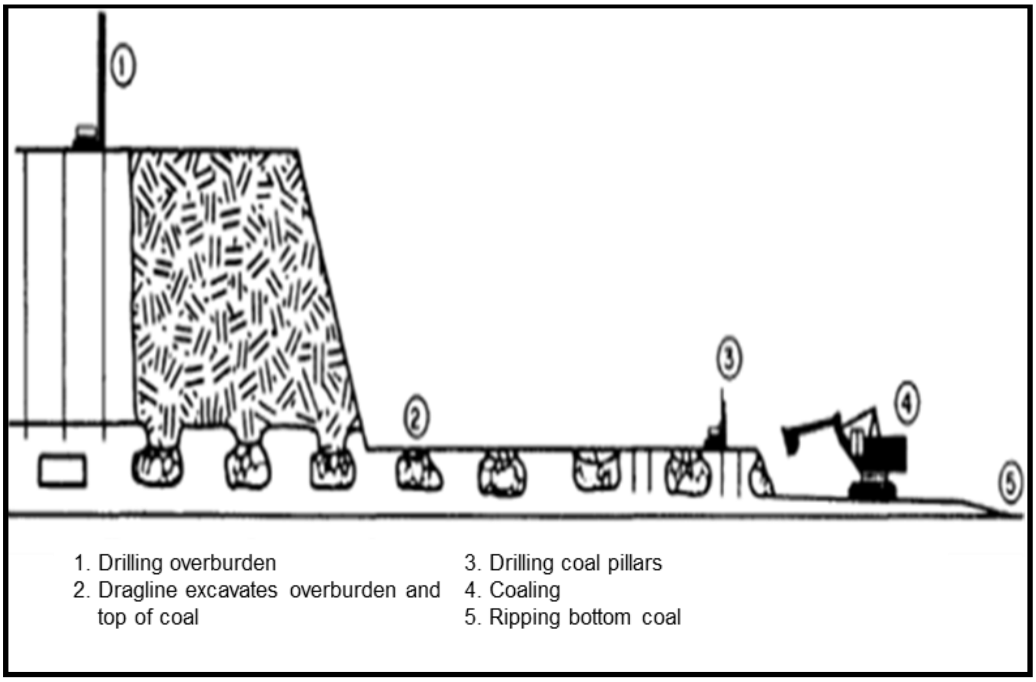


Figure 2-7: Method 2 (Clough & Morris, 1985)

Method 2 which is a variation of Method 1 was intended for achieving better quality coal by scalping the top of coal as waste to ensure a better quality. Activity 3 in **Figure 2-6**, which is the dozer clean-up, is not carried out due to the scalping process. Scalping is the cleaning of the low quality coal closer to the upper contact of the waste. The scalping process is achieved during the waste removal process after Activity 1. Both Method 1 and 2 would require the coal to be drill between the voids, as indicated by Activity 4 in **Figure 2-7**.

2.4.3 Method 3: Preservation of the workings

Method 3 was to ensure the underground was preserved. This was managed by leaving a beam above the coal seam where the beam was not blasted but ripped by a dozer. The intent is to reduce dilution as shown **Figure 2-8**.

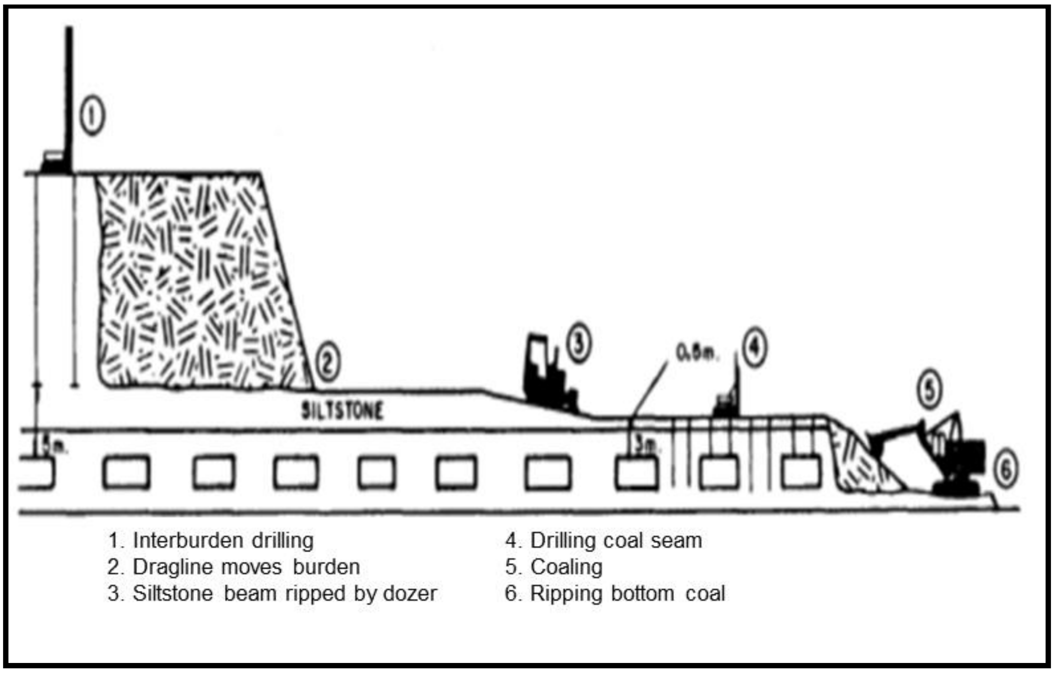


Figure 2-8: Method 3 (Clough & Morris, 1985)

Method 4 is very similar to Method 1, except for the Activity 4 in **Figure 2-6** is not carried out. It is important that the excavator chosen is able to free dig the coal.

2.4.4 Method 4: Collapsing of the bords and excavation of the un-blasted coal

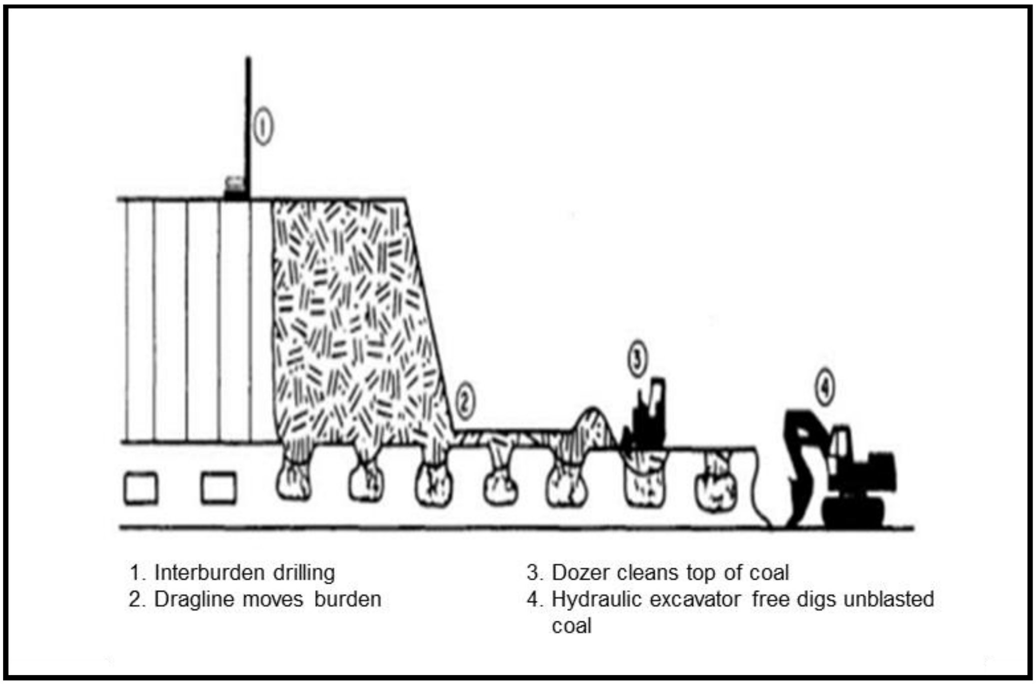


Figure 2-9: Method 4 (Clough & Morris, 1985)

2.4.5 Method 5: Preservation of the workings and excavation of un-blasted coal

Method 5 is very similar to Method 3, except for the Activity 4 in **Figure 2-8** is not carried out. It is important that the excavator chosen is able to free dig the coal.

Both Method 4 and 5 require an excavator with enough digging power to be able to mine or load unblasted coal.

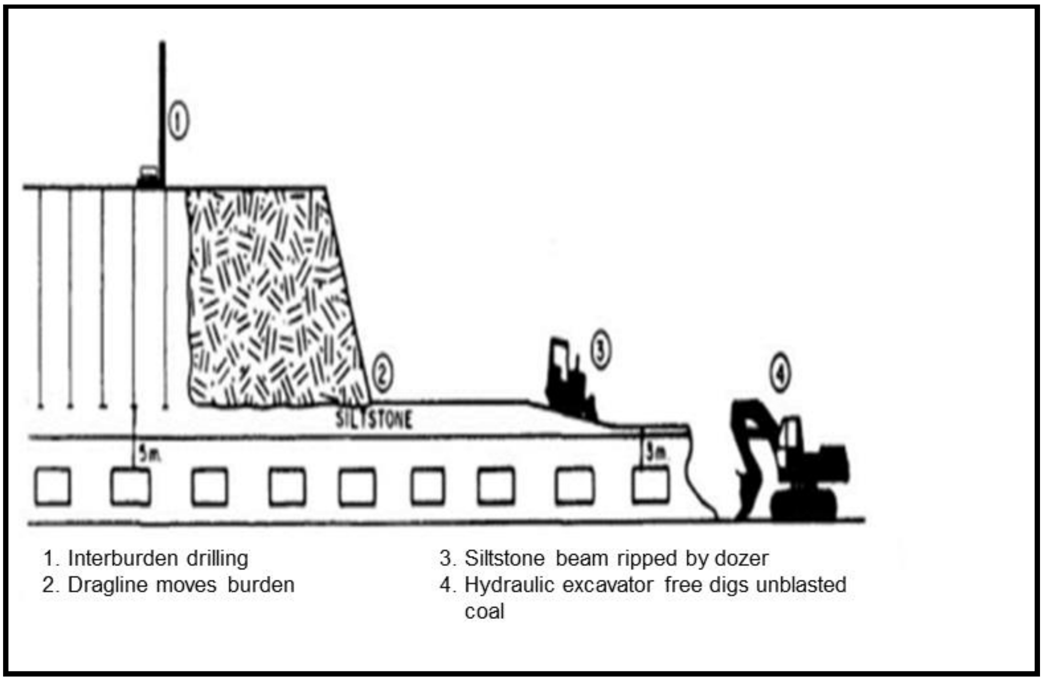


Figure 2-10: Method 5 (Clough & Morris, 1985)

2.4.6 Method 6: Collapsing of the pillars

Method 6 requires the blasting of the pillars, which means the old survey plans must be accurate to drill and blast pillars. The holes that have to be drilled must be drilled as close as possible to the centre of the underground pillars to ensure the pillars are blasted well enough to fill the voids, resulting in minimal dilution. In all six (6) methods the intent is to achieve a better yield on the coal quality, an efficient production section and mining as safely as possible

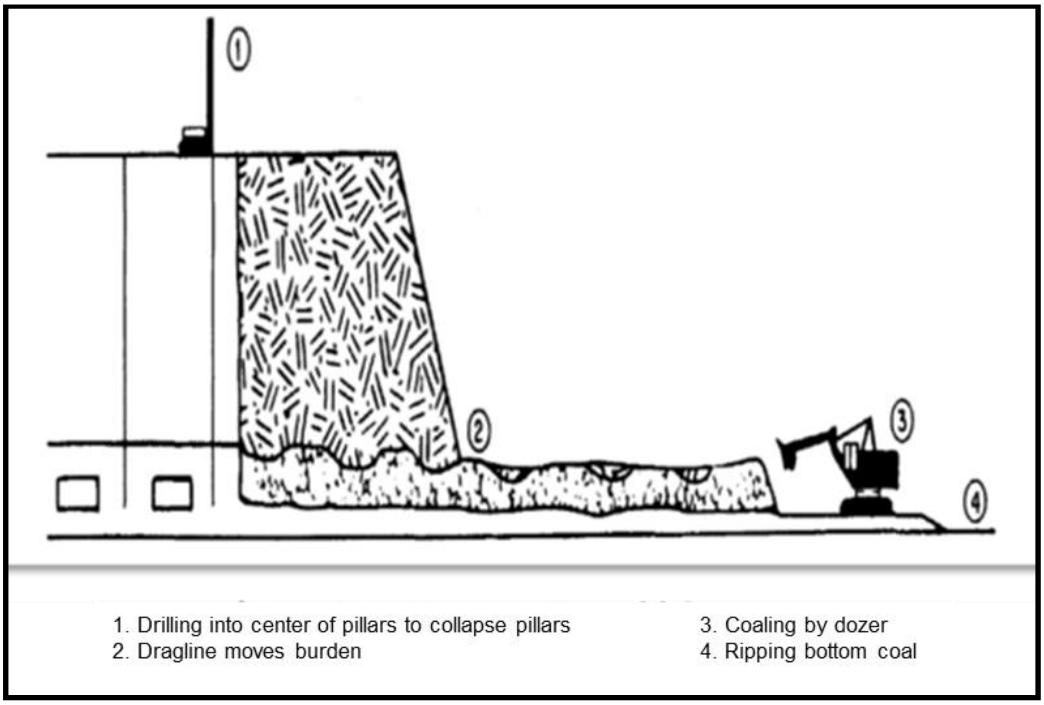


Figure 2-11: Method 6 (Clough & Morris, 1985)

The understanding of the previously mined out areas will assist the mine planning department to choose a suitable mining method as well as the correct choice of equipment. Although some of the methods look similar, it's the difference in certain activities, like not blasting or blasting the coal, which determines what type of equipment will be required to extract the coal. In all methods, collapsing of the pillars or the beam above the mined-out areas is extremely important to fill the voids, or else situation depicted in **Figure 2-12** will be encountered, where a large excavator can subside into a cavity which was a result of pillars not collapsing during blasting.

Figure 2-13 shows an open bord in old underground areas which is exposed during opencast mining. When using a dragline, this poses minimum or no risk to equipment or people. In the recent years, the capital outlay required in opencast mining is large, thus the choice of exploiting the overburden will favour truck and shovel equipment rather than a dragline. In **Figure 2-13**, Method 6 requires the underground coal pillars to be blasted, resulting in a safer platform for the truck and shovel equipment to travel on; however, the difficulty arises when survey plans are old and missing. The open bords are a great danger to equipment and people travelling on top of coal. **Figure 2-13** also shows that the coal in the roof is not thick hence the contamination is likely to be high when underground pillars are not blasted.

A new dragline BE1570W costs approximately R1.2 billion and a truck and shovel fleet in the region of R150 million. The truck and shovel fleet comprises of a shovel that has a loading rate of 1100 cubic meters of waste per hour complimented with four trucks that have a payload of 150t or 90 cubic meters of waste. Two of these will be required to match the capacity of the dragline. The dragline has a waiting period of approximately 3 to 5 years, whilst the truck and shovel is about 12 to 18 months. With 600Mt potentially available in underground pillars and potentially increasing yearly (van der Merwe, 2006), there is a need to identify underground pillars, especially in the Witbank Coalfields where majority of the virgin coal has been mined out.

Figure 2-12: Face shovel falling into a void (Tweefontein Opencast Colliery, 2015)

Figure 2-13: Voids that failed to collapse (Anglo American, 2012)

Prior to 1967 the spatial measurement of pillars was not compulsory; however, this only became compulsory after 1967 (Schalekamp, 2006). When a company is planning to mine pillars from pre-1967, this poses a challenge for drilling and the chosen method to drill and blast is based on the actual pillar position, size and shape. To avoid possible solid pillars left in the pit as shown in **Figure 2-14**, it is extremely important to prevent delays, maintain costs and the use of secondary blasting which makes this an unplanned activity in the mining sequence.

Figure 2-14: Pillars that are not blasted (Tweefontein Opencast Colliery, 2015)

Opencast mining of underground coal pillars poses various challenges as highlighted earlier; however, there are mitigating approaches to this mining. The mining methods mentioned earlier allow each reserve to be planned according to the coal seam characteristics. An understanding of the spatial characteristics of the pillars further assists in the reduction of equipment falling into cavities due to unknown pillar locations.

2.5 Available techniques in identifying underground workings

The two commonly used techniques are geophysical and down the hole. The geophysical techniques discussed are the Gravimetric, Seismic, Electromagnetic and Electrical and GPR. The down the hole techniques are Sonar borehole measuring tools and CALS Tool.

