Short-term geological modelling for improved mine planning at Isibonelo Colliery

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31st August 2018

Abstract

Isibonelo Colliery is an opencast operation employing the strip mining method, and for short-term planning, up-to-date geological information is required. The colliery currently depends on the annually updated geology resource model information for input into the three planning windows (short, medium and long term). To improve and optimise on short-term mine planning, short-term geological model information has become a requirement. This research project was undertaken to fulfil the Anglo-American Coal South Africa's Operation Management System (OMS) requirements. This research report focussed on closing the gap between OMS requirements and current practice, by creating a short-term modelling process to fulfil the requirements for both mine planning and rock engineering disciplines. Highwall mapping techniques such as digital photogrammetry from drone highwall flyover, as well as use of total station surveys to map lithological contacts for input into the model were investigated and tested. The study area focussed mainly in the far south portion of Isibonelo South pit where most of the data was collected to build the process of short-term modelling as a test case. Short-term planning requirements using latest geological information was achieved and mine designs started to improve. Subsequent strip reconciliations showed improved correlation between planned and actual, especially in the dragline volumes from 3% to 0.5% over two mining cuts in the South pit. Coal recovery improved by 2.1% between October 2017 and April 2018. There was good coal seam correlation between the short-term, survey and resource model. The softs(weathered) horizon still need some further work to close the gap between planned and actual thicknesses.

The author recommended the use of drones for highwall mapping and down the hole wireline logging of selected pre-split holes to be adopted as methods of acquiring data for short-term geological modelling, and optimise on short-term planning.

Key words:

Geology, Highwall, Mapping, Operation Management System (OMS), Short-term model, Drone.

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My appreciation goes to the Isibonelo survey department for making available a survey team to work with on this project for all the field mapping with me using the total station. The Isibonelo Colliery production geologist spent time with the author gathering data in the field and working with the surveyors. The Anglo American Coal Geological Services department management and staff, through Donavan Pretorius (Resource Geology Specialist responsible for Isibonelo Colliery) who worked tirelessly to guide me to develop the short-term geological model for this project. Samuel Mokele and Peter Roberts, my geology superiors for all the support and guidance during the research. I would like to thank Ester Varaidzo Dhege (New Vaal Colliery, Production Geologist) and Joanie Botha (Kumba Iron Ore) for sharing experiences on highwall mapping technology at their operations towards gathering data for short-term geological modelling.

The foundation of the short-term geological modelling process was laid down for the author by Sue De Klerk (Resource Geologist from Anglo American Coal Australia), by providing background to current practice at their operations.

The drone technology in highwall mapping was tested in this research project through the assistance of Frikkie Fourie (Anglo Coal South Africa, Drill and Blast Specialist) and Ernest Carpenter (Isibonelo Technical Services Manager) by facilitating a demonstration from Vidblast and Premier Mapping, amongst some of the local drone flight companies.

Geologists from other mining houses were also consulted by the author during the research project, a special appreciation goes to them all, for their valuable contribution through shared experiences. My final appreciation goes to my supervisor, Clinton Birch (Senior Lecturer, School of Mining Engineering, University of Witwatersrand for his valuable academic guidance throughout the research, spending time reading through the draft copies and giving advice.

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List of Keywords and Acronyms

Key words	
Data	Raw /unprocessed information collected for study purposes
Drone	Unmanned aerial vehicle
Highwall	The unmined, exposed face of overburden in an open cast mine
Geological mapping	Identifying rock types and structures and recording them on a map using prescribed symbols/codes and colours
Geology	A science that deals with the earth and its physical characteristics inclusive of processes that prevail upon
Short-term geological model	A geological model that is constantly updated with the latest geological data generated as mining progresses
Mine Planning Department	The department responsible for the mine's designs, scheduling and monitoring
Softs highwall	The weathered part of the unmined exposed face of overburden in open cast mine
Acronyms	
ACSA	Anglo American Coal South Africa
BCMs	Bank cubic metres (unit of measure for dug out material by a dragline in open cast mines)
BHSO	Base horizon of soft weathering (soil and soft weathered material)
BHFW	Base horizon of friable weathering (material that require ripping before removal)
BHWE	Base horizon of weathering
BHHW	Base horizon of hard weathering (marks lowest depth of weathering)
GDB	Geological Data Base
GDH	Gardner Denver Holdings (manufactures of drilling machines including overburden drills)
MAD	Mine Activity Document
MAE	Mine Activity Engineer (formerly mine planner)
OMS	Operating Management System
RPAS	Remote Piloted Aircraft System
SACAA	South Africa Civil Aviation Authority
RPAS	Remote Piloted Aircraft System
STM	Short-Term Model
THDW	Top of the Dywka
THPK	Top of Pre- Karoo
UAV	Unmanned Aerial Vehicle

1 INTRODUCTION

Mining is a business of extracting the mineral deposit from the ground which will have been discovered through a process of geological exploration. The life cycle of a mining project is heavily dependent on the size and shape of the orebody, hence the term, “the orebody dictates”. Gurgenli, Minnes, & Oommen, (2011) stated, “A well-known fact in the mining industry is that every mine has different conditions and requires a unique modelling and planning strategy.” Therefore, it is imperative to have a custom made geological model and planning system for a mine that can execute all the requirements to produce good and reliable plans. The research report outlines the purpose of the study that was conducted at Isibonelo Colliery and gives background detail as to what motivated the research to be undertaken.

1.1 Purpose of the study

The research project investigated in detail how feasible the process of short-term geological modelling is for South African coal operations with reference to Isibonelo Colliery and whether it adds value to mine design, increases productivity and coal recovery. Short-term geological modelling is currently not being practised hence this research project investigated why it has not been implemented by the operations. The annual geological model has been deemed adequate for the mine planning requirements to date.

The research project was also undertaken to fulfil partial requirements of the degree of the MSc. Engineering (Mining) course in the School of Mining Engineering (2016-2018) on part time and course work by the author.

1.2 Research background

Mine designs continue to be generated based on the shape and size determined by the geological model. The Isibonelo Colliery geological model is updated annually and is termed a resource geological model from which the mining model is built using a software package called XPAC (an Australian property of Runge Pincock Minarco). Anglo American Coal South Africa (AACSA), has over the years been using the resource geology model for annual mine designs and producing mining schedules using XPAC. In 2013, AACSA operations and Anglo American Coal Australia were put under one umbrella with headquarters in Brisbane, Australia. The mining systems started changing to follow the Australian way of doing business. The term, Operations Management System (OMS) was introduced to the South African coal operations which is a good management tool that assists in having well documented processes for the entire coal mining business.

The process documents in detail how different types of work operations are conducted, including standards and procedures amongst others. Geology has five areas in the OMS system that are audited for compliance annually, they include

- Exploration Planning and Delivery;
- Short-Term Geological Modelling (the subject of this research document;
- Operational Control;
- Operational Planning; and
- Reconciliation.

The process of managing these five areas requires input from other mining disciplines such as survey, planning and resource evaluation. The annual resource geological model has input from exploration and is built and maintained by the Resource Evaluation Department (a centralised service, away from operations). Meanwhile, the operations such as Isibonelo Colliery rely on the geological model from the Resource Evaluation Department updated once every year. The rationale behind OMS is that each operation should have its own colliery based model that must be constantly updated with actual measurements such as coal seam thickness, structural features (dykes and faults), elevations from the pit. This research project covered the process flow from generation of geological models through to the interface with mine planning processes, to try and answer the question," Does a short- term geological model add value to open cast strip mining through improved mine design, productivity and coal recovery?" The South African mining environment with its skills challenges was analysed and compared with the challenges Australian operations also face. The Australian based Anglo American Coal geologist, Susan De Klerk, said, "In Australia, the geological models are identified as Resource Models and Short-Term models. Essentially the model that gets updated every year is the equivalent of a Resource model. This is used for Resource and Reserve Estimation for reporting to Anglo American plc, and used for Life of Mine Planning, Medium- Term Planning, and shortly after release, Short-Term Planning. Some of these models are only updated every three years due to, mainly a shortage of people to do the work. " (Klerk, 2017)

Short-term models are built by mine geologists and they take the latest release of the Resource model, and add in data as it becomes available, such as surveyed high-wall seam roof and/or floor, faults, seam roof from blast holes, grade control holes and any other measurements deemed necessary. This process of short-term geological modelling allows for the incorporation of small-scale features, such as seam rolls and previously unidentified faults, which may not be obvious from just borehole data. While the new model is then used for short-term planning, the new data is to be incorporated into the next resource model". Short-term geological models are updated monthly with new data and kept live to be used for short-term planning (one month to three months). Improved coal recovery, dragline performance, pre-strip fleet performance is among some of the measurements of the success of better planning using the short-term geological model.

Field measurements were conducted by the author at Isibonelo Colliery and taken through the mine process, reconciliation (checking actuals against predicted) with the involvement of the resource evaluation department. The results from this research culminated in a renewed interest in short-term geological modelling to the extent of motivating for a presentation to the Anglo American Geoscience Innovation Colloquium held at its Head Office in Johannesburg on 11 May 2018 (the author and the resource geology specialist co-presented at the gathering, see Appendix.10.19, for the full presentation). The presentation to mine management, with recommendations, was also done by the author to close some of the shortcomings identified in previous audits highlighting the lack of a short-term geological model on the mine.

1.3 Research Motivation

The concept of short-term geological modelling at Anglo American Coal South Africa has not been considered seriously in practice. It was in the author's opinion, that this research project would close the lack of a short-term geological model in the operations management system (OMS) of the group. In the previous audits for Geology, Mine Planning and Rock Engineering, short- term geological modelling was highlighted as a shortcoming. The purpose of this research project was to develop a well detailed process of executing short-term geological modelling in Anglo American Coal South Africa operations that would eventually be adopted for use by the group. The research was conducted as part of the author's day to day normal work schedule on the mine.

1.4 Problem Statement

The current practice with Anglo American Coal, South African operations is that the geological model is updated once per year after the annual exploration drilling programme. This model is used for long, medium and short-term planning purposes hence the question arose as to whether it is adequate to address all of the time spans or not with one model. The geology is expected to vary insignificantly since the coal seams are generally flat in the Highveld Coalfield which hosts the Isibonelo Colliery deposit. However, the mine coal recoveries were generally not as predicted, hence the problem statement arose from the question, "Does a short-term geological model add value to opencast strip mining through improved mine design, productivity and coal recovery?”

It is a general assumption that short-term geological modelling is a solution to problems of coal recovery and effective mine designs that lead to safe mining since additional data taken closest to the active face is included. There are better mine designs that are produced with closely spaced geological data available.

1.5 Report Layout

This report introduction details the purpose of the research, which include development of a short-term modelling process to allow improvement in mine designs and reconciliations at Isibonelo colliery. The motivation and background to the research work is also covered in this section.

Chapter 2 of the report reviews the different ways in which geological data is gathered using various techniques. Geological modelling requires accurate and validated data to be generated and then uploaded into the modelling software to build a geological model. Spatial data acquisition can be done in various ways such as drone highwall mapping, Sirovision, laser scan mapping. The base geology models in Anglo American Coal, South Africa are built from exploration borehole data. Short-term geological models are an updated version of an existing resource model with the input of additional data gathered through other various means detailed in the second part of this research report. For open cast mining operations additional data is gathered through highwall mapping, blasthole drill data, field observations, photogrammetry and other techniques. There are several techniques such as the use of total stations for mapping highwalls and digital photogrammetry which are explained in the second part of this research report.

The latest technique used now in gathering spatial geological data is the use of drones (unmanned aerial vehicle) flying over highwalls and lowwalls of opencast operations collecting digitally referenced photographs and data points of the surfaces. Some mining houses in South Africa are using it among other benefits such as stockpile measurements and reconciliations with much success.

Wireline logging of blastholes on the drill benches at collieries is also generating data which is used successfully at Klipspruit and Optimum Collieries in South Africa. Isibonelo Colliery, through this research work undertook to test the process following the footsteps of another Anglo operation, namely Kwezela Colliery.

Chapter 3 of the report, gives a detail of Isibonelo Colliery property description including the geological setting of the area. The location of the colliery in relation to other Anglo American Coal operations as well as other mining houses' operations is shown by way of the location map. The stratigraphy of Isibonelo is illustrated and explained in this section of the report. Mining operations overview covers the machinery, strip cut mining method backed by concurrent rehabilitation process.

Chapter 4 of the report covers the methodologies used for the research which include both qualitative and quantitative methods and a review of the current practices in relation to short-term geological modelling. Mapping of the highwall with the aid of a total station, photographs and finally the use of drones were among the techniques used in generating quantitative data. The short-term geological model was built using the gathered data and was also used to update certain blocks in the XPAC model.

The results from the short-term model construction and interpretations were analysed and reported on, in chapter 4 of the report. The improvement validation techniques which also include some statistical analysis are covered in this section. Graphs and cross sections comparing before and after short-term models were drawn and variances explained, generally as improvements from the resource model.

The research findings and analysis is covered in chapter 5, while conclusions in chapter 6 summarises the benefits and improvements gained from an update of a resource model and having a short–term geological model. There is a list of recommendations (chapter 7) drawn from this research, however adopting use of the drone highwall mapping and introduction of wireline logging of selected blastholes proved can generate quality spatial data required for input into the short-term geological modelling process, at Isibonelo Colliery.

1.6 Conclusion

The whole process of short-term geological modelling has also been tested in other places of similar conditions to Isibonelo with some success. Good examples are Klipspruit and Optimum collieries. Some of the highlights of mapping techniques and the application of short-term geological modelling in mine planning designs are explained in detail in chapter 2.

2 REVIEW OF GEOLOGICAL DATA GATHERING TECHNOLOGIES

2.1 Introduction

There are several definitions for a geological model. One definition is that a geological model is a three-dimensional representation of an orebody complete with its physical and qualitative properties or simply the applied science of creating computerised representations of portions of the Earth's crust based on geophysical and geological observations made on and below the Earth surface. (Yachun, Defu, & Yongsheng, 2014). Short-term geological modelling in opencast coal operations in South Africa is not widely used due to the generally flat coal seams which are assumed to be geologically less challenging. Most of the mines only use the annually updated resource model built from exploration borehole data as the basis for all the three planning time frames (short, medium and long-term). However, to build a short-term model, additional geological data (preferably spatial data) is required and there are several ways of gathering (generating) such data which is detailed below with highlights on successes and failures at different operations.

2.2 Sirovision in mapping highwalls

"Sirovision is a geological / geotechnical mapping and analysis system that generates accurate, scaled 3D images of rock faces from stereo photographs taken in either open pit or underground environments. Sirovision allows mining professionals to quickly and accurately, map structures daylighting at the surface to automatically determine their properties, detect simple wedge and complex block features resulting from the structures, perform analyses to determine the failure risk and increase productivity and safety" (Elmouttie, n.d.)

Sirovision uses geospatially fixed /referenced pair of high resolution photographs to generate a 3D image and this is called digital photogrammetry. Mapping can be undertaken directly from this image with features imported directly to the resource modelling software. Sirojoint is another system used for the geotechnical analysis of joint spacing and orientation from the 3D image of photographs.

Sirovision, allows geological features to be picked up as a photogrammetric scan of the walls. This data can then be imported directly into the modelling software, but this may require more data manipulation to achieve the intended result. When Sirovision data is utilised in this way, it comprises of a detailed photographic image that is registered in the 3D space. This is good to work with and geological features can be drawn directly off this photographic image into a geological interpretation layer. (Anon (b), 2014). Some of the Australian mines are using this technology successfully.

2.3 Drone Technology

Drone technology has developed rapidly of late in South Africa following the regularisation of their use by the country's controlling body, the South African Civil Aviation Authority (SACAA). A drone is a small aircraft that has no pilot and it is remotely controlled. It is referred to as Unmanned Aircraft Systems (UAS), Unmanned Aerial Vehicle (UAV) or Remotely Piloted Aircraft (RPA) because they are aircraft without a pilot on board.

"The first appearance of an UAS occurred in 1849, when the Austrians attacked the City of Venice using explosive charges attached to tethered aerostatic balloons. The first prototype of radio-controlled drones was produced in 1916 during the First World War." (Bucalo, D'Allesando, Colteli, & Martorana, 2015). Currently drones are used for geological and topographic mapping, coastal control, landslide inspections, and are capable to integrate geophysical sensors such as magnetic, electromagnetic, infrared, radar and natural gamma ray sensors. Therefore, drones have become a very important tool in the field of geoscience where they have advantages over conventional airborne geophysics. They have great resolution since they get close to the ground and can zoom into an area. They are generally not expensive with small ones such as the Phantom 4 costing as low as seventy thousand rands. The drones are area focused, and therefore only cover the area of interest as set up by the controls, there are no excess flight lines required.

Drones are a useful tool for gathering geological information from difficult areas that are inaccessible by man and eliminates risk to personnel. The data is generated so fast that an area that used to take three days by physical mapping, only take an hour or less and with more data captured. In an open pit, the lithological contacts are mapped with great accuracy through extrapolation from the 3-D model built from the downloaded drone data.

Figure 2.3.1 shows one of the latest drones widely used in South Africa, the Phantom 4

Figure 2.3.1 DJI Phantom 4 Pro drone

(Caboz, 2018)

According to (Caboz, 2018), the Phantom 4 has cameras with the capability of capturing images in RAW format, which makes editing even easier. The Phantom 4 Pro, DJI’s latest model in the series, can capture images of up to 20 MB and 4K videos at up to 60 frames per second. This is a big advantage compared to the older methods whereby perspective was only accessible from suspending a Canon DSLR camera at the back of a helicopter. A drone captures digital images of the highwall being flown over, as well as a multitude points of the digital terrain, all in 3-D space. This process allows the softwares such as Agisoft, 3-D Rippler and Geo Arc to manipulate the data creating a 3-D model from a mesh through triangulation of a multitude of points and draping over the digital photographs to form a solid 3-D image of the pit. The data is validated against the resource model and actual survey data using software such as CloudCompare. In South Africa, consulting companies such as Vidblast (Pvt) Ltd and Premier Mapping who interacted with the author while conducting a demo at Isibonelo Colliery, as part of this project research, have had a lot of success building models for many of their customers.

The latest data from Business Insider indicate that there are 686 operators with Remote Pilot Licences (RPLs) in South Africa. There are different types of drones depending on their capabilities and uses. The European Association of Unmanned Vehicles Systems has produced the table below (Table 2.3.1) to show the classifications.

Table 2.3.1 Classification of Drones

UAVs classification	**Category (acronym)**	**Maximum Take Off Weight (kg)**	**Maximum Flight Altitude (m)**	**Endurance (hours**	**Data Link Range (km)**
Micro/Mini UAVs	Micro/ Mini	0.1	250	1	<10
	Mini	<30	150-300	<2	<10
Tactical UAVs	Close Range (CR)	150	3000	2-4	10-30
	Short Range(SR)	200	3000	3-6	30-70
	Medium Range (MR)	150-500	3000-5000	6-10	70-200
	Long Range(LR)	-	5000	6-13	200-500
	Endurance(EN)	500-1500	5000-8000	12-24	>500
	Medium Altitude, Long Endurance (MALE)	1000-1500	5000-8000	24-48	>500
Strategic UAVs	High Altitude, Long Endurance (HALE)	2500-12500	15000-20000	24-48	>2000
Special Task UAVs	Lethal (LET)	250	3000-4000	3-4	300
	Decoys (DEC)	250	50-5000	<4	0-500
	Stratospheric (STRATO)	To be defined	20000-30000	>48	>2000
	Exo-stratospheric (EXO)	To be defined	>30000	To be defined	To be defined

(Bucalo, D'Allesando, Colteli, & Martorana, 2015)

2.4 Use of laser scanners to map highwalls

The use of laser scanners to capture geological data from the exposed highwalls in opencast operations is also common. The mine surveyors are generally the custodians of these instruments and are used as part of their survey work. At New Vaal Colliery, the surveyors worked successfully alongside the production geologist to produce data that was used to update their short-term geological model. (summarised in Figure 4.1.10 in section 4 of this report). I-Site is a laser scanner that can quickly produce an image with millions of points, and because this data is captured in 3D, mapping of strings and points from the data will be in true space. These can be imported directly into the relevant resource modelling software. Figure 2.4.1 illustrates what I-site scanner data can produce when imported into the modelling software. The structural features are interpreted in real space and this is a short-term geological modelling built with the most accurate data.

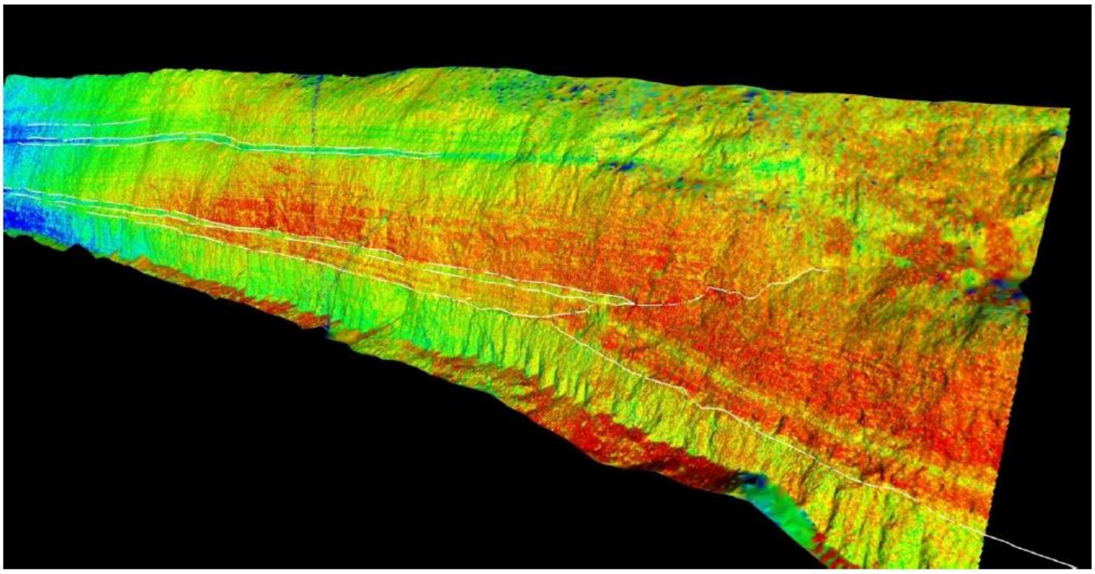


Figure 2.4.1 Example of I-Site image with interpreted geology in real space

(Anon (b), 2014)

Quality geological mapping is a key foundation to safe and efficient mining designs being implemented throughout the organisation. It should be recommended as a fundamental input to numerous aspects of short and long-term planning, operational control and safety, quality processing and geotechnical assessments. Dykes, faults and many other structural features need to be accurately mapped and added to the short-term geological model to ensure more accurate data is used by the mine planner. Geological mapping contributes to safe mining practice at operations. Most up to date geological information from highwall mapping is used in creating improved mine designs based on prevailing pit conditions where relevant controls are put in place to ensure the safety of personnel and machinery.

2.5 ADAM technology- Goonyella Mine Case Study

ADAM technology was developed by a Perth based company called ADAM founded in 1986 to develop and manufacture analytical stereo plotters. The technology was tested at Goonyella Mine in Queensland, Australia with much success, for highwall wall mapping and geotechnical data collection by generating 3-D surface data over a 700m section of the pit. A total of 108 digital photographs were taken using a camera from 36 locations which were surveyed using a total station within an area surrounded by 52 control points. The surface data was generated using the 3DM Analyst only, which required the use of all the control points and the second set was using 3DM Analyst in conjunction with ADAM's 3DM CalibCam block adjustment package, which allowed a subset of control points to be used, and demonstrated one method of reducing surveyed control requirements without compromising accuracy (Birch, 2004). The figure 2.5.1 illustrates the stereo image pair loaded into 3DM Analyst ready to be processed.

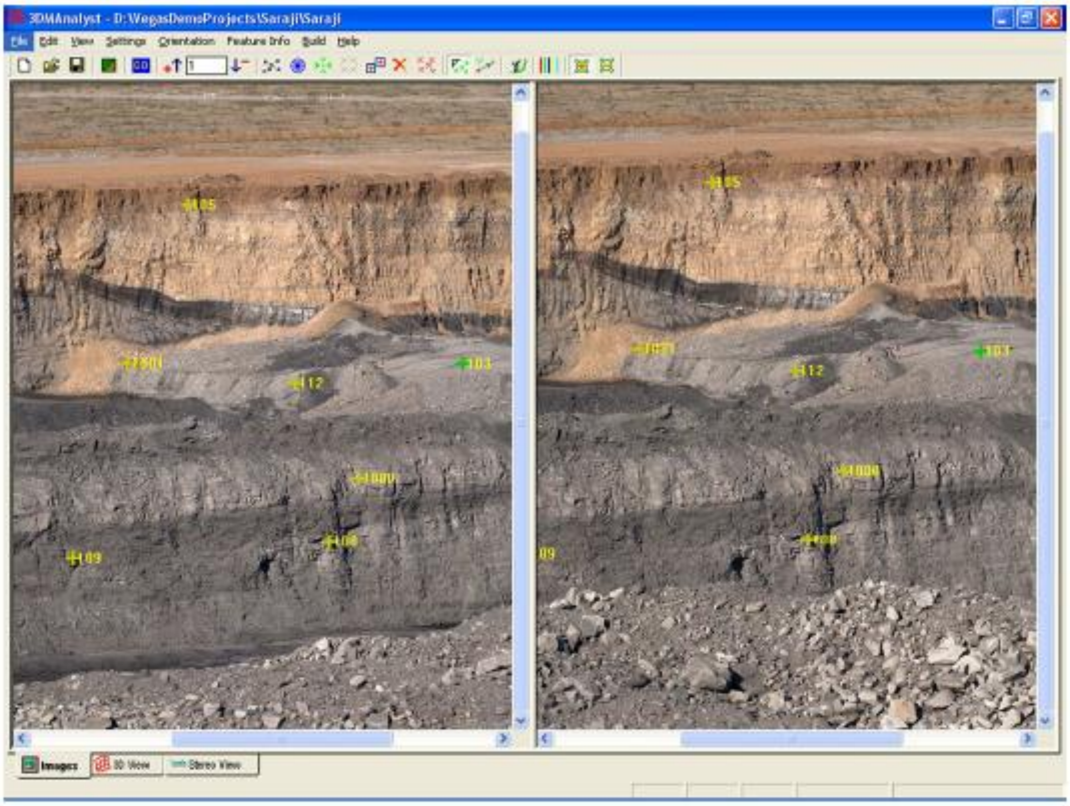


Figure 2.5.1 Stereo image ready to load into 3DM Analyst

(Birch, 2004)

Figure 2.5.2 shows the 3-D view of the automatically-generated surface model with the original image draped over it.

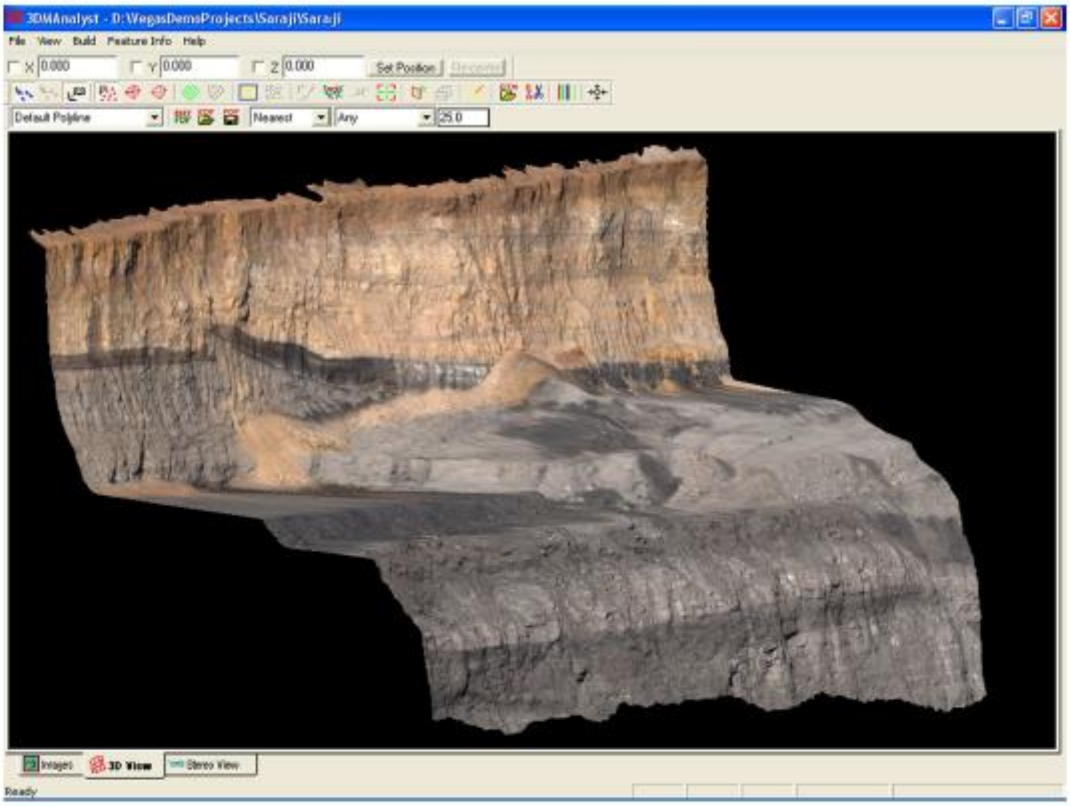


Figure 2.5.2 3D Model from the Stereo Images

(Birch, 2004)

The image was then imported into the modelling software package Vulcan, to carry out geological and geotechnical interpretations. Figure 2.5.3 shows the image with the annotations from interpretations. The different lithological contacts are quite clear and could be digitised.

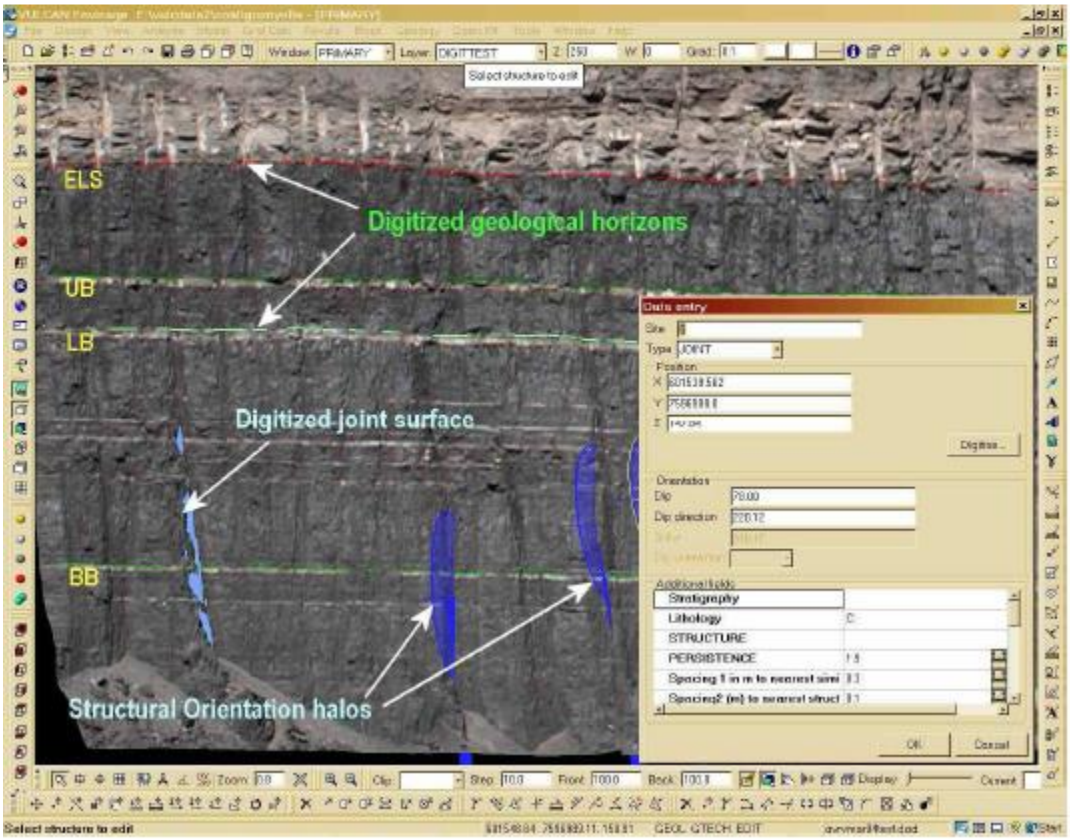


Figure 2.5.3 3-D Image of highwall loaded into Vulcan

(Birch, 2004)

The Goonyella Riverside mine case study showed that using this digital photogrammetric system at least 1km of highwall can be completely captured by a two-man team in about 3.5 hours. A day or so is required for processing the images back in the office. This technique according to Birch (2004), has many advantages over the old manual surveying technique, which include personnel spending less time on fieldwork from approximately six hours to approximately two hours. The detail is far greater than ever before, improving the accuracy of the resource model, the images are archived and can always be retrieved to construct what the highwall looked like after mining operations have been completed.