1. Scanning the surface using geophysical techniques, which are explained in the sections to follow, such as

- Gravimetric
- Seismic
- Electromagnetic and Electrical
- Ground penetrating radar (GPR)

2. Lowering an instrument into a hole that will be able to determine the geometries of the underground workings such as;

- Sonar borehole measuring tools.
- 3D Laser such as CALS Tool

The above techniques will be discussed as follows;

2.5.1 Geophysical techniques

- **Gravimetric** is the measurement of acceleration of gravity. The acceleration of gravity is based on the solidity or hardness of the underlying rock. The acceleration between the surface and underlying rock increases as the solidity or hardness increases however the acceleration decreases when voids are intersected. The density of the underlying strata or material is the basis of the acceleration. This method is time consuming and requires elevation control which is normally conducted by a topographic company at high costs. The high costs are driven by requirement for specialised field survey, complex equipment and highly skilled personnel. The data obtained can be affected by various factors such tides, instrumental drift and elevation, which makes the data obtained problematic to rectify. The suitable depths for open flat areas are between 12m to 15m (Johnson & Snow, 2002).
- **Seismic** method is the acoustic reflections and refractions from surface detectors to below surface objects or workings from a specific point or numbers of points established on surface as shown in **Figure 2-15**. It is used extensively in the search for oil and gas resources with a high cost resulting from the closely spacing of the data required which can reach depths of about 304.8m. This method has been trialled on oil and gas reserves and underground coal mines in Europe and the USA, however the high costs and limited skilled persons limits the use of this method (Johnson & Snow, 2002).

- **Electromagnetic and Electrical** is the measurement of change of resistivity in the underlying rock with the acidic water in coal mines having a low resistivity and coal itself having a high resistivity (Johnson & Snow, 2002). Surrounding electrical features such as, powerlines interferes with this process easily and is not good at identifying resistivity at greater depths (Johnson & Snow, 2002). There are few applications where this method has proven to be successful (Johnson & Snow, 2002).

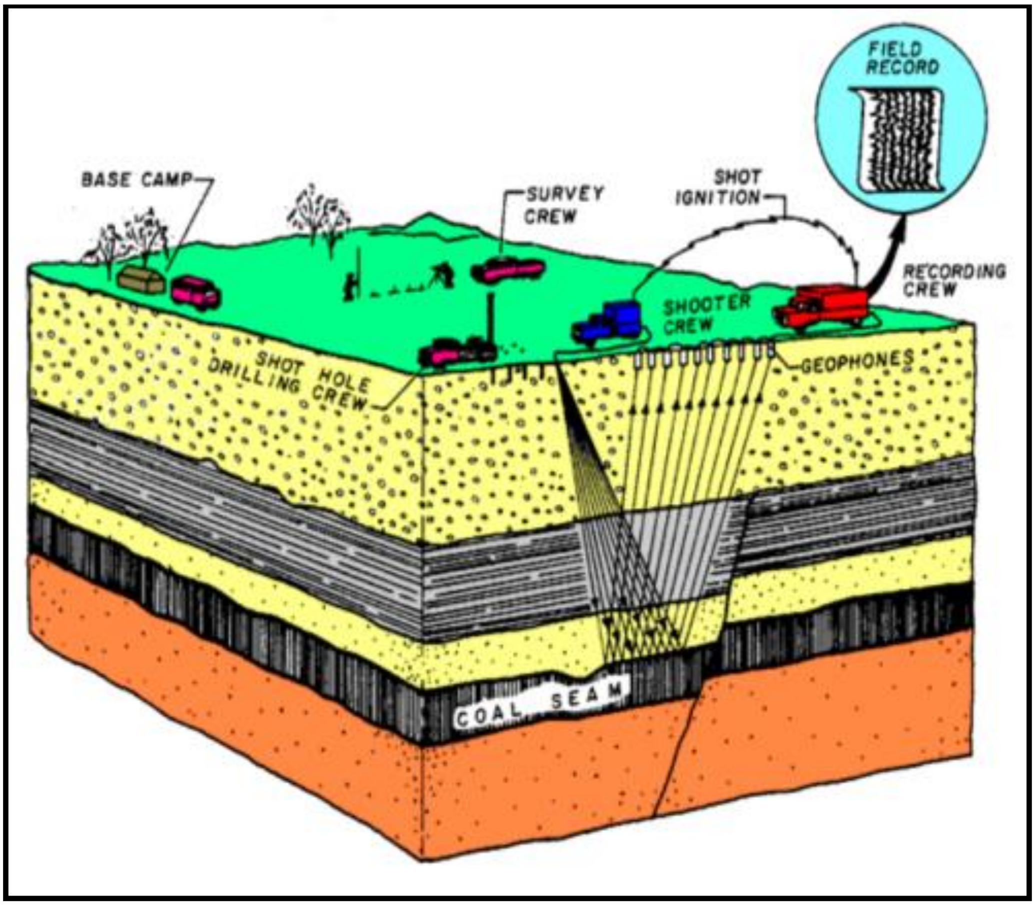


Figure 2-15: Typical layout of seismic survey (Johnson & Snow, 2002)

- **"Ground penetrating radar (GPR)** is a high resolution electromagnetic technique that is designed primarily to investigate the shallow subsurface of the earth, building materials, and roads and bridges” (Daniels, 2000, p. 1). GPR is a time dependent geophysical method that can offer a three-dimensional image as well as a fourth dimension which comprises of colour that is correlated to depth (Daniels, 2000). **Figure 2-16** illustrates how the transmission of electromagnetic waves scatters off various materials and hence finding buried objects or possible cavities. However, GPR depth of penetration is more appropriate to shallow depths in the region of around 40m.

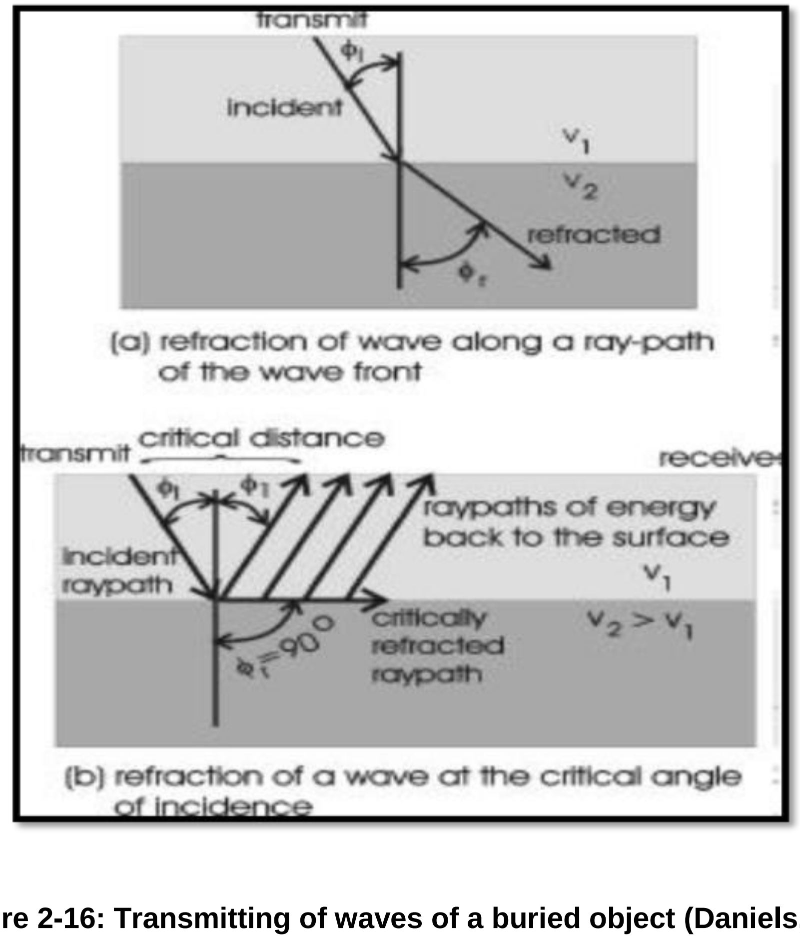


Figure 2-16: Transmitting of waves of a buried object (Daniels, 2000)

2.5.2 Down the hole techniques

This method requires an instrument or device to be lowered into a borehole which has intersected a void of the underground workings.

- **Sonar borehole scanning** became prominent due to the unavailability of old underground plans in Europe. It became important in identifying mining cavities after mining areas became highly populated. Old mining plans were lost due to the war and some not offsetted (Socon, 2015). Sonar tools were used to identify underground cavities due to the shallow coal seams that were mined. A sonar tool is based on echoing of sounds rather than measuring distances from point of sonar to a solid object in the cavity (Socon, 2015). Properties such as temperature and pressure can influence the results and is absolutely necessary to include all signals and shapes that were identified in the sonar scan (Socon, 2015). This is commonly known as Borehole Sonar scanning, where a sonar tool is lowered into a borehole or other type of hole and the scanning is carried out by the sonar tool rotating at the end or bottom.

Figure 2-17 shows the information that can be obtained from a typical borehole scan. The midpoint of the circles is the point at which the borehole scanner is put into a hole. The points closer to the centre of the hole have much detail indicating a higher confidence of accuracy. The points around the centre that looks like L-shapes are interpreted as corners of coal pillars because they are associated to be square or rectangular in shape. As the echoing reflection moves further away from the centre its reliability weakens. This sonar tool can be used in various angular positions.

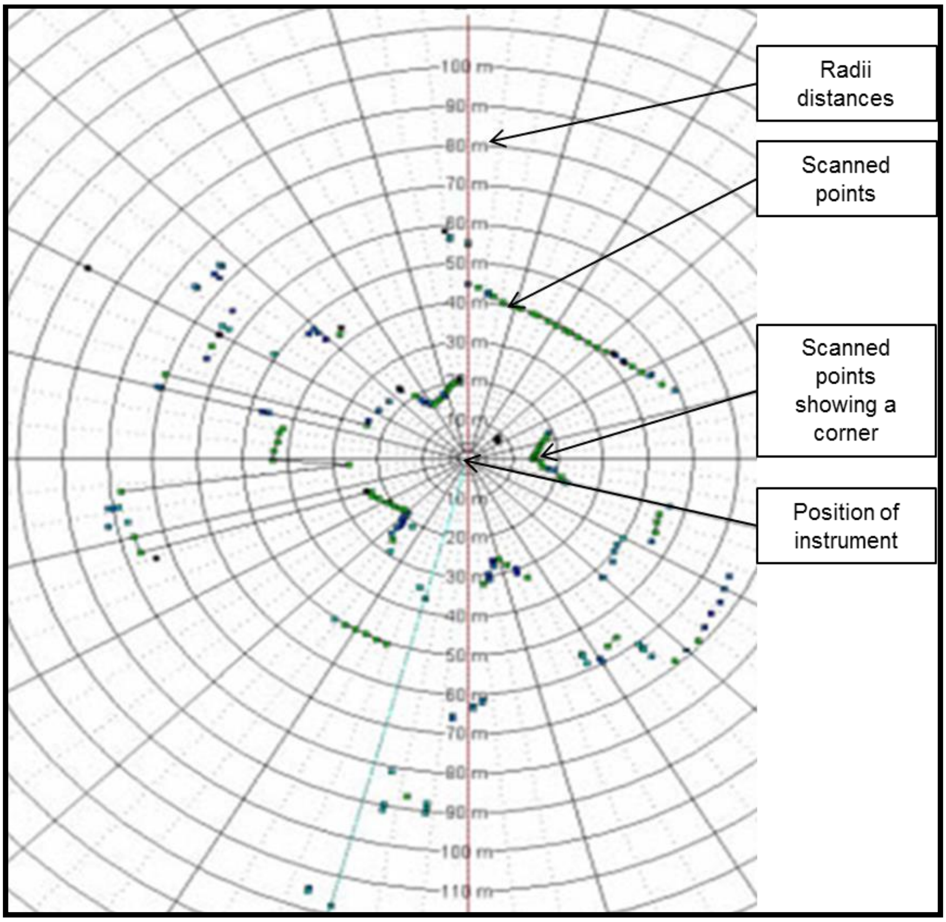


Figure 2-17: Information from a borehole scan (Socon, 2015)

- **3D Laser Scanning** such as the CALS Tool, is a survey device that can be lowered into borehole or drill hole which must intersect a mined out area. 3D Laser Scans is a measurement using high density continuous points determined by the operator which creates a number of points that form a cloud effect, commonly known as "point cloud". The point cloud can be used for digital viewing, distance measurement, volume calculations, spatial location and solid modelling (Lloydhill, 2013). The CALS Tool is a survey device that can determine most characteristics in a void in relation to the pillars that have been left behind.

2.6 Conclusion

It's evident that there are considerable amounts of coal still trapped within the underground coal pillars which has potential revenue upside. The mining method can vary from one operation to another depending on criteria such as equipment used.

With various geophysical and down the hole techniques the GPR and CALS Tool will be the techniques used to trial the validity at the TOC operation, whilst the Borehole Sonar will be used in areas where water is present.

3 RESEARCH ANALYSIS

3.1 Introduction

This chapter will discuss the techniques selected in identifying underground workings in an opencast mine. The techniques that will be trialled are the GPR, CALS Tool and the Borehole Sonar if the conditions allow for the Borehole Sonar to be tested.

GPR is a method that uses electromagnetic waves that reflect on different types of material using frequencies to determine the depth below surface. The CALS Tools and the Borehole Sonar are instruments that will be lowered into a borehole that will intersect a void of mined out underground workings. The CALS Tool is equipped with a laser that will measure by reflections against solid objects. As discussed earlier, the Borehole Sonar creates echoing sounds to determine the distance from the instrument to the object underground. This specific Borehole Sonar is a prototype that will be used if water is intersected in a borehole. The CALS Tool is focussed at underground workings that are not flooded and where no spontaneous combustion is evident and or present, whilst the Borehole Sonar will be used in any workings that are flooded.

The advantages and disadvantages of all the techniques used are discussed in **Table 3-2**. A tabulated weighting criteria will be used to determine which of the methods discussed in the previous chapter will be suitable for trialling at TOC. The techniques identified are planned to be trialled on the same underground area, thereby testing the validity of each of the results, however should there be any issues encountered they will be continued in different areas. The underground area being trialled will be the one that the survey department has confidence in terms of position and shape of the coal pillars.

3.2 Identified techniques tested

The techniques chosen were based on availability of resources such as equipment, skills and experience, software and hardware within South Africa. In choosing a technique, it was important to ensure that at first suppliers are willing to trial their products, at the mine, without charging any costs. There are a number of opencast mines in the Witbank Coalfields which have started mining previously mined underground pillars and therefore there is a need to identify the pillars to improve safety and planning. All the equipment was chosen on a hire and use principle, i.e. the supplier needed to ensure that they will provide all resources for work to be undertaken. Glencore Mining does not have any experience at TOC to assist with identifying underground pillars using techniques such as GPR, down the hole or even Borehole Sonar therefore, it was important that specialists on the selected techniques within South Africa are selected. The applicability of the current mine layout and the nature of the workings was also considered to ensure that the techniques being tested would most likely provide reliable results to analyse.

Table 3-1: Base scale method showing the different techniques and the criteria used to evaluate the presence of underground workings

	Depth of scanning (m)	Capital Cost (R mil)	Maximum Operating Cost (R per hour)	*Specialist Person	**Resolution of Data
Gravimetric	12 - 15 Maximum 15	Greater than 1 Minimum 1	Greater than 1500	Yes	Low quality
Seismic	12 - 15 Maximum 15	Greater than 1 Minimum 1	Greater than 2000	Yes	Low quality
Electromagnetic and Electrical	No information available at time of research			Yes	Low quality
Ground penetrating radar (GPR)	10 - 40 Maximum 40	Greater than 1 Minimum 1	Greater than 1200 but less than1500	Yes	Medium quality
Sonar borehole scans	Only prototype available			Yes	Good quality
3D Laser - Cals Tool	greater than 30	1,2	Maximum of 500	No	Good quality
Total	100	4,2	5500	1	1
Notes	* Yes = 0 and No = 1				
	** Low = 1, Medium = 2 and Good = 3				

In order to evaluate the techniques and the criteria most suitable to identify the underground workings, **Table 3-1** was used. The criteria used to evaluate included depth of scanning ability, capital costs, operating costs, need of a specialist and resolution of data. The depth of scanning is how far into the underground workings will the equipment be able to work in order to give reliable data. The technique that is able to identify underground workings at depths greater than 30m will be most suitable for use. The capital cost is the outright purchase of the unit and therefore the higher the cost of capital that means the more the mine has to pay for the acquisition of the equipment. The operating cost is a unit cost per hour and therefore the lower the operational cost that means the mine will pay less for the use of the equipment. The use of a specialist means that the mine does not have any trained personnel in using the equipment. The resolution of the data is basically the ease at which the raw information could be converted into a reliable data source. The poorer the quality of the data, the result was a longer processing time.