Birch, (2004), states that, “BHP Billiton Mitsubishi Alliance concluded that the ADAM Technology software is more accurate, faster, more flexible, easier to use, more robust and more rapidly developing, provides better quality models, has better software support and requires less training. Based on technical considerations of the trial results, ADAM Technology's 3DM Analyst plus CalibCam softwares provide the best solutions for BMA's high wall mapping.” This software programme can be utilised with easy at Isibonelo Colliery where less than 20km of highwall is exposed per year to provide accurate information for better short-term planning.

2.6 Marston & Marston Case Study

Mining companies require accurate short-term mining forecasts to plan for budget targets and customer needs. This case study proves that the ability to update geological models based on the latest information gathered from production drilling and mining activities can greatly enhance the ability to accurately predict short-term mining production. (Gurgenli, Minnes, & Oommen, 2011).

The information generated from the latest mapping should be incorporated into the model to ensure mine planning makes use of it for the next pit design. The information flow between geology, survey and mine planning need to be seamless as illustrated in Figure 2.6.1.

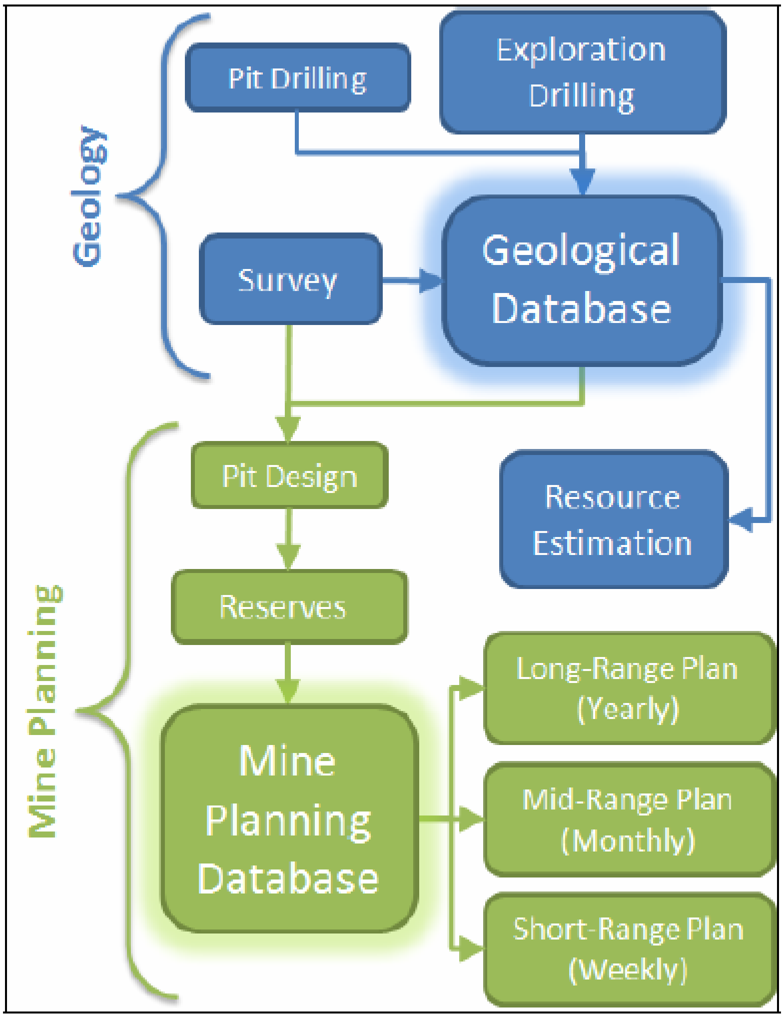


Figure 2.6.1 Mine Planning Flow Sheet

(Gurgenli, Minnes, & Oommen, 2011)

The two major data bases (geology and mine planning) must feed into one as illustrated in figure 2.6.1. The case study of a coal mine in North America handled by the consulting company Marston and Marston of St. Louis involved looking at the detailed mine plans of an operation with complex geology. The geology of this open pit mine included an anticline/syncline structure featuring multiple dipping seams and minor localised faulting. The planning engineers of the operation had managed, prior to engaging the consultants to produce both long and short-term plans to achieve production targets. However due to the complexity of the geology, there were always deviations from the plan due to a change in geology. This scenario prompted the operation to adopt a monthly updated geological model, but the software in use was manually intensive (rather cumbersome) which resulted in very inaccurate plans.

The consultants, selected a suitable software programme (Minescape) which integrates geology and mine planning. Oommen et al, (2009) states that, "One of the main advantages of this software for this operation was that Minescape's Stratmodel module is designed to create three-dimensional grid models of layered geologic deposits that allow new geologic data to be uploaded into the drill hole database, and used to regenerate grids of coal structure and quality". In addition, the Open Cut Design module provides excellent pit design tools, which are tightly integrated with the underlying geology, and automated block generation tools, which were commonly used in this operation. Another key advantage of Minescape is Mincom's Schedule module, which provides the required mine planning and scheduling solution, and allows a high level of customisation, while being tied directly to the mine planning tools and graphical model entities.

Geological data was gathered from both historical and new information to produce a comprehensive database of structure and quality information, which was thoroughly scrutinised and validated to be fit for purpose. Stratmodel works on a schema, which is a rule-based representation of a stratigraphic model which contains all the information required to create a stratigraphic model. The "rules" were then combined with a set of drill hole and survey data (gathered during the time on site at the exposed faces), resulting in an automated process of model update with no need for manual input. Cross sections and maps were produced to validate the model. According to Gurgenli et al (2011) one of the main goals of the system was the ability to quickly update the geological model with the latest information gathered from production drilling and mine activities (dragline, truck and shovel), to enhance the ability to accurately predict short-term mining production. Therefore, Stratmodel was an excellent tool for this operation. Another reason why the Stratmodel module was applicable to this mine is that this module allows modelling of inclined and deviated drill holes, which were common at this operation.

Planning was made easier with the creation of a customised scheduling system in an environment where data flow between the databases was seamless. Three months schedules could be produced easily and with a tracking system of the coal, waste and coal qualities. The process was properly documented to allow future use and succession planning.

The results were quite rewarding, with quick integration of the latest geological data, improved productivity of the planning personnel now spending only three days planning as compared to previously spending three weeks for the same amount of work. The system according to Gurgenli et al, (2011), also increased the accuracy and consistency of mine plan results.

Finally, Gurgenli et al (2011) concluded that, "Investing the time to develop an integrated planning system, which incorporates the latest geology, minimises manual input, and fully utilises automated processes, gives the planning engineers the best opportunity to produce high quality plans based on the latest information. This also allows the engineers to spend more time in evaluating the conditions and alternatives in the operations. Properly documented manuals and processes also address issues related to employee turnover, which is often the case at mining operations."

Isibonelo Colliery is striving to achieve such good results with the implementation of short-term geological modelling. The mine uses the same Minescape Stratmodel software programme used by Martson and Martson consultants with similar success.

2.7 Thiess Pvt Ltd Australia Example

In most mining operations, especially for large companies, the exploration work is centralised, servicing the operations. The borehole data base is managed by the same central office. The mining operation during production does generate a lot of valuable information through blasthole drilling and in most cases, this is not geologically logged or used to reconcile with the model. However, integrating exploration and operational blast holes into a single database improves geological modelling (Stedman, 2014). Thiess Mining in Australia has done this with great success.

The mining house adopted the practice of converting selected blast holes into structural points of observation to assist with remodelling the coal surfaces at a closer spacing. With most exploration holes spaced at more than 250m, obviously the blast holes data collected at 20m spacing meant a more detailed evaluation of the coal seam. The models became more accurate getting closer to what is in the ground and that improved their geological predictions and ultimately the mining performance because of fit for purpose plans.

The lithologies interpretations are derived from downhole geophysical data where coal and non-coal material is expressed in gamma and density measurements. The different lithologies are interpreted by the geologist who in turn submit or release reports to planning engineers detailing where hard and soft layers are, and this determines the drill and blast design with the correct explosives at the correct elevation. Thiess Mining also performs highwall mapping from the exposed strip and this information is used to also interpret the gamma trace. From the geophysical data areas with poor quality coal can easily be selected and data incorporated into the model for better planning around such situations, this is the practice at Thiess Mining.

At Thiess Mining, it has been proved that a model built based on 250m spacing does not provide sufficient structural detail which is required to accurately plan the stand-off enough to prevent coal from blast damage. The mechanism causing most of the coal loss and damage results from overburden blasting and excavations (Scott & Wedmaier, 1995) . It has also been proved at Thiess Mining that blasthole data gives a more realistic representation of coal structure and the gross tonnes in situ of the coal.

Coal reconciliation based on a resource model can potentially produce results that may not be true of what is in the ground and conclusions from such information may lead to incorrect business decisions. This assertion was also proved that with more detailed data, there is better coal reconciliation, and there is no such obvious or exaggerated over estimation or under estimation of coal volumes.

In conclusion, the Thiess Mining case study proved that the objective of a short-term geological model, is to accurately reflect the true volumes of coal and waste as well as identifying geological structure. An integrated blasthole and exploration database creates a model that better reflects the truth in the ground and subsequently true mining performance, accurate drill and blast designs and good coal reconciliations.

2.8 Kumba Iron Ore’s Clino Move Technology

Kumba Iron Ore belongs to the iron ore business unit of Anglo American Plc. The bulk of the iron ore production comes from Sishen mine, located in the Northern Cape Province near the mining town of Kathu. The mine has been producing since 1953, and Sishen mine is the flagship operation and one of the largest open-pit mines in the world (Anon, 2018) .

The author interacted with one of the Kumba Iron Ore Resource Geologists, Botha regarding geological short-term modelling practice at Sishen. Botha confirmed there is an issue of safety while mapping the highwall to collect data for input into the model. Hence the use of photogrammetry with an application for a tablet called Field Move, that can identify a satellite image and import it for reference. There is also another application for smartphone technology called Field Move Clino, which is also used, to map. However, both techniques are applied to capture geological data from the exposed highwalls for input into the short-term geological model to enhance planning of the next production bench. The FieldMove Clino technique is best suited for mapping structural data such as dips and strike of bedding planes, faults or any lineation's observed on exposed highwalls. This technique is safe in the sense that measurements are taken remotely for safety reasons and the smartphone captures the data just such as taking a photograph. According to the website information regarding the software, it is stated that, "When one has collected sufficient data one can then use the drawing tools that include a virtual mouse for precision drawing, to create geological boundaries, fault traces and other line work on the base map. It is also possible to create simple polygons to show the distribution of different rock types. The line work that one creates in FieldMove (and in Clino) is fully geo-referenced and this information is preserved when the project is exported to other applications. Getting the project out of the application is straightforward." (www.mve.com, 2018). There are several formats in which the data is exported in, such as comma separated values (.csv) and the Google Earth format "kmz". The modelling software from Midland Valley for modelling prefers the Field Move's "tm" file format. Figure 2.8.1 illustrates some of the field outputs of this software. Midland Valley is an exploration company that developed FieldMove software.

Figure 2.8.1 Field Move software outputs

(www.mve.com, 2018)

There is one major advantage with this application in the sense that geological measurements, notes, photographs and interpretation (drawings) are all captured in a single application which significantly reduces the amount of field equipment that a geologist needs to carry as compared to olden days where hammers, compasses needed to be carried in the field. The data mapped and interpreted (confirming traces of lithological contacts) is all geo-referenced and that makes it easier to import into the modelling software package.

The above described mapping technique can be applied at Isibonelo Colliery as an alternative to digital photogrammetry by a drone. During the research period, several mapping techniques were looked at such as Sirovision and simple photogrammetry using a digital camera.

2.9 Klipspruit Colliery experience

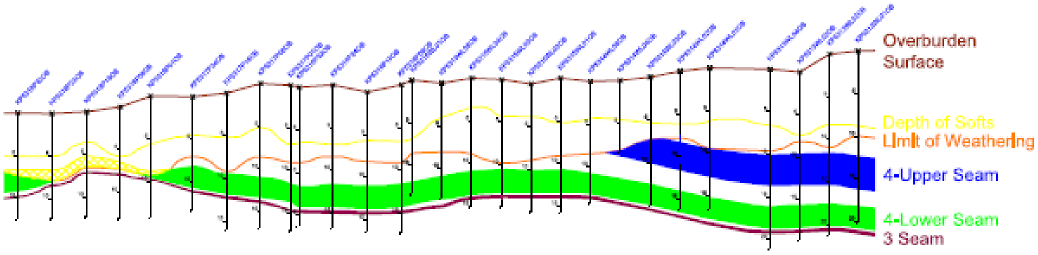
The author had the opportunity to visit the mine’s Chief Geologist, Conradie at the colliery after an approval by their Technical Services Manager, Mabuza. Klipspruit Colliery lies immediately north of Kutala Colliery near the town of Ogies, and is an opencast operation similar to Isibonelo Colliery. It is hosted in the Witbank Coalfield with all the coal seams 1, 2, 3, 4 and 5 present in the mining lease area (the No.3 seam, found in many other collieries in the same coalfield is very thin and uneconomic to mine.).

The colliery does employ short-term geological modelling, with respect to refining coal contacts to plan drill and blast designs more accurately as well as ensuring improved coal recovery. According to Conradie, drill plans require accurate depths of holes to prevent coal loss through over drills and blasting coal together with overburden. Conradie confirmed that capping, a layer of waste rock (not blasted) above the coal seam, is caused by poor drill plans when operators drill short holes without touching the top of coal.

Klipspruit does conduct wireline logging of the pre-split holes at a regular interval of ten metres. The logs help in fine tuning the coal contacts and new cross sections are generated from the updated model with the latest information obtained at closely spaced drilling as compared to the exploration borehole data. “I am an advocate for geophysics, downhole wireline logging for more accurate interpretation of coal and lithological contacts. You will never go wrong with wireline logging, (a measurement of downhole formation attributes using some special tools lowered into the hole).” stated Conradie (2018).

Figure 2.9.1 is an example of the success story at Klipspruit using wire logging of pre-split line blast holes. The detail of the geology in figures 2.9.1 and 2.9.2 is not available from sections generated from resource model because of the spacing of the points of observation. Wireline logging has proved at Klipspruit Colliery according to Conradie, that it is the best tool for gathering data for short-term geological modelling. The planning department is furnished with close to reality information for input into the short-term plans.

Wireline Section, KP5313__18, Overburden, Ramp 2-3
4-Upper Seam & 4-Lower Seam



KP5318	KP5317	KP5316	KP5315	KP5314	KP5313

Note: 4-Upper Seam weatheres out roughly halfway into Block KP5314
Note: Floor roll, thinning of coal seam and weathering profile results in the wash-out of the 4-Lower Seam in Block KP5318 (yellow hatched area)
Note: The burden thickness between the 4-Upper Seam and 4-Lower Seam ranges between 1.95m and 2.40m with an average thickness of 2.28m
Note: The parting thickness between the 4-Lower Seam and 3 Seam ranges between 0.10m and 0.90m with an average thickness of 0.33m. It is possible that the 3 Seam will be extracted along with the 4-Lower Seam in some areas

Figure 2.9.1 Cross section of Pre-split holes down to 3-seam

(Conradie, 2018)

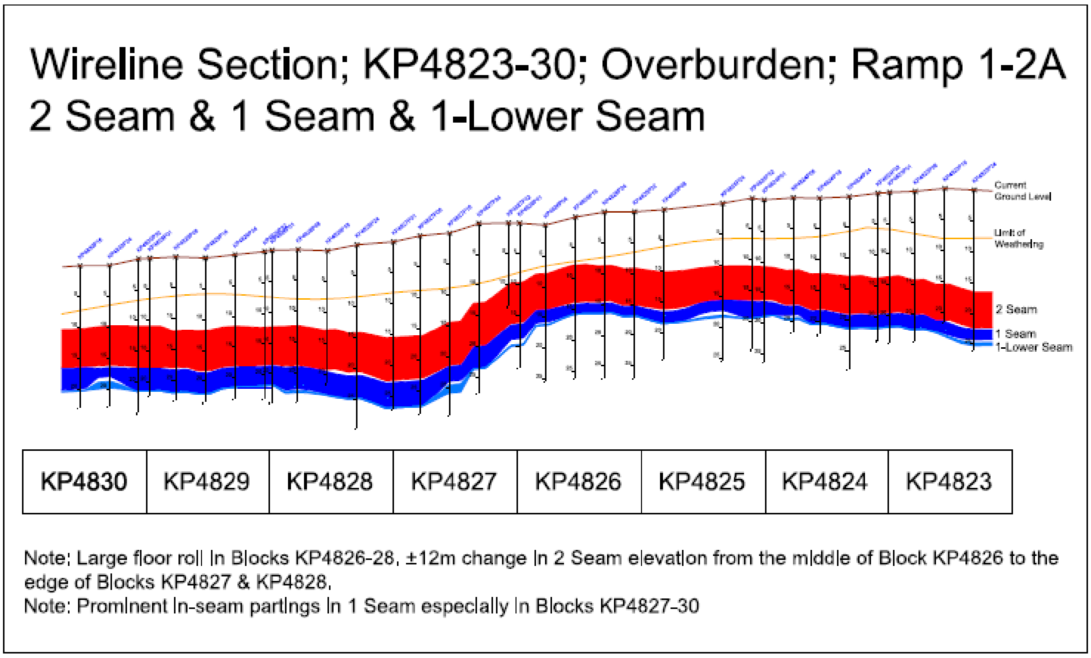


Figure 2.9.2 Wireline cross section for 2 and 1-seam

(Conradie, 2018)

Exploration boreholes are also wireline logged and the physical log lithological contacts are fine-tuned to ensure correct depths are captured for geology modelling purposes. The practice is also a great success for Klipspruit Colliery and the example in figure 2.9.3 illustrates a comparison between borehole physical log and the wireline log matching the zones.

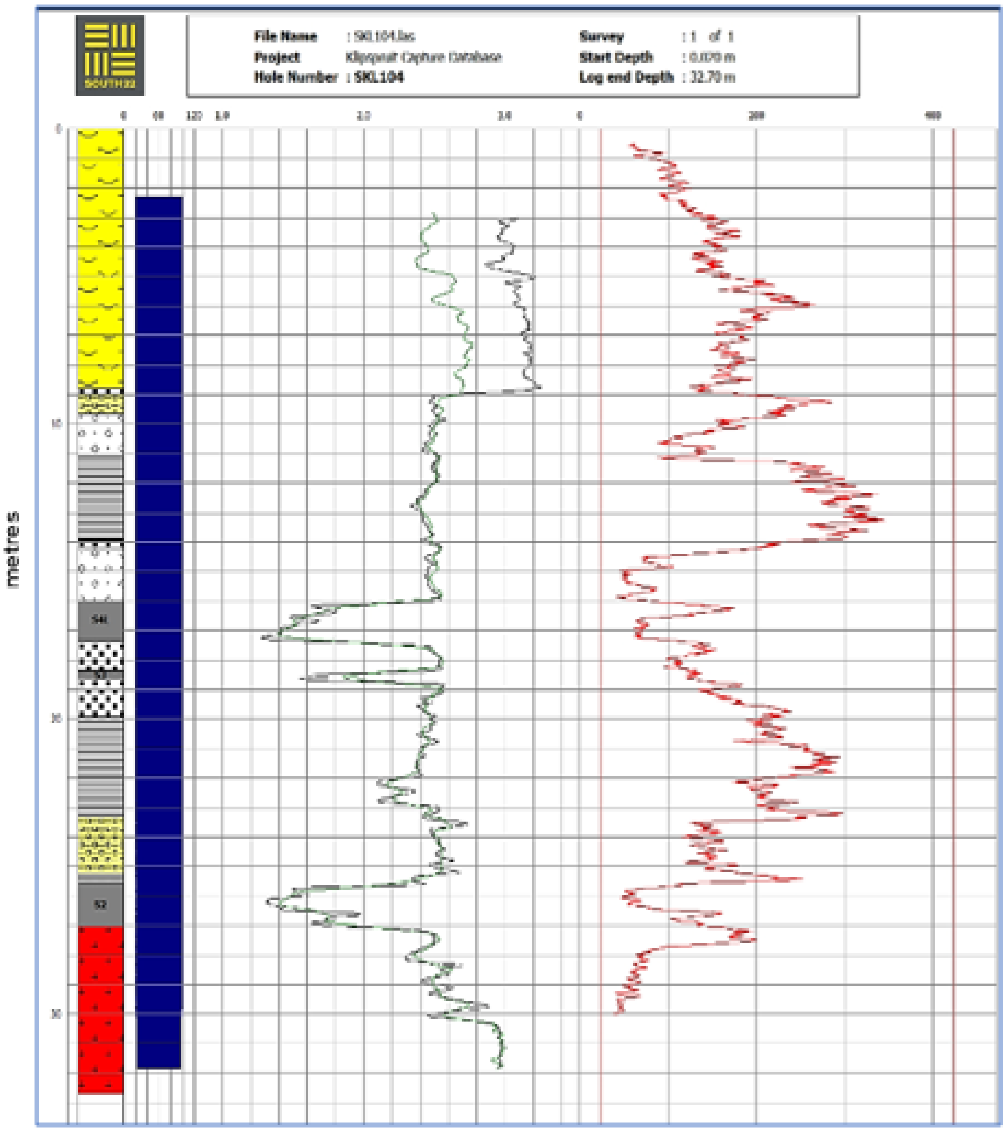


Figure 2.9.3 Exploration Borehole log against its wireline log

(Conradie, 2018)

The wireline log also enhances sufficient core recovery and proper packing of the core which also ensures more accurate sampling of the coal. Short-term geological modelling at Klipspruit Colliery is entrenched in the day to day activities of the Geology Department. Images of model grids showing the difference between Resource Model (using exploration boreholes) grids and Grade Control Model (also incorporating wireline logs from presplit/blast holes) grids is illustrated in Figures 2.9.4 and 2.9.5. In this example it compares the same area of 2 Seam roof elevations. The general overview is the same, but on closer inspection it shows that the Grade Control Model gives more information, especially in areas where the seam dips or rolls. If one is to use the 2 Seam roof elevations from the Resource Model, there is a greater chance that burden drilling will either result in scalping of coal during exposure (drilling too deep with subsequent blasting), or a hard capping to be left behind on top of the coal (due to drill holes not reaching the coal seam).

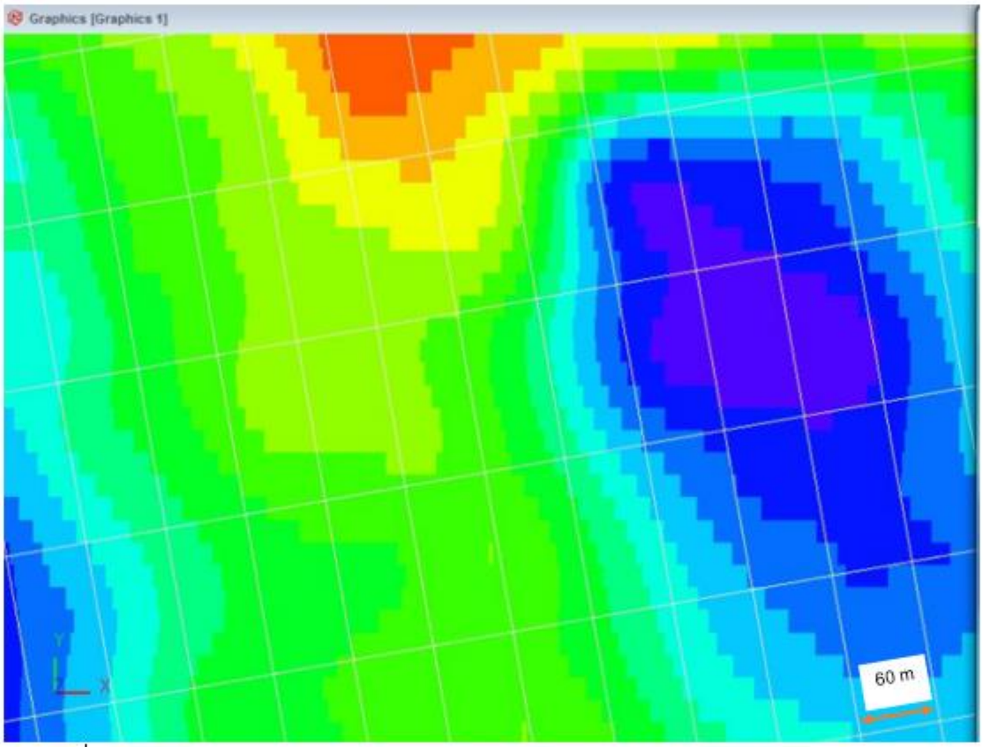


Figure 2.9.4 Resource Model Contour Plan

(Conradie, 2018)

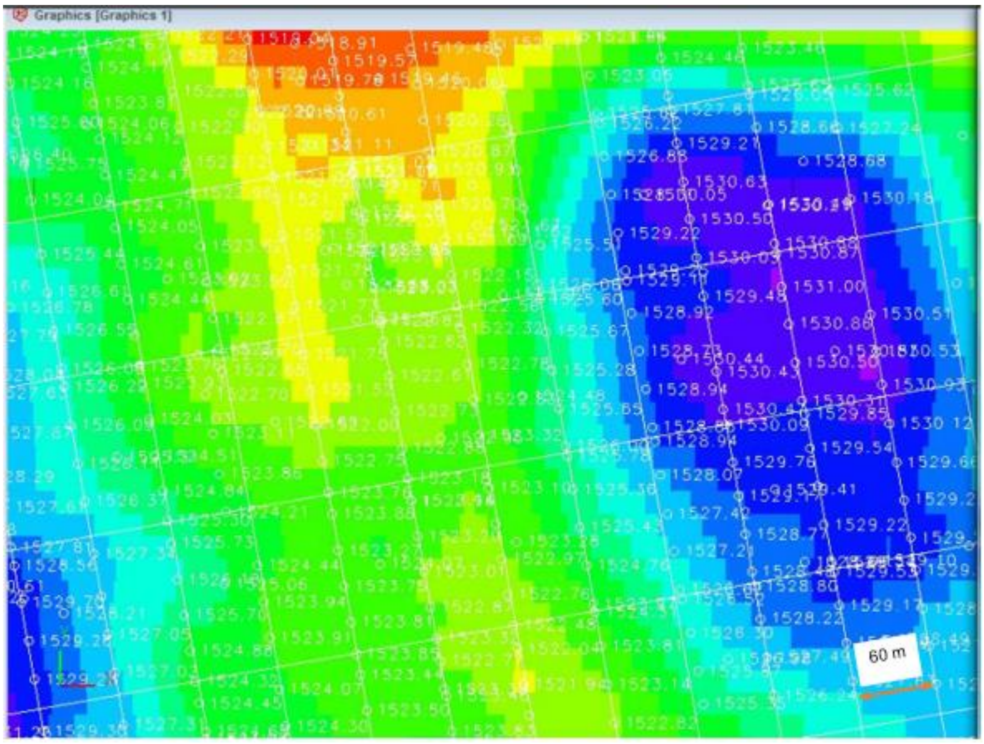


Figure 2.9.5 Grade Control Model Contour plan

(Conradie, 2018)

2.10 Optimum Colliery's Practice

Optimum Colliery is an opencast operation that lies in the Witbank Coalfield and is rated as the sixth largest producer and exporter of thermal coal in South Africa. In a wide-ranging discussion with the geologist from Optimum Colliery, the author was taken through the process the operation follows in incorporating new information into the geological model and how it is used by the mine planning department in the pit designs.

Optimum Colliery of Tegeta Resources produces an annual updated geological model that is used for medium to long-term planning. The operation does employ two methods of collecting new data from the active mining area, namely wireline logging of the pre–split production holes and highwall mapping data. According to Makongwana, (2018), the drill and blast foreman plans the drill holes on both the highwall and low wall sides of a drill bench. The holes are spaced at 12 metre intervals and are to be drilled to the floor of the coal seam. The sketch of the plan (developed by author during the telephonic discussion with the geologist) of the holes is illustrated in Figure 2.10.1.

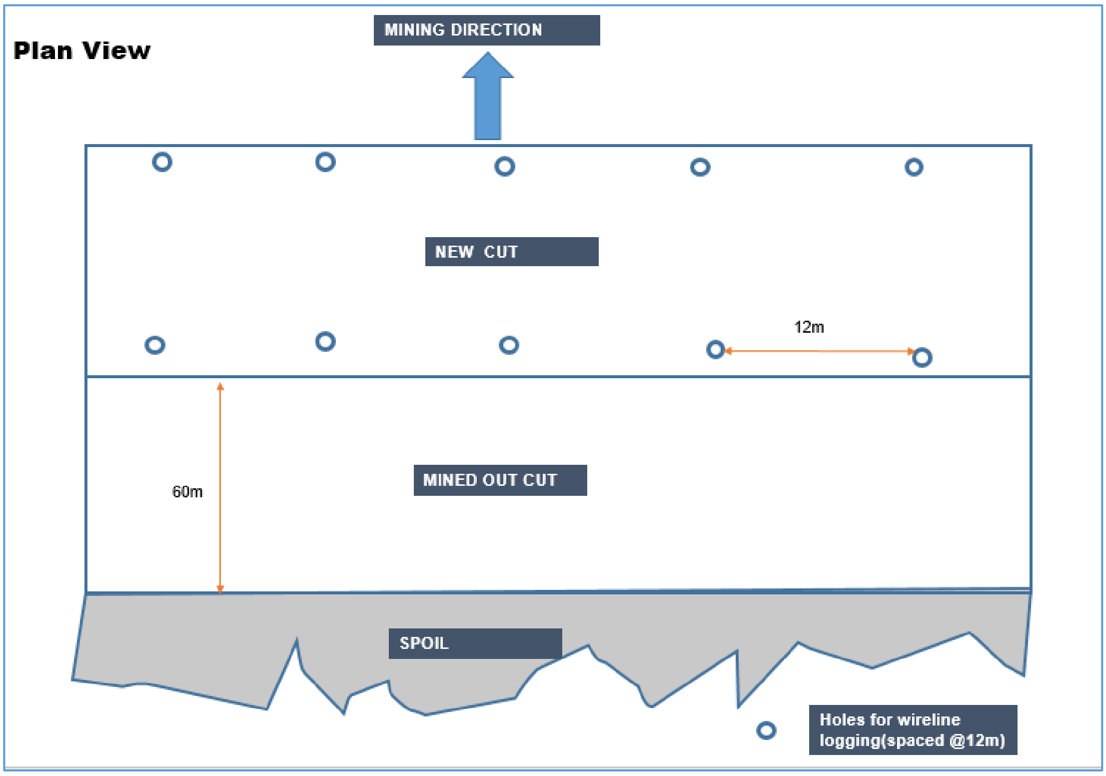


Figure 2.10.1 Plan of wireline log holes

(Katuruza, 2018)

A local company, Geoline Logging Services is contracted to conduct the wireline logging of the holes as soon as they are completed. The wireline logs are handed over to the production geologist for interpretation of the intersections, depths and rock types. The geologist then produces a table of information, which is handed over to the drill and blast planner, whereby they calculate the average depths and thicknesses for the entire drill design. This process is called short-term modelling since the final drill design is based on the latest information derived from this short-term drilling.

The data can also be imported into the existing geological model for further interpolations and updates for the next cut, although the same process is repeated for each subsequent new cut. The wireline logs provide detailed information such as insitu correct material thus ensuring competent stable highwall and low wall.

2.11 Challenges in Mine Planning

Mine planning should deal with complex geological orebodies in designing and scheduling production. According to Hendry(1988), structural complexity of a sedimentary deposit (such as coal) and high rate of mining requires one to consider large amounts of geological information which continually updates the interpretation. A mineral resource management (MRM) department is a vital cog in the mine value chain. Birch(2017), states that planning relies on knowledge of the geotechnical model, and always there is need to have a good geological model which is regularly updated.

For any mining operation to be profitable, it must have sound plans generated from a properly modelled ore body. The mine planners and geologists must work closely together to produce good and accurate mine designs that optimise the extraction of the orebody. “Fundamental to the long-term performance of an operation is geological modelling and mine planning. To maximise mine profitability, planners and schedulers must create mine plans that match the field as accurately as possible” (Sharma , 2011). The drilled and modelled geological information has many assumptions built in it that gets fine-tuned with results from what is eventually obtained from the field. Hence the term geological reconciliation which over time helps in developing close to reality modifying factors. In Australia, Theiss Pty Ltd, one of the major players in the mining of coal does add value by converting selected blast holes into structural points of observation and remodels coal surfaces at closer drill hole spacing. According to Stedman, (2014) the integration of exploration and blasthole data into one database significantly enhances geological modelling. There are benefits to this process which include amongst others improved coal predictions (volumes and thicknesses), stronger interpretation of any complex structural areas, detailed mapping of any burnt-out areas and finally additional roof accuracy for better blast designs that deliver improved coal production which is the essence of this research report.

This research report has attempted to answer the question as to whether short-term geological modelling adds any value to a mining operation. Stedman,(2014) concludes that, “Irrespective of outcomes from a mining operation’s perspective, the objective of the geological model is to accurately reflect true volumes of coal and waste and to, pick any geological structure. Hence creating an integrated blasthole and exploration database (short-term geological modelling), derives a model that reflects true mining performance which also provides an accurate base upon which drill and blast can be tailored”.

According to Sharma (2011), in his paper titled, Challenges in Mine Planning and Scheduling- Discussion, the geologists and mining engineers have a big role to play in the operations. They must account for an array of variables such as geological samples and data from the mine, production capacity of available machinery and equipment, production cost assumptions as well as the health and safety of workers. It is important to note that a poor geological model can result in a poor mine design which can be a safety risk to the personnel working on the mine.

Mine planning has some challenges as illustrated above, that accurate geological data can deliver good plans that can be achieved easily. Some of these challenges were outlined by Sharma (2011) as follows:

2.11.1 Capturing complexity of mineral deposits that match field conditions

Resource geological models are initially produced at the feasibility study stage. The borehole spacing might be quite wide and the model oversimplified missing some finer structural detail as some faults will not have been picked by the drill holes. Coal production forecasts in the initial mining plans may no longer be relevant when operations uncover the area hence making it difficult to predict and plan production. The suggestion is that every operation, should create a mine model (i.e. based on the short- term geological model) that matches the field as accurately as possible with the available time to stay ahead of operations (the mining window). In most cases for Anglo American coal operations, this is a 3-year window period.

2.11.2 Updating mine plans with new data from the field

Data collected from the field by geologists, mine planners as well as surveyors need to be incorporated on the plan. It seems historically that mine planning and scheduling has been such a time-consuming, labour-intensive process that it prohibits the timely generation of new or updated plans as quickly as new data is received. In some operations there is a problem of skills shortage and high staff turnover or even tight head counts, leaving the few people on site overwhelmed with work. Figure 2.11.1

illustrates field mapping of the softs above coal, i.e. data required for incorporation into short-term geological models.

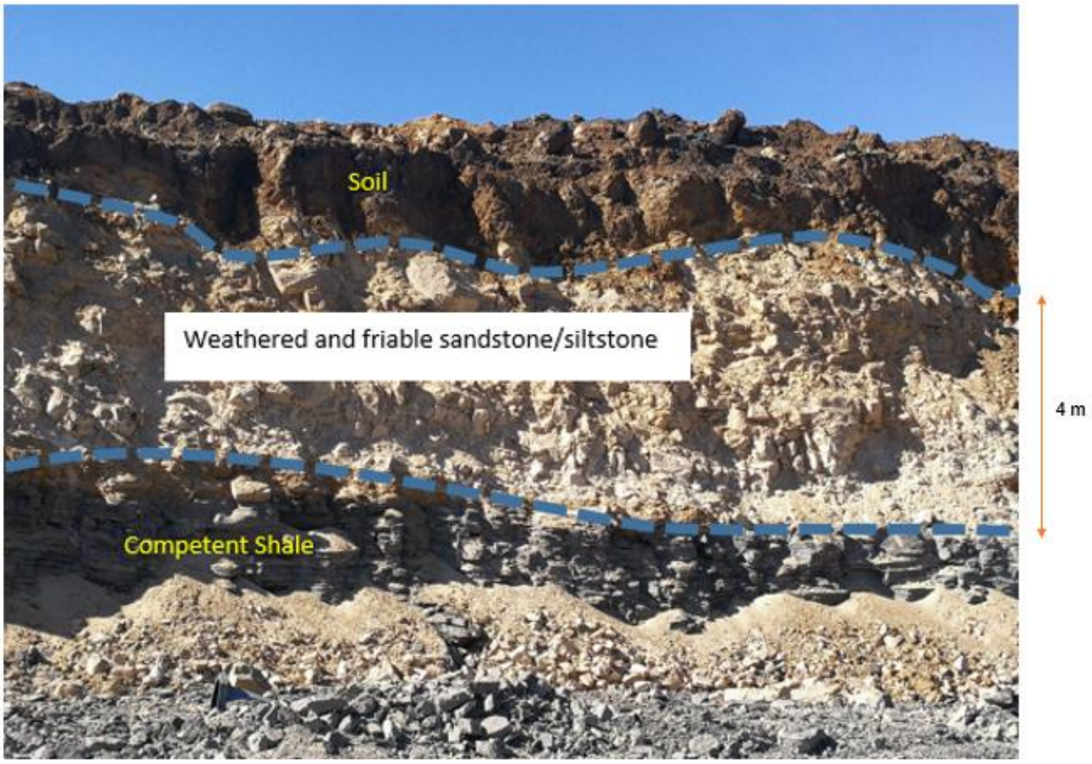


Figure 2.11.1 Highwall weathered horizon mapping at Isibonelo Colliery

(Photo by author)

According to Sharma (2011) an efficient software/module should be able to accelerate the process of geological modelling, mine planning, and mine scheduling by automating and streamlining the processes. The whole system should be such that plan updating is a continuous process as new data is added in from the field. The mining engineers will then have access to the latest and most accurate information from which to develop mining plans. There is a big advantage in integrating planning tools with geological modelling, because there is automatic access to geological surfaces and lithologies for developing mine designs can be obtained.

2.11.3 Generating accurate production and budget forecasts

Sharma (2011) further explains that the problem of planning target production figures and then failing to meet them, usually brings about pressure on the mining teams. The coal seam does vary in structure naturally, hence managing such variations can be an issue without the latest geological data being available. The assumptions used in planning may at times not be close enough. With new and updated geological data incorporated in the plan forecast, better production can be achieved. Therefore, accurate geological modelling provides for accurate mine planning and scheduling which in turn reduces the variances, which increases production predictability.

There is an efficient software system that can automate and streamline the processes and enable multiple mine plan scenarios to be run to select the most optimal plan. Anglo American Coal uses the XPAC planning software package that can perform this exercise. Therefore, up to date information helps in improving the accuracy of production forecasts and the elimination of surprises, it also instils confidence that mining plans would be achieved and sales targets will be met and results in greater budget accuracy. It should also be noted that, mine plans which can be executed to meet sales targets within the designed budget will ensure that the designed profit is also achieved.

2.11.4 Capitalising on quick changing market and operational conditions

The mining operational condition is subject to change, hence if the system is automated and fed with up to date geological information, then it is easy to adapt to the changing conditions. There is usually considerable time required to perform some of the geological modelling and mine planning tasks, hence planning frequency may not be keeping pace with the frequency of change. The mine plans and schedules are usually difficult to adapt to the changing conditions of a company's resources, such as its personnel, plant, or equipment. The whole planning process should be auditable, thus whatever changes are made, especially with the inclusion of new data, should be traceable as it must be properly documented; currently this is the emphasis through the OMS. Automation of the planning process can be quite beneficial as it releases more time for the geologists and mining engineers to check actual versus planned as well as tracking the product. They can even focus more on optimisation in other areas developing a plan, leaving more time available to examine ways to make the operation more efficient. There is available time for looking at areas such as optimising exploration drilling programs, increasing mine reserves by uncovering ways to mine in difficult geological conditions, and applying the skills of geologists and engineers in ensuring efficient execution of the final plans with field operations. This system ultimately improves the overall efficiency of the mine planning process (Sharma, 2011).

2.11.5 Streamlining the flow of information process

In current systems, mine planning and geological modelling are in different domains, information between the two is through the importation of files, and in some instances, there is manual input of data which may introduce errors. It is recommended to have fully integrated systems that pull through information from the two databases and run the mine designs and schedules. Anglo American Coal has XPAC for mine scheduling while Stratmodel is the geological package for modelling, and mine design. The output files from Stratmodel are imported into XPAC (which are compatible). According to Sharma (2011), by adopting a suitable integrated system, reductions of 40-60% in time spent updating long term mine plans may result.

Figure 2.11.2 illustrates the process flow of geological information into the mine planning and scheduling functions, which must be seamless.

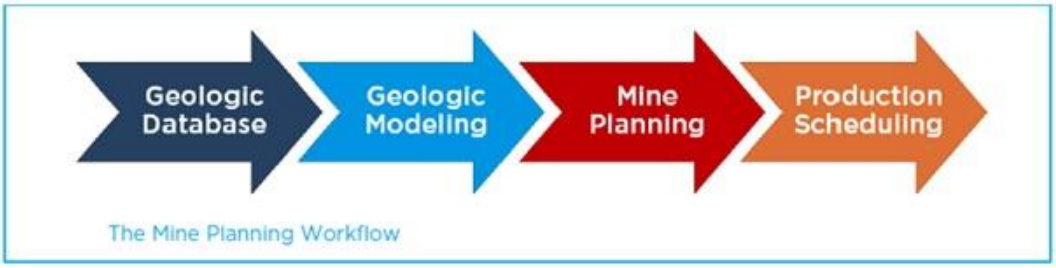


Figure 2.11.2 Geology and Mine Planning process flow

Source: (Sharma , 2011)

Sharma (2011) states that, **"**Strength of a building depends on its strength of its foundation. Same is true for mining as well. As the foundation of all mining activity, a mine plan and most accurately reflects the real-time reality of the geological structure in the ground, the process capabilities and the economic unpredictability of demand and commodity markets; which results in a productive, predictable and profitable system within mining structure**".**

Runge Pincock Minarco now called RPM Global, have a software package called Coal Seam AGG which makes the process of incorporating updated geological data in the mine plan faster and easier, saving time and money. The package is paired with XPAC Solutions to bridge the gap between geology and engineering, thus allowing one to work with scheduling blocks which have the most up to date geology, (RPMGlobal, 2017). Short-term geological modelling is therefore made simpler through such a package. The creation of mining models is said to be over ten times faster than other methods with no risk at all of getting the output wrong. Coal Seam AGG does allow one to move from geological models to scheduling options and production forecasts in one go, thus it is a very versatile package.

Planning is an essential component of the mining process giving direction to the accurate extraction of a mineral deposit. According to Meyer,(n.d.), "Productivity is never an accident. It is always the result of a commitment to excellence, intelligent planning, and focussed effort". Accurate and up to date geological information is important for such to be accomplished.

"A short-term model focuses on specific mining blocks of the mine and is generally created to ensure that the day to day mining schedule follows surfaces that are accurate in that area." (Britmindo, 2015). This statement qualifies the focus of this project to evaluate the use of short-term geological modelling in mine design and scheduling in an open cast coal operation.

According to Gurgenli, et al (2011), efficient mine planning in coal mining is crucial to meeting targets especially in the current economic environment of high competition at coal markets. It is quite clear that robust and accurate production forecasts, if achieved, can protect a company's profits in times of a price downturn.

Finally, mine planning is carried out considering different time frames that lead to long term (life of mine), medium-term, and short-term (i.e. the first year broken down into monthly, weekly and daily plans). Short-term plans require detailed information to drive production, hence the need for geological models with lower uncertainty according to Yarmuch & Ortiz, (2011).

2.12 Conclusion

Technology has developed over the years and has become even faster with the advent of the first computers. Geological mapping was a tedious job of having to walk carrying mapping tools and even failing to access some areas. Today there are techniques to gather data and build geological models within a very short space of time. The software programmes such as 3DM Analyst simplified model building. Drone technology is still developing further and has proved to be a fast mapping technique.

3 PROPERTY DESCRIPTION AND GEOLOGY OF STUDY AREA

3.1 Property Location

Isibonelo Colliery lies approximately 150km due east of Johannesburg, +/-80km south of eMalahleni (previously Witbank) and approximately 8km south of the town of Kriel. It is bordered by Seriti Resources' Kriel Colliery immediately to the northwest and Exxaro's Matla Colliery to the west of and adjacent to the Kriel Colliery. Sasol's underground Syferfontein coal mine is located directly south of the Isibonelo Colliery Mining Licence area. Reserves of the Isibonelo Colliery are situated in the Highveld Coalfield of Mpumalanga and form part of Anglo American Thermal Coal's greater Isibonelo Colliery resource area. (Nkuna, 2014)

Figure 3.1.1 Location map of Isibonelo Colliery

(Katuruza & Levings, 2017)

The Isibonelo Colliery mine offices and workshops are located, approximately 12km south of the mining area (now only two open pits), at what was formerly Sasol Syferfontein Opencast Colliery. Isibonelo took over the infrastructure associated with the Syferfontein Opencast Colliery on the 1st of April 2005. Access to the Isibonelo opencast mine is through the main entrance at the mine offices and then along a service road to the pit. The map in Figure 3.1.1, illustrates the location of Isibonelo and its surrounding environment

The greater area around the towns of Kriel, Trichardt and Secunda are well served by many provincial, district and farm roads, leading to the neighbouring towns of Ogies, Kinross and Bethal. The main tarred road (R545) connecting Ogies and Bethal runs approximately 2km to the northeast of the opencast mine and there is a dirt farm road that also link to the mine operations while at the same serving the farming community neighbouring the mine.

There is no railway line that cross the mine area or its closer vicinity, the closest railway station to the mine offices is at Trichardt, approximately 10 km by road.

3.2 Accessibility, Climate, Infrastructure & Physiography

The climate and physical environment description according to Mokoena & Nkuna, (2014) detail the area as forming part of the gently undulating Mpumalanga Highveld, with elevations from 1520 metres above mean sea level in the northern portion to 1630 metres above mean sea level in the south.

The western and eastern boundary of the area is formed by two main physical features, namely the northerly flowing Dwars-In-Die-Weg Spruit in the west and the north-westerly flowing Steenkoolspruit in the east. Close to the junction of the two rivers in the north is a wide flood plain, the western portion of which was mined as Pit 4 by Kriel Colliery some years ago. The eastern part of this flood plain comprises the current Anglo American Coal opencast mine. Both rivers are perennial and meandering within a wide valley, which is in places up to 1.5 kilometres in wide. The valleys along the two rivers tend to be marshy and can be flooded during heavy summer rains. The boundary of the topographically flat flood plain generally defines the 1 in 50-year flood line.

The normal Highveld weather conditions prevail, with warm to hot summers and cold winters. The rainy season during summer is normally from October to April with a typical rainfall being in the region of 690mm. The prevailing winds vary from northwest to northeast, with generally low velocities of around 15 km per hour.

3.3 Historical Information

All mineral exploration activities at Isibonelo Colliery have been on the coal resources found within the Highveld Coalfield of Mpumalanga. The type of exploration activities includes vertical surface boreholes, channel sampling and geo-physics with some geological information acquired from Sasol. A breakdown of the boreholes within the database was undertaken to determine the reliance on historical boreholes for the Isibonelo project. The Isibonelo model comprises of 2253 geological boreholes and of these, 170 boreholes were drilled prior to 1980. (Nkuna, 2014)

The sampling and analytical strategies have changed over time due to the takeover of Sasol Syferfontein by Anglo American Coal. The external independent audit report conducted in August 2013 by Runge Pincock Minarco concluded that Isibonelo sampling and analytical strategies are aligned with industry requirements. Thus, there is no impact on the resource and reserve estimations.

When Anglo American Coal took over the mine, all the geological databases (lithological and geological descriptive codes) were converted to their own naming conventions in line with the rest of the Anglo American collieries.

The original sampling protocol by Sasol for No. 4 Seam was just one, Full Seam Horizon, i.e. no zones sampled, while Anglo American Coal introduced zoned sampling of the three distinguishable zones. The sampling protocol allows the flexibility of building a Full Seam Horizon Model (for tonnages and reserve modelling) and a Zoned Geological Model for grade control purposes. The research project only focused on the structure rather than the quality model.

3.4 Mining operations

Isibonelo Colliery operates two open pits (North and South pit) as illustrated in figure 3.4.1.

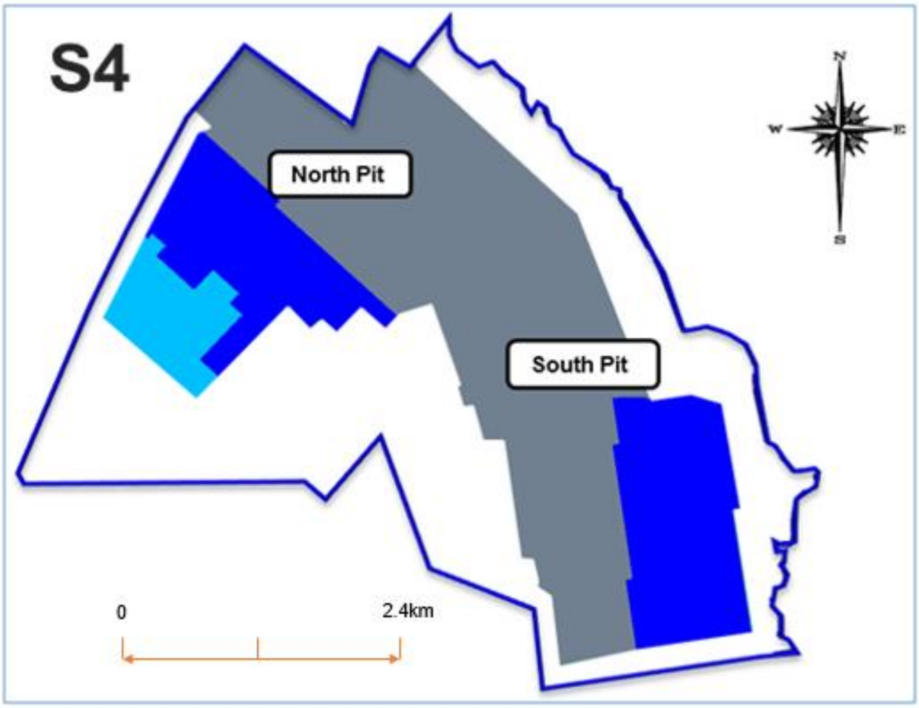


Figure 3.4.1 Isibonelo Colliery mining operations

(Levings, 2018)

The name “Isibonelo” is a Zulu word, meaning “to be exemplary”. The colliery produces unbeneficiated (raw) run of mine coal of the No.4 seam to supply Sasol Synthetic Fuels. The Isibonelo pit is 16km from the main office block and workshop area. Coal is conveyed 14 km from the pit to point of sale at the Isibonelo bunker. From this point it is conveyed a further 22km to the Sasol Coal stockyard situated at the Sasol Synfuels plant immediately south of the town of Secunda, (Levings, 2018). Isibonelo Colliery was developed on the South Kriel reserves to fulfil the supply of coal to Sasol and it operates the North and South pits.

According to Levings (2017), the colliery is an opencast mine and operates two Marion 8200 draglines in as the primary coal exposure machines, one dragline is deployed per pit respectively. For drilling and blasting, two Gardner Denver 70s drills are being used. The primary machine for pre- strip is a P&H rope shovel which operates mainly in the North Pit with it fleet of six trucks. Coal is extracted by two EX3600 shovels and four EUCLID EH3000 trucks are used to load and haul the coal to the tip. (Levings, 2018)

The colliery employs on average 320 permanent employees and an almost equal number of contractor employees in various sectors of the operation.

3.5 Geological setting of the study area

Isibonelo Colliery is situated near the northern margin of the Highveld Coalfield of Mpumalanga. Figure 3.5.1 illustrates the general geology of the mine.

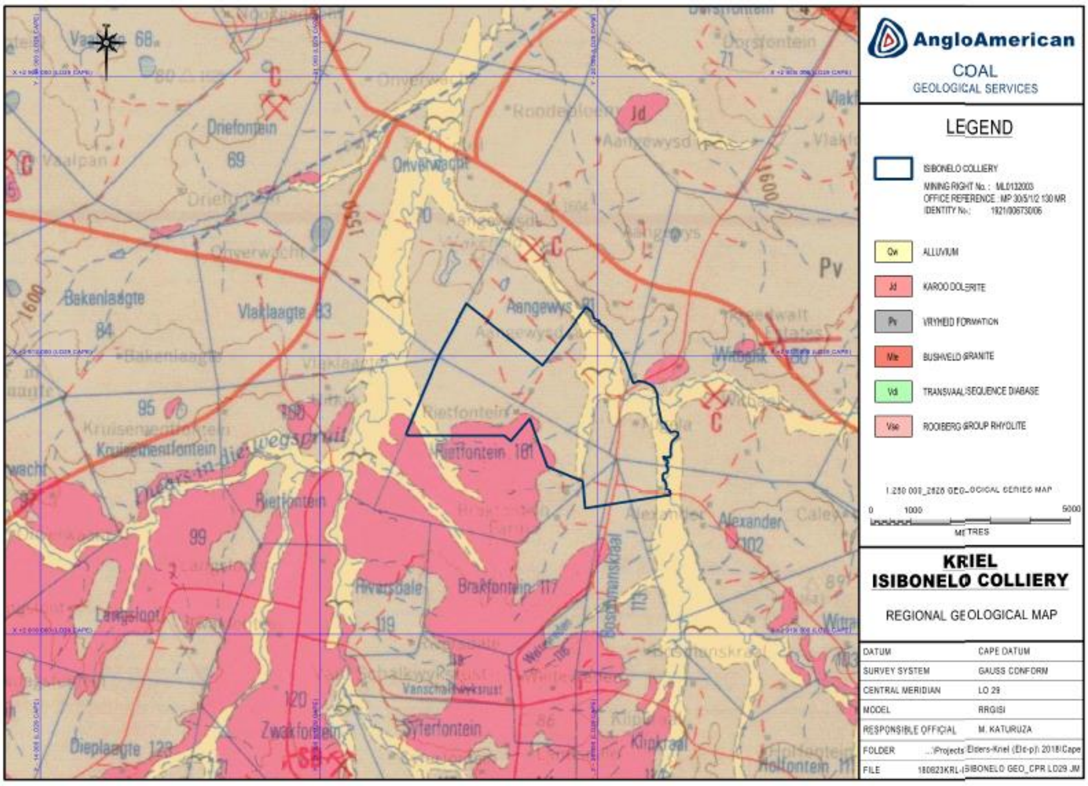


Figure 3.5.1 General geology of Isibonelo Colliery area

(From mine geology department.)

The area is underlain by sedimentary strata of the Karoo Supergroup which was deposited in the Permian period (248 - 290Million years) (Anhaeusser & Maske, 1986). The Karoo Sequence is made up predominately of sediments and is capped by a sequence of volcanic strata. Three stratigraphic units define the sedimentary strata of Karoo Supergroup. From oldest to youngest, the units are the Dwyka, Ecca and Beaufort Groups, respectively (Cadle, 1995). Coal seams of the Highveld Coalfield are hosted by the Vryheid Formation of the Middle Ecca Group (270Million years). Sediments of the Vryheid Formation represent coal-capped upward fining cycles of clastic sediments deposited in a fluviodeltaic/shallow marine environment. A variety of sandstones predominate the sedimentary succession with lesser amounts of coal, siltstone, shale and occasional grits and mudstones. The Vryheid Formation, at the base of the Ecca Group overlies diamictites and other associated glacially derived sediments of the Dwyka Group, which were deposited on a glacially sculpted pre-Karoo ancient granitic surface (Simakuhle, 2009) .

Bituminous coal seams hosted by the sedimentary strata in the Isibonelo Colliery Mining License area include, from the base up, the 1, 2, 3, 4 and 5 Seams of the Highveld Coalfield. At Isibonelo Colliery, the 5-seam and 4 Seam are presently considered to be economically viable. The 5-Seam overlies the 4-Seam in the underground areas and extends into a portion (approx. 40%) of the opencast mine. (Nkuna, 2014)

To optimise the Isibonelo resource base, the 5-Seam resource has been re -evaluated with the bulk of it transferred from indicated to measured resource based on current borehole data. (Katuruza, 2017). The borehole data indicates a thick parting (+/-0.7m) within the seam making it uneconomic as a full mining horizon. The No. 5-Seam was previously mined by Syferfontein Opencast with the aid of an on-site de-stoning plant. The mine has over the past few years been investigating a potential market for 5-Seam, the optimum mining methods thereof focusing on the Far South Pit as a case study for this exercise.

Potential positive spin-offs from mining the 5-Seam include, a reduced environmental impact as most of the coaly material is not left in the spoils to pollute the environment especially from water contamination. If the 5-seam is mined together with 4-seam the overall mine stripping ratios improve. The final benefit is the improved run of mine tons (ROM) recovered and delivered to the customer and improved financial returns.

Coal seams underlying the 4-Seam, i.e. the 3-Seam, 2-Seam and the 1-Seam all occur in the Mining License area, however, the 3 Seam is thin (approx. 30cm), the 2-Seam is poorly developed and the 1-Seam only sporadically developed. Currently, there are no plans to mine any of these coal seams and they do not form part of Isibonelo Colliery resources. A generalised stratigraphic column for the Highveld Coalfield is presented in figure 3.5.2 as depicted at Isibonelo Colliery.

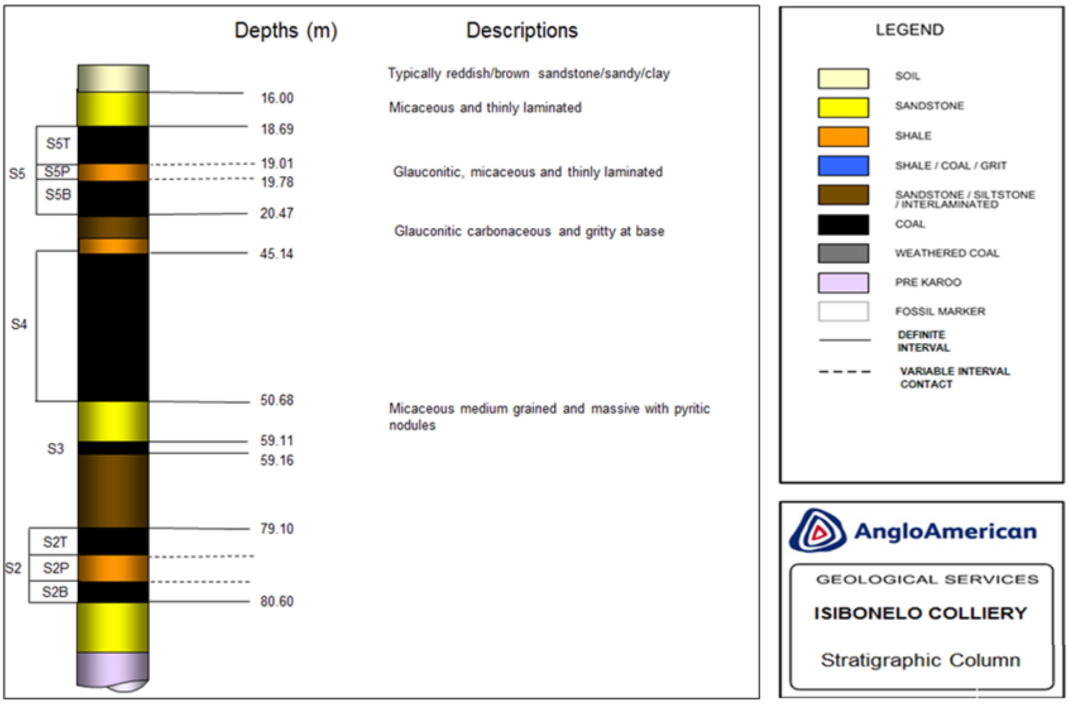


Figure 3.5.2 Isibonelo Colliery Stratigraphic Column

(Nkuna, 2014)

3.6 Conclusion

Isibonelo Colliery is a medium size opencast operation hosted in the Highveld Coalfield, producing at least 5 million tonnes of coal per annum and has been in operation for Anglo American Coal South Africa for the last 13 years. The 4 and 5 seams are the only economic seams meanwhile seams 2 and 3 are poorly developed and not economic to exploit. (Note: they are not part of the colliery coal resources).

4 GEOLOGICAL MODELS AND THE MINE PLANNING PROCESSES

The research methodology included both qualitative and quantitative approaches to gather as much information as possible to be able to make sound conclusions and come up with more practical recommendations. The following are some of the approaches undertaken during this research project.

4.1 Qualitative Approach

4.1.1 Review of current planning process and geological models

Generation of geological models

The exploration drilling and resource modelling functions are centralised for all the collieries for Anglo American Coal South Africa (ACSA). Exploration geologists run projects for specific collieries with all the core logging data and samples being submitted to the resource modelling department. The data is managed in a central database as well as the resource models. The drilling is done annually depending on the stage at which each site is at, then the model is updated with new borehole information. The resource model is handed over to the colliery geologists to check and confirm the changes, and is then signed off and handed over to the mine for use. The geology data flow process is shown in Figure 4.1.1

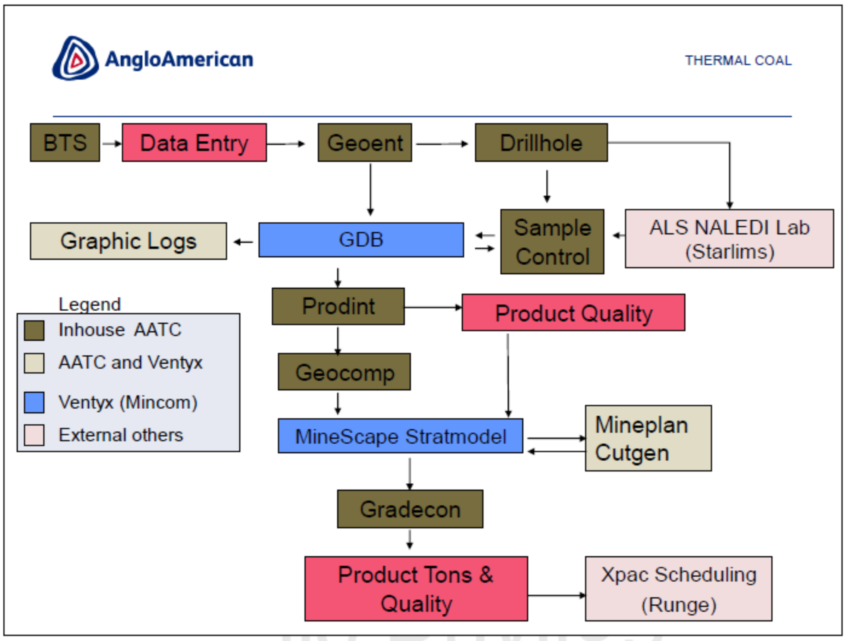


Figure 4.1.1 Schematic geology data workflow

(Nkuna, 2014)

The original logging of the exploration boreholes is done on paper and entered into the electronic database called GDB, where all the relevant data, including the survey, lithology, sample intervals and core recovery as well as the type of analysis requested are stored. Nkuna (2014), states that, when all the information for a borehole is available, the resource geologist downloads the survey, lithology and analytical data from the database in ASCII format, to be loaded into the geological model. Various validations of the data are undertaken upon loading it into the geological model. Survey data is also checked for possible duplication of co-ordinates and a comparison between the topographic model and collar elevation is conducted. Borehole positions are compared with the original planned position and that they plot within the expected area. Any discrepancies are reported to the colliery geologist or project geologist responsible for the respective area, for checking. (Nkuna, 2014)

Lithological and analytical data is checked simultaneously to ensure that analytical results are reflecting the lithological units described and that the analytical data is within the expected range of values for the relevant seam, sub seam or zone. Correlation of seams, sub seams and zones are based on qualities of the coal.