The five main criteria were given ratio based weightings and this was done in the following manner:

- For the depth criterion, the total score is 100. Gravimetric technique with a maximum depth of 15m has a relative score of 0.15 and GPR with a maximum depth of 40 has relative score of 0.4

- For the capital cost criterion, the total score is 4.2. Gravimetric technique with a maximum cost of just over R1 million has a relative score of 0.76 (1 - 0.24) and the 3D Laser with a total maximum cost of R1.2 million has a relative score of 0.71 (1 - 0.29). The capital cost weighting was calculated in this manner to ensure that the lower cost had the higher weighting. This calculation was applied for the operational cost as well.

- For the operational cost criterion, the total score is 5500. Gravimetric technique with a maximum cost of R1500 per hour has a relative score of 0.73 (1 - 0.27) and the 3D Laser with a total maximum cost of R500 per hour has a relative score of 0.91 (1 - 0.09)

- For the specialist person, qualitative criterion, the total score is 1. This means that it is either the mine hires a specialist to operate the equipment or the mine has somebody internally who can operate the equipment. If the mine hires a specialist the relative score is 0 and if the mine has someone who can operate the equipment internally the relative score is 1. The Gravimetric technique relative score is 0 and the 3D Laser a relative score is 1.

- For the resolution of data criterion, the total score is 3. This means that if the data is of low quality the relative score is 1 and if the data is of good quality the relative score is 3. The Gravimetric technique relative score is 1 and the 3D Laser a relative score is 3.

The above relative ratings were used to draw up **Table 3-2**.

Table 3-2: Weighting showing how the different techniques were evaluated using a relative score criterion

	Maximum Depth of scanning (m)	Capital Cost (R mil)	Maximum Operating Cost (R per hour)	*Specialist Person	**Resolution of Data	Total
Gravimetric	0,15	0,76	0,73	0,00	1,00	2,64
Seismic	0,15	0,76	0,64	0,00	1,00	2,55
Electromagnetic and Electrical	0,00	0,00	0,00	0,00	1,00	1,00
Ground penetrating radar (GPR)	0,40	0,76	0,73	0,00	2,00	3,89
Sonar borehole scans	0,00	0,00	0,00	0,00	3,00	3,00
3D Laser CALS Tool	0,30	0,71	0,91	1,00	3,00	5,92

From **Table 3-2** it is evident that the CALS Tool with a relative total score of 5.92 will be most suitable technique followed by the GPR with a relative score of 3.89 in identifying the pillars from previously mined underground workings. The Borehole Sonar with a relative total score of 3.00 was next followed by the Gravimetric with a score of 2.64, thereafter the Seismic with a score of 2.55 and lastly with a score of 1.00 was the Electromagnetic and Electric.

The Borehole Sonar technique with a relative score of 3.00 was included because of the possible underground water in the underground area being trialled; however, the identified areas did not have sufficient water to accommodate the testing of the Borehole Sonar.

The 3D Laser with a total higher relative score is the best equipment to identify underground workings because it has the following features; digital viewing, distance measurement, volume calculations, spatial location and solid modelling. The above rating on the 3D Laser also confirms what the literature review study identified.

3.3 Tests conducted on chosen applications

The initial testing was planned to be carried out on the same area; however, after the results of the GPR were obtained it was decided to continue into other mining areas using only the CALS Tool. The testing of the GPR was done by a consultant who had access to the GPR unit. However, the consultant was given a scope of work required for the purpose of the study. All reports generated by the consultant were for TOC's use until the project was completed.

3.3.1 GPR Testing

3.3.1.1 GPR – Test 1 (Tweefontein Opencast Colliery, 2013; van Schoor, 2013)

The first step was to identify an underground area that has been mined out with accurate survey plans identified by the survey department. The area had to be cleaned by removing the topsoil to create a fairly flat surface for the ground penetrating radar equipment to work on. The topsoil has to be removed in any event as part the opencast mining process which towards the end of the mine life will have to be placed back during rehabilitation process. TOC used their topsoil fleet to remove the topsoil for this purpose. **Figure 3-1** shows how the area was prepared prior to any scanning taking place, with the hundred meters (100m) by hundred meters (100m) highlighted in red in **Figure 3-2**. **Figure 3-1** is a surface representation of the red 100m by 100m block shown on the survey plan as indicated in **Figure 3-2**

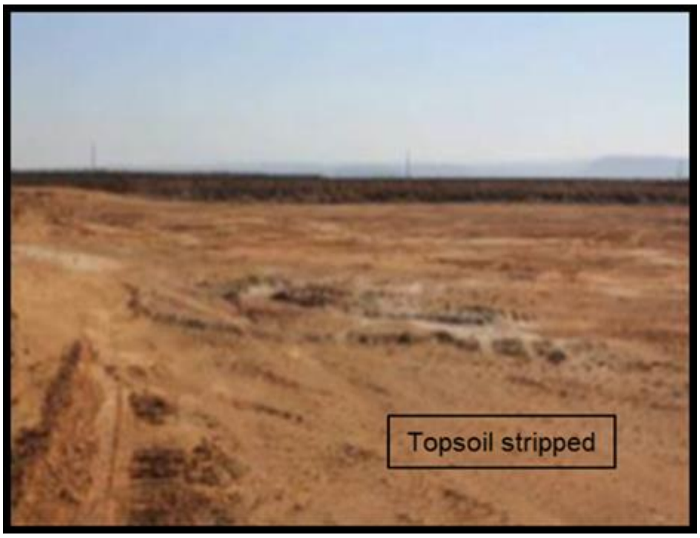


Figure 3-1: Topsoil removed for scanning using GPR (Tweefontein Opencast Colliery, 2013; van Schoor, 2013)

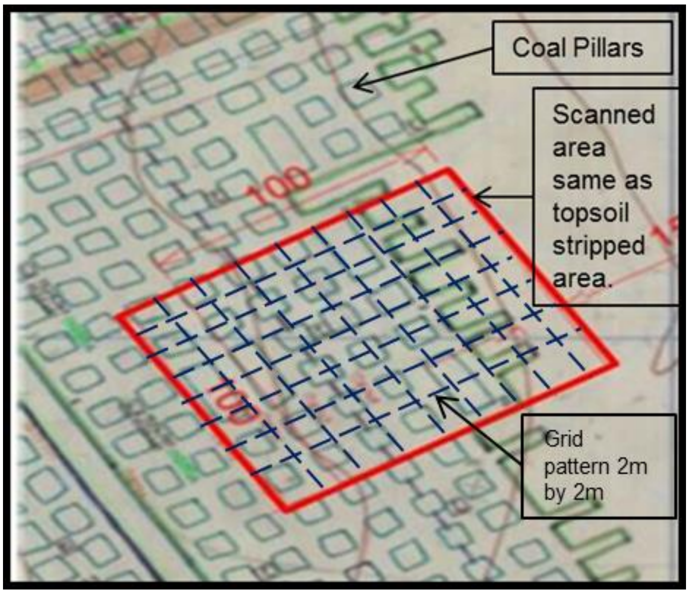


Figure 3-2: Topsoil removed in relation to the underground (Tweefontein Opencast Colliery, 2013; van Schoor, 2013)

The preparation required the topsoil to be stripped, area to be levelled, and where possible the area has to be dry and underground orientations of the workings have to be staked or pegged out by the survey department, to assist in the analysis of the data. The equipment used during this stripping and levelling process was a small excavator with articulated dump trucks and a grader to complete the final level. The scanning equipment was a trolley type unit which was pushed by an operator as shown in **Figure 3-3**.

Figure 3-3: Scanning unit (Tweefontein Opencast Colliery, 2013; van Schoor, 2013)

Table 3-3 shows the frequencies that are planned to be applied when working at different depths, with the resolutions that will be achieved at different depths and frequencies.

Table 3-3: Scanning criteria (Tweefontein Opencast Colliery, 2013; van Schoor, 2013)

Frequency (MHz)	Wavelength	Typical Range	Typical Resolution
1000	5-10 cm	1-2 m	2-5 cm
400-500	10-20 cm	4-5 m	5-10 cm
200-250	25-50 cm	6-8 m	15-25 cm
~50	~ 2 m	20-30 m	1-2 m

GPR has the capability to;

- Outline the pillars in old work workings at depths up to 30m,
- Detection of near surface voids
- Detailed mapping of pillars

Based on previous experiences by GPR suppliers in the Witbank area, the above three capabilities increase in difficulty from the first to the last because of the mapping resolution accuracy increasing for that required purpose. Initially the GPR was tested at higher frequencies, but for this research a lower frequency will be used to scan depths greater than 18m hence the ability to detect the No. 4 seam workings which was between

32m and 40m deep. **Figure 3-2** was scanned at 2m intervals in a grid format, ensuring maximum coverage for the best resolution or mapping. **Figure 3-2** is not to scale but just an illustration of the pattern followed by the scanning unit. A low frequency Pulse Ekko 50 Mega Hertz was used from a GPR scanning unit rented from Sensors and Software Incorporated, based in Canada. Once the data was collated it was processed to ensure that the deeper reflections were captured. Using distance on the horizontal axis and depth on the vertical axis, a greyscale or coloured image called a radargram is generated after the data is processed, as shown in **Figure 3-4**.

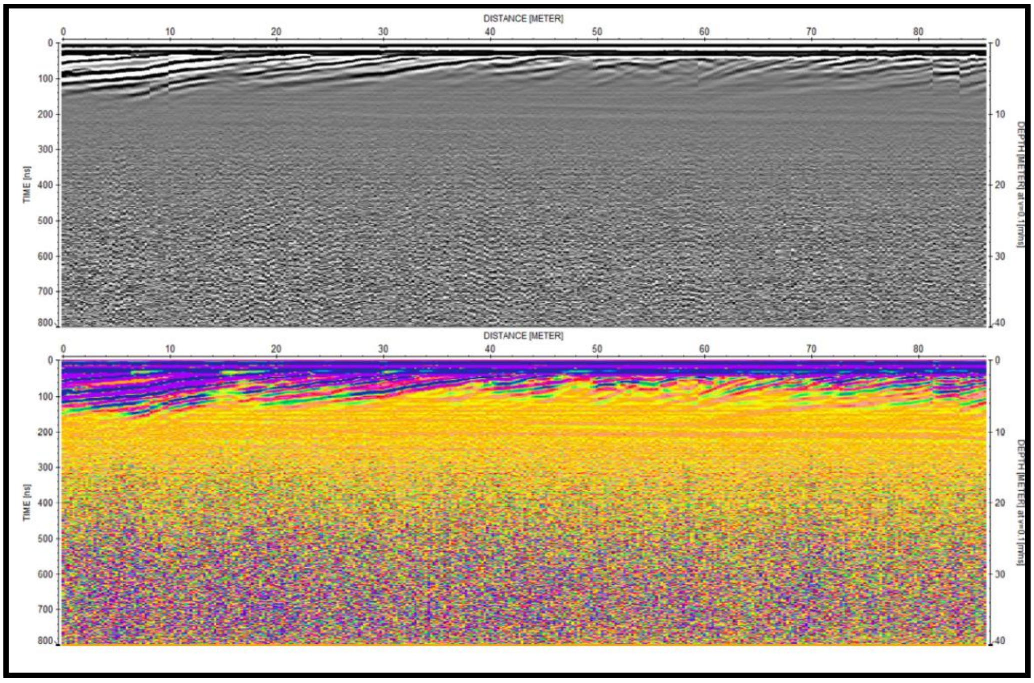


Figure 3-4: Radargram produced after GPR scanning is completed (Tweefontein Opencast Colliery, 2013; van Schoor, 2013)

“A radargram is made up of hundreds of individual dashes displayed side-by-side and a dash is a plot of signal amplitude and time, for a given x-position. The secondary axis of a radargram shows the approximate depth below surface of reflection events – this depth axis is derived by estimating the radar velocity in the rock and converting the measured two-way travel times to values of depth" (van Schoor, 2013, p. 7). Expressing it in simple terms the radargram calculates the radar velocity in the rock, and then converts the travel times in both directions. The depths are calculated using the time and velocity. The results obtained from this initial testing produced somewhat disappointing data that could not be correlated to the underground workings.

3.3.1.2 GPR – Test 2 (Tweefontein Opencast Colliery, 2013; van Niekerk, et al., 2013)

The first GPR test did not produce any conclusive data; hence a second GPR supplier, Structure Scan was approached. The second GPR testing proclaimed the following as advantages to their GPR scanning system;

- Ability to scan conductive and non-conductive material
- Ultra-wide spectrum radio frequency energy pulses
- Scan into medium and back to the antenna
- Detect objects, changes in material, and voids
- Sensitive to changes in material composition
- Minor changes to the hardware that was used

The process behind preparation of the area to be scanned was similar to the preparation done in GPR Test 1. The equipment used was similar except the changes in the hardware; however this GPR was dragged by a quad bike with the belly of the scanning unit dragging itself on the floor as indicated in **Figure 3-5**, which was expected to produce better results in identifying the pillars in the underground workings compared to first test.

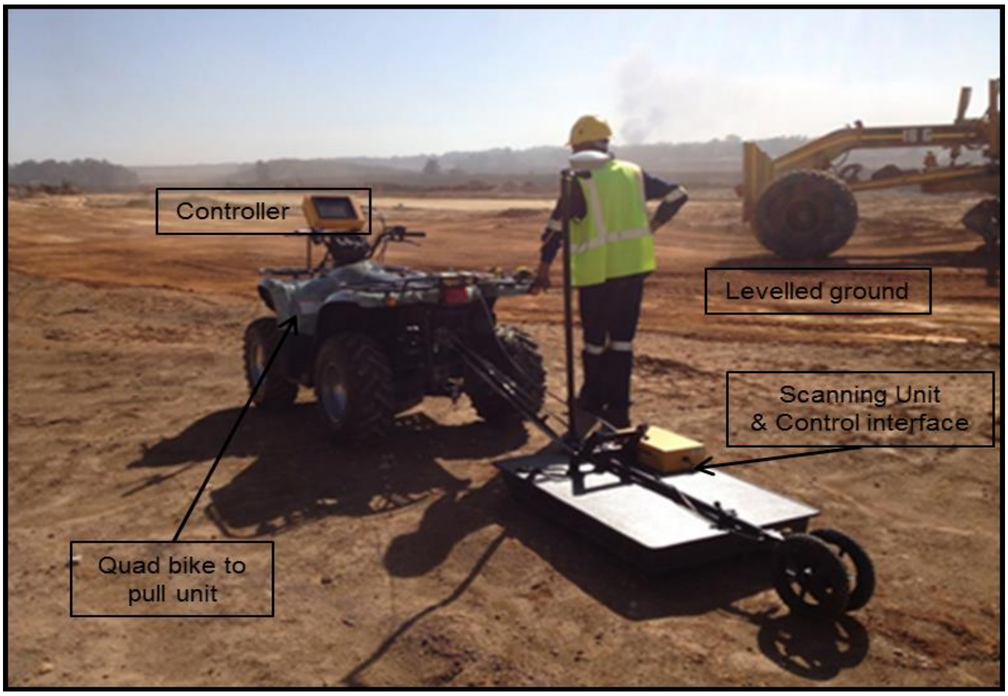


Figure 3-5: Scanning unit used in Test 2 (van Niekerk, et al., 2013; Tweefontein Opencast Colliery, 2013)

Figure 3-6 is a completed processed image of the scanned area in relation to the underground workings. The red rectangular blocks are the possible position of underground pillars based on the supplier's interpretation. The plan of the underground workings is shown in light red in the background. This specific depth according to the scan was at 13m to 14m deep, however as indicated earlier the depth of these workings are in the region of 30m to 40m to the floor of the No 4 seam workings. Therefore, the results do not solve TOC's purpose or goal of identifying underground workings.

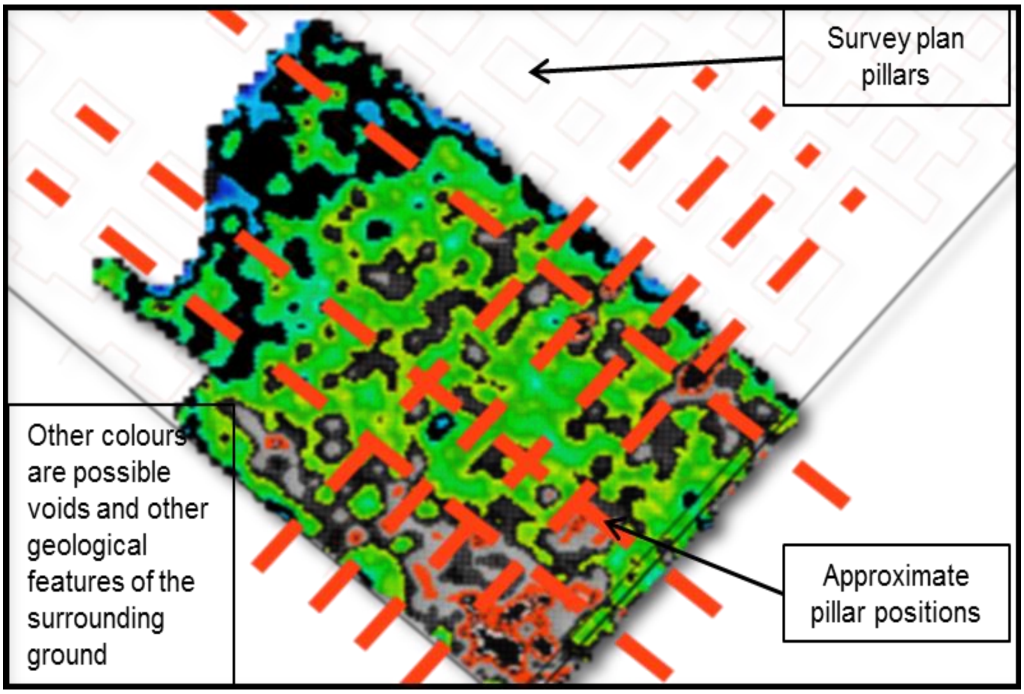


Figure 3-6: Results from Test 2 (van Niekerk, et al., 2013; Tweefontein Opencast Colliery, 2013)

3.3.1.3 Conclusions of GPR testing

The two GPR tests were equipped with different hardware and software systems however in the end they both could not identify underground workings. The processing time ranged from 1 to 2 weeks and the field data had no correlation to the pillars associated with the underground workings that were being verified. The results obtained from the radargrams in **Figure 3-4** and Test 2 shown in **Figure 3-6** were not easily understood with regards to where the pillars were located.

It was therefore concluded that the GPR method of identifying pillars is not suitable for TOC's conditions in identifying underground pillars. Since the GPR failed, the Borehole Sonar had to be trialled.

3.3.2 Borehole Sonar (Tweefontein Opencast Colliery, 2013; van Schoor, 2013)

The Borehole Sonar was to be tested in workings that are flooded, however on drilling test holes it was found that the No 4 seam workings identified for the testing were dry. Consequently, a simulation test using a tank filled with water and objects was carried out in a laboratory. Therefore, it was not possible to test this equipment onsite. The Borehole Sonar method involves drilling boreholes in the workings as shown in **Figure 3-7**. Each borehole was to be surveyed with the exact coordinates including elevation. The Borehole Sonar was planned to be lowered into the hole and based on the acoustic functions, the underground workings along the indicated borehole positions will be mapped or surveyed.

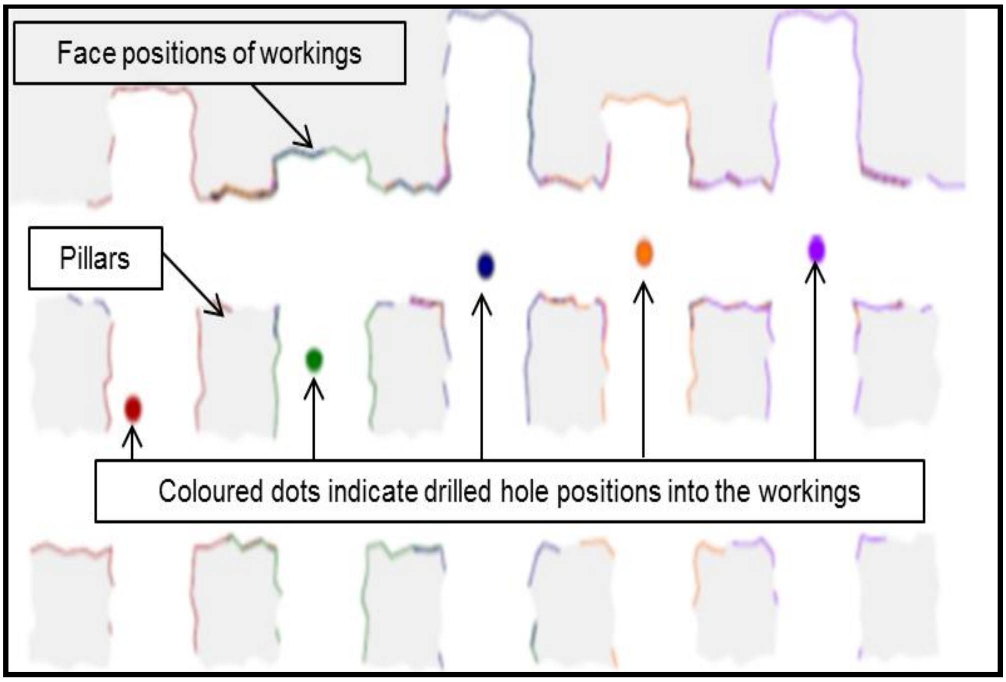


Figure 3-7: Simulated underground face positions with borehole positions (Tweefontein Opencast Colliery, 2013; van Schoor, 2013)

The acoustics waves will travel through the water filled areas and bounce of solid objects, creating data points for every solid object, similar to **Figure 3-8** and **Figure 3-9**. The supplier proceeded with a model tank study to verify if the Borehole Sonar will be able to produce the results anticipated. **Figure 3-8** and **Figure 3-9** demonstrates the test of the Borehole Sonar in a tank filled with water. **Figure 3-8** shows the dense portions of points where the green and dark blue points resemble noise reflections.

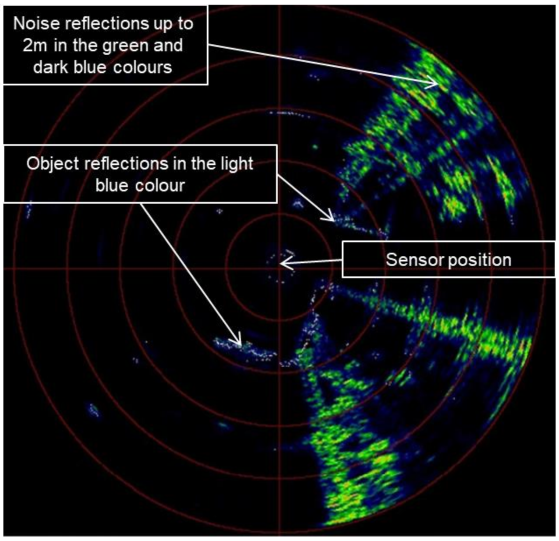


Figure 3-8: Model tank test (Tweefontein Opencast Colliery, 2013; van Schoor, 2013)

Towards the middle are fewer light blue points which start showing portions of a shape. These shapes in **Figure 3-9** are wooden and metal objects however this was placed in the tank purposely for this exercise.

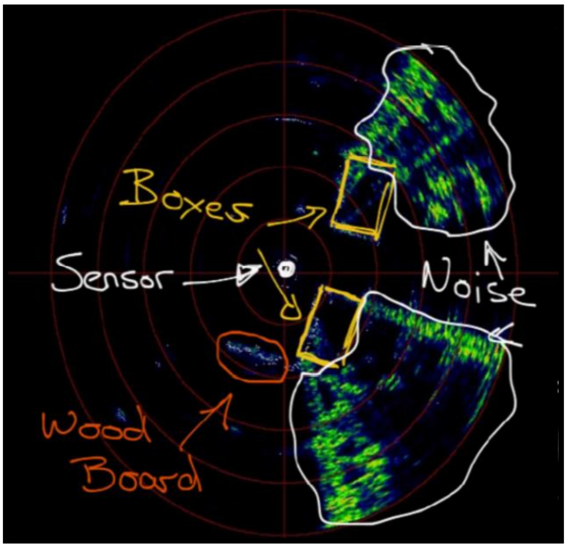


Figure 3-9: Model tank test (Tweefontein Opencast Colliery, 2013; van Schoor, 2013)

3.3.2.1 Conclusion of the Borehole Sonar

The Borehole Sonar displayed results in lab conditions that may possibly provide similar results in underground workings that are flooded; however, the real situation tests must still be carried out to validate how effective this technique will be. The Borehole Sonar requires underground workings to contain water and opencast mining dewaters underground areas prior to mining these areas therefore it was impossible to use the Borehole Sonar practically in the current mining plan. Since the Borehole Sonar could not be tested in a practical situation it was decided that the CALS Tool will be trialled next.

3.3.3 CALS Tool (3D Laser Scanning)

The CALS Tool is a Cavity Autoscanning Laser System. It has a combination of reflectorless surveying, navigation, and on-board software. **Figure 3-10** is a list of the components that are included as part of the CALS Tool. The important component is the probe on the right hand side of **Figure 3-10**, which has the ability to rotate 360 degrees around the horizontal and +90 to -90 degrees vertically. This provides the tool with the exact same capabilities as a survey total station. This means that the CALS Tool can locate the exact location of pillars which are the X, Y and Z coordinates of a survey system.

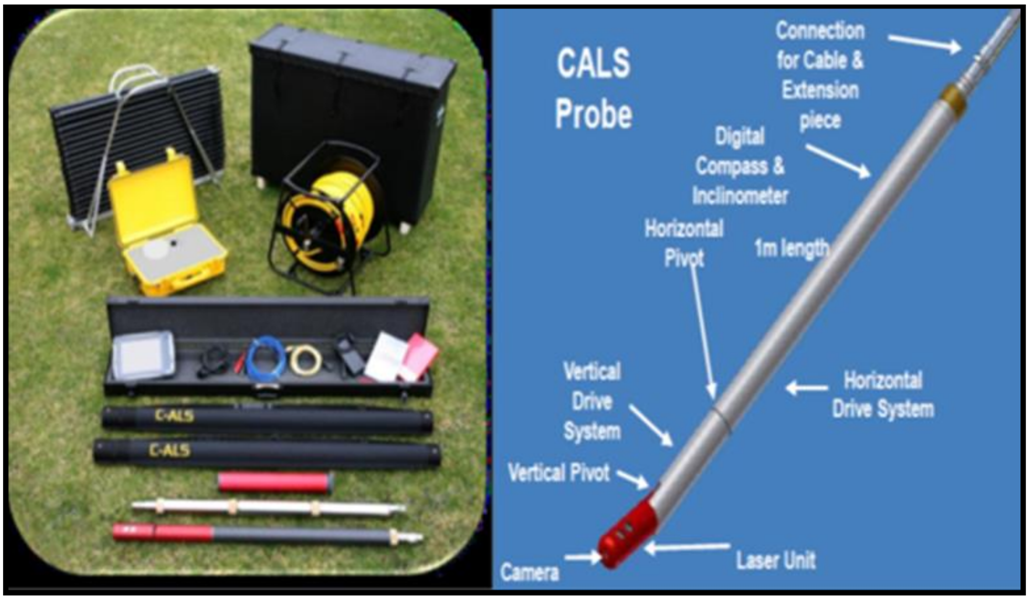


Figure 3-10: Components of a CALS Tool (Dane, 2012)

As mentioned previously, the CALS Tool is a down the hole device, which means that holes, must be drilled into the underground workings, allowing the scanning to pick up as many surfaces of possible underground pillars. When operating the CALS Tool, three people were required to assist in lowering the instrument into a drilled hole, as shown in **Figure 3-11**. This is to ensure the unit does not get damaged and the camera on the end is progressing correctly down the hole. The camera was stopped at a suitable point between the roof and floor. The person observing the camera visuals indicated to the other people that the probe is not submersed in water accumulations or any other obstacles in the path of the CALS Tool. Water can damage the camera at the end of the probe if submersed for long periods, whilst any obstacles will produce incorrect scan data. The lowering process can be very tedious.

Figure 3-11: CALS Tool being lowered into a hole

During the set-up phase, it is important that the orientation between the rod basket and drill hole is surveyed accurately to plot the scan data in the correct spatial location. In a hole of 20m deep this process can take up to 5mins lowering the probe to a measuring point where accurate positions of the pillar can be identified. Once they have lowered the CALS Tool into the workings a surveyor will monitor the scan measurements on the controller as shown in **Figure 3-12**. The CALS Tool uses a laser combined with its reflectorless technology to measure the surfaces of the pillars. This data is then converted into survey coordinates which is plotted on the controller screen.

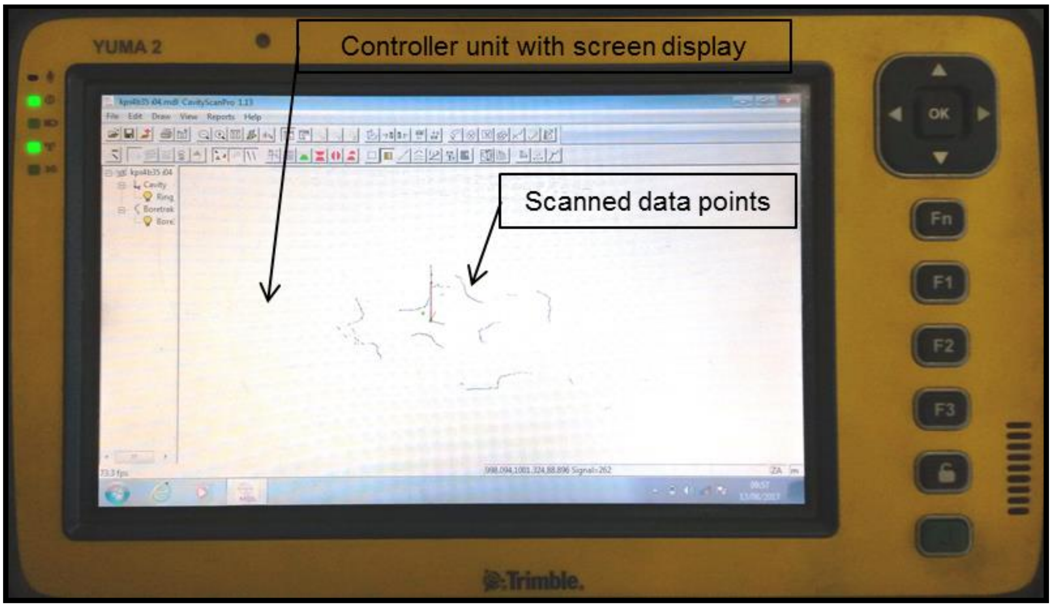


Figure 3-12: Screenshot of CALS Tool controller whilst scanning

Figure 3-12 is the results of what the CALS Tool indicates on the controller display screen when scanning for underground workings. The screen is displaying scanned data points which show portions of the underground pillars.

Figure 3-13 demonstrates the processes or steps involved from the time the scanning takes place until a reasonable set of data is acquired. The three steps have been named as Scanning, Sanitising and Comparing as shown in **Figure 3-13**. Step 1, Scanning, is the lowering of the CALS Tool down a hole to obtain scanned data. The different web like colours are the raw data scanned points of different holes scanned. Step2, Sanitising, is a manual process of cleaning the data by eliminating points that don't make sense using the Cavity Scan Pro software, thus creating a line drawing indicated in a grey colour which shows the shape of the pillars.

Step 3, Comparing, is simply overlaying the newly measured grey line diagrams and comparing it with the digitised old underground workings for that particular area.