The generation of cross sections is used for validation of correlations and contour plots of thickness and floor elevation. When this process is complete resource model is handed over to the relevant geologist who should also independently run a few contours and cross sections to check the geological model has no anomalies.

4.1.2 Mine planning processes

The life of mine process usually starts off the mine planning activity. The mine scheduler generates from XPAC a mine block layout showing where the future mining will take place (the mine plan). The block layout is handed over to geology to run the reserves for the plan. The output file with tonnes and coal qualities is then imported into XPAC and two models are built from there, the Reserves Model and the Mine Schedule Model.

The built models are then used for the life of mine plan, the medium term and the monthly plans. Pit designs are generated using the same model for the rest of the year until a new model becomes available the following year after another exploration drilling programme. There is no other data that is currently being added to the annual resource model during the year, the update is only once per annum.

The survey department is currently providing mine planning with cross sections and elevations of the actual excavations which is then interpolated to the next cut during pit design process.

Geological cross sections of the next strip being designed are generated from the same annually updated resource model, and submitted to mine planning to use in the pit designs. The sections currently show the following major layers as modelled: base horizon of softs (BHSO), base horizon of friable weathering (BHFW), base horizon of weathering(BHWE) and base horizon of hard weathering(BHHWE,) interburden and the coal seams (5 and 4-Seam). Figure 4.1.2 shows these horizons at an exposed highwall in the South pit (study area) with a face height of 10metres.

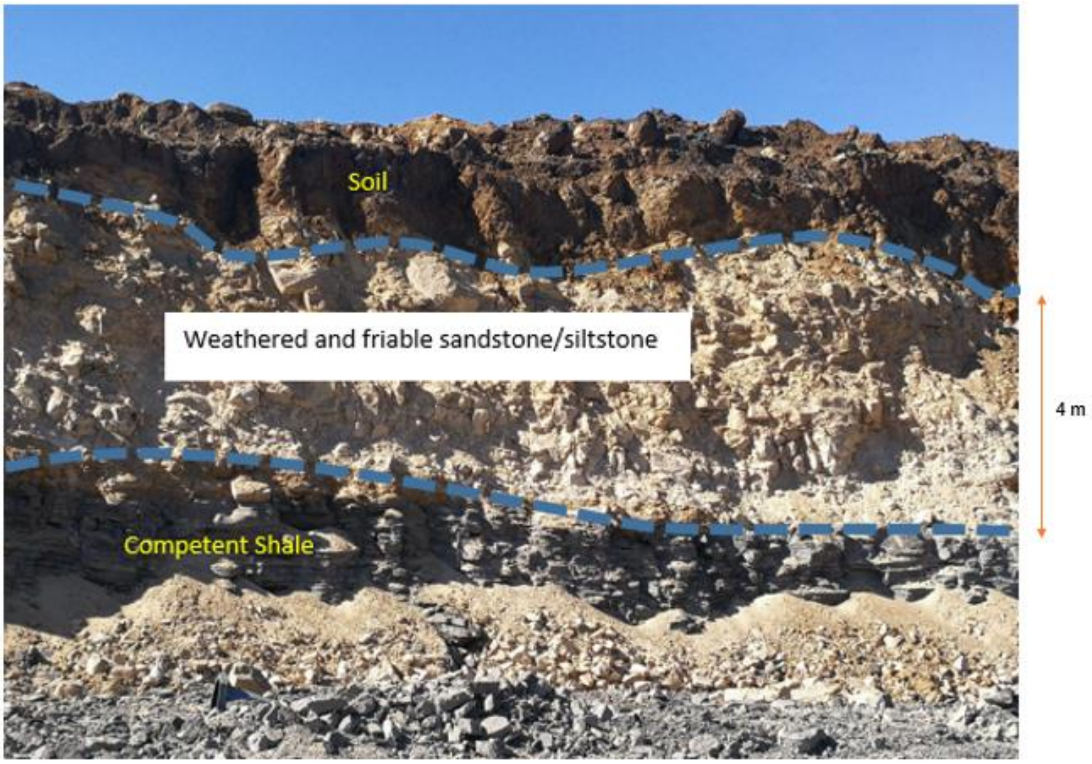


Figure 4.1.2 Typical Highwall weathering horizons South Pit (S5_S6 ramp)

(Photo by author)

The sections are exported in .dxf format to enable the mine activity engineers to import direct into their designs so that they can evaluate the horizons clearly and assign the correct equipment for each layer. Figure 4.1.3 illustrates a typical geology cross-section that is handed over to mine planning for use to design the next strip. (See also Appendix 10.1)

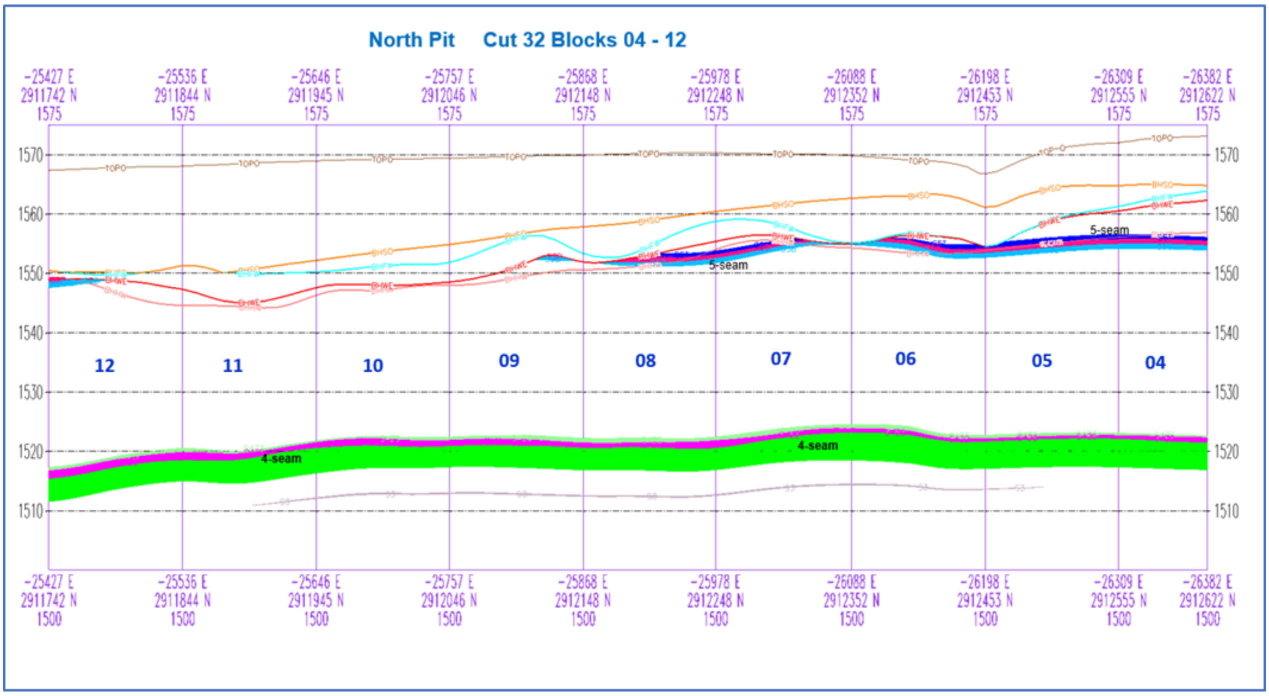


Figure 4.1.3 Typical Geology Cross Section

(By author)

The block data information supplied to mine planning is summarised in table format appended to the section. The mine activity engineers use these sections in conjunction with survey elevations to design the next strip.

The geological data generated from the model does provide the estimated thicknesses and volumes that will determine the design. The closer to reality in the field the information, the more accurate is the design and the plan. Table 4.1.1 illustrates typical geology data output used by the mine activity engineers to design the pre- strip, dragline and drill and blast activities. The data shows in columns from left to right: block names, block area, volume from topography to BHFW, depth from topography to BHFW, volume from topography to BHWE, depths from topography to BHWE, volume from topography to 4-seam roof, and depth from topography to 4-seam roof. (See also Appendix 10.2).

Table 4.1.1 Horizons Block data from Geology Model

[Q:\Group Shares\Share\Geology\LOM 2017\August2017Layout_Updated_22_08_2017 Geology Data\Runs_23082017\softsfile_m4_aug_2017.rpt] - UltraEdit

softsfile_m4_aug_2017.rpt

P4N2603	8403	113772	13.54	211301	25.15	325073	38.69
P4N2604	9000	105605	11.73	276176	30.69	381782	42.42
P4N2605	9000	94880	10.54	266329	29.59	361209	40.13
P4N2606	9000	93508	10.39	290549	32.28	384058	42.67
P4N2607	9000	105669	11.74	294997	32.78	400665	44.52
P4N2608	9000	102073	11.34	298187	33.13	400259	44.47
P4N2609	9000	140801	15.65	244819	27.20	385620	42.85
P4N2610	9000	150458	16.72	253220	28.14	403678	44.86
P4N2611	9000	151678	16.85	239437	26.60	391115	43.46
P4N2612	9000	145383	16.15	232082	25.79	377464	41.94
P4N2613	9000	127064	14.12	241567	26.84	368630	40.96
P4N2614	9000	141337	15.70	231878	25.76	373215	41.47
P4N2615	9000	130944	14.55	251506	27.95	382450	42.50
P4N2616	9000	64447	7.16	315998	35.11	380445	42.27
P4N2617	9000	60757	6.75	316536	35.17	377293	41.92
P4N2618	9000	73966	8.22	294921	32.77	368887	40.99
P4N2619	8999	114459	12.72	221485	24.61	335944	37.33
P4N2620	9521	168908	17.74	150131	15.77	319039	33.51
P4N2703	7162	99372	13.88	190411	26.59	289783	40.46
P4N2704	9001	98414	10.93	286143	31.79	384558	42.72
P4N2705	9001	82688	9.19	286751	31.86	369438	41.05
P4N2706	9001	83209	9.24	308560	34.28	391769	43.53
P4N2707	9001	100833	11.20	312134	34.68	412968	45.88
P4N2708	9001	105511	11.72	301782	33.53	407293	45.25

(Geology Department, 2017)

The cross section (Figure 4.1.3) as generated from the current resource model only shows the modelled surfaces as summarised in Table 4.1.2.

Table 4.1.2 Key unconformable Surfaces used in the modelling

Name	Type	Relationship	Unit Relationship	Continuity
BHSO	Surface	Non-conformable	Base horizon of soft weathering: Soil and soft weathered material. All highly weathered material and soils that can be removed with a bowl/scraper without the need to rip. Fresh or un-weathered material cannot occur above this horizon.	Continuous
BHFW	Surface	Non-conformable	Base horizon of friable weathering: moderately weathered material that need to be ripped before removal. Fresh or un-weathered material cannot occur above this horizon. Overburden above this horizon can be removed by free-digging and does not require blasting.	Continuous
BHWE	Surface	Non-conformable	Base horizon of weathering: moderately weathered material above which coal would be	Continuous

			considered weathered if present. Overburden above this horizon needs to be blasted, and cannot be removed with free digging.	
BHHW	Surface	Transgressive	Base of hard weathering: Marks the lowest depth of which oxidation/alteration due to weathering has occurred.	Continuous
THDW	Surface	Transgressive	Top of the Dwyka, i.e. end of the coal sequence.	Pinch
THPK	Surface	Nonconformable	Top of Pre-Karoo.	Continuous

(Katuruza, 2017)

In the weathered horizon between the surface topography (TOPO) and BHWE (base horizon of weathering), it is currently assumed in the mine design that all material is soft and free digable. The Isibonelo mining experience over the years has shown that there are some layers of competent sandstone and siltstone which has rendered mine planning having to add another activity termed “sandstone drill and blast”. The challenge currently for mine activity engineers is that cross sections provided by geology do not show these competent horizons to allow for more accurate design of the drilling. Mapping from the exposed softs highwall (section 4.5 of this report) confirmed the elevations which had to be incorporated into the short-term model. The drilling in some cases does start in softs (311mm diameter holes) and rods have been getting stuck or holes simply collapse when finished drilling. The short-term geological modelling process, by incorporating mapped highwall data, would enable better cross sections to be generated and thus improved mine planning.

4.1.3 Review of the current Operations Management System status

Geology, Mine Planning and Rock Engineering have been audited over the last few years on compliance to the Operating Management System (OMS) and short-term geological modelling has always been an audit finding. “The OMS are a set of standards and guidelines that have been developed to establish and maintain the technical standards that Coal South Africa (CSA) requires across its operations to plan for and deliver on a high level of performance.” (Roberts, 2017). There are gaps that have been reported every year pointing to lack of short-term geological modelling, which prompted the necessity to embark on this research project.

The following are some of the key findings:

4.1.4 Geology OMS audit

Some of the compliance questions in the audit of the current system are summarised in the table 4.1.3. A full audit template on short-term modelling is included in Appendix 10.10.

Table 4.1.3 Geology Short-term Modelling Audit example

	Compliance Question	**Current status**
1	Formal process for short-term modelling established and documented	Annual model update is considered to be short-term model. The annual geological model report is specific and updates / changes are tracked as the report is circulated to site Geology Manager as part of model handover process.
2	Regular short-term modelling undertaken that supports OMS operational planning / control requirements	Yes, annual update as stated above. Adhoc updates as and when required
3	Short-term models completed and validated in timely manner to be incorporated in mine planning and scheduling. Including model grids of roof, floor, thickness and key quality parameters	Yes, as managed by Resource Evaluation Department
4	Documentation of short term modelling process	Yes, See Geological model report

(Roberts, 2016)

The questions are centred on whether the site has a formal short-term geological modelling process in place and that there are documented procedures in place. According to the current status, the annual resource model update is taken as short-term since new data is only updated annually after the exploration drilling programme. There is no other data besides borehole data that is used to update the model. Currently mapping information is not being incorporated, hence the motivation through this research project and to fill the “gap”.

The short-term planning requirements are currently being fulfilled by the same annual resource model. In the last audit in 2017, the auditor’s comment on short-term modelling stated, “Follow up on highwall mapping practices used by Metallurgical Coal,” (Roberts, 2017).

Short-term models are used to ensure that planning and operational teams have access to the most current information for, short / medium term planning, improved prediction/management of geological hazards and optimising reconciliation. Therefore, processes should exist for ensuring short-term models are reasonable representations of the geology, (Brady,2007) and the same should apply to Isibonelo Colliery, and other Anglo American Coal South Africa collieries.

4.1.5 Mine Planning OMS

Mine planning audits have also been highlighting the importance of short-term geological modelling. Some of the comments from auditors include requirements for short-term scheduling and the importance of full strip reconciliations. The absence of a short-term geological model implies that strip reconciliation is not complete, that is the most up to date geological data on the mined (or exposed face) is not available. The auditor’s comment in the last 2017 audit was that on strip reconciliation there is a need for stakeholders to entrench themselves in a full strip reconciliation meeting and then address all actions in a register. Figure 4.1.4 illustrates the expected input from geology to the short-term planning process

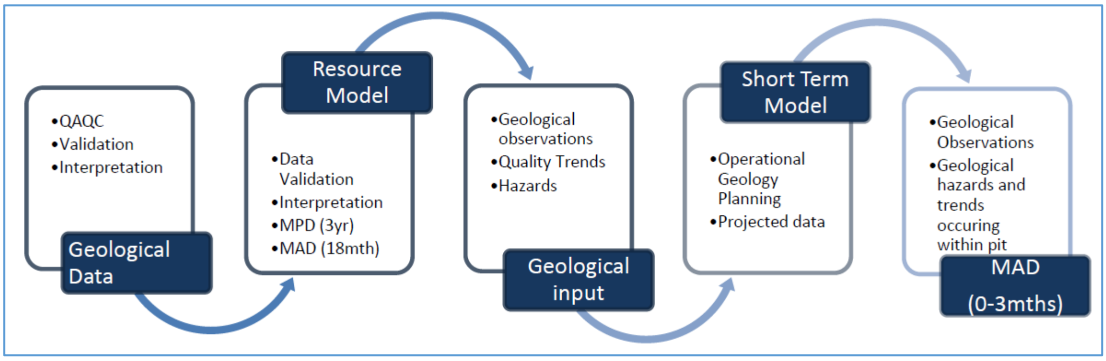


Figure 4.1.4 Operational Geology Planning process

(Anon (a), 2014)

The recent and past audits have continued to find that geological input into short-term model is not in place at Isibonelo Colliery and other sister operations in South Africa. The current Mine Activity Documents (MADs) are being fed with Resource Model data thus depriving mine planning the use of the latest information based on geological observations through mapping and any interpretations from the exposed highwall.

Table 4.1.4) is a snapshot of some of the OMS audit comments over the years.

Table 4.1.4 Mine Planning OMS Audit extract

	Compliance Question	Current status
1	□ Data exists to adequately represent the adjacent mining area and has been incorporated into Short-term model (or has confirmed that no Short-term model changes were required) - sources can include survey, drill and blast data □ Survey data includes adequate pick up of coal seam roofs and floors, coal edges, actual pit shell limits □ Survey data is complemented and confirmed by drill hole toe data □ Short-term model updates occur as required □ Short-term model adequately represents the mining environment, both for structural and quality representation	Drill hole toe data incorporated Short term Geological Models not in existence (only annual**)** Highwall Mapping was introduced by the site Geotech drilling commenced
2	Review and confirm performance Inputs: Details to include changes to: □ model updates □ changes in stage plan sequences (3D snapshot in time, phases,3-month plan)	Short term geological models not in existence

(Roberts, 2016)

4.1.6 Rock Engineering

In opencast operations such as Isibonelo Colliery, it is imperative that unfavourable geotechnical conditions are realised at an early stage before designing the pit. Major structures have huge impact on coal loss and when noticed at a late stage that causes a change of design. A short-term model informs better geotechnical designs with exposed current highwall structures incorporated in the design.

Figure 4.1.5 is an extract from one of the OMS audit reports with special mention to short-term geological modelling and its use for geotechnical applications and mine planning purposes.

Design, Coaling Scheduling & Reconciliation

Δ *Top 10 Improvement Opportunity*
↻ *Top 10 Recurring Item*
Δ *Additional Improvement Opportunity*

- ✓ Implementation of an activity based One Page Plan (OPP) , MAD Pack and MAD Document
- ✓ Embedded VMP Intersection Register (Best practice)
- ✓ Implementation of Strip Reconciliations
- ✓ Improvement on MAD activities to include truck and shovel
- ✓ Good quality MAD's conducted on dragline activities

- ↻ Short Term Geological Models to be finalised and implemented for Planning & Geotechnical applications
- ↻ Improve detail in coaling MAD and collate comprehensive OPP
- ↻ Formalise and implement Change Management System
- Δ Continuity of improvements under threat due to personnel movements

Drill & Blast Planning

- ✓ Survey team provides drill pattern layouts
- ✓ Operators are currently being trained on the DrillNav system

- Δ Investigate blasting techniques along the pre-split to ensure the toe design line is achieved on the overburden so that high wall lockups are minimised (e.g. Project X)

Figure 4.1.5 OMS Audit Report Extract 2016

(Roberts, 2016)

4.1.7 Interaction with various stakeholders in the value chain

- Business Improvement team leader

Isibonelo Colliery embarked on a business improvement initiative as part of the whole Anglo American coal group, to look at ways of increasing productivity through optimising the entire mine operating systems. The process was spearheaded by a team of people dubbed the MOS team (Management Operating System). The author spent some time discussing with the then Business Improvement Manager, Pleasure Mnisi who asked me, "Meaker, what do you see as the most important thing that will change mining in the future?". Changing technology is the only way mining would look different in the future. Mnisi said that integrated technology on the mine of all the systems with input from departments, will make management of optimisation simpler. Geological information will be input into the system and will be available to people to make decisions should there be bottlenecks in the system and they are flagged for all to see with a press of a button. Therefore, coal recovery in the pit will be managed easily even with the geologist being away from site (Mnisi, 2017). From the views of the Business Improvement Manager, the author was convinced that if the geological model is uploaded into the integrated system being investigated, mine designs and ultimately optimised coal recovery at Isibonelo Colliery will improve.

- Rock Engineering

The Rock Engineering Specialist, in an interaction with the author said, “Meaker, our slope designs require detail from the geological model. The OMS audit on rock engineering is always finding a lack of a short-term geological model as a gap” (Joel, 2017). The short-term geological model is a requirement to achieve 100% in the OMS audits every year.

In an interaction with the Principal Rock Engineer, “The requirements for rock engineering are so simple, people tend to complicate issues, all we need is your mapped structures such as dykes, major joints along the exposed highwall and that information projected forward” (Priest, 2018). It became clear from the interaction that Rock Engineering, in their pit design analysis, need historical geological data of the behaviour of the highwall and nature of the stratigraphy. The Isibonelo Colliery stratigraphy is characterised by thick softs (weathered horizons) in some sections of the pit, hence from a slope analysis perspective such information according to Priest is needed to be availed upfront. The geologist does map such horizons in the strip/cut currently being mined and projected into the new cut and that will be used to analyse the new strip design.

- Mine Planning,

The mine activity engineers on the mine have been finding the geological cross section information provided to them for pit designs rather inadequate. One of the mine activity engineers got to the stage of asking for borehole logs so he could compare with what is exposed in the pit. “Just give me the boreholes for the next cut, and I build a profile for my designs. The sandstone band in the softs highwall is not reflected in the geological cross sections, how can we get it, for the pit designs?” (Van Deventer, 2017). The short-term geological model would be the only the answer to provide mine planning with the latest up-to-date information for more accurate pit designs which will result in optimised coal recovery.

In a follow up, interaction with draglines mine activity engineer, he had this to say, “You only need to give me from your geological model, is a grid file with all the data I need to simply import into my model, then I can start running my designs. It is a simple file” (Van Deventer, 2018). The mine design software used is called 3-D Dig and the step by step design process shown to the author is summarised in figure 4.1.6.

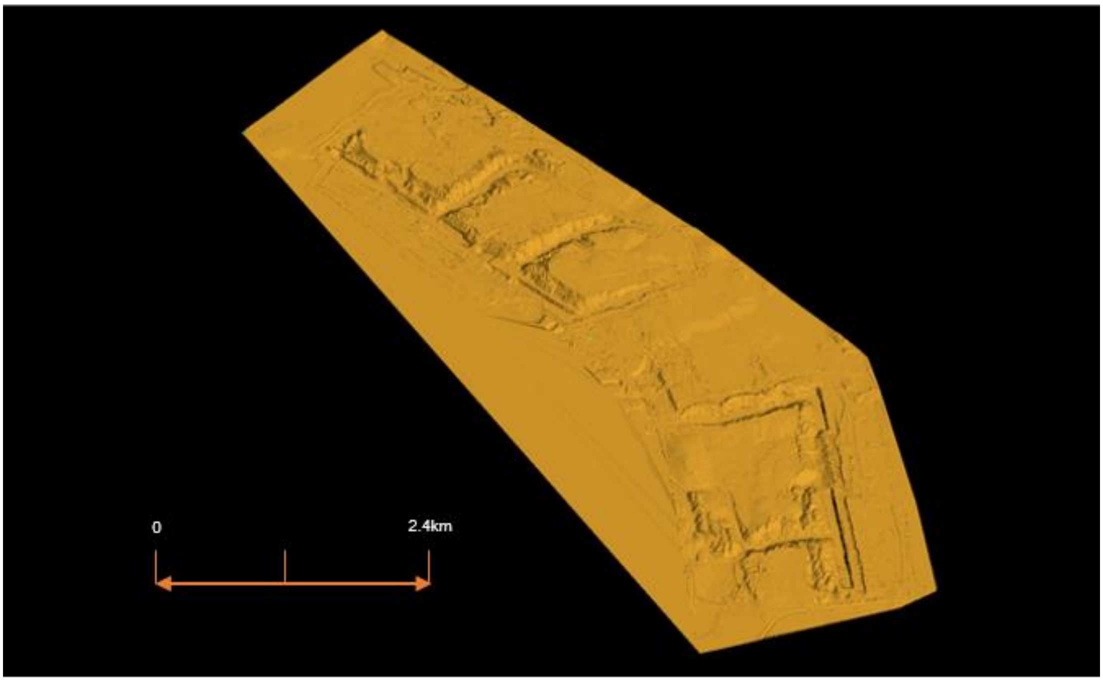


Figure 4.1.6 Pit Design step at Isibonelo Colliery

(Van Deventer, 2018)

The Digital Terrain Model (DTM) data from the weekly survey flyovers, is imported into the 3-D Dig model. This information gives the most up to date topographic elevations of the mined area. The cloud points are then triangulated (meshed through the process of building triangles) as shown in figure 4.1.7.

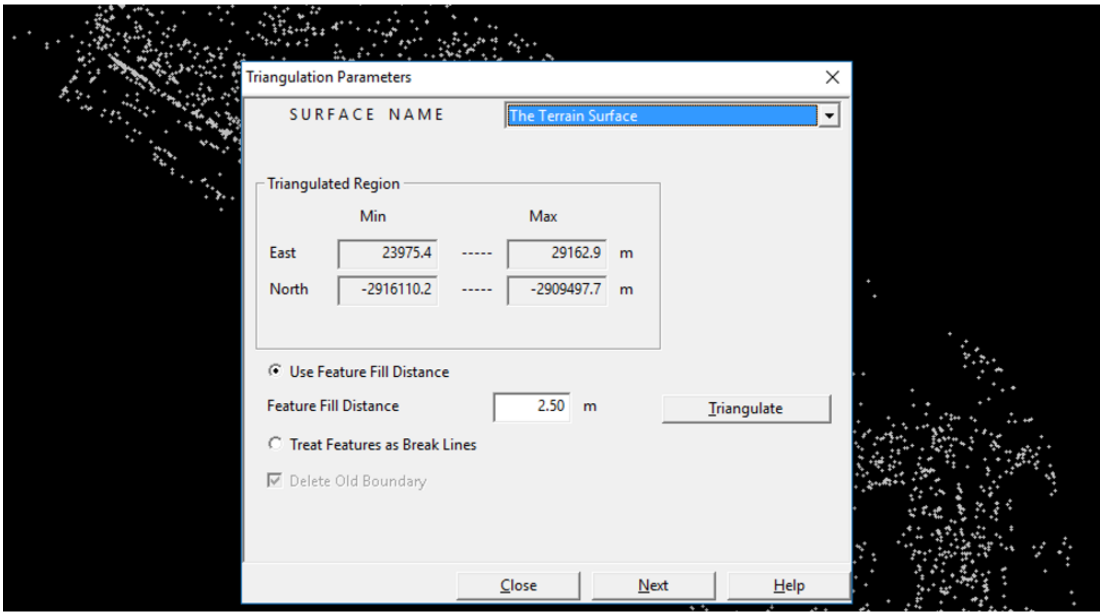


Figure 4.1.7 Triangulation of cloud points

(Van Deventer, 2018)

The process will result in the terrain being filled up with data, thus producing a surface. The geological data for the various stratigraphic layers is then imported into the 3-D Dig model as illustrated in figure 4.1.8

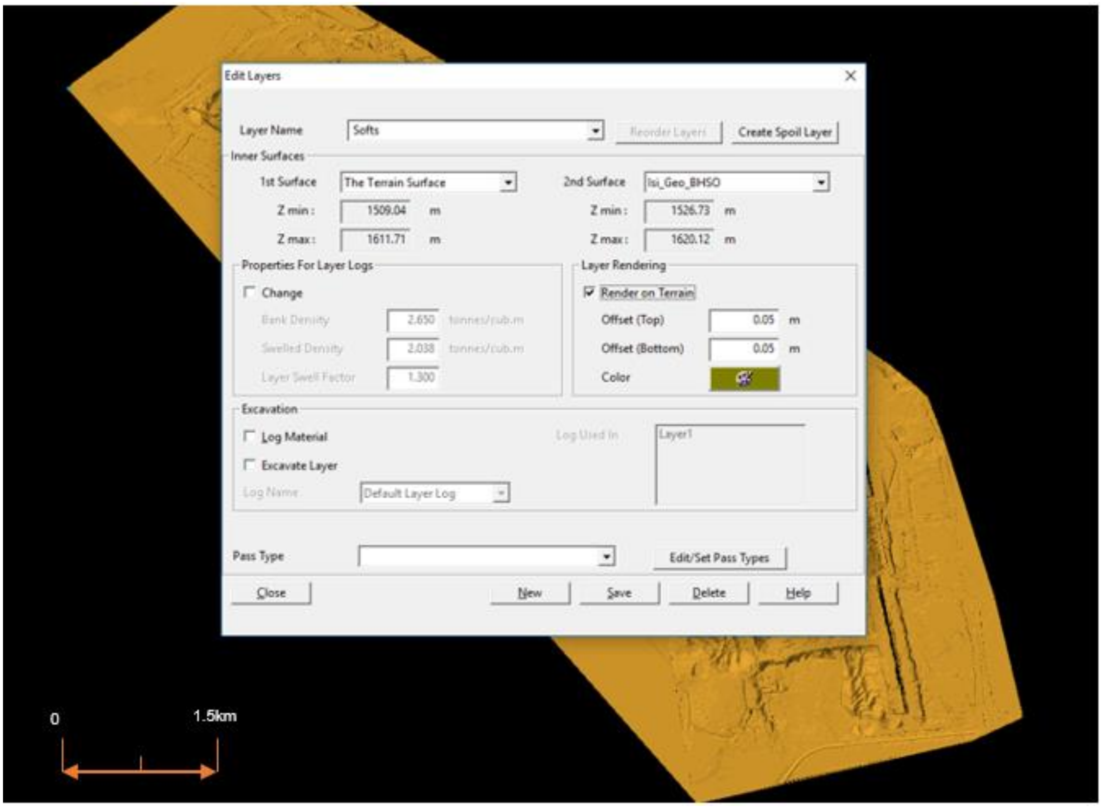


Figure 4.1.8 Importing Geological Data

(Van Deventer, 2018)

The geological data that is imported into the model would further be processed to generate the different lithological layers from which cross sections can be made. Figure 4.1.9 illustrates a cross section generated from 3D-Dig model.