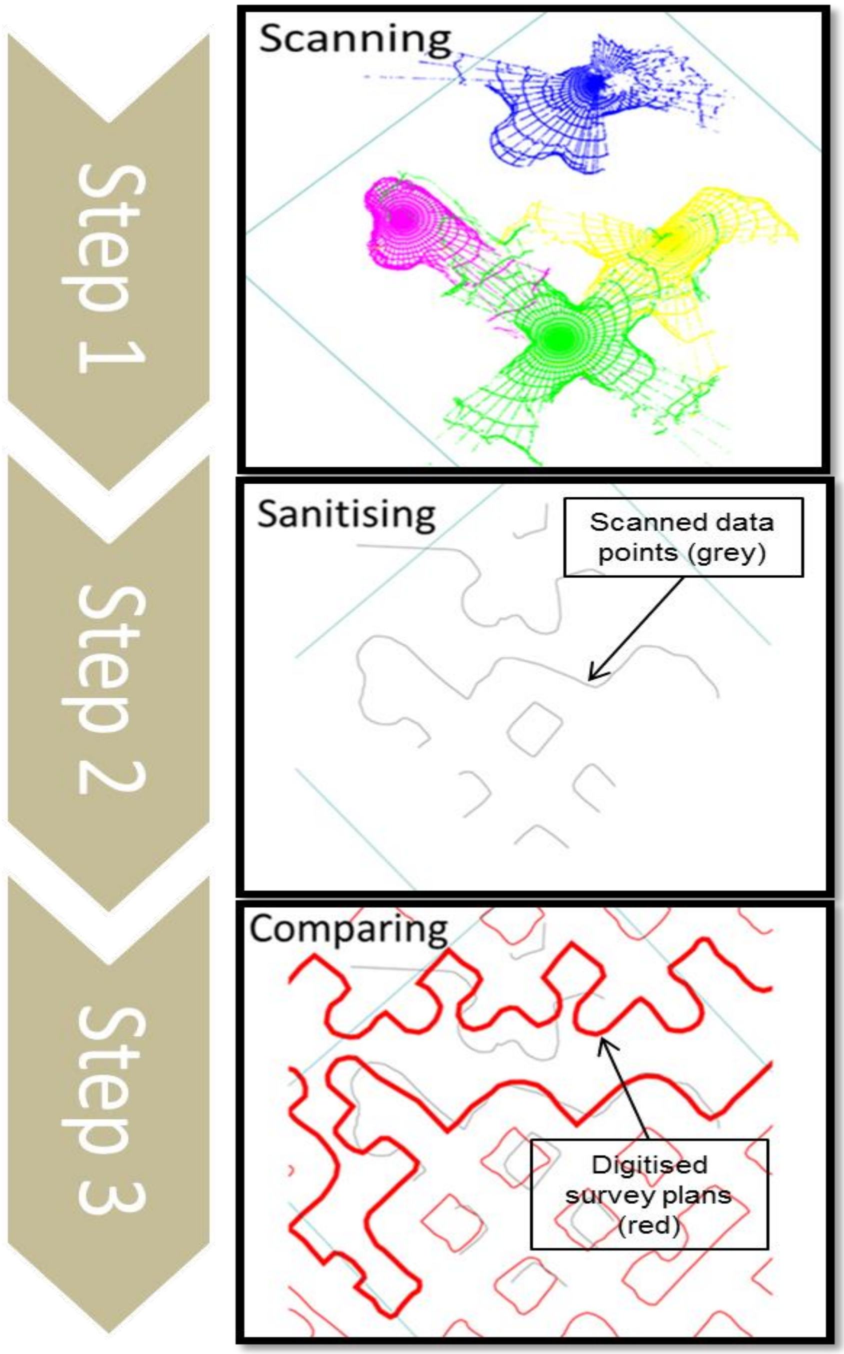


Figure 3-13: Processing information stages

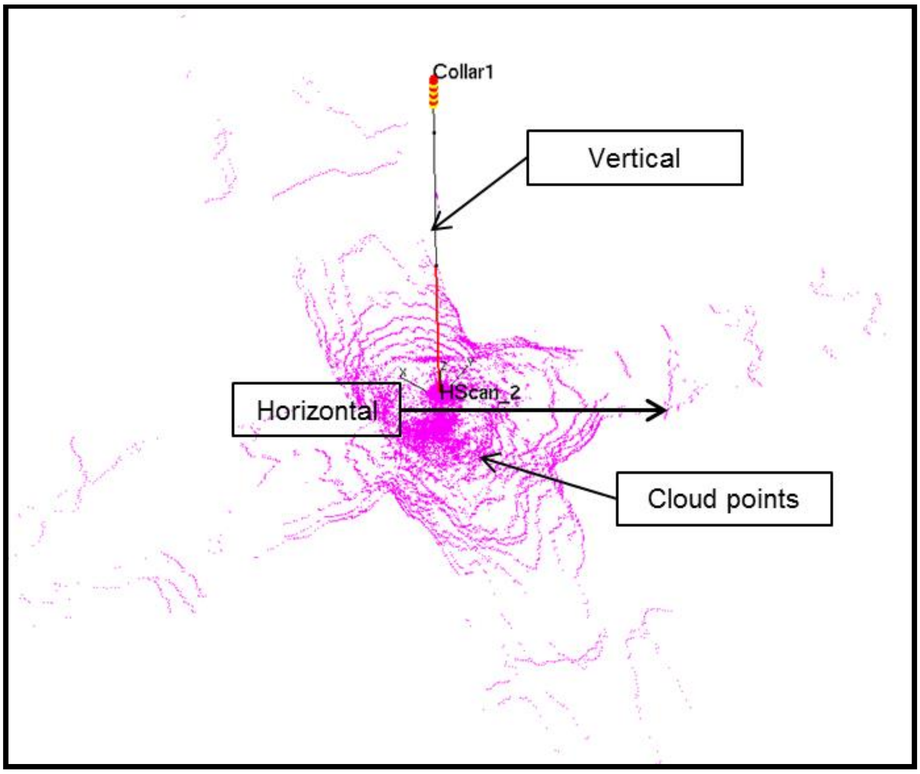


Figure 3-14: Full scan

A full scan as shown in **Figure 3-14** is when the measurements are taken in all directions, including measurements along the horizontal and vertical axis of the CALS Tool. This method measures the roof, floor and all sides that can be scanned by the unit. This scanning process can take between 30 to 35 minutes after the unit is lowered into the hole. This type of scan produces large amounts of data points hence the time taken, however the units' battery system can only complete five scans at a time. **Figure 3-15** on the other hand is a scan that only scans around the horizontal axis, meaning that it only measures the side walls of the underground pillars. The Ring Scan takes between 15 – 20 minutes to complete a scan after lowering the CALS Tool, but can produce up to 20 scans at a time using the same battery system used for the full scan.

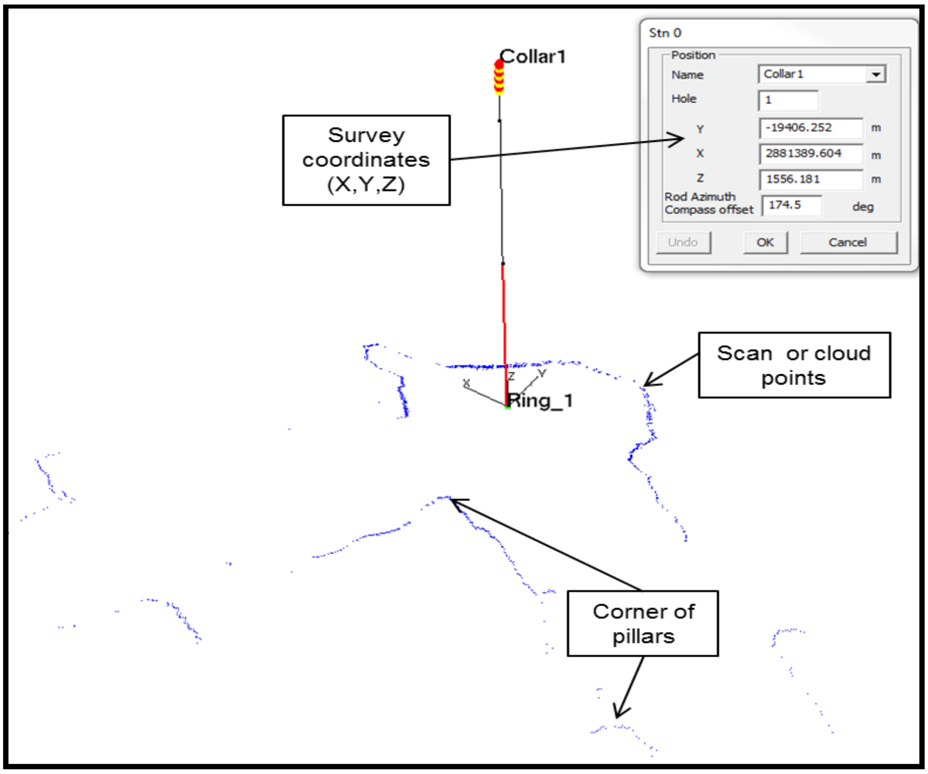


Figure 3-15: Ring scan

The Ring Scan is quicker, producing more scans on current battery power. However, the scanned data point is much less hence it lasts longer with regard to battery backup. The data produced has the same accuracy as the Full scan and will be verified during the testing.

The Full scan has much more data points because its measures everything during the scanning process but requires a longer scanning time. The display as shown in **Figure 3-14** requires much more battery power which results in lesser down the hole scan time. If and when a hole needs to be re-scanned the same day, it is not possible to do so if a Full scan is done first. Both scans produce X, Y and Z coordinates that can be used to determine the location and shape of underground pillars. Hence, going forward the rest of the research will be done using the Ring Scan method, nonetheless, the Full scan will be used if need arises for any verification. The Ring scan is chosen because it scans faster and produces reliable scans like the Full scan and has fewer interruptions to mining activities.

3.3.3.1 Techniques used during the CALS Tool Scanning

The opencast block layouts are not always aligned to the underground workings due to the nature of how the underground workings were mined in the early days of mining. To determine how the CALS Tool scanning is to be done would require agreement between mining, mine planning, survey and the researcher to acquire information in the underground workings to be scanned. Scanning was done on a 100m by 60m block, which is typical opencast mining block size at TOC. Such block sizes make it possible to limit any possibility of spontaneous combustion. The alternative method is to scan only drill holes that were to be drilled for the shift.

The techniques used for scanning were; Diagonal scanning, Parallel scanning along the roadway and Around the pillar scanning.

3.3.3.1.1 Diagonal scanning

Diagonal scanning requires holes to be drilled as shown in **Figure 3-16.** This method was to keep the holes to a minimum and attempts to cover a wide enough area in a mining block size as discussed in the previous paragraph. The holes are planned to be drilled as such allowing sufficient pillar corners and sides to be scanned. The scanned information will be used to check for any alignment concerns. The position of the holes is based on the underground plans and it is anticipated that some holes might not intersect the underworking or may not be in the desired position. The suitable desired position is when a hole intersects in the middle of an intersection which allows the scanning to pick up pillars as far and wide as possible.

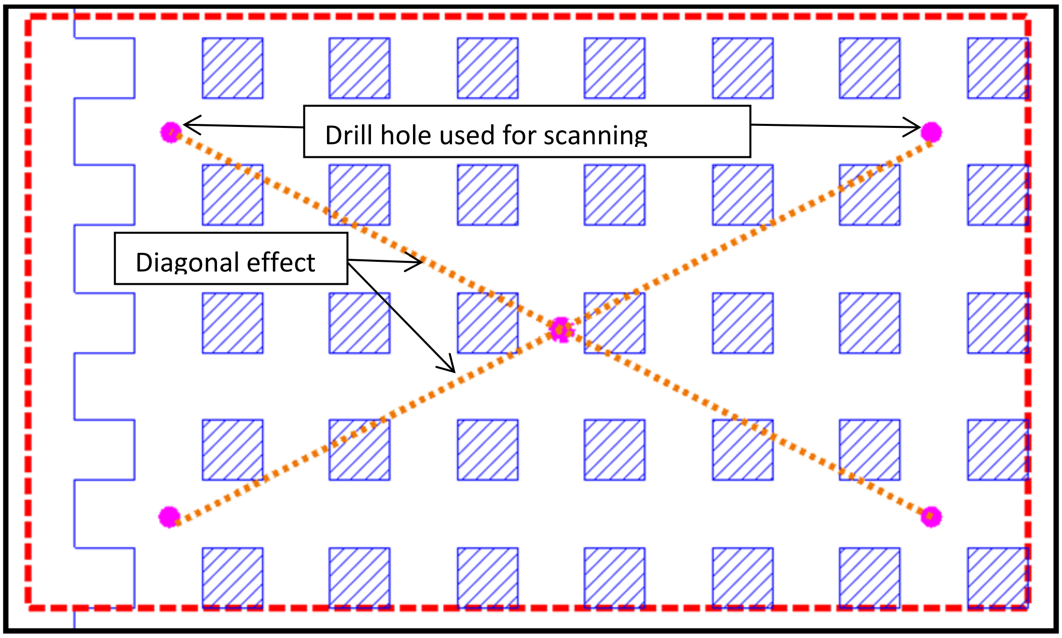


Figure 3-16: Diagonal scanning method

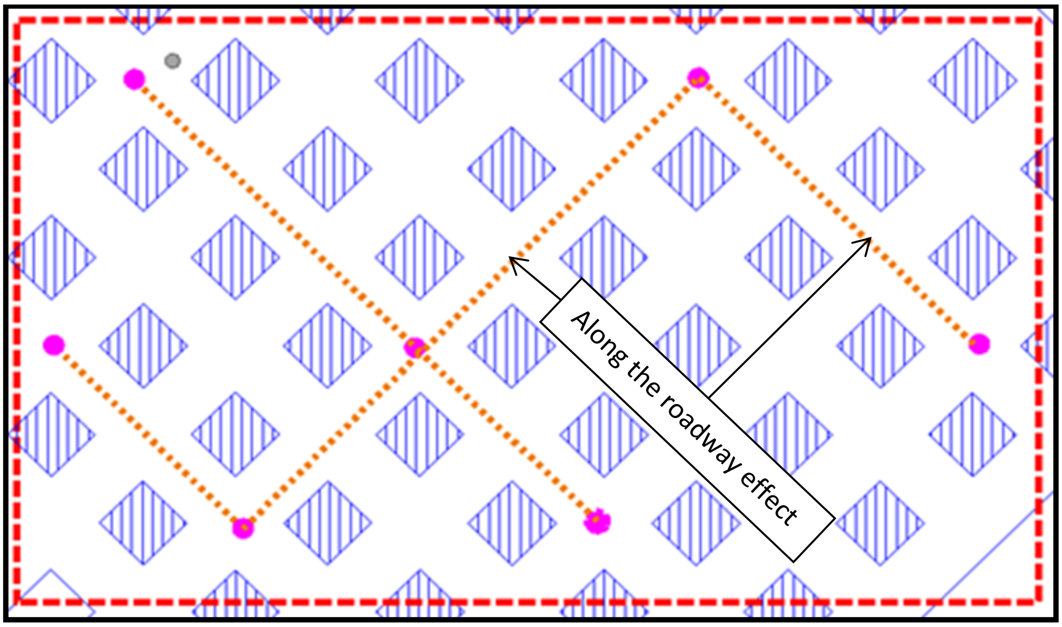


Figure 3-17: Parallel scanning along roadways

3.3.3.1.2 Parallel scanning along roadways

Parallel scanning along roadways requires holes to be positioned in the middle of roadways as shown in **Figure 3-17.** With the holes drilled in such a manner, the scanning between holes will pick up as many sides of pillars as possible, along the roadway. At least 2 holes per roadway can be drilled, with at least six holes per mining block. The alignment from hole to hole can run parallel as well as perpendicular to each other.

3.3.3.1.3 Around the pillar scanning

Around the pillar scanning requires holes to be drilled around a pillar as shown in **Figure 3-18** . The means that to scan a pillar adequately, three holes drilled should be able to measure the four corners of the pillar. The planning of these holes was based on the underground plans available.

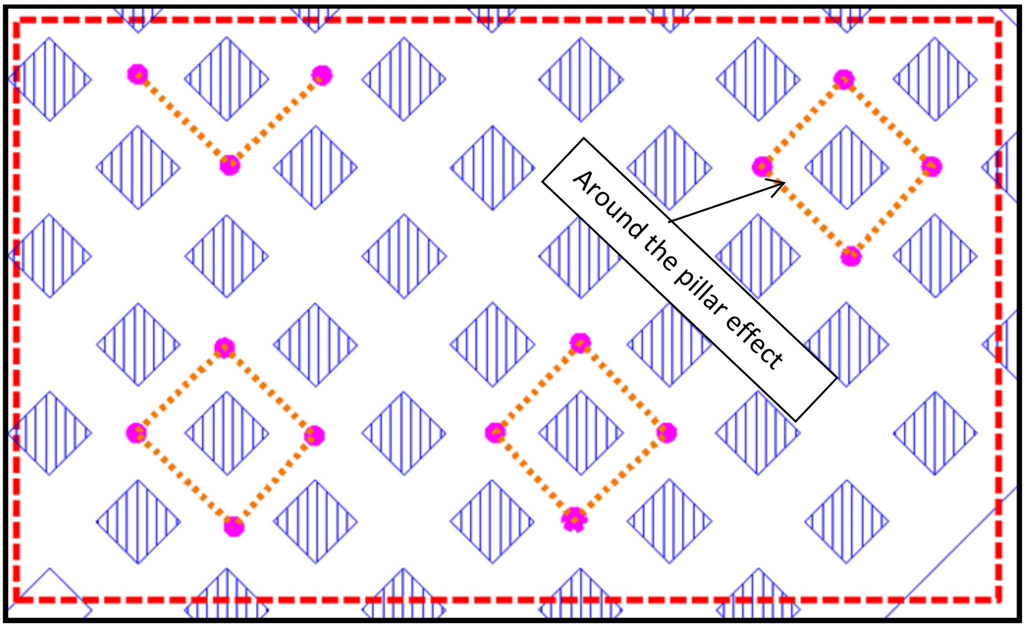


Figure 3-18: Around the pillar scanning

The plans shown in section **3.3.3.1** are all depicting the same legends. The broken red line along the perimeter of the picture is the opencast mining block size, the squares that are crosshatched are the pillars left behind after mining by bord and pillar method, the purple circles are the planned positions of the scanning holes and the broken brown lines are focus directional lines between holes. On the initial positioning of these holes, the holes were planned according to the initial drill plan layout. This was done to minimise the amount of re-drilled holes and to coincide with the current drill layout, hence reducing the number of drill holes that can supply oxygen to the underground workings which supports spontaneous combustion.

3.3.3.2 Results of the CALS Tool

Two different seam areas were scanned using twenty-five (25) holes, meaning twenty-five (25) scans were successfully completed. Twenty-seven (27) holes were planned to be drilled but two were not scanned because these holes collapsed or closed up. The scanning was completed as soon as the holes were drilled to avoid holes collapsing and unnecessary ingress of air and surface water. The Diagonal method shown in **Figure 3-19** resulted in five scans being completed successfully. Along the roadway method concluded with six successful scans whilst the last method Around the pillar resulted in fourteen successful scans. The original scanned data produces the scans in one colour. During the processing stage the colours were changed thus allowing the user to view overlapping scans, making it easier to sanitise the data as shown in **Figure 3-19, Figure 3-20** and **Figure 3-21**

Figure 3-19, **Figure 3-20** and **Figure 3-21** have shown that the CALS Tool can identify the shape and location of pillars in the underground workings. The three different scans emphasises that as the number of scan hole increase, the appearance of the pillar become easily visible. On all scans, it is evident that the scanning ability of the CALS Tool does have a distance limitation. It is noticeable that the data starts to fade away around two pillars, about 25m in this testing, provided no obstructions are encountered.

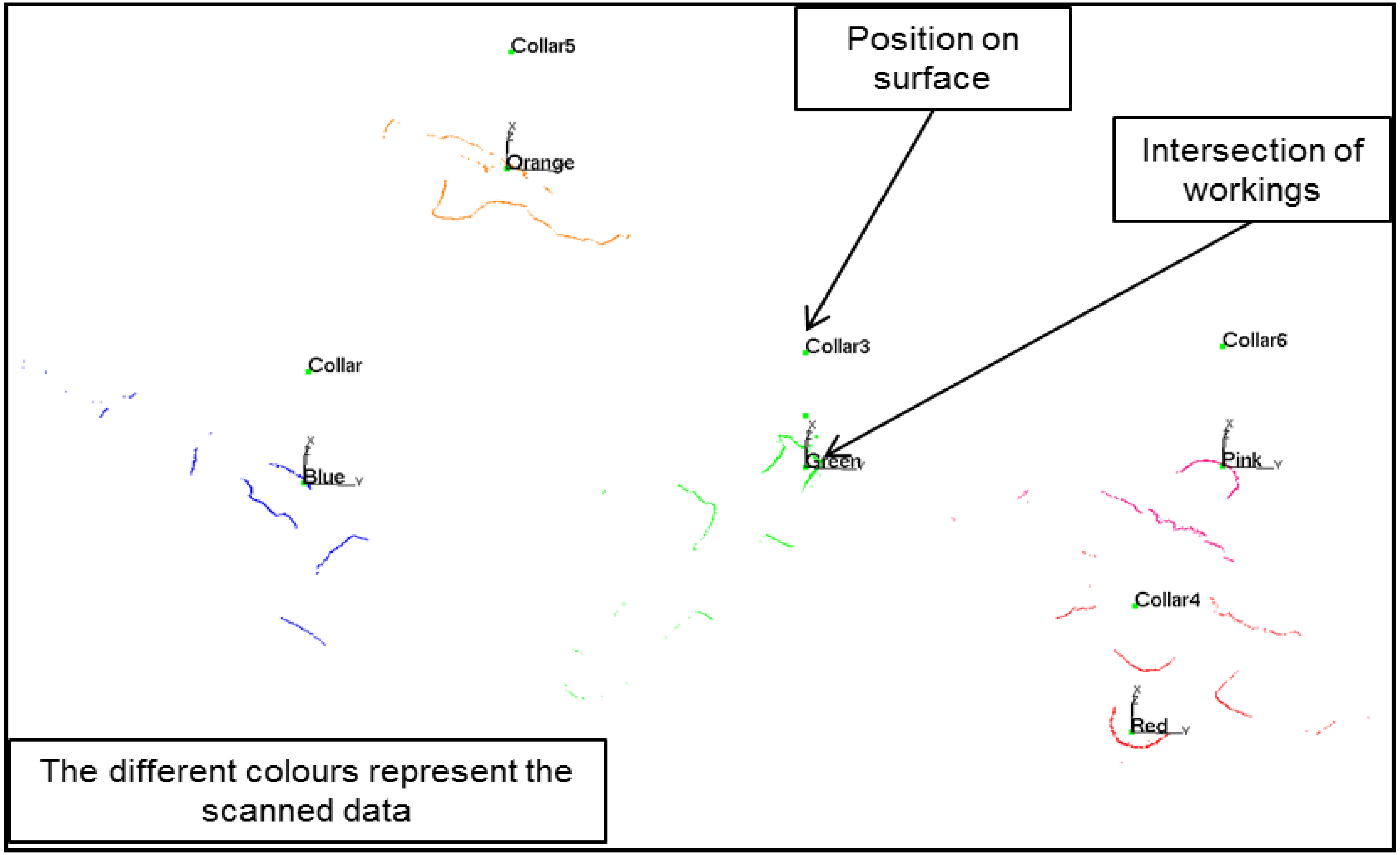


Figure 3-19: Results of Diagonal scanning method

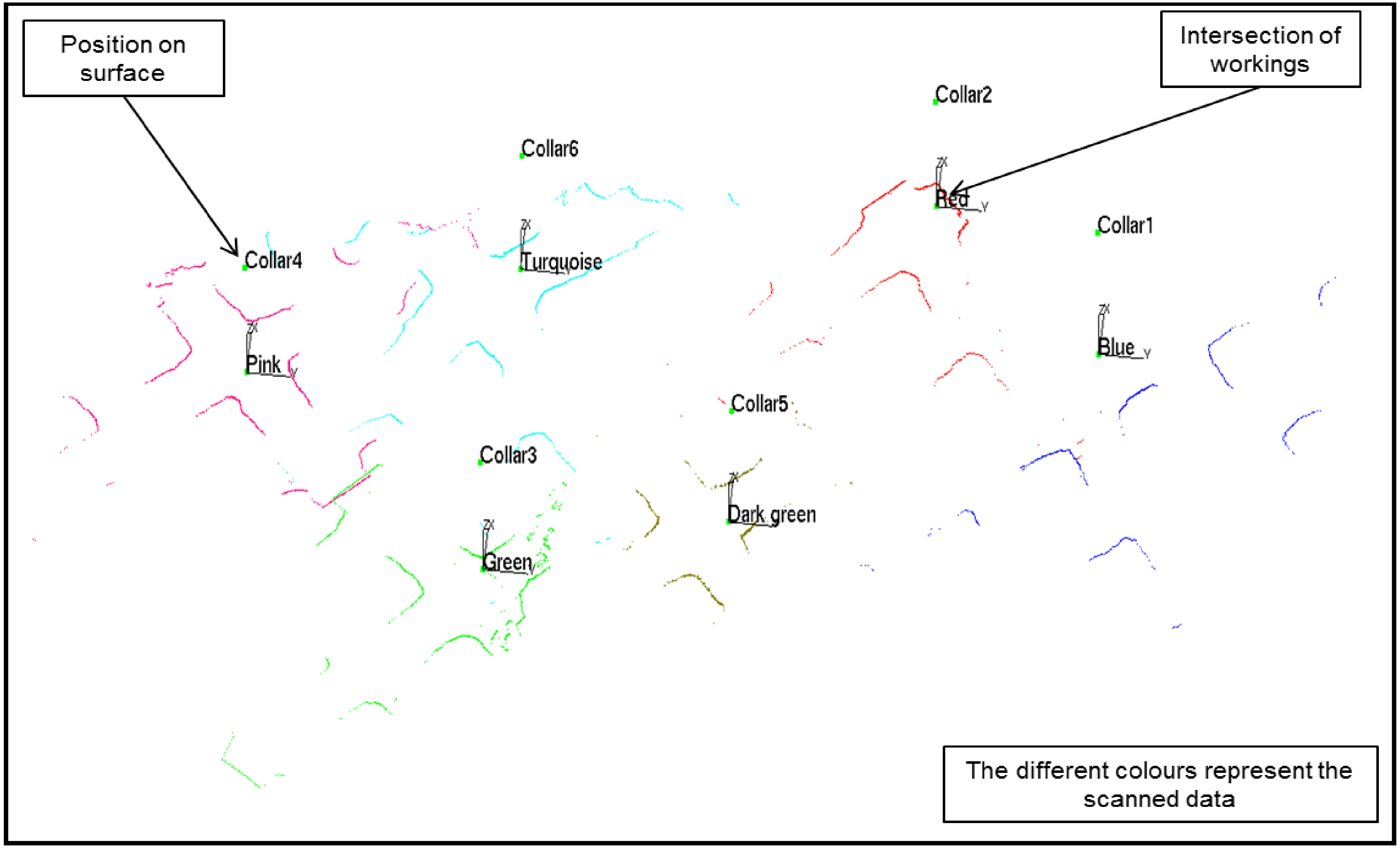


Figure 3-20: Results of Along the roadway

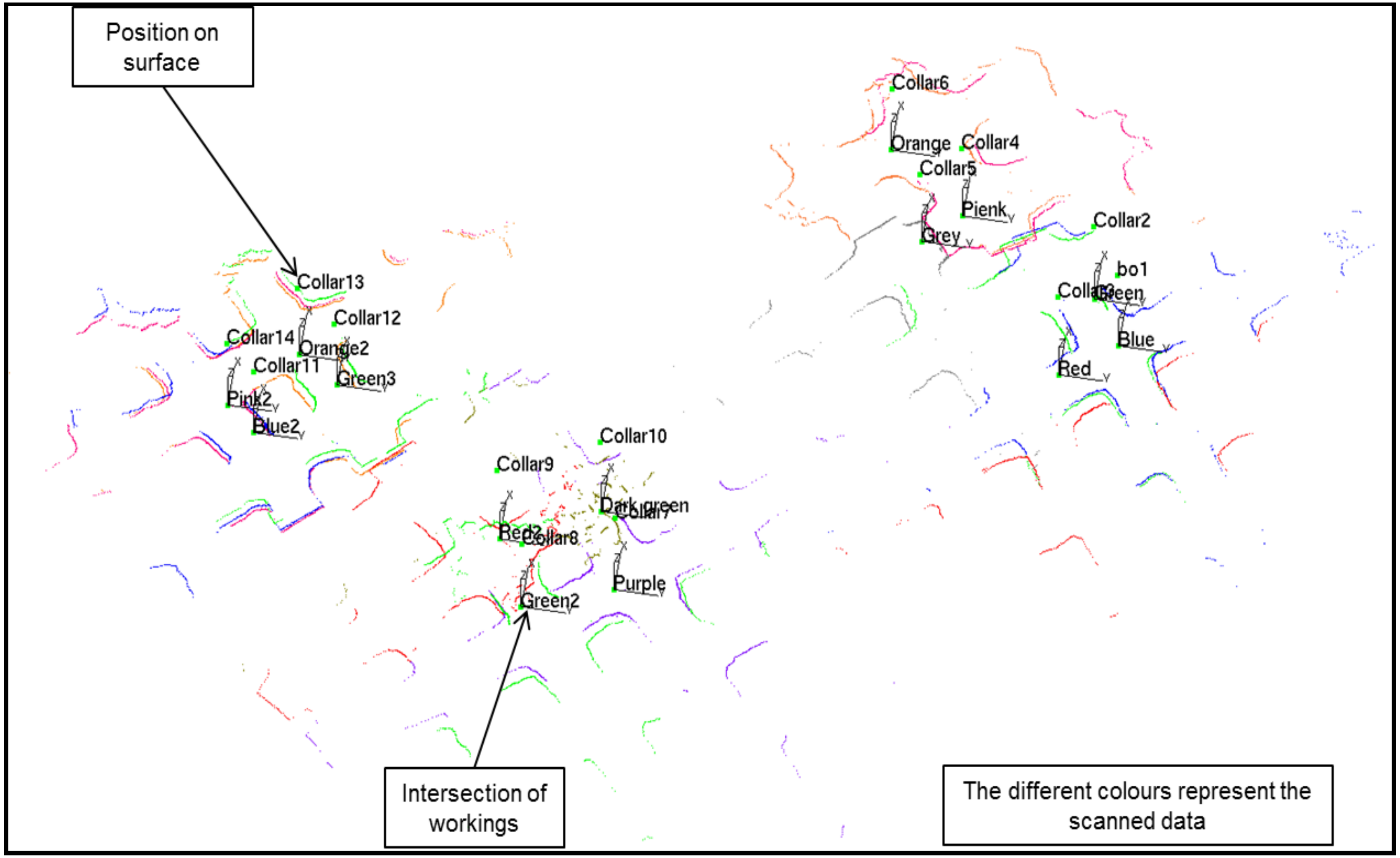


Figure 3-21: Results of Around the pillar

3.3.3.3 Conclusions on CALS Tool

The previous three figures; **Figure 3-19, Figure 3-20** and **Figure 3-21,** are the results of the raw data obtained from the CALS Tool. During the scanning phase, it is very important to note that the measure of the bearing between the scanned hole and the rod basket shown in **Figure 3-11** is important to acquire the orientation or else the results would be meaningless or the scan must be repeated. The orientation is based on survey principles where the scanned hole position of the CALS Tool is the survey station and the rod basket is the back-sight direction. This process is carried out for every single hole that is scanned, which ensures the scanned data is correctly positioned with regard to the X, Y and Z coordinates.

All of the 3 methods show a degree of characterisation of how the shapes of underground pillars are mined. The CALS Tool data has shown better results when compared to the GPR techniques and will be analysed in more detail in the next chapter. The analysing process indicated in **Figure 3-13** will be carried out in more detail in the chapter to follow.

4 ANALYSIS OF TECHNIQUES OR METHOD TRIALED

4.1 Introduction

The review of the fieldwork carried out at TOC is conclusive that the GPR technique it not suitable for obtaining any decent correlation of the underground bord and pillar workings of previously mined out seams when surface mining is carried out. Thus, no element concerning the GPR technique analysis is necessary. The Borehole Sonar was not used during the field studies because of the lack of water and will also not be discussed in much detail. However, focus will be on analysing the CALS Tool which has shown results of shapes that resemble underground bord and pillars.

4.2 GPR Test 1

From GPR test 1, not much information is available beyond depths of 10m with the GPR. This does not support the case at TOC where depths reach far beyond 10m of the underground workings. It is also important to note that the processing of the data when GPR is used takes anything between 2 to 3 days to process and at this stage is only prepared by that specific supplier. This relates to a cost being incurred during every scan and a lead time depending on the amount of area that has been scanned. The results were disappointing as it did not provide any conclusive data in detecting any underground workings.

4.3 GPR Test 2

The second supplier using a similar scanning device provided information about the difference in the system that proved that the system will work. Once again, this supplier had to do the processing of the data. The depths scanned reach between 13m to 14m only, which proved inadequate for TOC's application. The results shown in **Figure 3-6** indicate that it was not possible to locate underground pillars. There was no correlation between the scanned processed image and the underground pillars.

4.4 Borehole Sonar

This device shares similar characteristics of the CALS Tool but only works in water filled areas. The ability to provide a detailed scan in controlled situations, i.e. laboratory shows that it can provide good information, as shown in **Figure 3-9**; however as underground bord and pillar workings are found, situation still needs to be in areas where water is normally present. The workings were dry and thus the Borehole Sonar was not practical to use.

4.5 CALS Tool

The CALS Tool is able to produce superior set of raw data that can be used to analyse and understand the shape of underground coal pillars. The process shown in **Figure 3-13** will be used to provide a good interpretation of the value of the raw data.

4.5.1 Analysing and interpreting the scans

During this phase, it was identified that when the scanning unit was at different elevations, it produced different scan plots resulting in a variation of the scans for a particular pillar. The reasons for the different elevations were due to the following contributing factors; scaling of underground pillars that may have resulted in the changed shape of the pillars, obstruction of ventilation brattices that have deteriorated over time that are still hanging from the roof, material sagging from the roof, old equipment and infrastructure that was left behind.

This section also proves that there is negligible difference in the accuracy of the Ring scan compared to the Full scan shown in **Figure 4-1** because the Ring scans measures along the horizontal axis whilst the Full scan measure on the vertical and horizontal axis. The three methods reveal that the CALS Tool does locate underground bord and pillars shown in **Figure 3-19**, **Figure 3-20** and **Figure 3-21.** The analysis and interpretation of this data will be discussed in the sections to follow.

4.5.2 Diagonal Method Analysis

This scan was carried out on the No 4 seam workings which were mined in the 1948's using drilling and blasting mining methods. The first five holes were planned using the ring scan but a further two were scanned using the full scan. **Figure 4-1** shows five ring scan positions identified by small black circles and various colours for the scan data. A further two full scans highlighted in the lighter green represents the positions of these scans. This was done to verify the accuracy of the ring scan compared to the full scan, hence the extra two holes used to complete full scans. The ring scans are annotated by a black circle with each scan in a different colour whilst the full scans are in the light green. The digitised pillars are in a lighter red, the underground centre lines in turquoise derived from the survey pegs and the magenta lines showing the alignment using the scanned data.