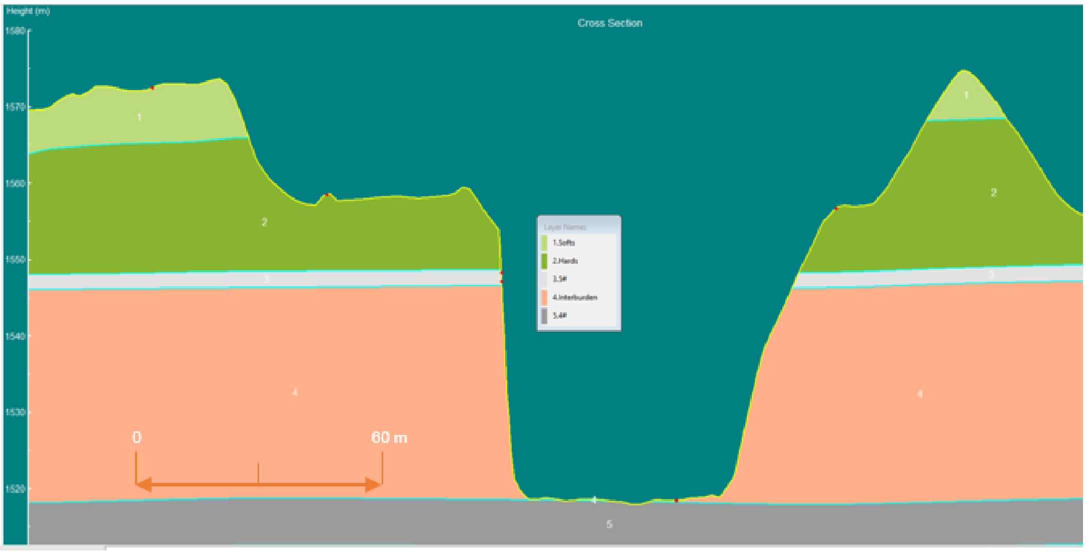


Figure 4.1.9 3-D Dig generated cross section

(Van Deventer, 2018)

The different lithological layers are illustrated in different colours with the softs representing the top soil and that part of the friable softs (BHFW is the bottom surface of the unit). The hards would refer to material that is not free digable (which could be weathered or partially weathered). The bottom horizon of this unit is the BHWE. In some cases, the layer requires drilling and blasting as it is characterised by sandstone.

- Technical Services Manager

The Technical Services Manager of Isibonelo Colliery interacted with the author during the research period in a few times. He stated that, “The short-term geological model is my passion, I would like to see it developed and see the gap in OMS closed, pit designs improved. This idea of using the annual resource model for short term scheduling has proved inadequate. We have seen a lot of discrepancies especially on the volumes, Carpenter, was always giving support to the author to get some traction on the project and in one other discussion he stated that, “In these last few audits we have been criticised for lack of a short-term geological model and strip reconciliations, therefore you need to push harder to get through this project. We have to show something in the mid-year OMS audit”. (Carpenter, 2018)

- Operational Geology Specialists

The Operational Geology Specialist in an interaction with the author said that, “I have always wanted to get this short-term geological modelling off the ground since the inception of OMS, but it did not get much traction. I strongly believe, it adds a lot of value to the planning and reconciliation processes. I would urge you to vigorously consider it. New Vaal Colliery, have through Dhege, their production geologist attempted to gather data using a scanner to update their geological model, therefore you can contact the mine to latch onto the experience and take to Isibonelo Colliery" (Mokele, 2018)

- Principal Opencast Mine Planning Engineer

The author interacted with the Principal Opencast Mine Planning Engineer for Anglo Coal South Africa with regards to the importance of the short-term geological model to mine planning. Treadwell stated that, "From a short-term planning point of view, there is need for actual data generated from the exposed highwalls so that it can be imported into the XPAC short term model which is already built from the annual geological model data" (Treadwell, 2018). Treadwell further explained that such information would be projected into the next strip to be mined. The critical point highlighted was that the data needed to be validated against the model. This was needed to ensure the correct lithologies and surfaces are being compared correctly. The survey fly over data currently being used for blast volume reconciliations would need to be validated against actual survey pick-ups.

Treadwell further clarified that for Isibonelo Colliery, which does not have structural complexity issues, the focus should be on the overburden. The short-term model measurements should target the softs where current geological boreholes do not give sufficient data due to poor or no core recovery in that horizon. The information is provided to mine planning in Excel spreadsheet format per each mining block. The interaction also covered issues such as what triggers the short-term model. "The variances that we usually get between the geological model softs volumes and the actual measured by survey is a good trigger for short-term modelling" (Treadwell, 2018). The burden between the 5 seam and 4-seam roof was deemed consistent between geological model and actuals, hence that should be used as the reference point while conducting short-term geological modelling for use by mine activity engineers.

- Other Anglo-American Coal South Africa collieries

New Vaal Colliery situated on the Sasolburg Coalfield in the Free State is a multi-seam opencast operation employing the same strip mining method as Isibonelo Colliery. The production geologist, confirmed the colliery has partially attempted to employ short-term geological modelling to fulfil the requirements of the OMS. The geologists have been working in conjunction with surveyors using a scanner to map the highwall. The data generated would be interpreted by the geologist to mark the mapped seam contacts. The seam contacts would then be sent to the resource geology specialist who would update the annual resource model. Figure 4.1.10 summarises the process flow at New Vaal Colliery (now owned by Seriti Resources).

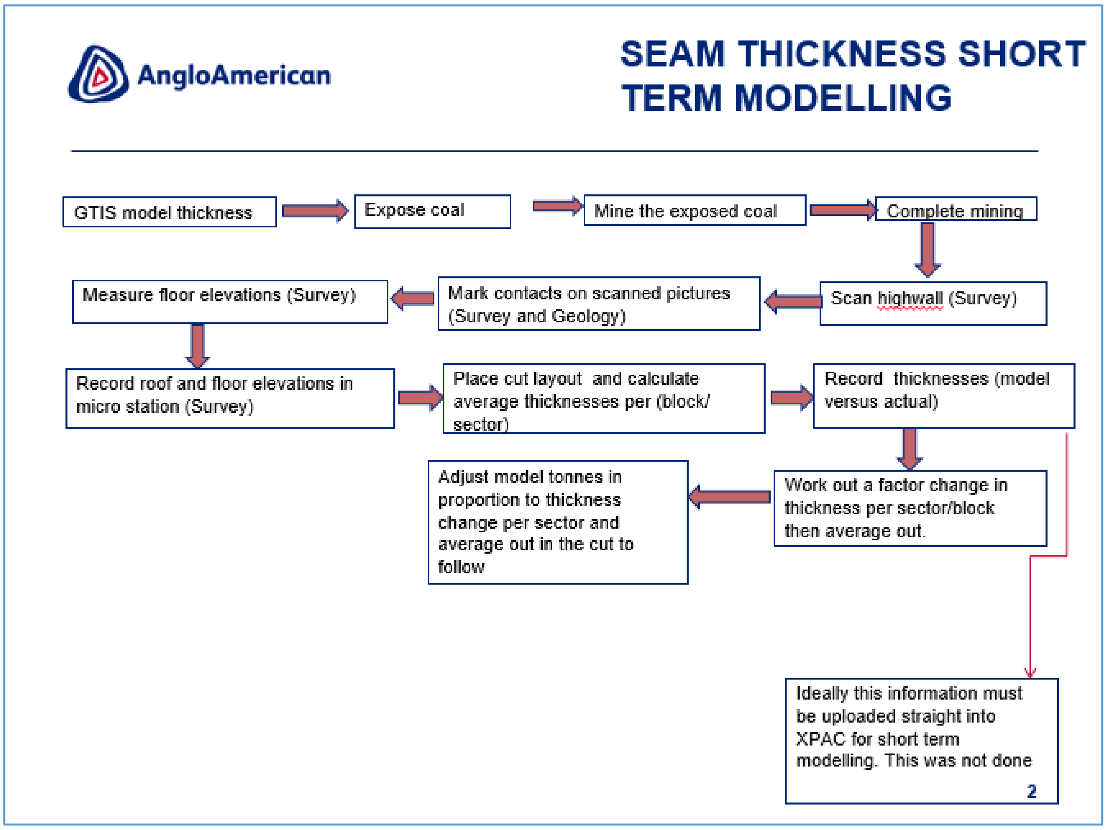


Figure 4.1.10 New Vaal Short-term modelling process flow

(Dhege, 2018)

The production geologist of New Vaal Colliery in sharing information with the author, said, “Please find a short version of what we tried implementing for short-term modelling. The scanned images for the high walls are with the surveyors (not sure if they keep them forever in the system). Each time a scan was done, I would sit with a surveyor to analyse the data. I was receiving data with already calculated elevations which I would work use to calculate the thicknesses.” (Dhege, 2018).

New Vaal Colliery focused on measuring the actual seam elevations along the exposed highwall in the pit using a scanner and produce images where the geologist would extrapolate the coal contacts. The surveyors would measure the floor elevations and avail the data to the production geologist to compute the seam thicknesses. The calculated seam thicknesses would be averaged per each mining block and then applied to each of the blocks in the next mining strip. The process results in coal tonnages and waste volumes being adjusted based on the new data obtained from the short-term model.

4.1.8 Anglo American Coal Australia compared to Isibonelo Colliery

The author interacted with some of the geologists and mine planners from Australia where short-term geological modelling is being practised. According to Klerk (2017), the short-term model (STM) will be an updated representation of the resource model of a specific area, by including new survey and drill data. The mine activity engineers (formerly known as mine planners) would ensure the short-term model focus on an area and not necessarily the multiple strips. The planning window of more than 18 months is conducted using the current resource model. The major difference between the two models is the quality of the data included and how that data is represented in the model. The resource model is created to indicate the confidence in the resource or reserve in the mining lease area, meanwhile the updates in the short-term model are meant to refine this aspect. The resource model is built mainly on borehole data points of observation; hence they may lack inclusion of some minor structural features such as faults throws or seam floor rolls. It was confirmed through the interaction with Klerk that short-term models aim to provide greater resolution around an area in the strip which can have an impact on design and eventually coal recovery. According to Tapomwa (2017), the short-term model places more emphasis on representing smaller scale features that will have an impact on coal recovery, if overlooked by the engineer designing the pit shell. Mine Activity Engineers require the most up to date information to produce accurate designs that optimise coal recovery, reduce safety risks and improve dragline performance during coal exposure.

According to Klerk (2017), each mine has its own procedure for short-term modelling, depending on the software used (generally between Stratmodel and Minnex) and on the colliery conditions and issues. Some of the collieries have slightly complex structural geology with dipping and sometimes faulted coal seams. Three Australian collieries were considered in this section as examples demonstrating the success and pitfalls of short-term models.

- Dawson Short-term modelling

Dawson coal mine is situated in the Bowen Basin in the state of Queensland, Australia. It is characterised by dipping and sometimes faulted coal seams. It is one of the three Australian collieries that is covered in this section demonstrating short-term geological modelling. It is a large mine with a 60 km strike length and has metallurgical coal in the north and thermal coal in the south. Due to its size and shape (long and thin), it has seven models along its length. There are eight major coal seams that are mined, and split into sub-seams and coalesce into compound seams, and are faulted. Again, short-term modelling is important because faults with less than a 5 m throw are not likely to be picked up in normal drilling, but when intersected in a pit, can be included in the short-term model, and later updated in the resource model (Klerk, 2017).

The 18 months Mine Planning Document (MPD) or any planning beyond this period is conducted using the current resource model for the specific design area. The resource model at Dawson does not include for example, structural features of less than 5 metres magnitude. The short-term geological model gives greater resolution of the focus areas as the smaller scale features are captured.

In the generation of the short-term geological model, the naming convention is taken cognisance of, to maintain consistency and order. These include schema, pits, faulting, design files and project definitions.

The short-term geological modelling is triggered by the following events at Dawson:

a) drill and blast data when fully analysed and compared to the model prediction would cause moderate changes to mining method or design or even the tonnages in the mining blocks.
b) survey coal contacts pick-ups done on an adhoc basis are compared with model prediction (current cross sections) and these also have potential to cause some changes to mining method or design or tonnages in the mining blocks.
c) geotechnical observations in the pit such as slope failures, material properties variations have the potential to cause moderate changes to mining method, design or tonnages, if reviewed.
d) new borehole data when received and reviewed also has potential to trigger moderate adjustments to the mining method or vary the design with resultant tonnage changes.

The above scenarios all trigger the generation of a short-term geological model to address the issues identified. The result is an improved mine plan and the delivery of results.

Isibonelo Colliery has had similar issues where the highwall horizons observed in the pit (field) showed some distinct variance with the geological model cross-sections especially in the study area (South Pit between Ramp S4 and Ramp S6). The volumes of waste assigned to the dragline became more than planned, thus linear coal exposure was compromised.

- Callide Mine Short-term Modelling

Callide Mine is a thermal coal operation which used to be owned by Anglo American Coal Australia and has recently been disposed of. It is in a small (22 km x 8 km) isolated basin characterised by a few discrete seams that coalesce to thicknesses of 10 m to 22 m, in the four mining areas. It is an opencast strip mining operation employing truck and shovel only (there are no draglines).

According to the Geology Superintendent of Callide Mine, short-term geological modelling is important to ensure that both planning and production departments have the latest and most accurate information about the strip to be mined. "Current JORC resource models are primarily based on exploration drilling and don't include short-term information from recently mined strips. Historically information input into the model may have had different assumptions and interpretations. Therefore, it is important to update grids with the latest information and to check seam picks and correlations, base of weathering, depth corrections, sampling," (Colbourne & Hypponen, 2015). Callide Mine has the following additional sources of information incorporated into the short-term geological model:

a) Previous strip reconciliations (roof and floor surfaces, quality variances, etc.).
b) Pre-split and production hole logging which is the blast holes geophysically logged.
c) New exploration data gathered since last model (resource or STM).
d) I-Site scan (laser scanning) strings for roof and/or floor of coal seams.
e) Fault information (surveyed with recorded throw).
f) Mined-out polygons.
g) Additional geometry strings as required (e.g. Base of weathering or channels picked from highwall scans).

The data is checked for integrity and quality in the areas of focus especially the highwall coal pickings. Mine designs require up to date geological information for planning to be as close as possible to reality in the field. There are many triggers for short-term geological update at Callide, (Colbourne & Hypponen, 2015), which are summarised as follows:

a) Significant variation identified between existing model and new data (exploration borehole structure and/or quality data, operational drilling seam picks, highwall scan seam picks and/or fault pickups).
b) Significant variations identified during reconciliation between existing model and mining data.
c) Significant erroneous or inconsistent data identified within the model.
d) Significant quantities of new data.

The geologist works with the drill and blast engineer in the selection of holes for geophysical logging. The geophysical logger discusses the plan with the geologists to ensure the tools to run density, gamma, calliper and verticality are in order. Isibonelo Colliery and all the other ACSA operations do not have this process in place. The only geophysical operation is currently being applied to new exploration projects where coal seam correlation needs verifying. Hence current variations in the model to mining reconciliation are not being fully addressed thus leading to mine planning variances in some instances. (Less volumes planned than achieved or vice versa).

- Foxleigh Mine Short-Term Modelling

Foxleigh Mine is a thermal coal operation which was previously owned by Anglo American Coal Australia and was part of the divestment by the company in 2016. It is an opencast strip mining operation employing truck and shovel operations.

Foxleigh was mostly PCI coal, with small amounts of thermal type coal. It is in a plunging syncline between two regional thrust faults, there is extensive faulting and seam repetition. Short-term modelling was important as structural changes occur over a very short space and may not be observed up in the drilling (even though borehole spacing was ~100 m) (Klerk, 2017).

The short-term geological modelling process starts with identifying varying data collection methods and how it is used to then update the model. The timing, responsible person, reporting structure and how the updated model is communicated to the stakeholders is a well manged process. Table 4.1.5 summarises the type of data, person responsible and frequency of collection of data.

Table 4.1.5 Data Collection Summary

Type of Data	Person Responsible	Frequency of collection
Survey Scanning	Pit Geologist/Modelling Geologist to request scan from survey.	When required e.g. significant unexpected change to model.
Annotated Images	Pit Geologist/Modelling Geologist	When very short-term changes to model are encountered.
Survey coal pick up	Survey responsible for pick up, Geology responsible for use	Whenever coal roof or floor is exposed on dayshift, on weekdays.
Survey pick up of structure	Pit Geologist/Modelling Geologist to request scan from survey.	When required e.g. significant fault in floor not in model.
Drill and Blast data	Drill and blast engineer responsible for input, Geologists responsible for use.	Infrequent, depends on where the production rigs are drilling in relation to the coal.
Boreholes (GHD)	Modelling Geologist to identify gaps and identify if GHD can drill and information be loaded into model in a timely manner.	When required by modelling geologist.

Source: (Sharma, 2015)

When the model is updated, a report is produced and circulated to the key stakeholders and the technical services personnel, for their use.

Significant changes observed from in-pit observations are photographed by the pit geologist who is responsible for a monthly model versus actual report which is communicated to the modelling geologist/senior site geologist. (Sharma, 2015)

The other type of data that is collected onsite is blasthole geophysical logs that is imported into the modelling software for update of the model with latest field information.

The trigger and responses are similar to Callide Mine's list of triggers. Isibonelo Colliery currently has a weekly in- pit geotechnical observations and reporting meanwhile the data ends up as just reports only instead of being used further in updating the geological model.

The survey coal pick-ups are only used for monthly survey reports of run of mine tons produced. The information can be very useful in updating short-term geological model and making planning better.

Unlike at Foxleigh, the monthly reconciliation of model versus actual on the mined polygons at Isibonelo does report numbers only and encourage mining to improve the coal recovery. The information does not find its way into any model update, it is archived in the strip reconciliation cabinets where any significant variations will be taken cognisance of while planning the next mining strip.

The good practice at Foxleigh, which the author appreciated, is the fact that the modelling geologist is based on the mine and must have experience with the deposit. The updated model is, as part of quality assurance and quality control (QA/QC), is peer reviewed by senior modelling geologists for accuracy. According to Sharma (2015), "The major difference in short term and resource models is the quality of the data included, and how that data is represented in the model. Resource models are primarily created to determine the confidence in the reserves and resources on a mining lease and updates tend to focus on refining this aspect of the model. Typically, resource models will not include structural features less than 5m in throw. In addition, resource models weight boreholes as the highest confidence data points, which consequently mask some smaller scale features in the model. It is unrealistic to expect small scale features to be modelled in resource models. Short term models aim to provide greater resolution around an immediate area, placing more emphasis on representing smaller scale features likely to affect localised coal recovery." Therefore, more accurate planning is achieved with a more resolute geological model; Isibonelo Colliery is still planning based on the resource model.

4.2 Quantitative Approach

4.2.1 Creation of a working geological model

The study area for this research project was focused on the South Pit of Isibonelo Colliery and is illustrated in figure 4.2.1.

Figure 4.2.1 Project study area with the plotted data points

(Author own diagram)

The aerial view of the study area figure 4.2.2 in the South Pit illustrates the active Strip19 being mined (January 2018) in relation to the previous Strip 20 and the next Strip 18 that was prepared for the next mining window. The exposed softs highwall (Strip18) is where the manual softs highwall mapping was conducted between July and November 2017 using the total station survey technique.

Figure 4.2.2 Aerial view of study area in January 2018

(Author own photo)

The current resource model was copied to create a working model where newly acquired data was uploaded. The mapping exercise (referred to in section 4.5) formed the basis for this short-term model building process. The different lithological contacts were surveyed as points using the total station thereby obtaining the xyz coordinates.

The short-term modelling process requires the boreholes collar file, survey file (with depth from and to, for the intersections). For this research project, each of the surveyed points became a dummy borehole. The collar coordinates were projected to topographic elevation from the surveyed coordinates (xyz) positions. The process for creating the final file to be uploaded into the short-term model was created as follows:

Each survey point was made to represent a "borehole", hence was named as such. The survey work generated a total of 255 "boreholes". The base horizon of softs (BHSO) survey points all were named with BHSO as part of the name for example BHSO1, BHSO2 and the file is shown in Appendix 10.12. The base horizon of friable weathering (BHFW) which defines the depth at which the pre-strip shovel can free dig to without requiring blasting, had boreholes defining the contact as well. The boreholes were named accordingly, such as BHFW1, BHFW10 and the list is show in Appendix 10.13.

The base horizon of weathering (BHWE) which defines the transition from weathered overburden and fresh rock and the boreholes were named accordingly. The naming was as follows; 7BHWE1, 7BHWE2 and the list is shown in Appendix 10.14. These points were surveyed at the base of the weathered horizon.

Within the weathered horizon, the experience at Isibonelo Colliery is that not all of it is of a free dig nature, there are hard sandstone bands that require drilling and blasting. However, these bands are not modelled in the current resource model. The highwall mapping project had these bands and the boreholes that intersected them were named using codes such as SS and SSFLO for sandstone top contact and sandstone floor contact respectively. In the horizons where there was more siltstone, the boreholes were named using codes such as SSTTOP and SSTFLO for siltstone top contact and floor contact respectively. The borehole list is shown in Appendix 10.15.

The coal contacts were mapped along the highwall following behind the coaling fleet. The boreholes were generated to capture the top contact that was then compared with the resource model contacts. The boreholes were named to include the term HW (highwall) and the list is shown in Appendix 10.16.

a) The mapped lithological contacts including coal were re-named according to the codes used in the modelling software programme (Stratmodel) to ensure proper correlation of the lithology already in the resource model. The borehole collars were projected to the topographical elevation to create a full column and enable calculation of the depth of the respective mapped intersections. The other surfaces, BHSO, BHFW and BHWE were named as such.
   Sandstone and siltstone codes used are SD and SL respectively, and were compared to the nearest borehole, since these lithologies were not modelled in the resource model. The list file is shown in Appendix 10.17.
b) The files were converted to .csv format, which is compatible with Stratmodel, the modelling software package used at Isibonelo Colliery as well as for the rest of the Anglo American Coal South Africa operations.
c) The “boreholes” were then imported into the working short-term model where a new design file termed “short-term” was created and were plotted as points on plan. An example of the plotted points is shown in figure 4.2.3.

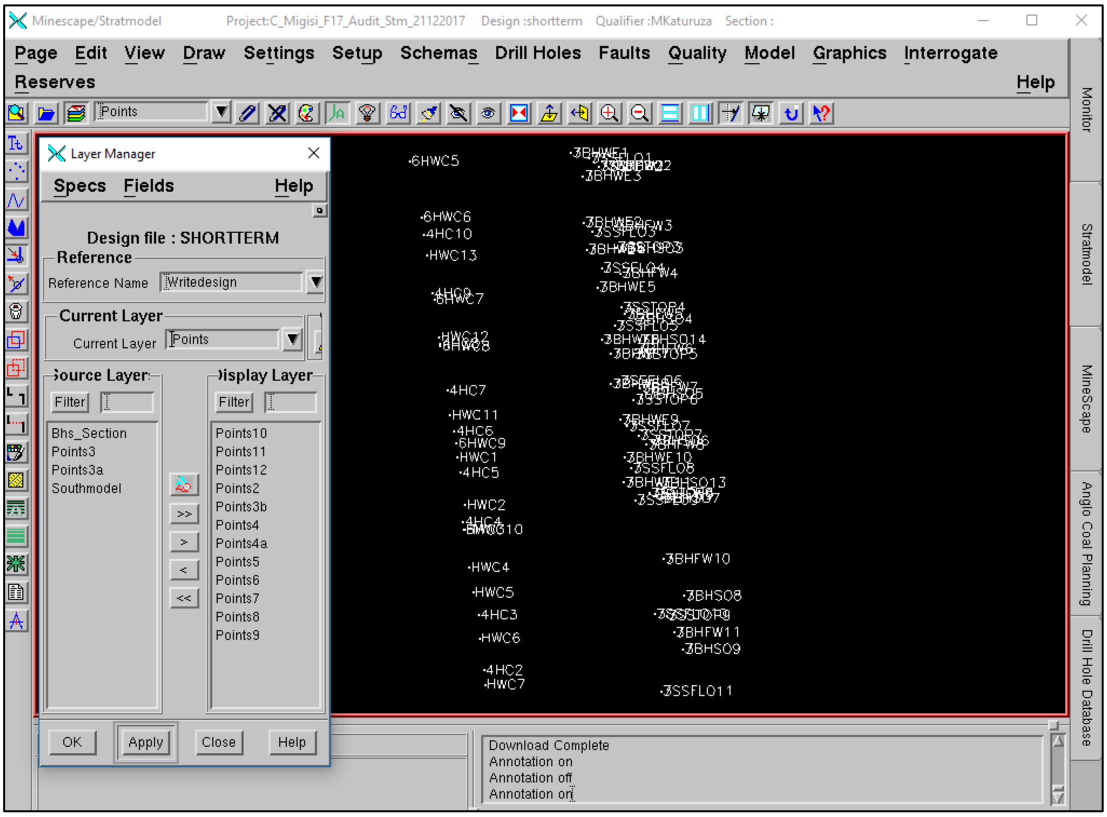


Figure 4.2.3 Imported borehole points

(By author)

d) For each "borehole", predictions were run from Stratmodel to produce a full column borehole indicating the existing modelled surfaces and lithologies in the model such as BHWE, BHFW and S4Z3.The boreholes were then shown with the projected collar elevation (at topographical elevation). The topographical elevation was then used to calculate the depth of the intersections generated from the highwall mapping exercise. The predictions thus are a very important step towards the creation of the survey file (with depth from and to). The borehole predictions files are shown in Appendix 10.5.

e) The survey file was then constructed from the borehole predictions file, the depths of intersection of the lithological contacts and surfaces (mapped) were calculated by subtracting the surveyed elevations of the intersections from the topographical elevation of each "borehole",

   The survey file, created using the predictions data, is shown in Appendix 10.6. The boreholes were projected to a depth of 60m which is the average maximum borehole depths in the Isibonelo model. The collar coordinates were shown at topographical elevation.

f) The lithology file was then created from the same "boreholes" by extrapolating each depth to maximum 60m. The lithology file is shown in Appendix 10.18

g) The two files, survey and lithology were both uploaded into the model through the process explained below.

The Excel file was cleaned up to remove the column titles. The column widths were set up to match the format of the specs file as illustrated in figure 4.2.4. The first column of the data represents the borehole name (borehole ID) and the column width is set at 8 cm, second column is the borehole type set at column width of 2 cm. The next three columns represent the easting, northing and elevation were all set at column widths of 12 cm and the last column set at width of 6 cm is the borehole depth (in this project, all set at 60 metres, the maximum drill depth of boreholes in the Isibonelo mining area. This file was then saved as a formatted text delimited file (. prn) ready to be imported into the design file called Drill Holes, where all the exploration boreholes, building the current resource models, are uploaded.

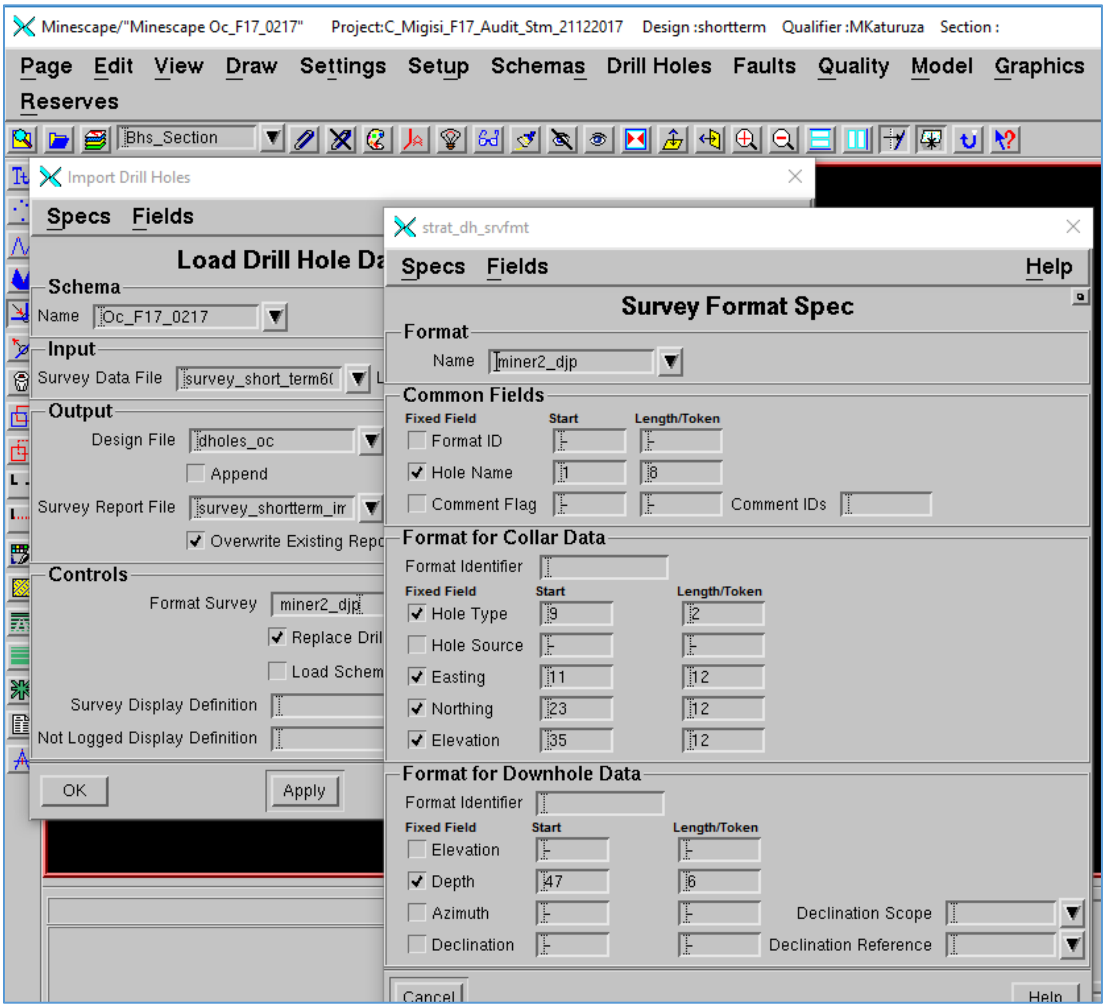


Figure 4.2.4 Survey File format

(By author)

The lithology file format is illustrated in figure 4.2.5. The borehole name in the first column was set at 8 cm, meanwhile the Stratigraphic unit in the second column was set at 4 cm, the third column represents lithology and width was set at 2 cm. The last two columns in the file format represent the top and bottom depths of the intersections and the column widths were set at 13 cm. This file was also saved as a formatted text delimited file (. prn).

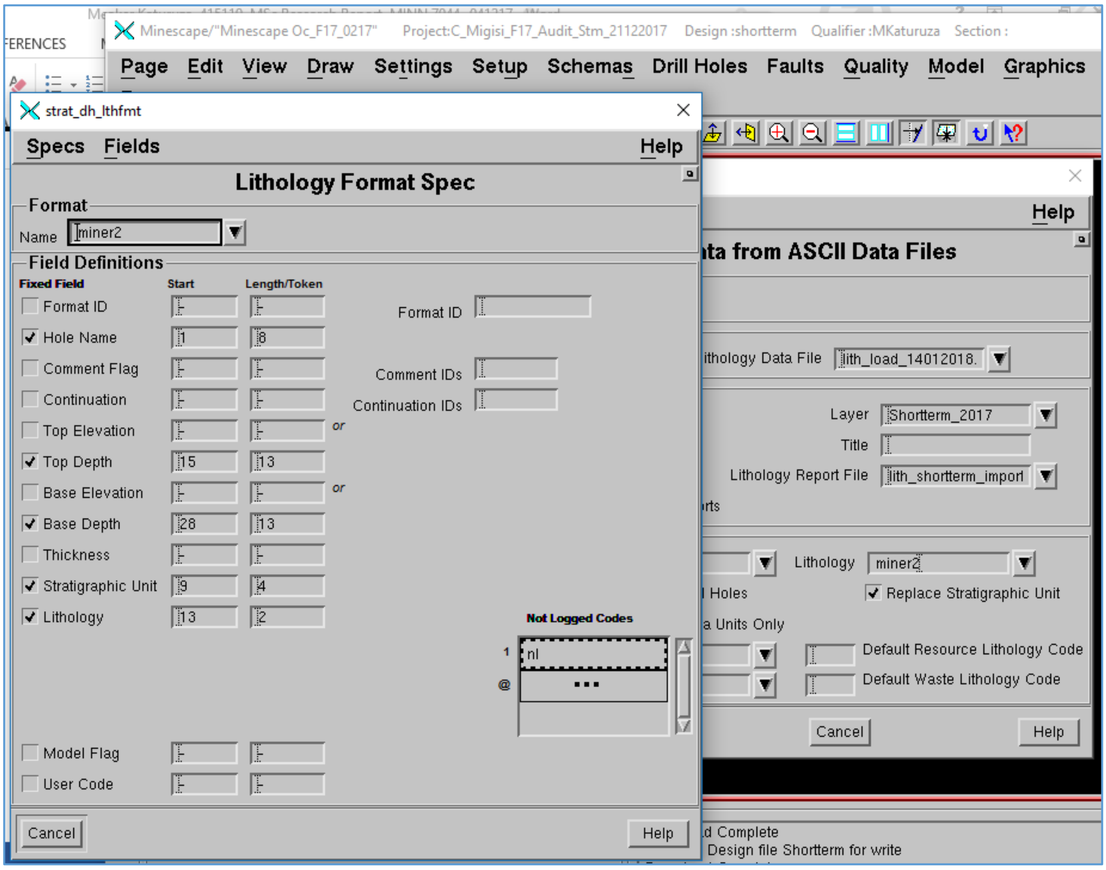


Figure 4.2.5 Lithology File format

(By author)

The boreholes were plotted on plan illustrated in figures 4.2.6 and 4.2.8 for Strip 17 and Strip 19 respectively. Cross sections along the new data points were generated as illustrated in Figures 4.2.7 and 4.2.9.

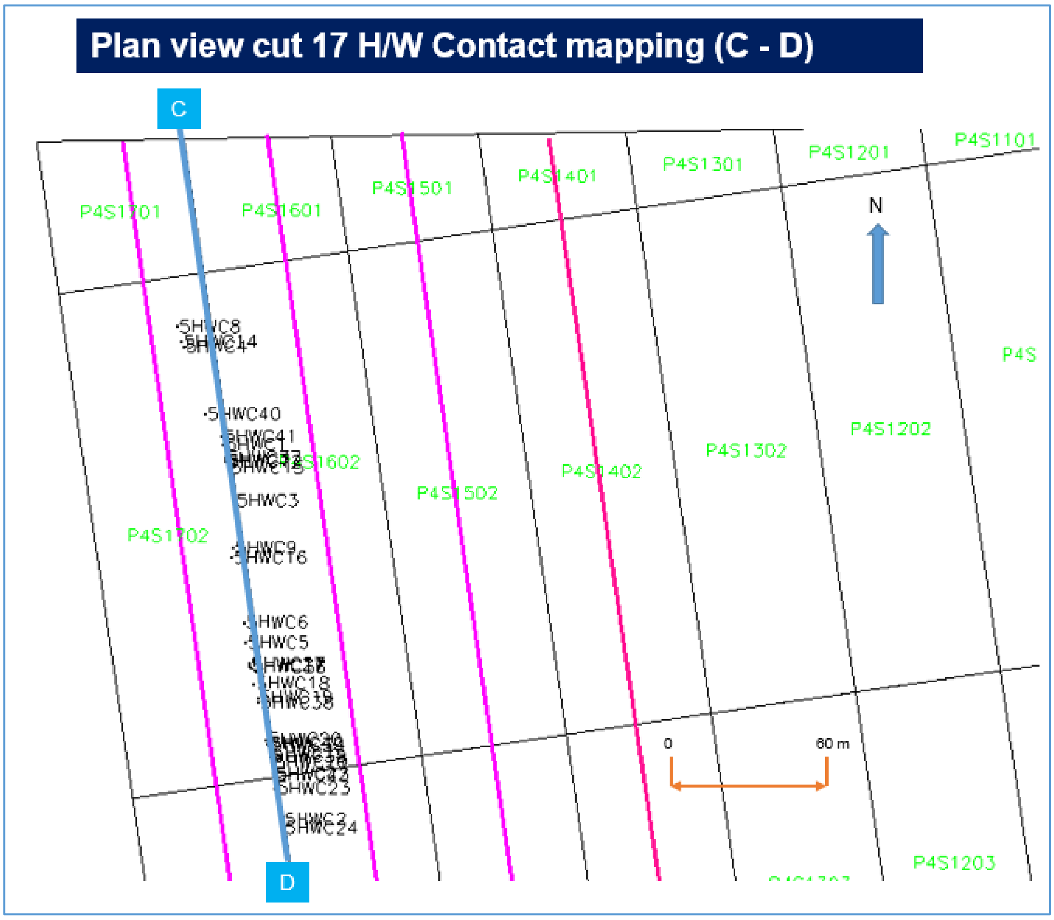


Figure 4.2.6 Strip 17 Coal contacts boreholes

(By author)

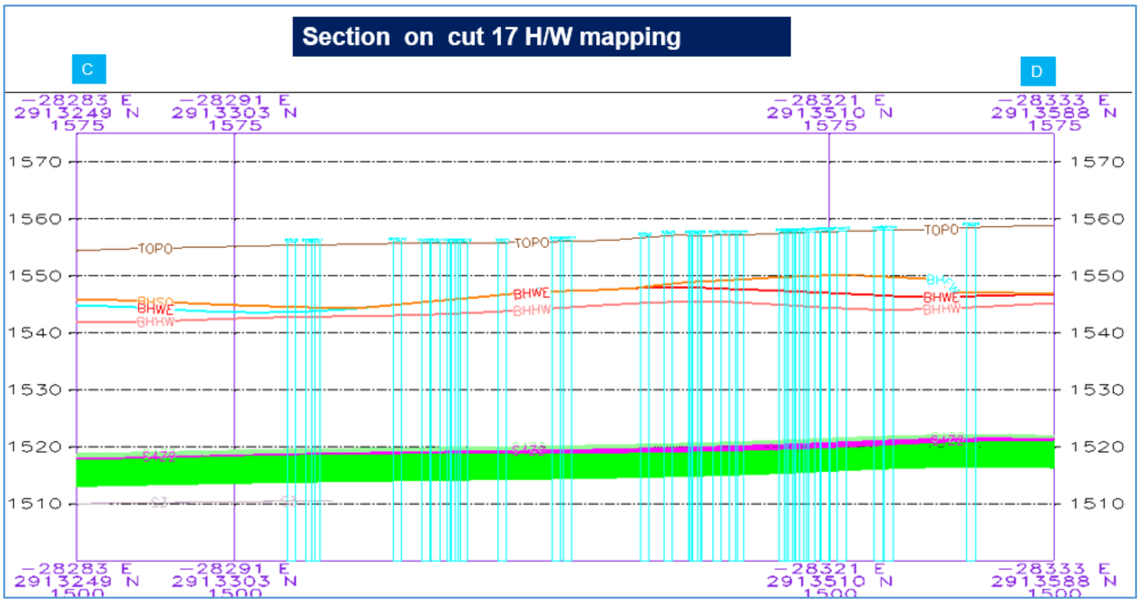


Figure 4.2.7 Cross section Strip 17

(By author)

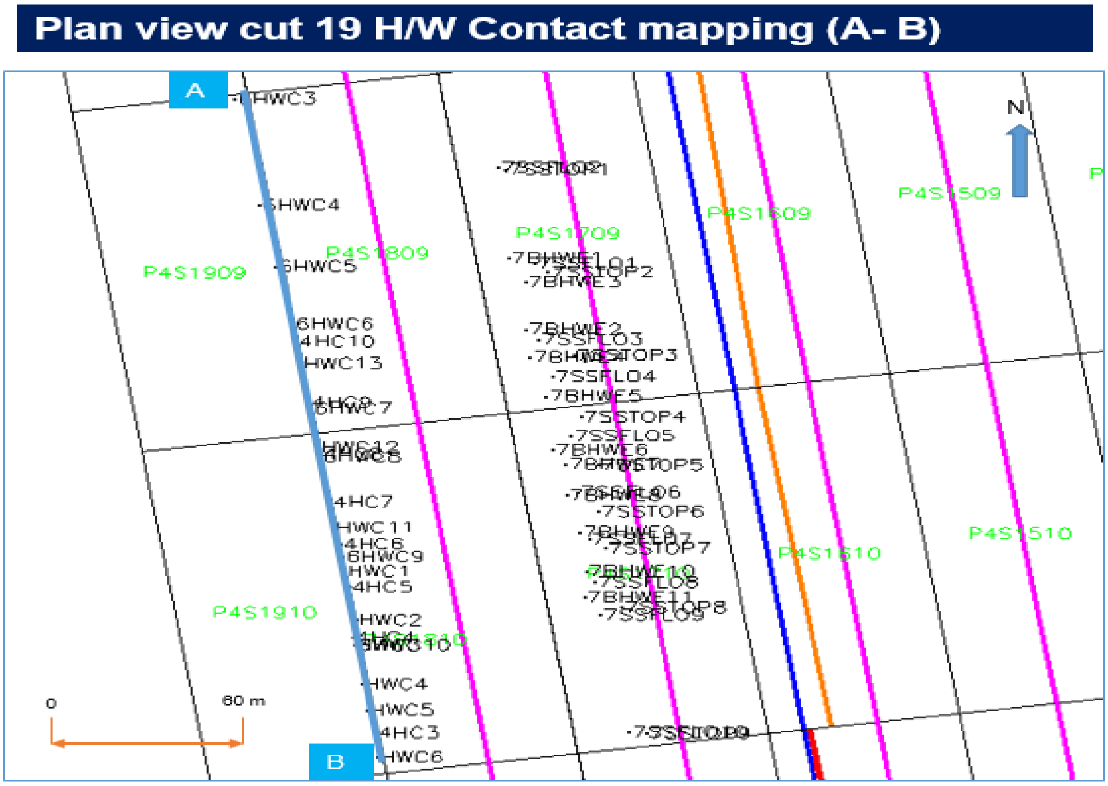


Figure 4.2.8 Plan view of mapping contacts Strip19

(By author)

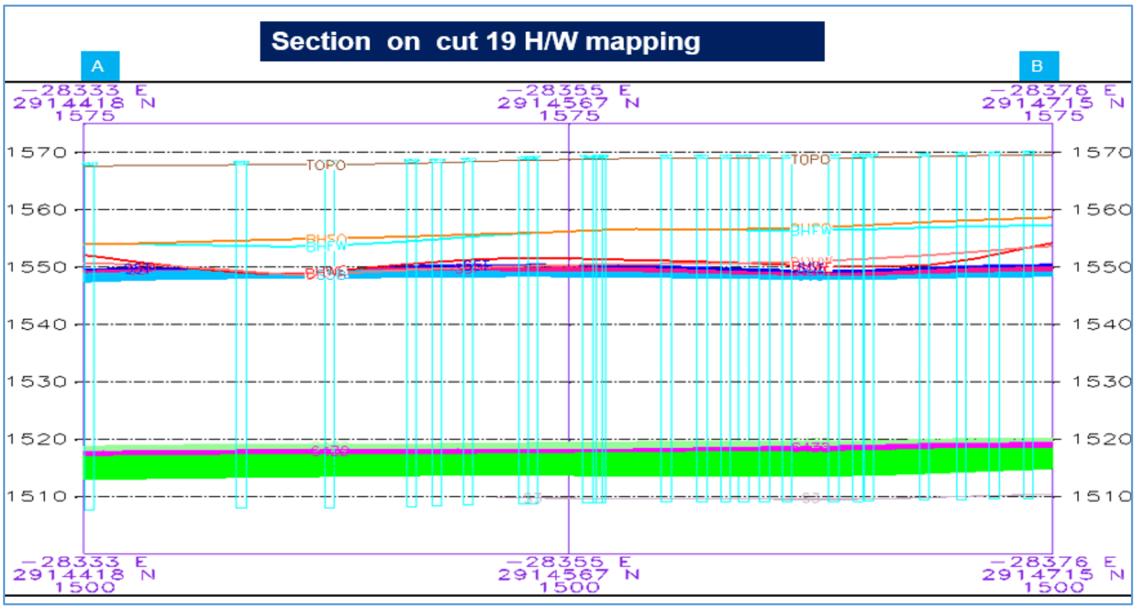


Figure 4.2.9 Cross Section Strip 19

(By author)

4.3 Requirements for geotechnical designs

The Rock Engineering section provided at least two reports the by Strata Control Officer on a weekly basis of the highwall conditions. The author, with the aid of highwall mapping, did produce some plans and sections as part of the short-term geological modelling requirements for geotechnical designs. Some of the work by the author is shown in the sections 4.3.2 to 4.3.4.

4.3.1 Highwall inspection report

The mapping information provided by the Strata Control Officer is in the form of a risk rating report. The focus of these inspections is to identify structures and conditions that have potential to cause slope failure (highwall or low wall side) and an extract of some of the mapping/inspection reports by the Strata Control Officer is illustrated in figure 4.3.1. It is also clear from this report that data for short-term geological modelling is also gathered and shared with the geology department.

ISIBONELO COLLIERY

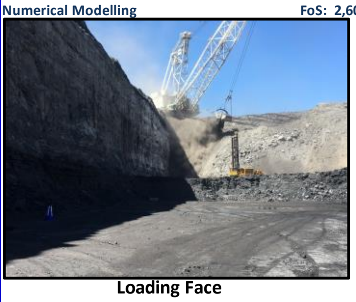
Highwall Inspection

AngloAmerican

Date: 2017/11/01 **Block: PIS1912-PIS1914** **Conditions**

Area: S5-S6 **Report No:** ISI-17-029 **Performance**

Numerical Modelling **FoS: 2,609** **PoF: 0,000%**



Loading Face

Highwall

	Conditions	Rating	Comment
a	Is the highwall weathered?	partial	Weathered zone along of the high wall crest.
b	Are there any cracks on the highwall crest? Perpendicular to cut	no	
c	Are there any cracks on the highwall crest? Parallel to the cut	no	
d	Is the height of the highwall greater than 45m?	partial	loose material on the crest of the highwall resulting in increase in high wall height.
e	Is there water seepage from the highwall?	partial	High wall damp in some areas.
f	Is there any water ponding on the highwall crest?	no	
g	Are geological structures present? (Faults, dykes etc.)	no	
h	Are there any sloping / rolling strata on the HW face?	no	
i	Are there any cracks on the floor?	no	
j	Is there any loose material on the safety berm that has the potential to fall?	partial	Safety berm on the crest of the high wall.
k	Are there any other hazardous conditions on the highwall face?	partial	Frozen portions towards top of coal contact.
l	Are there any exposed underground workings?	no	
m	Is there any spontaneous combustion?	no	
n	Are there any venting bords / cracks on the highwall face?	no	
o	Are there any spoils on the highwall in the direction of mining? (Surcharge loading)	no	
p	Are there any existing failures - circular / wedge / planar / topple [large failures]?	no	
q	Are there any existing failures - Isolated rock fall?	no	
r	Are there any potential failures?	partial	Loose material on the crest of the highwall with the potential for sloughing.
s	Is there any potential for an isolated rockfall?	no	

Figure 4.3.1 Highwall Risk Rating Report at Isibonelo Colliery

(Marolene, 2017)

The Strata Control Officer rate a highwall condition based on the presence of dykes or faults which data is then incorporated into the short-term modelling process as shown in figure 4.3.2.

4.3.2 Mapping dykes in North Pit

One of the process steps in the pit design includes carrying out a strip risk assessment. The Mine Activity Engineer (MAE) requires input from geology and rock engineering while designing for the next pre-strip activity in the next strip to be mined. Through interpolation from previous mined strips the projected positions of the two dykes intersected in the North Pit was produced. The information provided in the short-term model is illustrated in the plan in figure 4.3.2

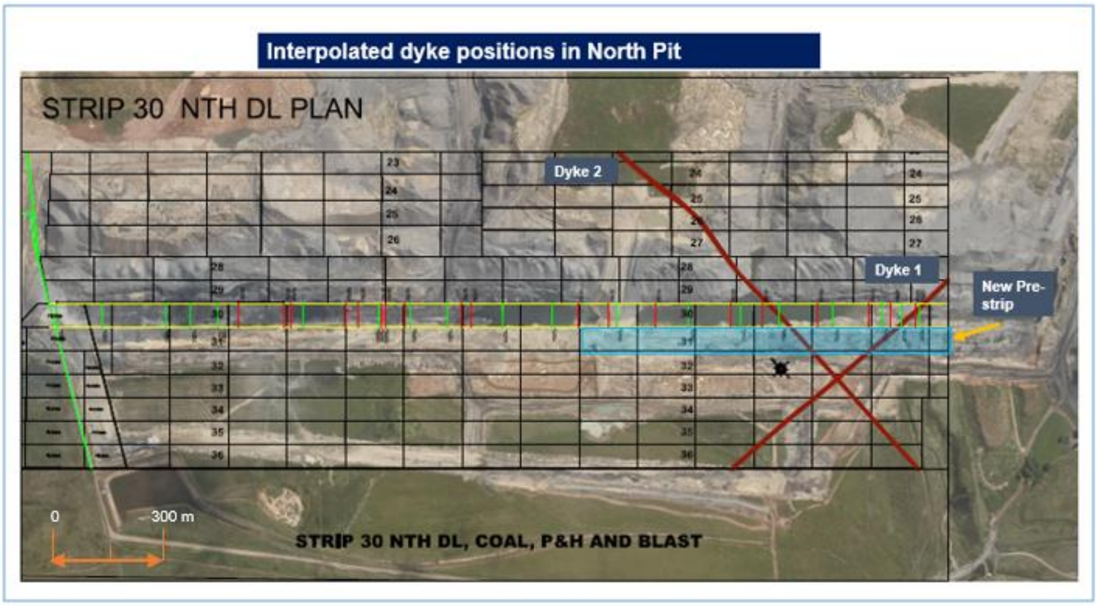


Figure 4.3.2 Dykes in North Pit

(Isibonelo Survey Department)

The dykes 1 and 2 illustrated in figure 4.3.2 were observed in the highwall in strip 30. The intersection points were surveyed with the aid of the mine surveyor and plotted on plan. The data was imported into Stratmodel and the previous projections adjusted with the actuals as per the survey. The information was then supplied to the MAE (Drill and Blast). The Rock Engineer used the same information while doing the slope design analysis for Strip 31 in the area shown in figure 4.3.2. The drill and blast specialist also advised on the type of blasting to be implemented to prevent any back break along the weak zone.

The point of intersection of the two dykes is flagged way ahead in the strip risk assessment, see figure 4.3.3 (with a full copy shown in Appendix 10.7).

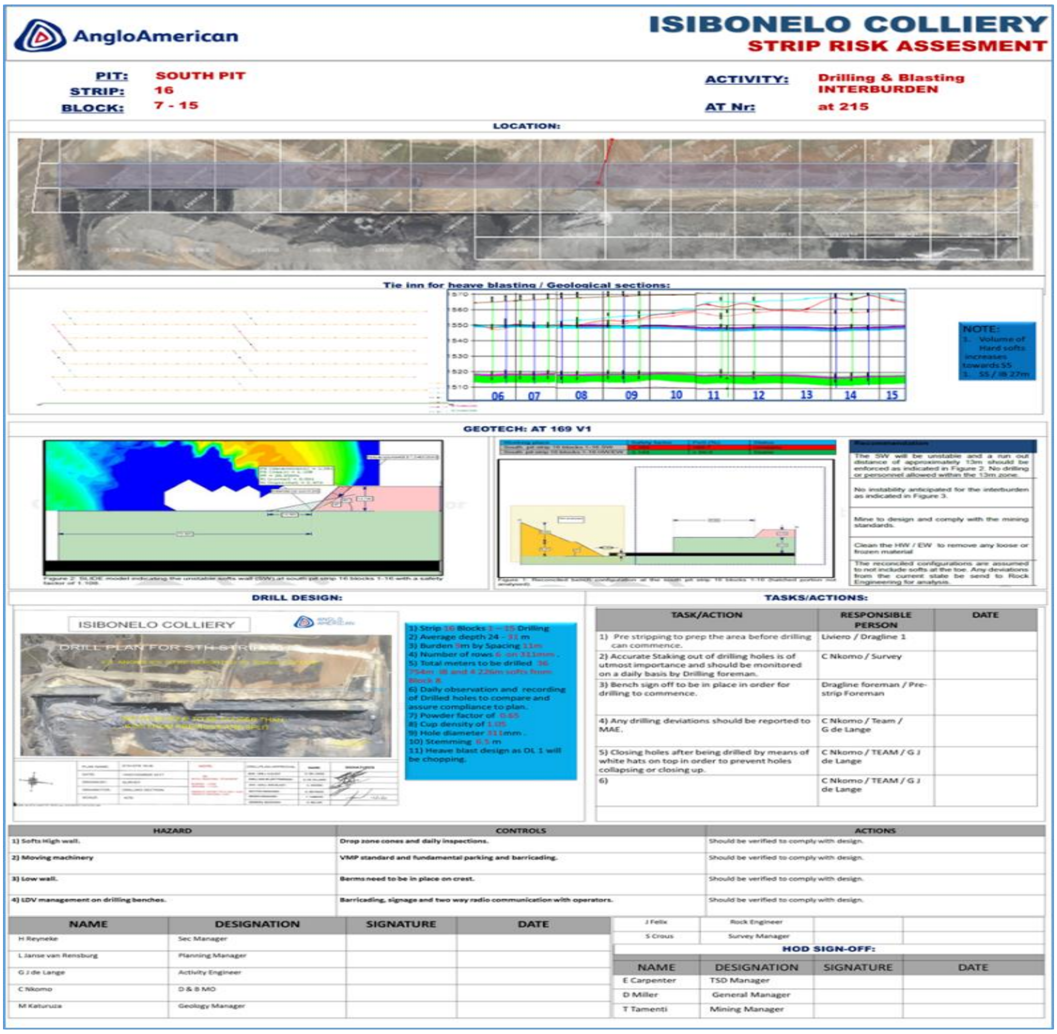


Figure 4.3.3 Strip Risk Assessment example

(De Lange, 2017)

During blasting of the pre-split line in Strip 31, that resulted in the development of cracks sympathetic to the dyke orientation and with potential to go beyond the pre-split holes. The developed cracks are shown in figure 4.3.4.

Figure 4.3.4 Blast induced cracks sympathetic to dyke 1 in Strip 31 North Pit

(Photo by Author, 2018)

Planning of the next overburden drill plan in Strip 32 would require the use of the latest information regarding observed and mapped pit conditions to be incorporated in the plan. From the short-term modelling information, a cross-section of Strip 32 indicating mapped areas of concern especially low-lying zones with potential for in-pit water accumulations and projected positions of the two dykes with a blasting challenge. The cross sections are illustrated in figures 4.3.5 to 4.3.6.

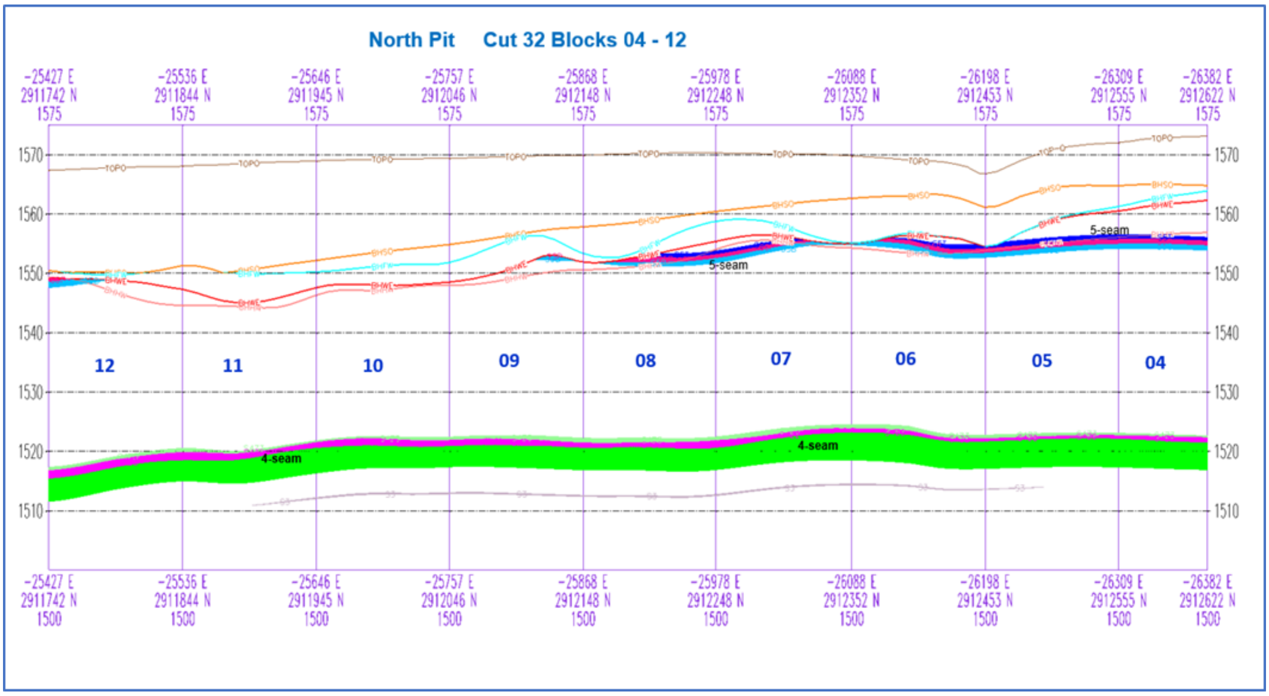


Figure 4.3.5 Strip 32 Cross Section Blocks 4 to 12

(By author)

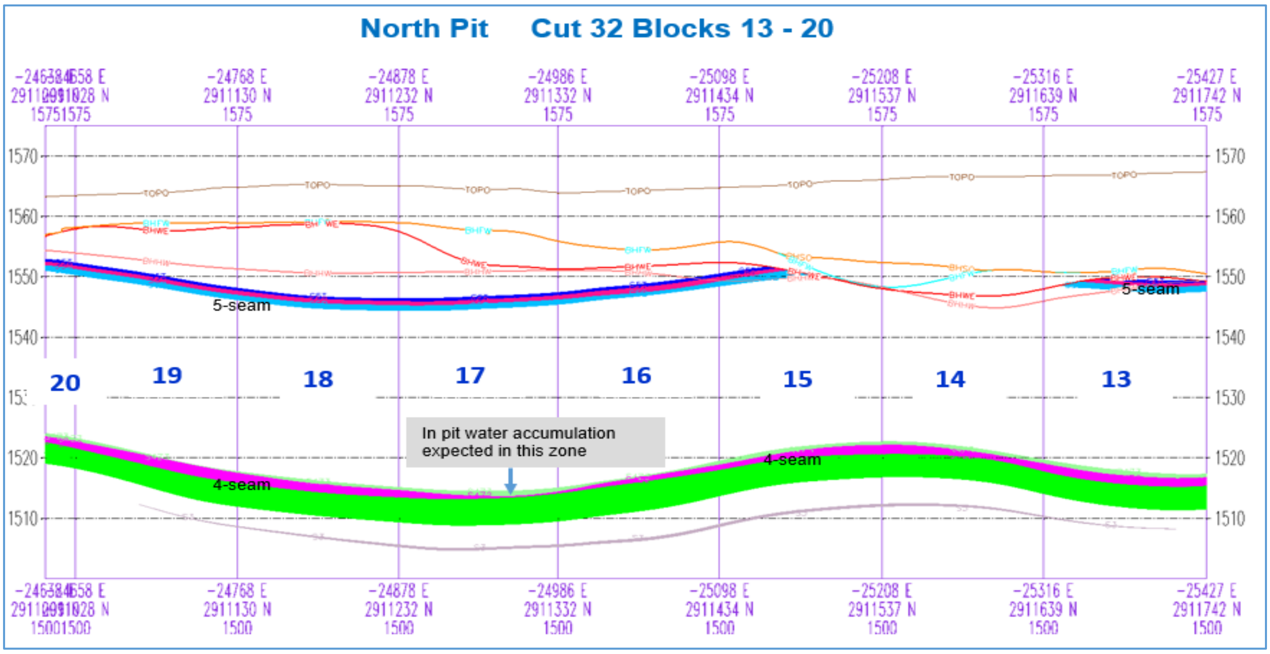


Figure 4.3.6 Strip 32 Cross Section Blocks 13 to 20

(By author)

The projected position of the two dykes in Strip 32 (from the mapped positions in previous Strip 31) and their potential effect to blasting is highlighted in figure 4.3.7. The drill and blast MAE would then have to design the blast in such a way that there are no back-breaks with the intersection of two dykes that could result in a damaged highwall with overhangs and wedges.

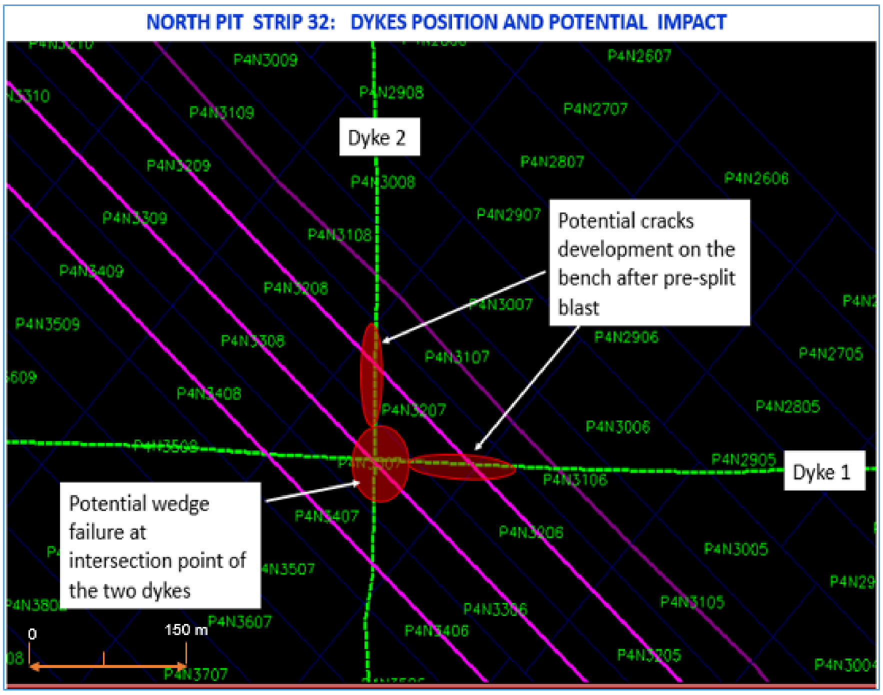


Figure 4.3.7 North Pit the two dykes

(By author)

4.3.3 Geo hazard plans North and South Pit

As part of short-term geological modelling, some geo hazard plans were produced based on the cut off depth of +/- 16 metres which is generally the capability of the biggest pre-strip shovel on the mine. The machine is in danger of being engulfed by softs material if the digging face exceeds 16 metres, sloughing will occur, hence all areas with softs of such depth are colour coded red. The range between 12 and 16metres is deemed safe but operations must be cautious that there is a potential for sloughing and is colour coded orange. The areas where softs are less than 12metres are deemed safe to mine and hence are colour coded green. The information generated from short-term geological model informs the various depths used in creating the hazard plan. The hazard plan is illustrated in figure 4.3.8.