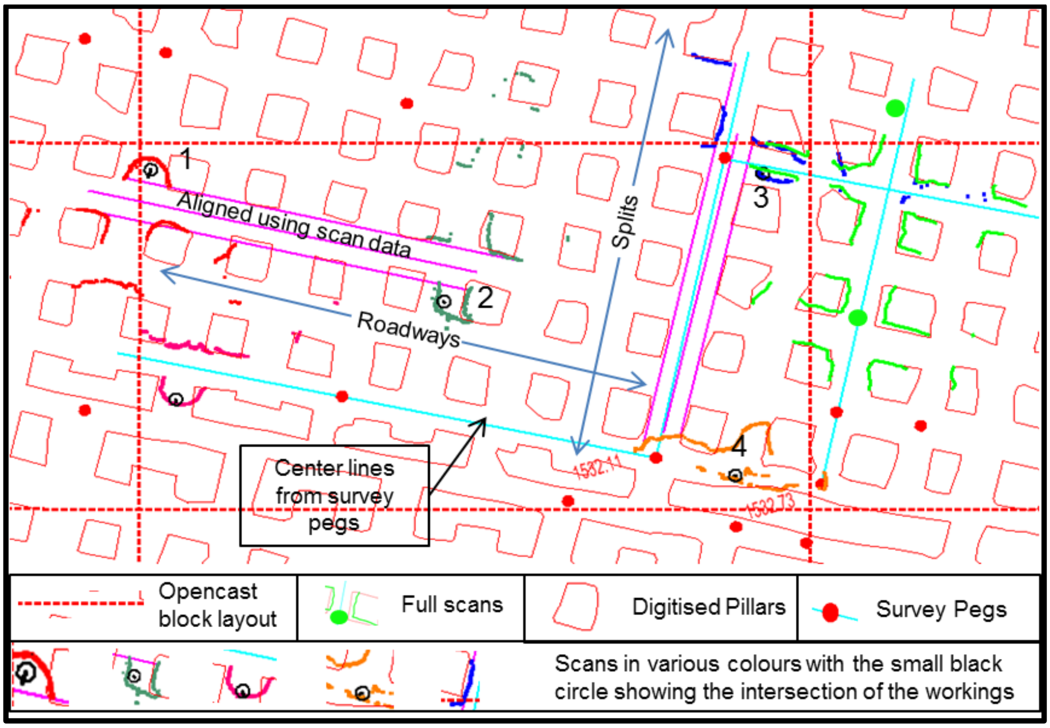


Figure 4-1: Digitised underground versus Diagonal method scan data

Road ways are the areas mined in the right to left direction whilst the splits are the areas mined in a top down manner, in the same figure. The average mining centres along the roadway were 12.5m and along the splits 12.0m. The bord widths averaged at 5.5m resulting in pillars width of 7.0m along the roadways and 6.5m along the splits. The depth below surface to the roof of the coal was on average 22m. The latter dimensions were measured from the underground plans for the area being scanned. The scan data from the left (red points) to the middle (dark green points) of the figure shows a good correlation of the alignment along the roadways meaning that the digitised pillar alignment correlates with the scan data. The scan points labelled 1 and 2 were used to determine the alignment of the scan along the roadway whilst 3 and 4 were used for the splits as shown in **Figure 4-1.** Both the roadway and splits showed a 0.9 degree and 1.0 degree difference respectively when compared to the survey peg alignment, the turquoise lines. This angular difference was measured using a survey CAD program called Microstation.

On close examination of the scan data in blue, it's noticeable that there appears to be an alignment issue along those roadways, however when compared to the full scans they align reasonable well. This is an indication that the ring scan produces reliable results despite fewer data points. This test was done on purpose to confirm if any major discrepancies existed between the two types of scanning. This also highlights that the CALS Tool is accurate in determining shape and locations of pillars.

A digitised survey plan is when the original survey plan is converted into an electronic version by using the survey points as the orientation points and thereafter tracing over the old underground plans using a digitising machine. The tracing is very dependent on the person operating the digitising machine. The steadiness of the tracing tool will determine the accuracy of the underground pillars. In **Figure 4-2** the comparison between the original underground plan and the digitised plan does not reveal any discrepancies which highlights a high quality of digitising. Therefore, it is easier to see the digitised plan over the original pillars as the two plans are superimposed.

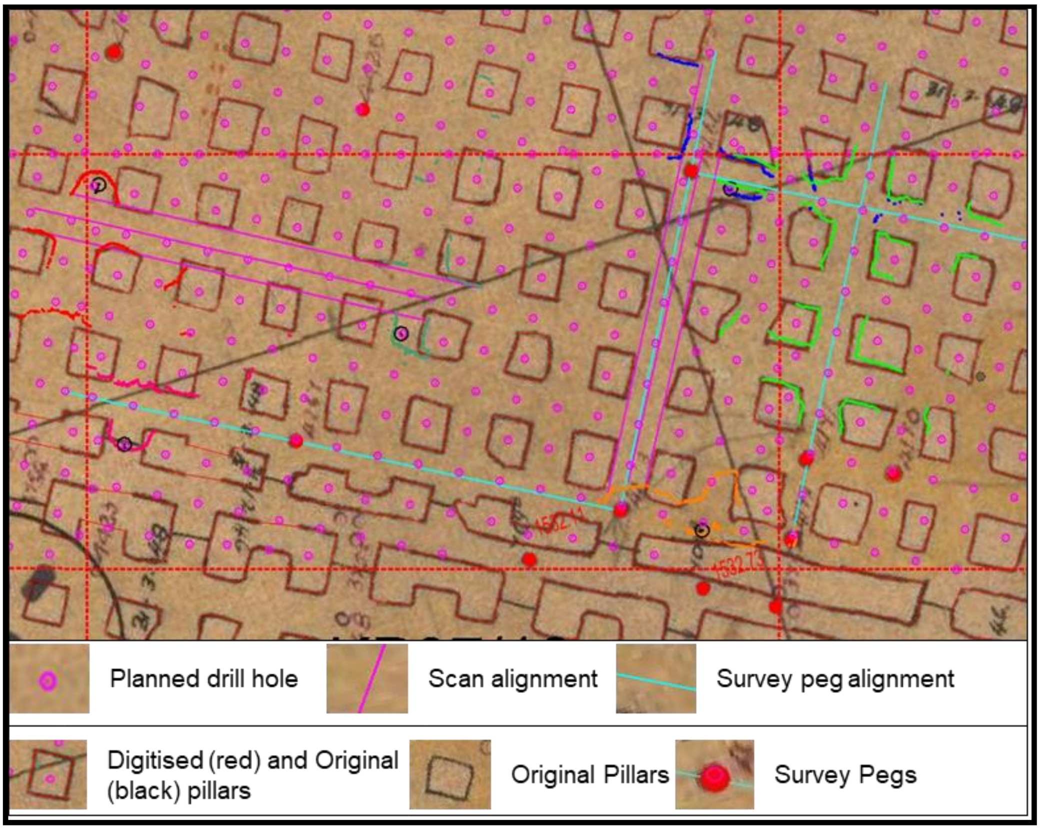


Figure 4-2: Original underground plan versus Diagonal method scan data

4.5.3 Along the roadway analysis

The following two scans were completed in an area where the No 2 seam was mined out. The average depths recorded by the CALS Tool were 20m, to the roof of the workings. **Figure 4-3** shows the following; the digitised underground pillars in light red where the pillars are showing fairly straight sides, the thicker red lines in a rectangle grid shape being the opencast block layout, the small purple circles are the initial planned drill holes, the small black circles are the scanned hole positions and the other colours showing pillar corners and sides of pillars are the scanned data.

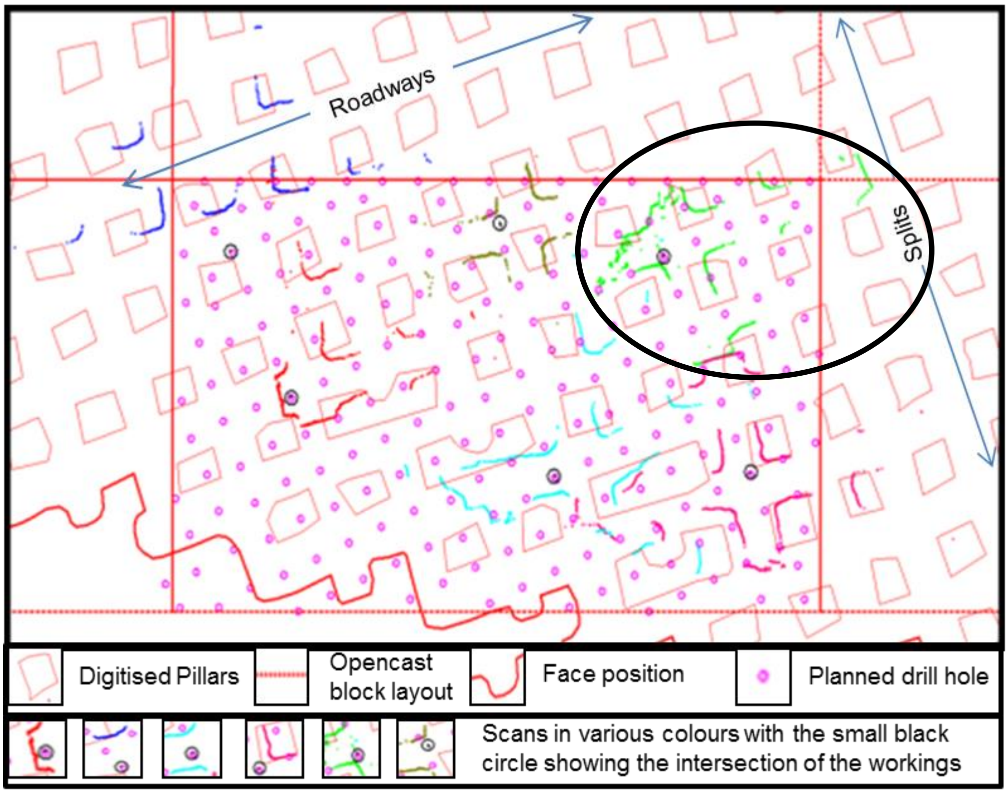


Figure 4-3: Digitised underground plan versus scan data

On close scrutiny using a suitable computer aided drawing package (CAD), there are points that are in isolation and show no real value, however it was decided for reference purposes to keep the scan points if the need arises to compare. The positions of the drilled holes compared to planned scan position correlated reasonably well except for one hole which was out by two meters. This particular drill hole intersected into a solid pillar; hence a new position was drilled to intersect the underground workings. Towards the right hand side of **Figure 4-3** and **Figure 4-4** inside the black circle are light green scanned data, however on the points on the left hand side show a bit of clustering of the data points. On the right side, some corners are more defined. Such data plots suggest that there is some sort of obstructions which could be; water accumulations, old ventilations brattices, accumulation of rubble or even old infrastructure as discussed earlier.

From **Figure 4-4** the correlation between the original underground plan and the digitised plan do not reveal any major discrepancies, however, the alignment of the original plan is different from the scanned hole data. The dark brownish more or less parallel lines in **Figure 4-4** were drawn in using the scanned data. This was simply done by looking at the sides of pillars and drawing it into the underground plan. These lines were also drawn in both the roadways and splits of the workings. The roadways orientated on the plan run from right to left, whilst the splits are in a top down direction as shown in **Figure 4-3** and **Figure 4-4**. The distances between the alignment lines average 6,0m wide, which is the bord width. The second check was the angles created by the alignment lines which should be as close as possible to 90degrees but after measuring varied between 90.4degrees and 89.9degrees which are acceptable according to the surveyor.

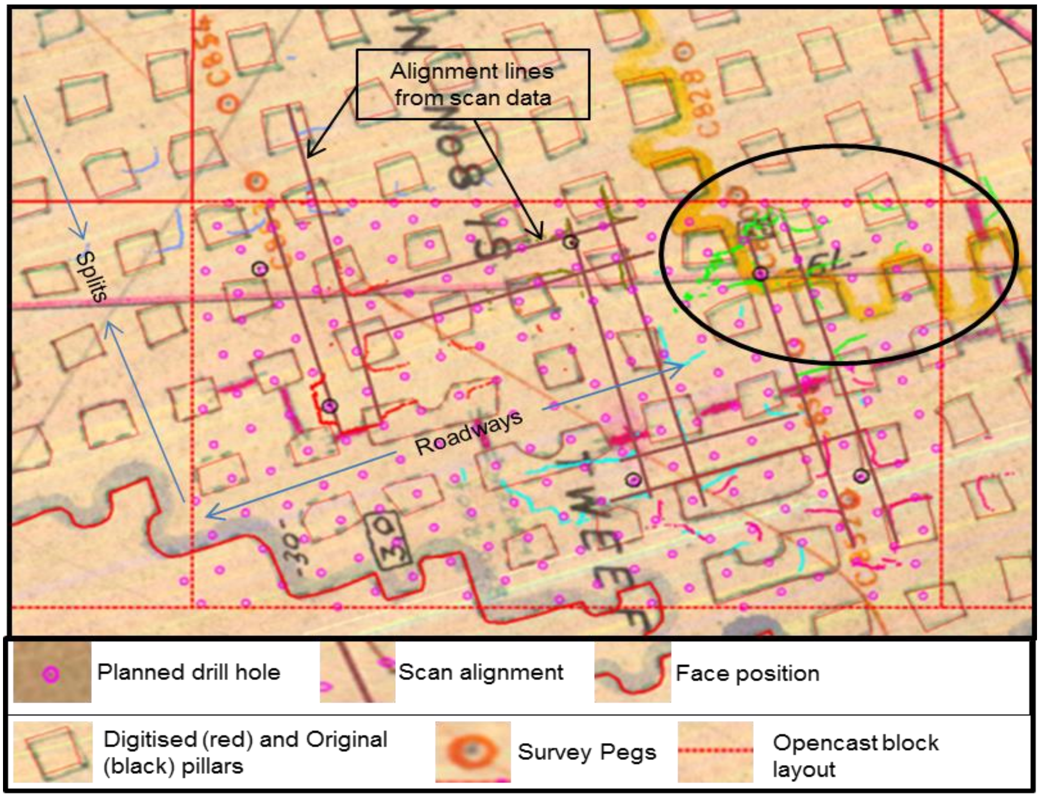


Figure 4-4: Scanned holes of along the roadway compared to underground plans

These measurements were derived using a CAD program. The difference between the old underground workings and the scanned data resulted in an average angular difference of 2 degrees in the direction of the splits and a smaller variance in the direction of the roadways of 0.5 degrees.

The big question arises is which information is correct; the underground plans or the scanned data. Going into the next method; Around the pillar it was decided to continue with extra scanned holes in the same block to confirm the accuracy of the CALS Tool. As mentioned earlier the time taken to apply the process indicated in **Figure 3-13** was less than one day which meant that new holes were drilled overnight, proceeding to the next method, Around the pillar, in the mining block.

4.5.4 Around the pillar analysis

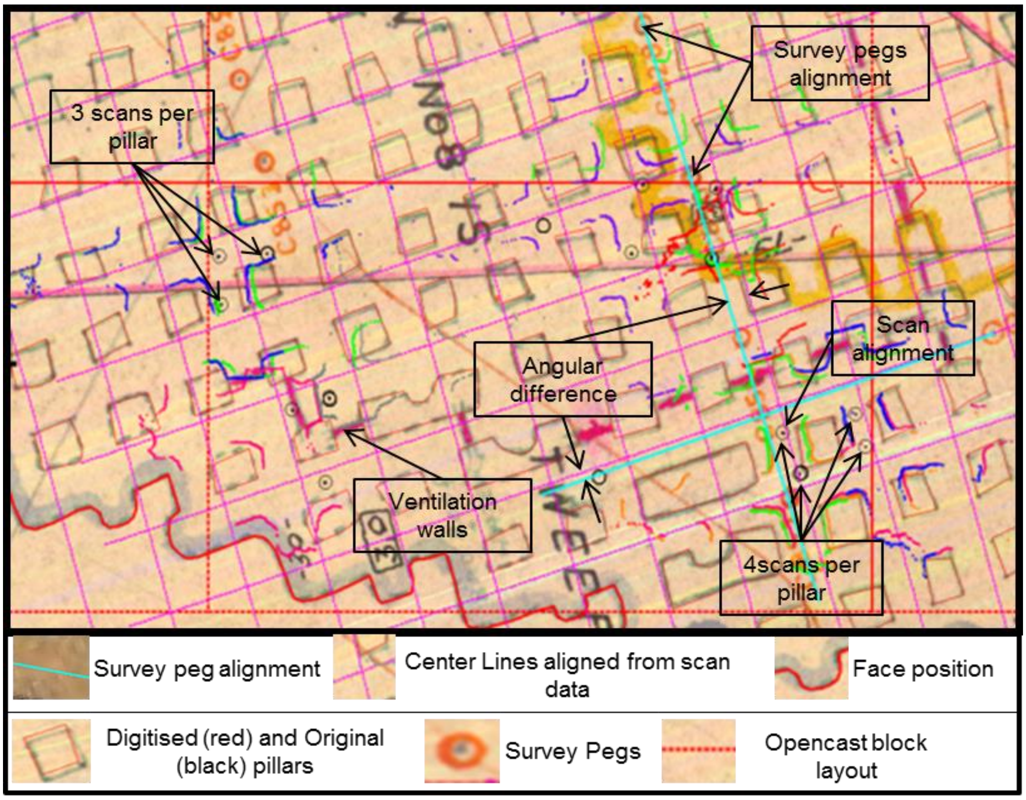


Figure 4-5: Scanned holes of Around the pillar compared to underground plans

Figure 4-5 shows the holes scanned for Around the pillar method. On the left-hand side of the plan only three holes per pillar were obtained whilst on the right-hand side four holes per pillars were completed. The centre lines in purple was derived using the bottom right hand corner scan data whilst the turquoise lines were drawn using the survey peg information from the plan highlighted a faint orange colour. In the next figure the details are zoomed to show why this specific scan data was used.