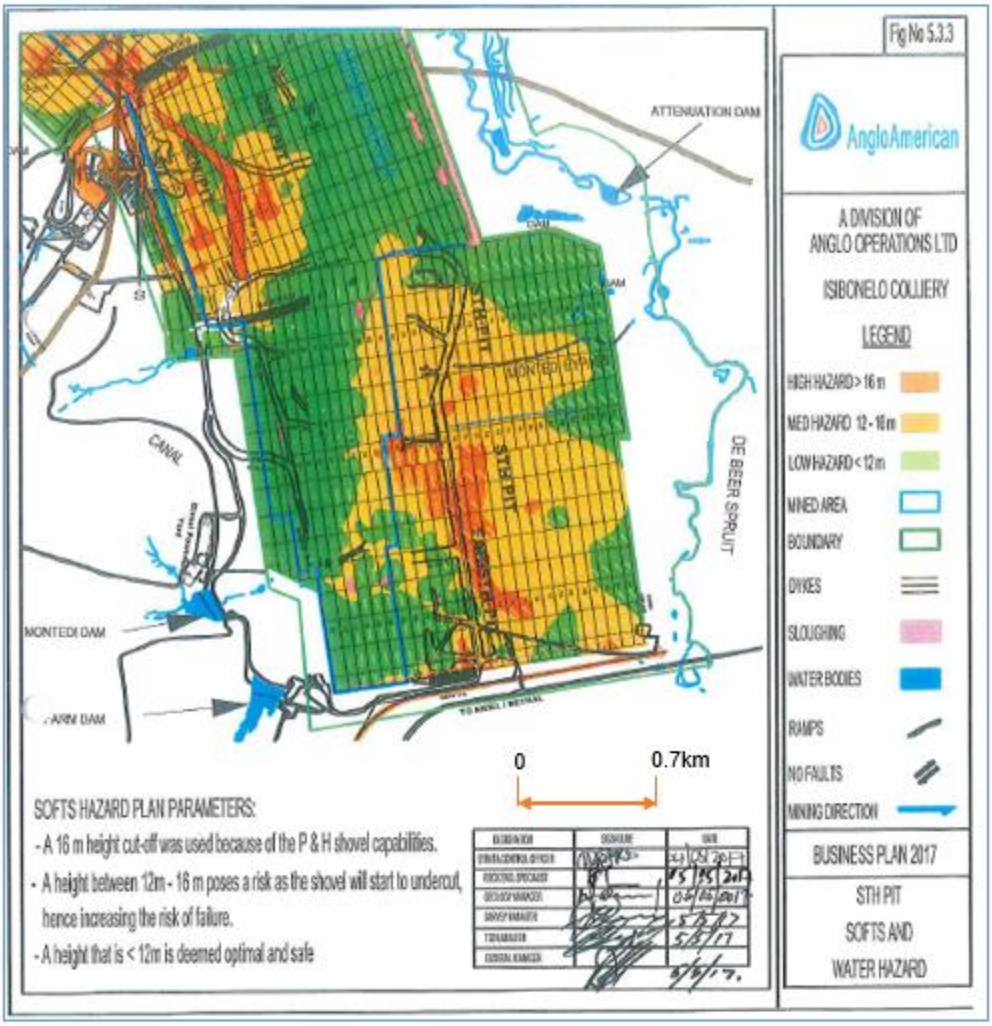


Figure 4.3.8 Isibonelo Colliery GeoHazard plan

(Rock Engineering Dept., Isibonelo Colliery)

4.3.4 Projected Sandstone and softs thickness on sections

The Rock Engineer for Isibonelo Colliery, had over the last few years, been asking from geology if they can produce cross sections from highwall mapping and geological model interpretation. This research project produced such sections as shown in figure 4.3.9. The sandstone mapped from the softs highwall would be plotted on the sections to indicate areas of competent material that assisted the Rock Engineer to correctly use in the process of slope design analysis. The mapped data would be projected into the next strip and used in the design. In the South Pit the, Strip 18 highwall mapping information was made use of in the design of Strip17. The competent and partially weathered sandstone would usually mislead the designs (previously all considered weathered enough to be chopped by the dragline). The short-term geological modelling came in handy by determining the elevation of the sandstone see figure 4.3.9 and its thickness which would allow proper design for its drilling and blasting.

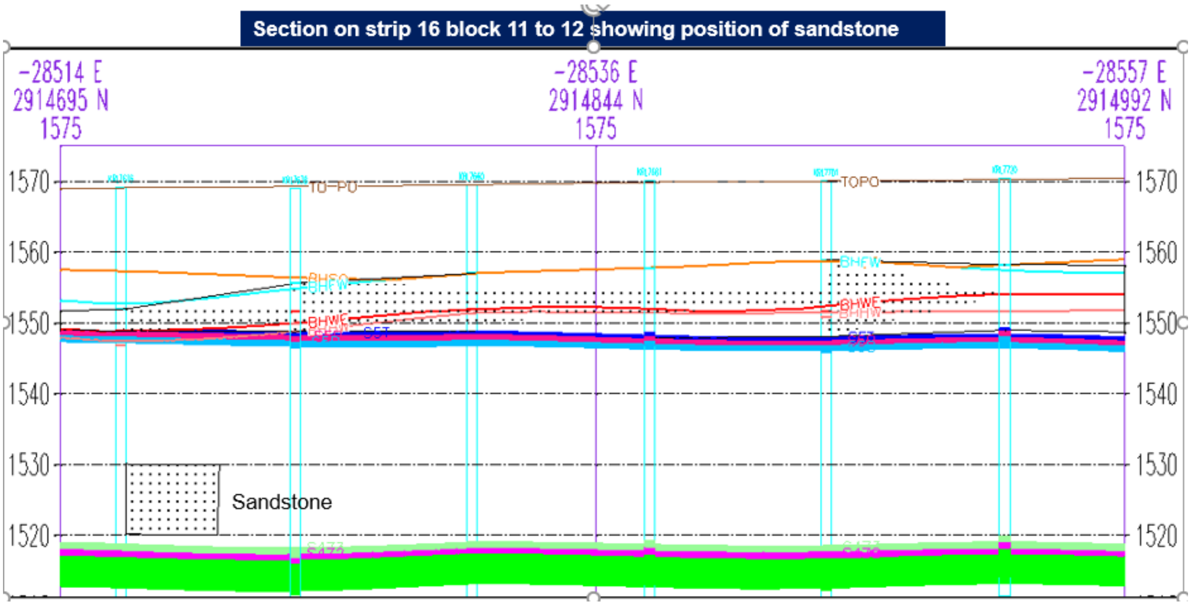


Figure 4.3.9 Strip 16 showing Sandstone position in softs

(By author)

4.4 Overburden drills hole depths or wireline logging

The Rock Engineer responsible for Isibonelo Colliery during his routine bi-weekly inspections made some recommendations regarding use of the short-term geological model in mine designs, figure 4.4.1 is an extract of part of the report. The emphasis was to ensure that any new drill bench designs take into account of the current highwall profile.

Status	Way forward	Responsibility
Short term geological model	• Enforce use of the short term geological model to influence the slope design change based on actual field data.	M Katuruza

Figure 4.4.1 Rock Engineer Recommendation

Extract from (Joel, 2017)

The need for a short-term geological model to enhance mine designs has been emphasised at every annual OMS audit. The drill and blasting section under the auspices of the drill and blast specialist, came in to support the initiatives of this research project. The current geological cross sections from the resource model do not show the different lithologies, save for coal only. The drill and blast design requires the type of rock to be blasted to assign the correct powder factor and to have effective blast. The mine has, in the recent times, experienced poor highwalls in some sections of the pit due to poor blasts as in some cases would be overcharging or undercharging. The assumption on blast design is that the interburden is all sandstone, meanwhile in some areas there are bands of shale and siltstone or even mudstone intercalations. The short-term geological modelling initiative has prompted the Resource Geology Specialists to start investigating a way to model lithologies. The illustration in figure 4.3.5 shows no lithologies between 5-seam and 4-seam (the interburden) and this is where blast design would assume that the rock type is all sandstone and shale. The following is an extract of communication from the Geology Specialist to the author and the Drill and Blast Specialist regarding initiatives from the Resource Evaluation Department to facilitate the short-term geological modelling.

> "Good day Frikkie and Meaker,
> Frikkie for your info I am the Resource Geology Specialist for Isibonelo Colliery. Currently we have found a method to import borehole lithologies into the geological model but cannot model the lithologies due to the inconsistent logging over decades as well as changing in geological environment, hence not all the strata will have the same sequence of occurrence.
>
> I have attached an example of the cut where the dragline was operation at the fly rock incident (this method of importing the lithology was developed after the hand drawn cross sections you have seen going around). If you zoom in you can see the lithology abbreviations next to the boreholes (the text can be enlarged in the software). The colours of the lithologies were standardized this week within our departments.
>
> The question is: Can this lithology information assist with blasting techniques and planning? Kind Regards" (Pretorius , 2018).

The original plan to carry out downhole wireline logging of the production holes did not happen within the time frame to submit this research report. However, the process is one of the recommendations of this report.

4.4.1 Pre-split holes checks

The drone flyover demonstration picked the drilled pre-split holes in Strip 17 between Ramp S4 and S5 such that the hole depths would be checked against model prediction as part of the short-term geological modelling processes. Due to the lack of wireline logging data, the drill and blast mine overseer's measurements were used to reconcile with the model. The predicted depths of coal contacts in Strip 17 were compared to the contacts from the drone flyover highwall face mapping (in Strip 18).

The position of the pre-split holes in Strip 17 is illustrated in figure 4.4.2.

Figure 4.4.2 Pre-split holes in Strip17

(De Bruyn, 2018)

The hole positions comparing planned versus actual drilled showed very negligible offsets. The short-term geological modelling exercise brought about better scrutiny of the drill and blast practice at Isibonelo. The current practice has been that holes are marked by survey at certain intervals, then the drill and blasting miner, using a tape measure, follows the drill plan and stakes out the missing holes in between. With the use of drone data, it has become easier to reconcile planned drill hole positions and actual ones hence a better blast reconciliation once fully implemented.

4.5 Highwall mapping with a survey total station

The dragline, in the process of exposing coal in Strip 19 in the South Pit, would extend and dig the softs highwall thus fully exposing the different weathering horizons. The exposed softs highwall would be visited by the author to carry out reconnaissance work in preparation for actual mapping with the assistance of a mine surveyor. The work involved field surveying of the different lithological and surfaces contacts along the softs highwall as well as the coal contacts inside the pit along the highwall.

The author first indicated to the surveyor on the required data to be surveyed, using the total station. The mine surveyor would set up the total station at different positions at a distance away from the highwall. The author would then point to the surveyor the contact where to survey. Figure 4.5.1 shows the team mapping the highwall contacts using a total station.

Figure 4.5.1 Mapping the highwall contacts

(Photo by author, November 2017)

The data generated from the fieldwork was imported into a copy of the current resource model in the correct format (.csv) to start the short term geological modelling process. The team would walk along the highwall surveying the contacts of the horizons. The existing resource model has the following modelled surfaces in the softs horizon from the surface to the bottom as derived from the borehole log sheets: TOPO - BHSO - BHFW - BHWE – BHHW. (Full description in Table 4.1.2. in section 4.1 of this report).

The field work information captured is as shown in the image in figure 4.5.2.

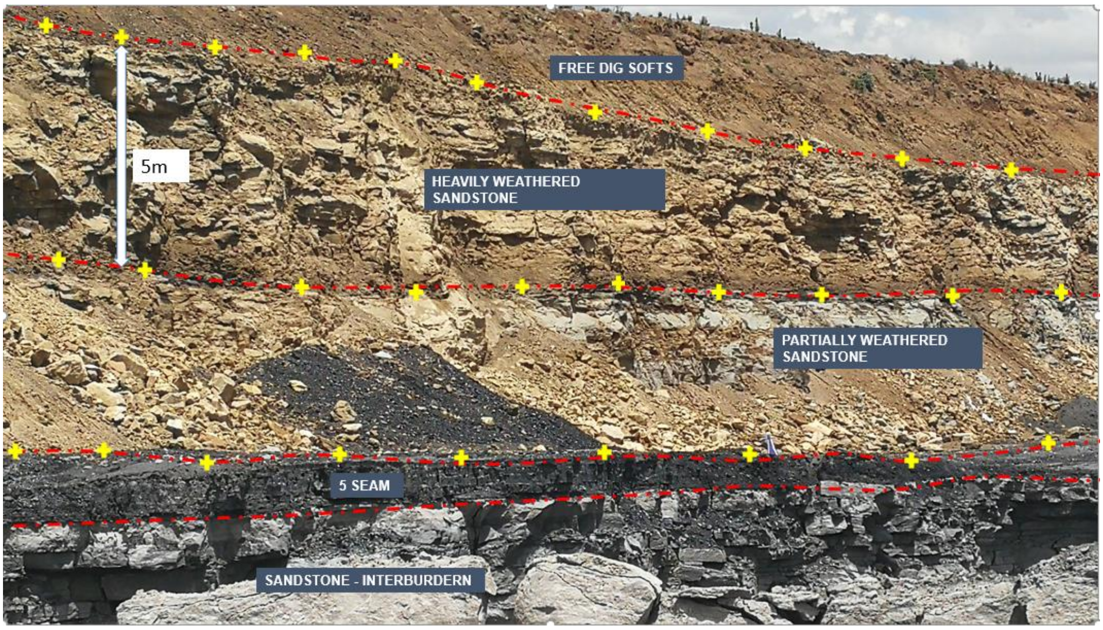


Figure 4.5.2 Highwall Mapping points

(Photo by author, November 2017)

The respective contact points on each section have xyz coordinates and the mapped area is illustrated in figure 4.5.3.

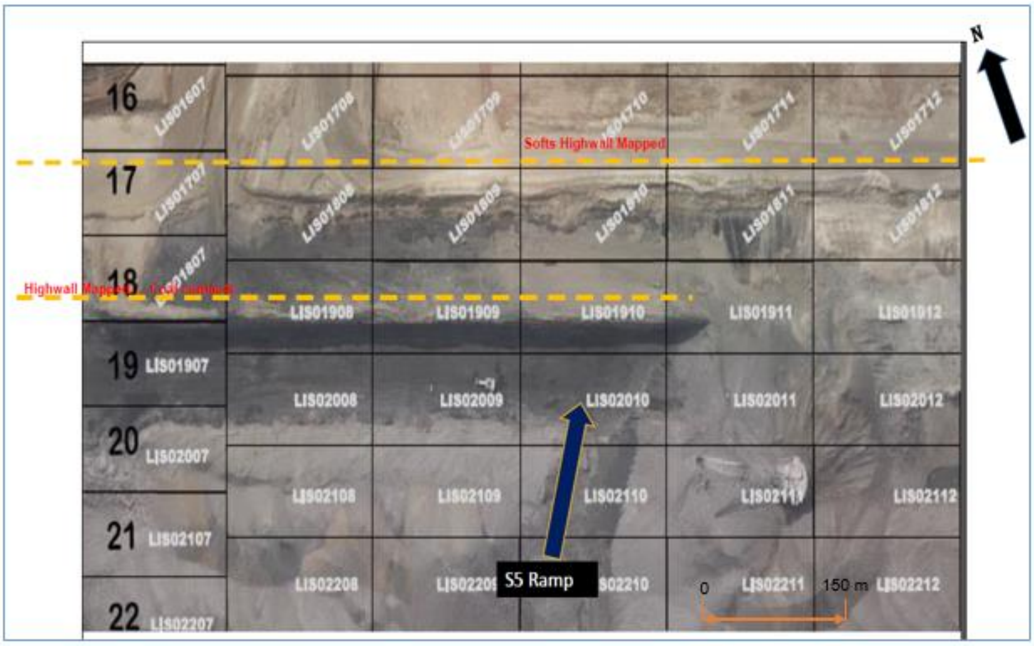


Figure 4.5.3 Mapping Area (Ramp S4_S5)

(Survey Department, Isibonelo Colliery)

4.6 Drone highwall face mapping technology

4.6.1 Drone flying process

During the project research period, a further development prompted the approval by mine management for a demonstration by Vidblast to fly their drone to conduct highwall face mapping.

The demonstration was planned to cover both North and South pits of selected areas only. The South Pit covered the same study area shown in figure 4.2.1 between S5 and S6 ramps and through to end of cut, meanwhile for North pit was between N1 and N2 ramps (Strip 31 and 32). The figures 4.6.1 and 4.6.2 illustrates the drone flyover focus area respectively as planned in the survey office.

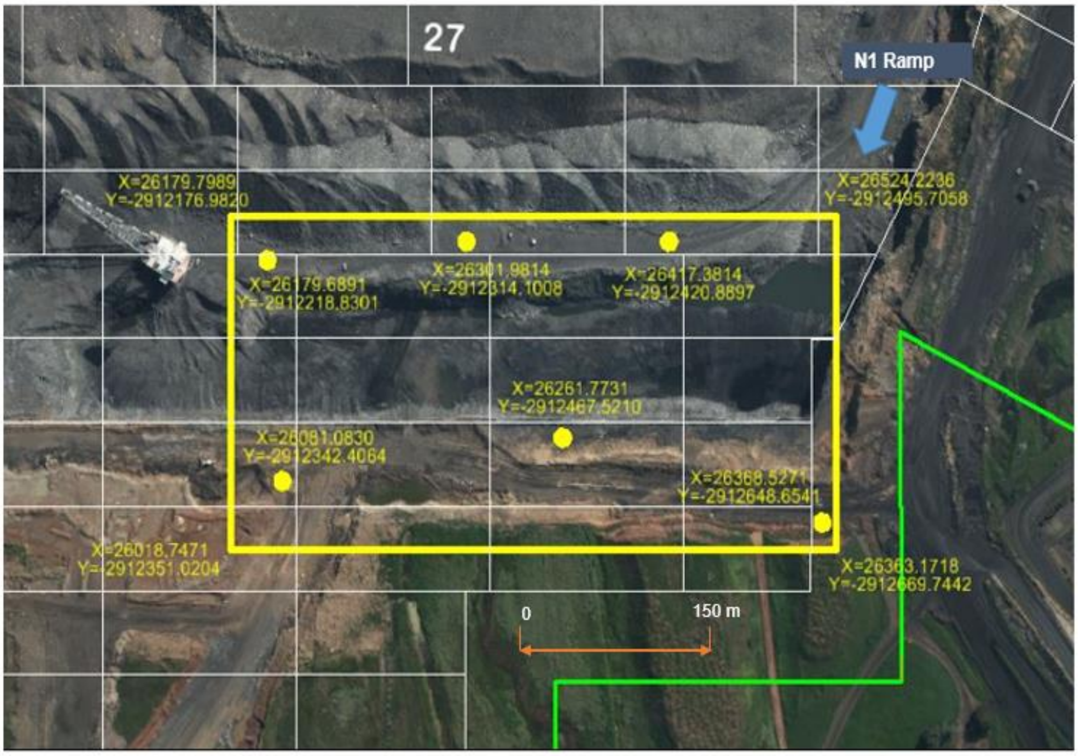


Figure 4.6.1 Drone flyover North Pit

(Survey Department, Isibonelo Colliery)

The drone demo flight was planned for both pits on the same day. The area delineated in yellow in both figures 4.6.1 and 4.6.2 is defined by control points pegged on the ground by the mine surveyor prior to the actual flight. The coordinates were sent to Vidblast (the drone service provider) so they could download and plan the flight paths.

The process required a mine surveyor on site on the day of the flight since this was a maiden flight, hence the support required for any additional control points after assessing the area was required. Additional control points were eventually pegged on the day of the flight to ensure data extrapolation was suitably geo referenced.

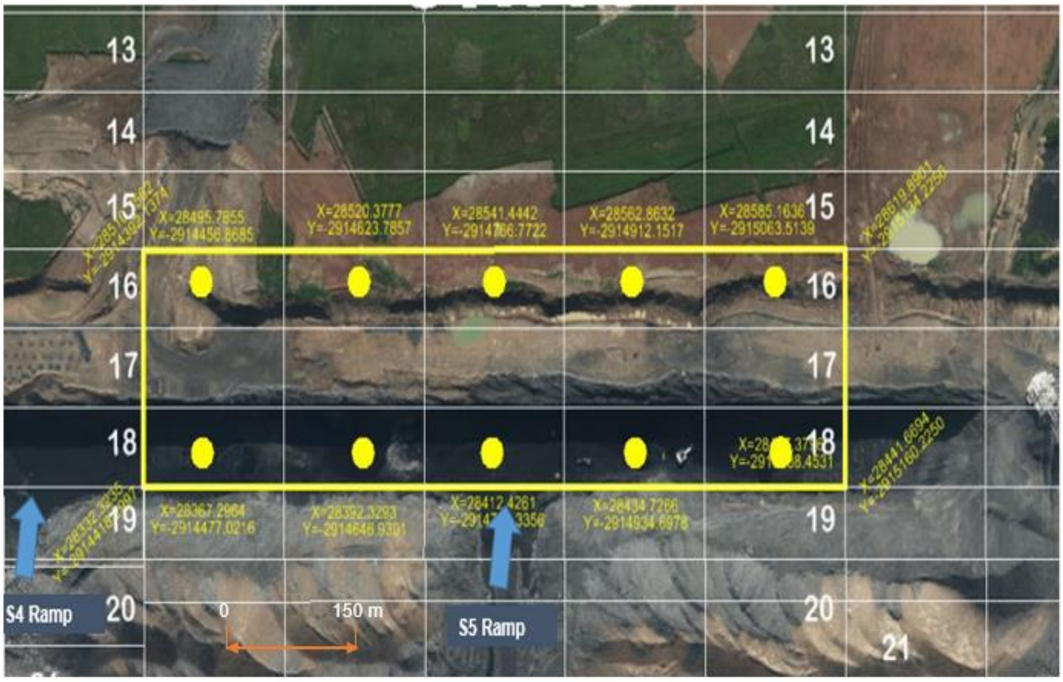


Figure 4.6.2 Drone Flyover South Pit

(Survey Department, Isibonelo Colliery)

The demo was conducted using a Phantom 4 drone with the licenced pilot and the geology resource specialist as the only team (crew) with their iPad and laptop to download data after every flight. The following figures 4.6.3 to 4.6.5 shows the demo in progress at N1 in the North pit. The drone was flown from a mini pad at the back of the utility vehicle.

Figure 4.6.3 Drone flight demo team

(Photo by author, 2018)

Figure 4.6.4 Phantom 4 Drone at N1, North Pit

(Photo by author,2018)

Figure 4.6.5 Pilot setting off the drone at N1, North Pit

(Photo by author ,2018)

The following figure 4.6.6 illustrates the drone flying over the pit at N1 on the way to start mapping the softs highwall face as well as the interburden and the coal contacts. The drone flies at an altitude of 50 metres above the pit during highwall mapping.

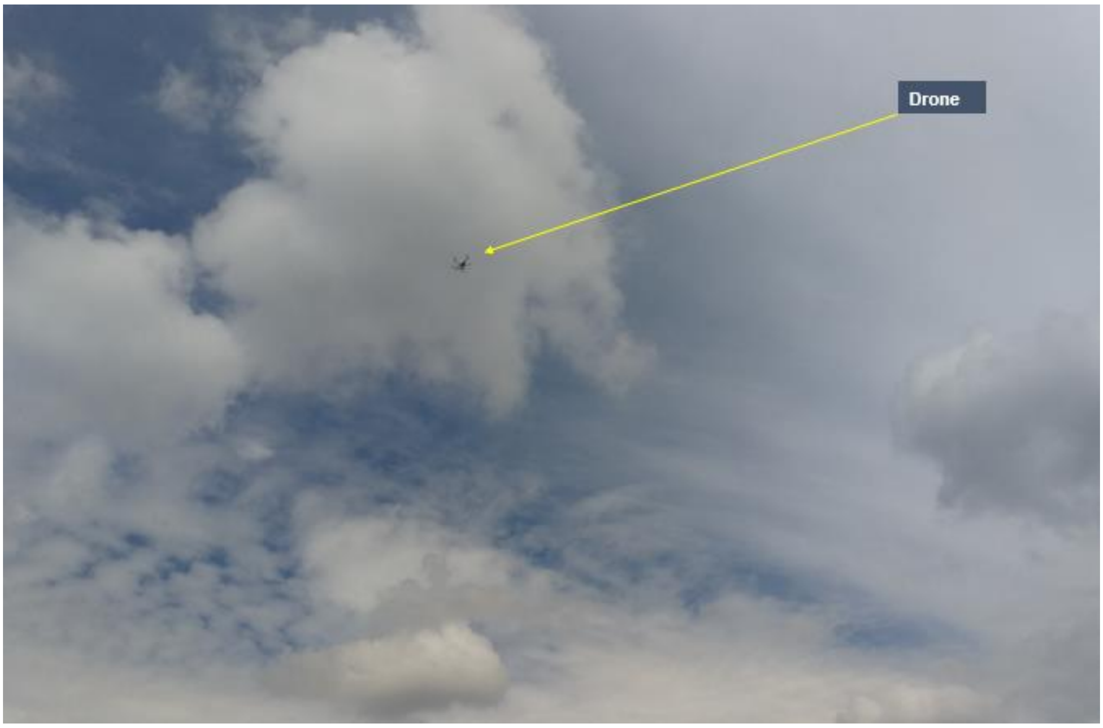


Figure 4.6.6 Drone mapping highwall faces at N1

(Photo by author,2018)

4.6.2 Drone data processing

The data captured during the highwall mapping was points each with xyz coordinates. Thus, millions of data points are captured as well as digital photographs with a 60% overlap. In the demonstration at South Pit, a total of 11 million data points was recorded.

The data was processed with software called Agisoft thereby building a 3-D model of the flown area through triangulation of the data points. The data points were cleaned out to remove any anomalies especially the mining machinery that was working in the pit during the flyover. The survey control points assisted in the correct geo referencing of the data points and that the model was located in the right place. The control points pegged on the ground are visible in the model (figure 4.6.7), meanwhile the software also processed the digital photos forming a 3-D (photogrammetry) surface image that was draped over the 3-D model.

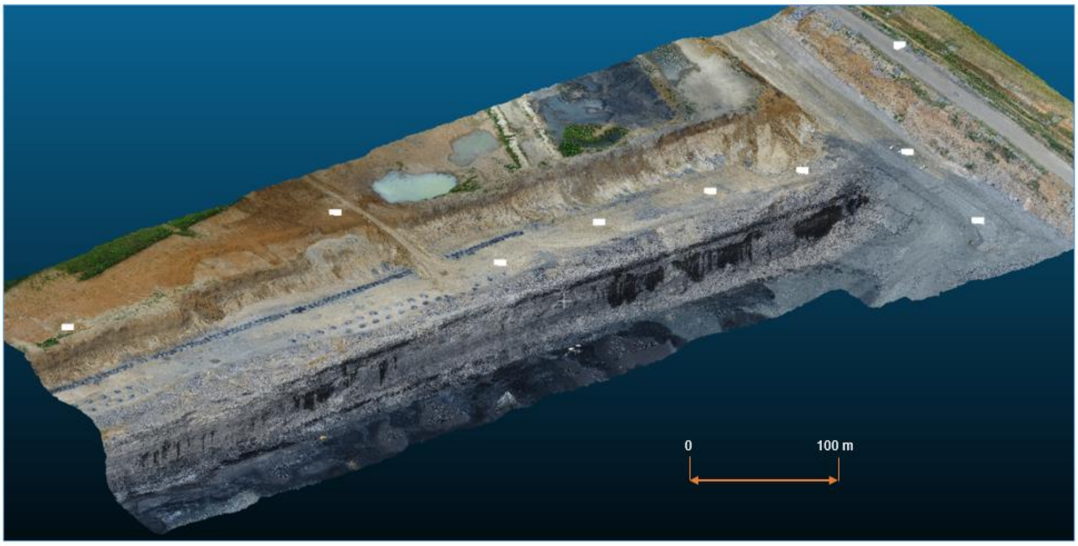


Figure 4.6.7 Far South Pit, Drone 3-D model

(De Bruyn, 2018)

CloudCompare, a free software, was used to extract valuable data by the Resource Geology Specialist and, to run some checks against the existing resource model. The drone model was further validated by getting a mine surveyor and geologist to map the 4-seam and 5-seam top and floor contacts in selected places using the total station. The points of observation are illustrated in the image in figure 4.6.8.

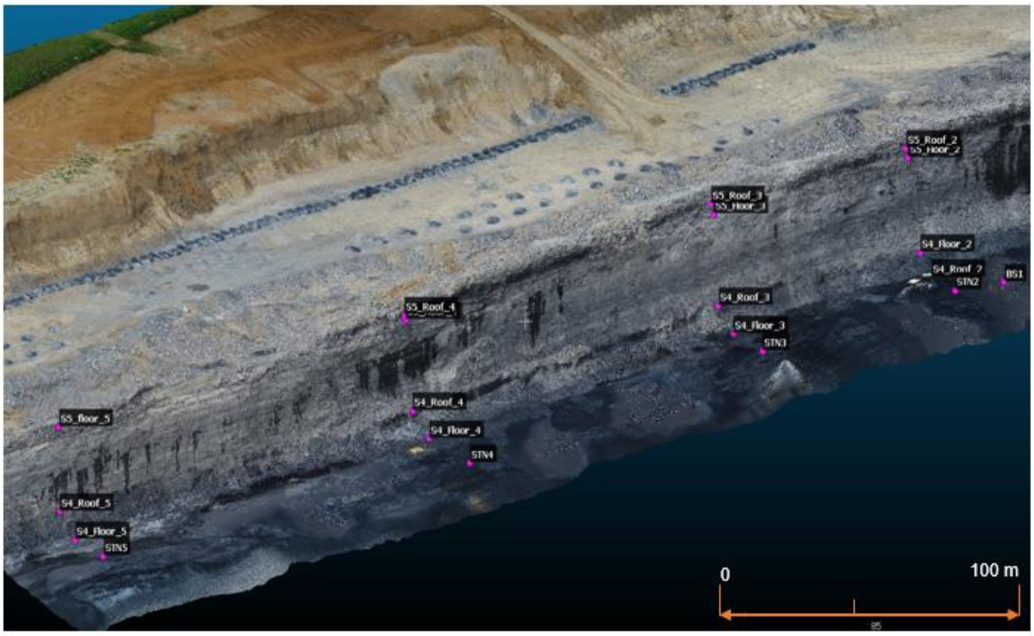


Figure 4.6.8 Mapping 4 and 5- Seam contacts

(Katuruza & Pretorius, 2018)

4.7 Building of the Short-term XPAC model

According to Treadwell (Principal Mine Planning Engineer), the XPAC short-term model is readily available once geology supplies the short-term information. The XPAC annual model is built from the information supplied by geology from the annually updated resource model. The XPAC model is split into two, the Resource and Reserve model and XPAC Schedule model. The short-term XPAC model is simply an update of the resource and reserve model with the new data generated from geological short-term modelling.

One of the key requirements is that for any short-term mapping to take place, the mining activity should be signed off by all stake holders as being complete first before proceeding with the mapping. The flyover data, especially the DTMs for topographical surface is signed off by the mine survey department, validated and conformed as fit for purpose to use, only then can it be imported. The topography is very critical for calculation of volumes or for any modelling package because it is the starting point of reference. Borehole collars must be at the correct elevation or else the coal seam plots at wrong elevation and the mine design will not be representative of the true position.

XPAC short-term modelling follows strict reconciliation process, hence there must be a big variance that triggers an update of the model with new information. Isibonelo has in some sections of the pit where the softs volumes would not reconcile to the model hence one of the triggers of this research project is to investigate and develop a process for short-term geological modelling.

The following figure 4.7.1 illustrates a section of the South Pit where the BHWE was mapped using the total station and the information generated was used to update the XPAC model in that specific area (Strip17 blocks 9 and 10, a three hundred metre linear distance), meanwhile figure 4.7.2 shows the plotted point of observations (termed the ‘’boreholes”).

The new top and floor elevations from the mapping of the BHWE horizon is the critical data required for the short-term XPAC model.