When looking inside the black circle in **Figure 4-6** it can be seen that four different colours were produced, representing four scans. The pillar formation from the scan data is very conclusive in that each hole scanned was in close correlation with each other, with most of the data points being within half a meter of each other, but still provides a similar shape, rather than a square like pillar shown in the underground plans. The centre lines generated were based on 12m derived from the underground plan. The angular differences were 1.7degrees along the splits and 0.7degrees along the roadways. This was very similar comparing to the Along the roadway method, however the detail shown in Around the pillar provides much more confidence when comparing the scanned data to the old underground plans. Further confidence alludes that the scan is accurate where the ventilation walls are picked up by 3 of the scans also showing a slight angular shift in the old underground plan.

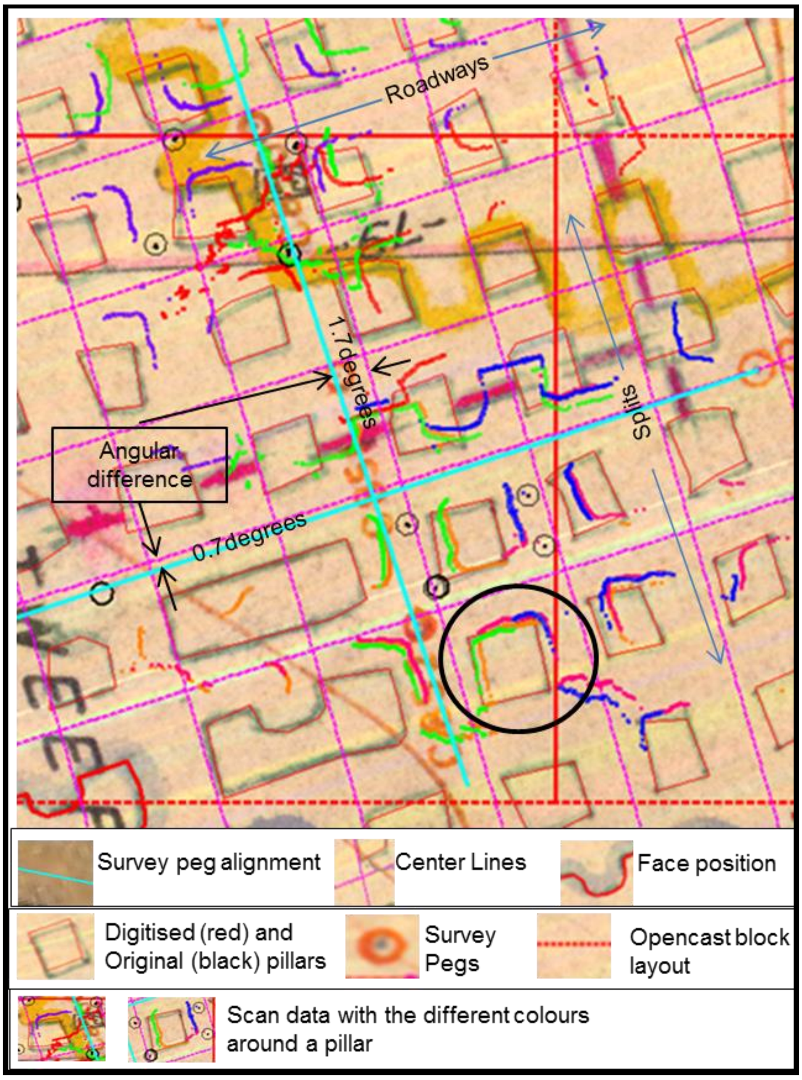


Figure 4-6: Zoomed in view of Figure 4-5

4.5.5 Interpreting the results

The Diagonal method showed good correlation to the underground workings despite being far apart, using five ring scans and a further two full scans. On closer examination of the original underground plan it was observed that the survey pegs were adequately installed over this specific underground working. This proves the accuracy of the CALS Tool with the underground workings. In this case, there was no need to redraw the pillar positions or realign the plan using the scanned data.

The second two methods eventually became a combined process due to the variances between the underground plans and Along the roadway method, however Around the pillar method proved that the once again the CALS Tool provides accurate information by showing that four different scans picked up the points of a pillar within half a meter of accuracy and that there is an angular shift in this block scan. The survey peg data on the original plan indicated that no surveys pegs were installed in the majority portion of the left side on the scanned block. This is illustrated in **Figure 4-4** and **Figure 4-5** where the survey pegs are limited in this block; hence the offsetting completed is not accurate due to insufficient survey pegs to determine the correct shape and location of pillars in this portion of the underground workings. The differences in alignment between the scan data and the underground plans highlight that the tapes used during offsetting was not aligned correctly resulting in the alignment problems identified but the shapes of the pillars were reasonably associated.

4.5.6 Conclusion

Before the CALS Tool is used the following must be asked;

1) Are the workings flooded or excessive accumulations of water evident?

2) Is there a potential of spontaneous combustion possible or encountered in the previous close by mine blocks?
3) What is the depth of the workings?
4) Are there survey pegs adequately covering the block or not?
5) Is there missing underground pillar information on the plan?
6) Will the Ring or Full scan be appropriate?
7) How soon is this information needed?

If question 1 or 2 is a yes then the CALS Tool cannot be used, but if no, the process can continue. The depth is important in that the CALS Tool is limited to the number of rods available. If the underground is deeper than the CALS Tool capability, further stripping will be needed before the scanning process can continue. Knowing the survey information allows the user to decide which method to start with, such as in the Diagonal Method with the sufficient survey pegs it would be quicker to correlate the data and make a decision for mine planning to continue with other specific designs. This would also indicate how many scan hole positions are required. On the other hand, when survey pegs are far and few, the scan must start from the survey peg area to ensure a comparison is correlated to proceed into the lesser defined areas. Once this part is completed the following holes can be extrapolated and set out to be drilled and then scanned. From the scanned data, it is also noted that the scan data points have much more definition and fades away after the second pillar. The limitations on the CALS Tool are that it cannot work in water or areas associated with spontaneous combustion. It can provide good detail scan data points up to the second pillar when scanning, although the fewer fading scan data can be maintained as a check, rather than using it as a conclusive deciding scan point.

The following decision tree is a simple guide to manage questions 1 to 7 discussed in this section and demonstrated in **Figure 4-7**.

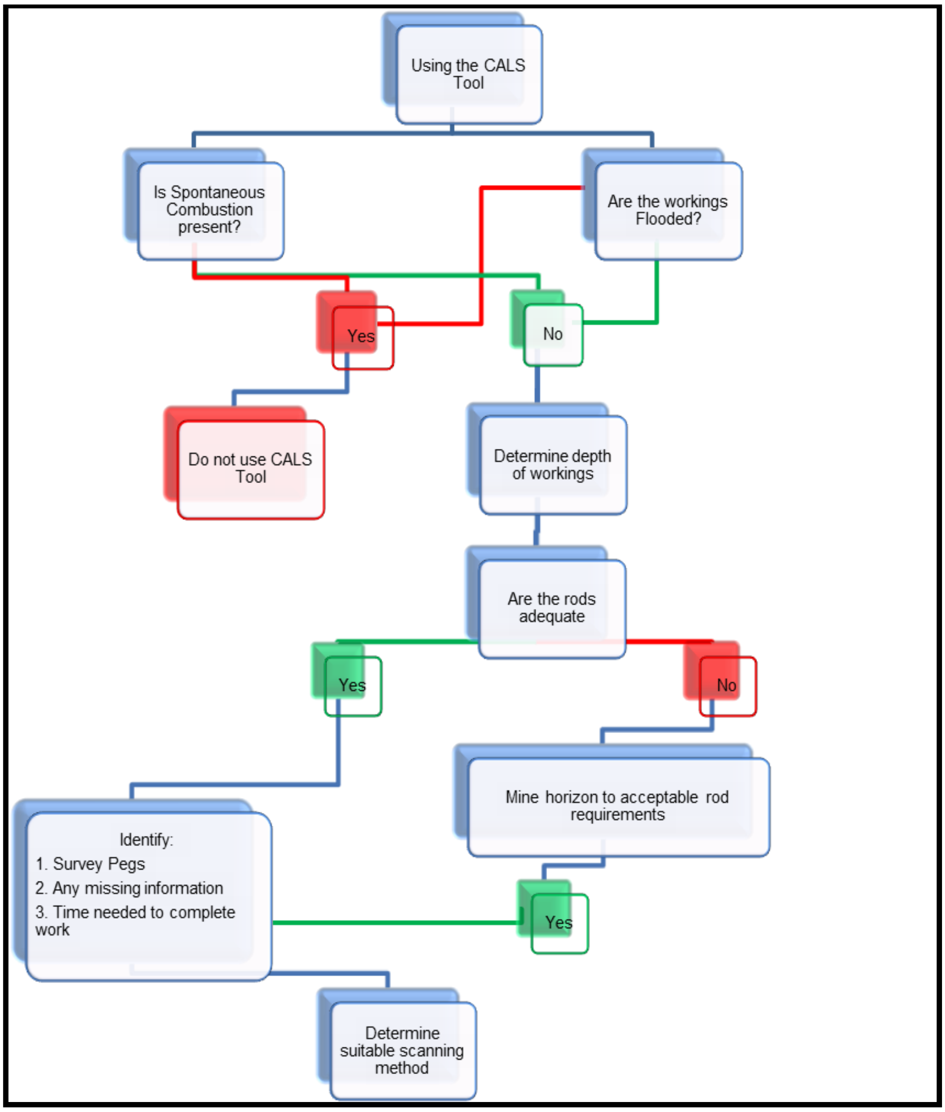


Figure 4-7: Simple decision tree

Two pillars equate to 25m in one direction within this area at TOC. Should the scan have no obstructions it potentially would be able to scan in four directions provided the scan drill hole is position intersects in the middle of a roadway and split. **Figure 4-8** illustrates the position of the scan hole and the red arrows the four directions, whilst the blue scan data accentuates how the data is collected as well as the fading of the data after two pillars. This process can be applied when underground pillars are missing, starting from a known area with special emphasis on adequate survey pegs. Using the Ring or Full scan will be reliant on time, how soon is this information needed? As mentioned earlier the Full scan takes much longer and with the data obtained the interpretation will also take longer.

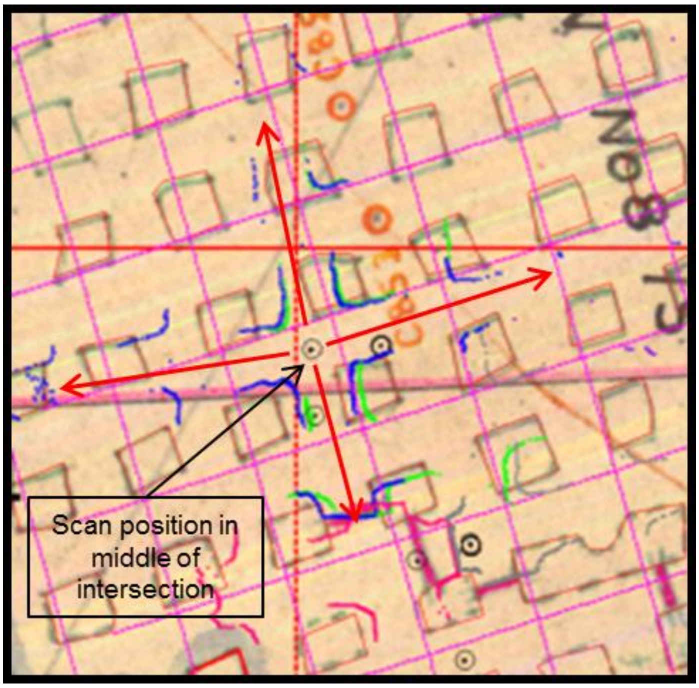


Figure 4-8: Scan hole in the middle of an intersection

5 CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

The Witbank Coalfields has vast areas of underground mining where various seams have been mined. Many of the shallow (15m – 50m below surface) seams in the early 1900's has been mined by underground mining methods, however over the past few decades these areas have become economically viable, with large reserves of high quality coal trapped in pillars within this field (Ngwenyama, et al., 2017). Mining companies have become more efficient and productive over the years and have proved that these reserves are profitable to mine using opencast mining methods.

The literature review indicated that the GPR had the potential to identify underground workings up to 40m deep. However, the two GPR tests done at TOC did not provide any suitable data that could be correlated to the underground workings i.e. the processed information was not easy to interpret. The literature review indicated that the CALS Tool ability to identify the spatial location of underground pillars and digital viewing. This was confirmed by the results obtained from the 25 holes tested. However, to get the correct results the orientation of the hole and the rod basket must be measured accurately. In addition, the CALS Tool was not tested in water and spontaneous combustion areas as the equipment used was borrowed from the supplier and therefore could not afford to damage it unnecessarily.

The purpose of the research was to find a practical method in identifying the shape and location of the underground pillars. The techniques trialled have shown that GPR does not provide adequate results in identifying underground coal pillars at TOC. The CALS Tool on the other hand has been successful in providing detailed information with regard to the shape and location of pillars. The CALS Tool is limited to scanned information up to two pillars in four directions if there are no obstructions underground as shown in **Figure 4-8**. The three different methods provided adequate scan data to determine a reasonable shape of pillars and checking the accuracy of the alignment of the underground workings. The accuracy of the original underground plans compared to the digitised plans show a high quality of digitising, hence the scan data could be compared to the digitised plans. The Diagonal method and Along the roadway can be used as a quick check when survey pegs are adequately spaced out in the underground workings, whilst Around the pillar method provided a detailed shape and location of the underground pillars by using at least three scans per pillar. The latter method can be applied in underground workings where survey pegs and pillars are missing from the underground plans.

However, to complete a detail scan such as Around the pillar for a large underground reserve, hundreds of holes will have to be drilled to attain a completed plan of the underground workings. This will be a costly process in terms of the holes that will have to be drilled as well as sealing off the drill holes after the scan is completed to prevent spontaneous combustion. The identification of the underground pillars using the CALS Tool is supportive to short term planning rather than LOM planning in improving the reserve accuracy because of the potential cost implication of drilling and sealing.

The CALS Tool provided the results anticipated and indicated by the supplier. It provided data that can be used to determine the shape and spatial location of the pillars. The training of the surveyors was completed after one practical and software session, thus easing any delays for a successful set of data points as compared to the GPR.

The CALS Tool produced good results that can be correlated and interpreted with the underground workings; hence the focus on the latter part of this research was on the CALS Tool. The CALS Tool can measure pillars underground, however it has its limitations when encountering water and spontaneous combustion. When using the CALS Tool, the simple questions highlighted in the previous chapter, demonstrated in **Figure 4-7** will provide a guide on how to approach an area that is planned to be scanned. This can vary from block to block; hence it is suggested to do an analysis on a block before continuing with the next block.

5.2 Recommendations

The focus of the report was to identify a suitable method in scanning or the surveying of underground workings. This has proved to be successful with the CALS Tool. The trials completed in areas of known reliable underground mapping indicates that this tool can provide the information needed at TOC, hence one unit has already been purchased.

Within GCSA a pre-emptive risk assessment is conducted prior to any strip being mined. During this stage the blocks that need to be scanned can be identified and the method on how the scanning will take place can be determined. This risk assessment involves various departments on the mine hence, it becomes a tool to assist other departments such as rock engineering should they require a full scan. The full scan is abundantly defined and will detail any areas of concern; such as excessive scaling of pillars.

5.3 Suggestions for future research

Spontaneous combustion is common where underground coal bord and pillars workings are present and surface mining is done. Identifying the shape and location of underground pillars in these areas will be extremely valuable in determining how reserves should be mined. Spontaneous combustion causes the underground pillars to burn resulting in the shape of the pillar to change if the pillar is not burnt completely and where the pillar is completely burnt it would be difficult to determine the shape. This decision also involves identifying the safety risk and how it will be mitigated.

I therefore recommend the CALS Tool manufacturer should consider this technology to be modified to identify underground workings where spontaneous combustion is evident and there is flooding in the workings.

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