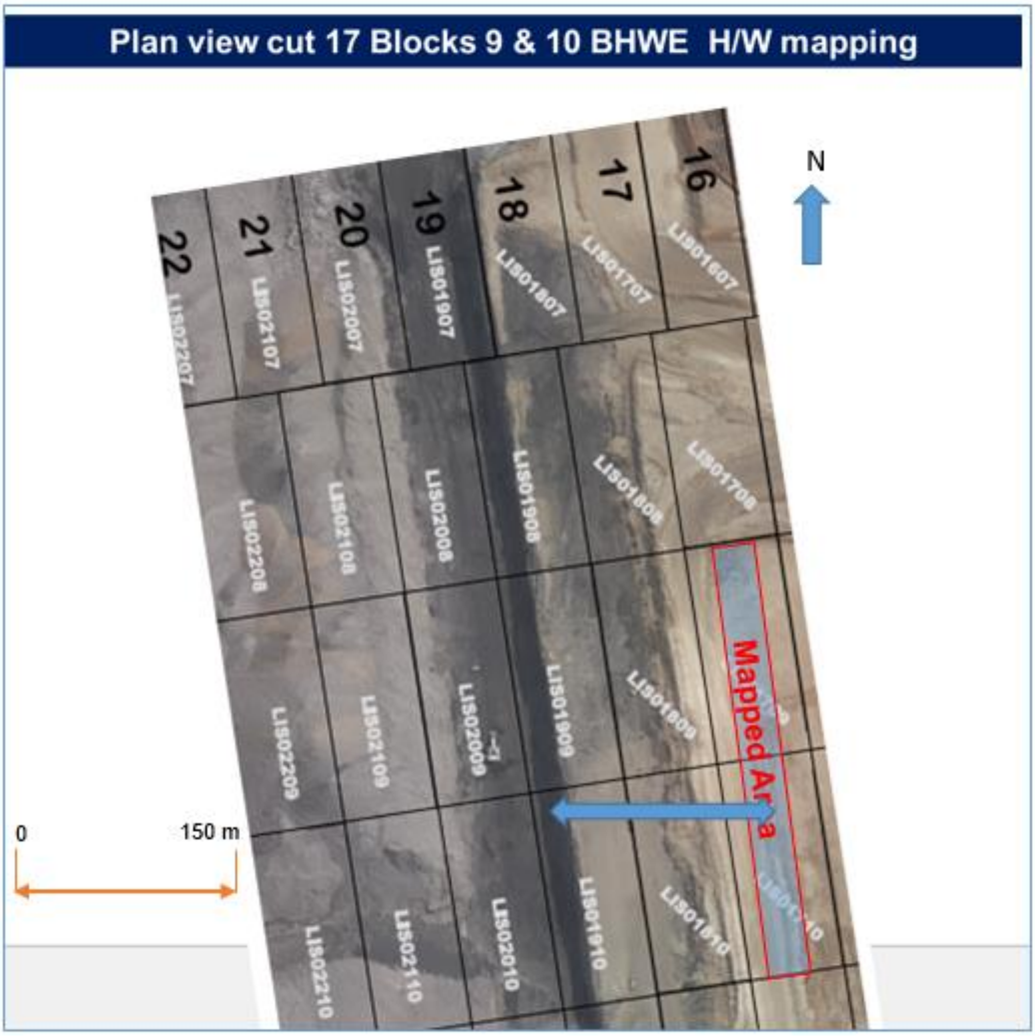


Figure 4.7.1 BHWE Mapped Area in Strip17.

(By author)

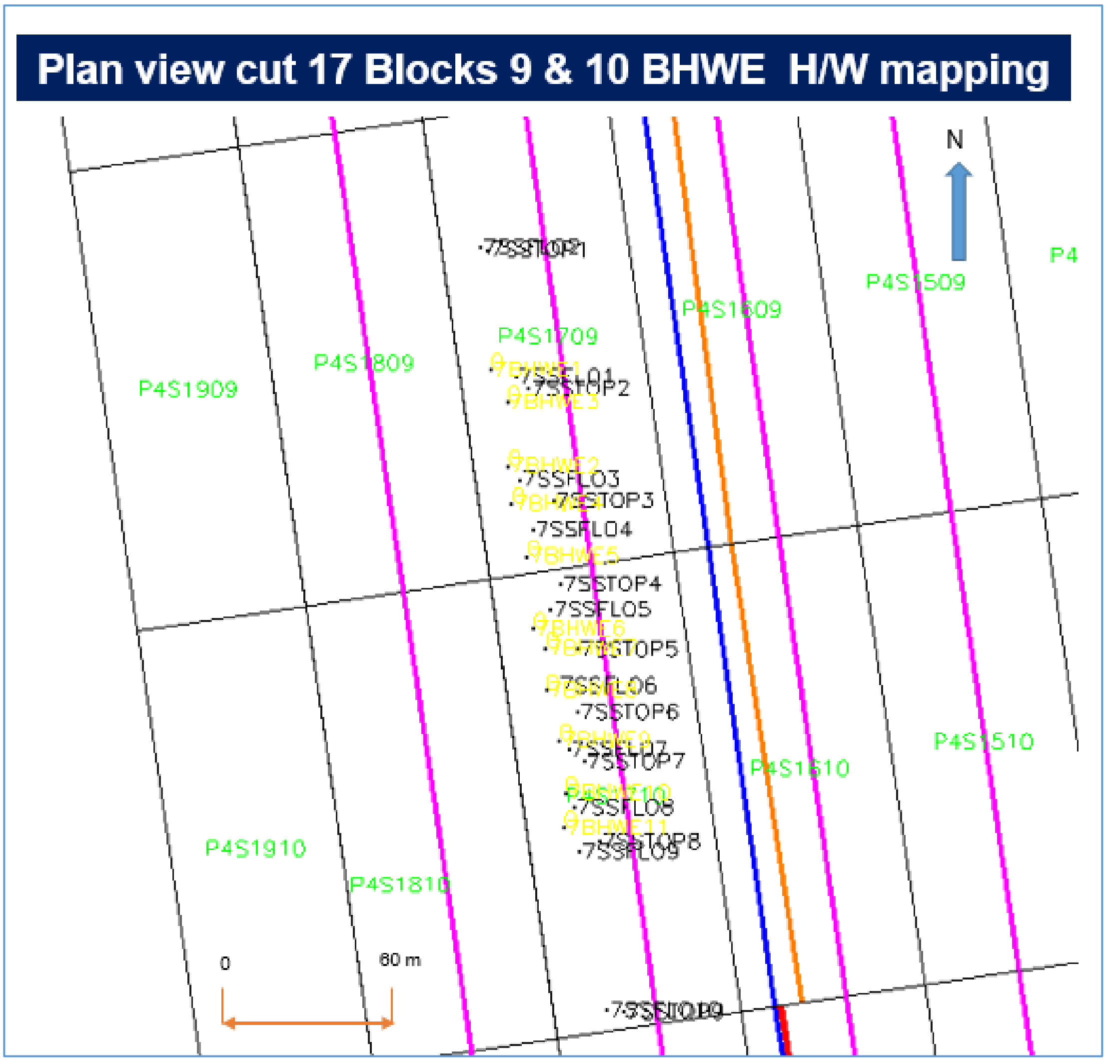


Figure 4.7.2 Data points mapped area - Strip17

(By author)

Following the completion of the actual mapping using a total station, a table file was then generated for mine planning to use to update the XPAC model. The old (resource model) and new elevations (short-term model) are illustrated in Table 4.7.1 for blocks P4S1709 to P4S1710 where changes were realised from the updating of geological data.

Table 4.7.1 XPAC Short Term Model input file

		Resource Model						
Block	Subname	Interval	Centroid x	Centroid y	Top elevation	Bottom elevation	Plan area	Block area
P4S1709	T1	Topo to BWE	-28454.57	2914626.43	1568.85	1550.89	0.9000325	0.900032461
P4S1710	T1	Topo to BWE	-28477.15	2914777.11	1569.72	1552.29	0.9000327	0.900032699
		Short Term Model						
Block	Subname	Interval	Centroid x	Centroid y	Top elevation	Bottom elevation	Plan area	Block area
P4S1709	T1	Topo to BWE	-28454.57	2914626.43	1568.21	1549.61	0.9000325	0.900032461
P4S1710	T1	Topo to BWE	-28477.15	2914777.11	1568.81	1549.11	0.9000327	0.900032699

(By author)

Drone flyover highwall mapping data was interpreted for the blocks P4S1712 to P4S1715, a linear distance of 600 metres. The comparison of softs and hard volumes between the resource model and short-term model is summarised in Table 4.7.2 .

Table 4.7.2 Volumes Comparison Resource versus Short-term Model

Block	Resource Model Info	Elevations	Block Area	Resource Model Softs Volume (m3)	Short Term Model(Actual) Softs Volume m3)	Difference %	Resource Model Hards Volume (m3)	Short-term Model(Actual) Hards Volume (m3)	Difference %
P4S1712	Topo	1569.26	9000	119610	60315	-50	344610	403905	17
P4S1712	BHFW	1555.97							
P4S1712	M4 roof	1517.68							
P4S1712	M4 floor	1511.67							
P4S1713	Topo	1570.33	9000	114930	61351	-47	357750	411329	15
P4S1713	BHFW	1557.56							
P4S1713	M4 roof	1517.81							
P4S1713	M4 floor	1511.8							
P4S1714	Topo	1570.94	9000	82260	38713	-53	395910	439457	11
P4S1714	BHFW	1561.8							
P4S1714	M4 roof	1517.81							
P4S1714	M4 floor	1511.78							
P4S1715	Topo	1572.45	9000	65790	33379	-49	425970	458381	8
P4S1715	BHFW	1565.14							
P4S1715	M4 roof	1517.81							
P4S1715	M4 floor	1511.78							

(Pretorius,2018)

The drone flyover information generated at least 15 points of observation per block (“boreholes”), hence the short-term model gave an improved interpretation of the base of softs resulting in more realistic volumes per block. The softs volumes decreased generally by between 47 and 53% in this 600m stretch meanwhile the hards volumes increased by between 8 and 17%.

4.8 Conclusion

Current practice of using the resource model for all three mine planning windows was proved in this research report to have shortcomings. Previous OMS audits singled out lack of short-term geological model and most of the stakeholders interacted with during the research, shared the same sentiment. The initiative of the research to put a short-term model in place gathered support during the period from management, the resource evaluation department and other departments. Field work included manual highwall mapping and drone flyover, culminating in building a 3-D Model for this project with the input from the outsourced service provider. Good correlation was found when short-term (drone data model) was compared against the resource model in the study area.

5 RESEARCH ANALYSIS AND FINDINGS

5.1 Introduction

The results from the various research activities were analysed and presented as detailed in the following sections. The analysis covered geotechnical issues, highwall mapping techniques comparing the resource model and the short-term model using cross sections and tables.

5.2 Geotechnical

Cross sections from the resource model do not differentiate between weathered sandstone that is digable with excavators and that which is competent (partially weathered) requiring drilling and blasting. In the current modelling practice, lithologies are not modelled except for coal intersections and the surfaces (BHSO, BHFW and BHWE). The short-term modelling process produced more detailed sections including the missing sandstone and one example is shown in figure 5.3.4 in section 5.3.

The short-term model process produced further extrapolated information especially from highwall mapping thus getting new elevations of different layers as well as reporting structural issues of geotechnical interest. The new data is used for the next strip design analysis.

The following is an example, see figure 5.2.1 illustrating the findings from the drone data extrapolation showing the clearly defined weathered sandstone top contact and floor contact which were not visible in the resource model.

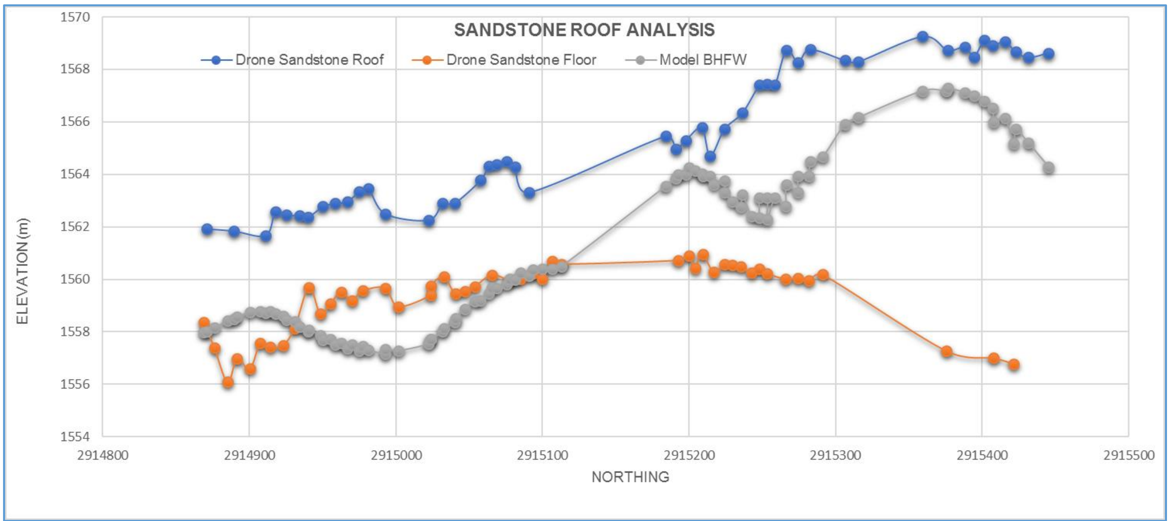


Figure 5.2.1 Far South Pit: Sandstone Resource vs Short Term model

(Pretorius, 2018)

It is clear from figure 5.2.1 that in the resource model information given, has always shown that soft material which is digable as indicated by BHFW (grey line). The data from the drone highwall mapping fully delineated the sandstone contacts top contact (blue line) and floor contact (orange line).

5.3 Highwall Mapping analysis

The different horizons where mapping results were compared with the resource model elevations are summarised in the tables and figures that follow. The Base Horizon of Softs (BHSO) analysis (an extract from Appendix 10.8) is shown in Table 5.3.1.

5.3.1 Base horizon of Softs (BHSO)

Table 5.3.1 BHSO comparison Model versus Mapping

	Mapped BHSO Elevation (m)	Model BHSO Elevation (m)	Variance (m)
BHSO1	1568.74	1559.75	8.99
BHSO2	1569.28	1562.08	7.20
BHSO3	1568.56	1559.30	9.26
BHSO4	1569.34	1562.35	6.99
BHSO5	1569.75	1563.48	6.27
BHSO6	1569.45	1564.02	5.43
BHSO7	1569.39	1564.30	5.09
BHSO8	1569.89	1564.21	5.68
BHSO9	1569.56	1564.18	5.38
BHSO10	1573.33	1564.62	8.71

(By author)

The Base Horizon of Softs (BHSO) in the study area shows that on average there is a difference of 7.55m in elevation between the mapped surface and the elevation in the resource model. The variance is 48%, which is greater than 5% (the tolerance limit) hence would trigger a model update. This short-term geological modelling process provide up to date cross sectional data to Mine Planning. The trend shown in figure 5.3.1 indicates a consistent shift from the model.

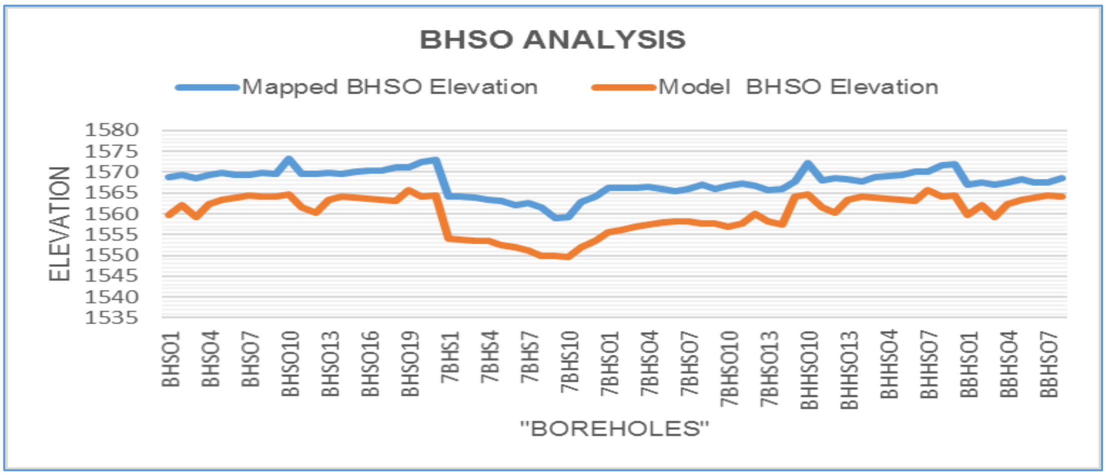


Figure 5.3.1 BHSO: Short-term Model versus resource Model

(By author)

The base of “softs” as captured in the exploration boreholes is on average 7.55m lower. However, the mapping exercise data (using a total station also needed to be validated further). A proposal during this project was that data should also be acquired using a drone flyover along the “softs” highwall of the next Strip 17 (since Strip 18 had now been mined out, see figure 4.2.2 under section 4.2). The status with regards to softs volumes provided to mine planning for designs has been a challenge. The planned volumes would be more than what gets mined at times, hence this short-term modelling was initiated to close that gap by providing latest geological data for design purposes.

5.3.2 Base Horizon of Friable Weathering (BHFW)

The Base Horizon of Friable Weathering is critical in mine planning as it determines where free digable material ends, thus determining the deployment of the correct equipment at the right level. Isibonelo uses contractors in the South Pit to strip top soil and all softs. The double bench method was introduced to alleviate the removal of softs through digging with the dragline, hence more accurate volumes are required to ensure correct spoil balance as well as dragline linear advance.

The analysis of the data in table 5.3.2 (an extract from the table in Appendix 10.9) the base of friable weathering BHFW from the manual mapping using a total station. The average elevation difference between the model and mapped surfaces in the study section is 4.63m. The resource model did show more friable material as compared to reality on the ground. This part of the study area has had issues of serious hard digging on the part of the pre-strip equipment, thus necessitating deployment of a drill machine to drill and blast the weathered but rather competent sandstone.

Table 5.3.2 BHFW Short- term vs Resource Model

	Mapped BHFW Elevation (m)	**Model BHFW Elevation (m)**	**Variance (m)**
BHFW1	1565.88	1563.85	2.03
BHFW10	1567.42	1563.05	4.37
BHFW11	1567.74	1562.64	5.10
BHFW2	1566.21	1564.20	2.01
BHFW3	1566.89	1563.99	2.90
BHFW4	1567.60	1563.70	3.90
BHFW5	1567.29	1562.87	4.42
BHFW6	1568.15	1560.81	7.34

BHFW7	1568.55	1561.51	7.04
BHFW8	1567.92	1564.44	3.48
BHFW9	1568.29	1565.71	2.58

(By author)

The trend plot shown in figure 5.3.2 shows how the resource model exaggerated the actual depth of friable material leading to issues referred to above. The weathered sandstone, as logged in the exploration boreholes, appears to be friable in nature yet in reality it is more competent. It is clear from this project investigation, that in some areas of the pit, the data provided to mine planning for designs from the resource model may vary in accuracy, hence the importance of short-term model to fine tune and optimise in pit designs.

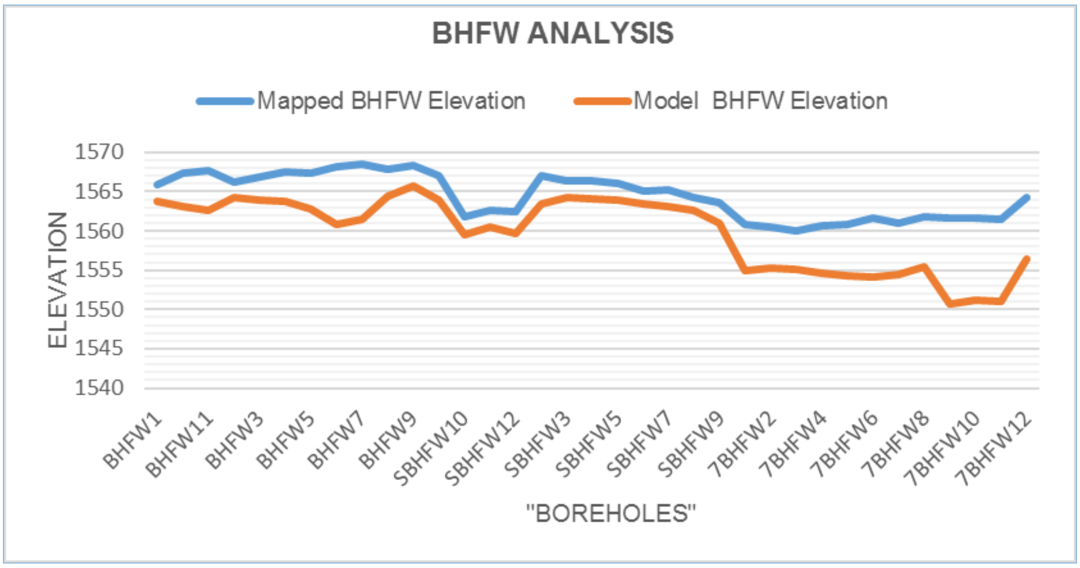


Figure 5.3.2 BHFW Short-term Model versus Resource Model

(By author)

The competent sandstone lying between the BHSO and the BHWE was mapped during the project research as shown in figure 5.3.3.

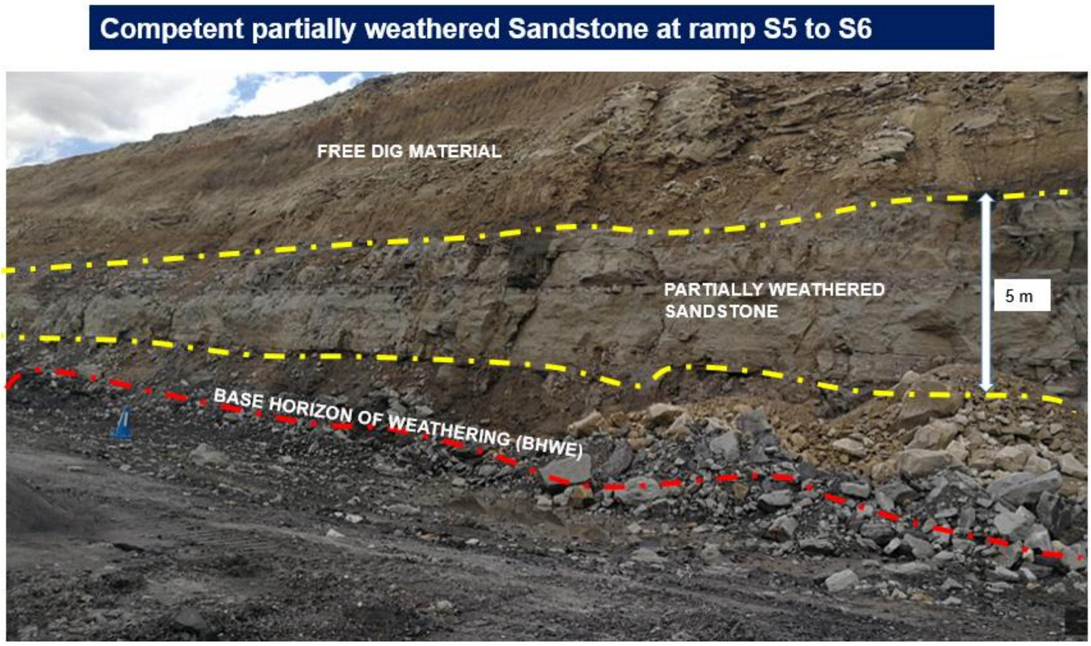


Figure 5.3.3 Partially weathered sandstone (Ramp S5 to S6)

(Photo by author, Nov 2017)

The information derived from the highwall mapping exercise is also confirmed by the short-term geological cross-section of the same area shown in figure 5.3.4.

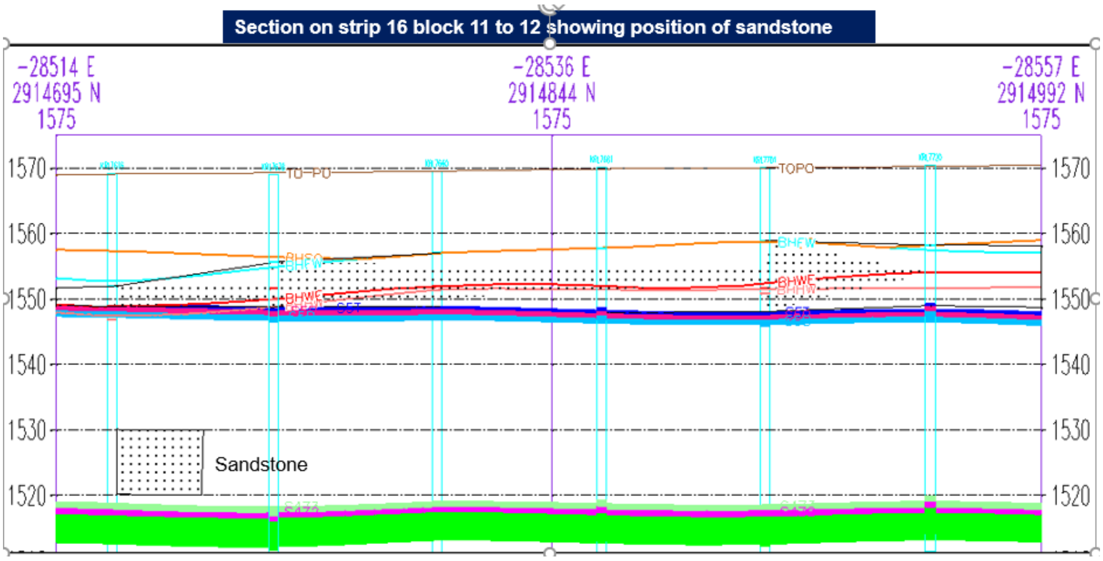


Figure 5.3.4 Sandstone in Strip 16 block 12 to 15

(By author)

The Base Horizon of Friable Weathering (BHFW) in the cross-section above, is cutting through the sandstone, hence short-term modelling has assisted in depicting the correct position of this important surface. The drone flyover highwall mapping also confirmed that the resource model shows the BHFW transgressing the weathered sandstone (Figure 5.2.1 under section 5.2). Planning for pre-strip was adjusted accordingly to allow for the additional activity of drilling and blasting the hard sandstone to allow the dragline to dig this material and place it at the correct place without compromising slope stability.

5.3.3 Base Horizon of Weathering (BHWE)

Mine designs focus on this transitional surface from weathered material to fresh rock as this is where drilling and blasting is planned to start to create inventory for the dragline. The following is an analysis from the study area between ramp S5 and S6. The BHWE from the short-term model shows that on average there is an elevation difference of +/-1.90m with the resource model in this study area alone, see Table 5.3.3.

Table 5.3.3 BHWE Short-term vs Resource Model

	Mapped BHWE Elevation (m)	**Model BHWE Elevation (m)**	**Variance (m)**
7BHWE1	1550.09	1553.09	-3.00
7BHWE2	1549.72	1551.79	-2.07
7BHWE3	1549.98	1552.82	-2.84
7BHWE4	1549.50	1551.36	-1.86
7BHWE5	1548.77	1550.90	-2.13
7BHWE6	1549.27	1550.56	-1.29
7BHWE7	1548.81	1550.45	-1.64
7BHWE8	1549.22	1550.47	-1.25
7BHWE9	1549.04	1550.55	-1.51
7BHWE10	1549.12	1550.76	-1.64
7BHWE11	1549.22	1550.88	-1.66

(By author)

From the trend plot shown in figure 5.3.5, the resource model's BHWE is shallower than the short-term model elevation (as mapped on the exposed highwall using a total station). The gap between the two elevations is consistent with the variances having a standard deviation of 0.55.

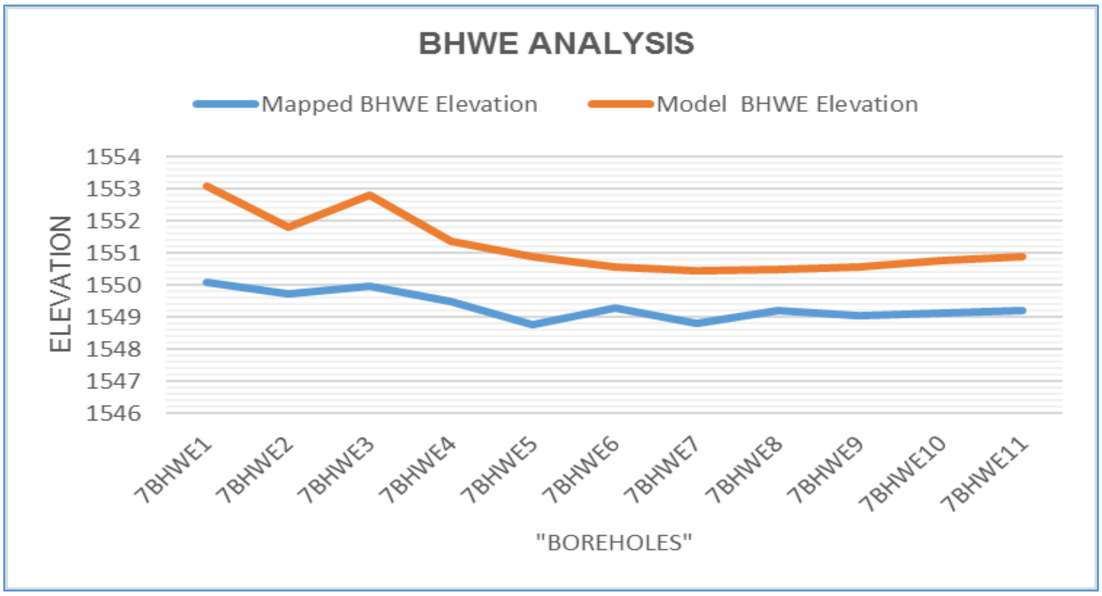


Figure 5.3.5 BHWE Short-term versus Resource Model

(By author)

The information illustrated in figure 5.3.5, is from Strip 17 blocks 9 and 10 only. A comparison of the resource model data and the short-term model is shown in Table 5.3.4 showing the changes in top and bottom elevation per block in the mapped area. The block and planar areas remain the same before and after update from highwall mapping, thus for the resource model and short-term model. The short-term XPAC model for block 1709 shows that the volumes increased from 161 653m^3 to 167 406m^3 which is a 4% increase, and for block 1710 the change was from 156 805m^3 to 177 306m^3, a 13% increase. Such changes are quite significant in terms of pre-strip planning. The planning for Strip 17 became better with the latest volumes.

Table 5.3.4 XPAC Short-Term Model input file comparison (before and after)

		Resource Model						
Block	Subname	Interval	Centroid x	Centroid y	Top elevation	Bottom elevation	Plan area	Block area
P4S1709	T1	Topo to BWE	-28454.57	2914626.43	1568.85	1550.89	0.9000325	0.900032461
P4S1710	T1	Topo to BWE	-28477.15	2914777.11	1569.72	1552.29	0.9000327	0.900032699
		Short Term Model						
Block	Subname	Interval	Centroid x	Centroid y	Top elevation	Bottom elevation	Plan area	Block area
P4S1709	T1	Topo to BWE	-28454.57	2914626.43	1568.21	1549.61	0.9000325	0.900032461
P4S1710	T1	Topo to BWE	-28477.15	2914777.11	1568.81	1549.11	0.9000327	0.900032699

(By author)

5.3.4 The 4-seam roof contacts (S4Z3)

The 4-seam roof highwall contacts were mapped and plotted for comparison with the resource model contacts. Table 5.3.5 is an extract of some of the data on roof contacts from Strip19 physical mapping using the survey total station.

Table 5.3.5 Seam roof contacts

	Mapped S4Z3 Elevation (m)	Model S4Z3 Elevation (m)	Variance (m)
6HWC1	1518.29	1518.4	-0.11
6HWC10	1520.33	1519.74	0.59
6HWC2	1518.31	1518.4	-0.09
6HWC3	1519.06	1518.83	0.23
6HWC4	1519.05	1519.1	-0.05
6HWC5	1518.97	1519.12	-0.15
6HWC6	1518.94	1519.16	-0.22
6HWC7	1519.21	1519.37	-0.16
6HWC8	1519.47	1519.48	-0.01
6HWC9	1519.7	1519.62	0.08
5HWC1	1520.57	1519.89	0.68
5HWC2	1521.83	1521.82	0.01
5HWC3	1520.3	1519.48	0.82
5HWC4	1519.86	1519.54	0.32

(By author)

The trend plots shown in Figure 5.3.6 illustrates the good correlation of the resource model and short-term model with respect to 4-seam roof contacts along the highwall. The variance between the two elevations averages at 0.25m which is only 2% difference. However, the data shows a few outliers (5 data points) and when these are filtered out, the difference only averages to 0.14m that translates to 1%. The resource model of 4-seam roof contact elevation average is 1520.32m, meanwhile the short-term model is 1520,08m.

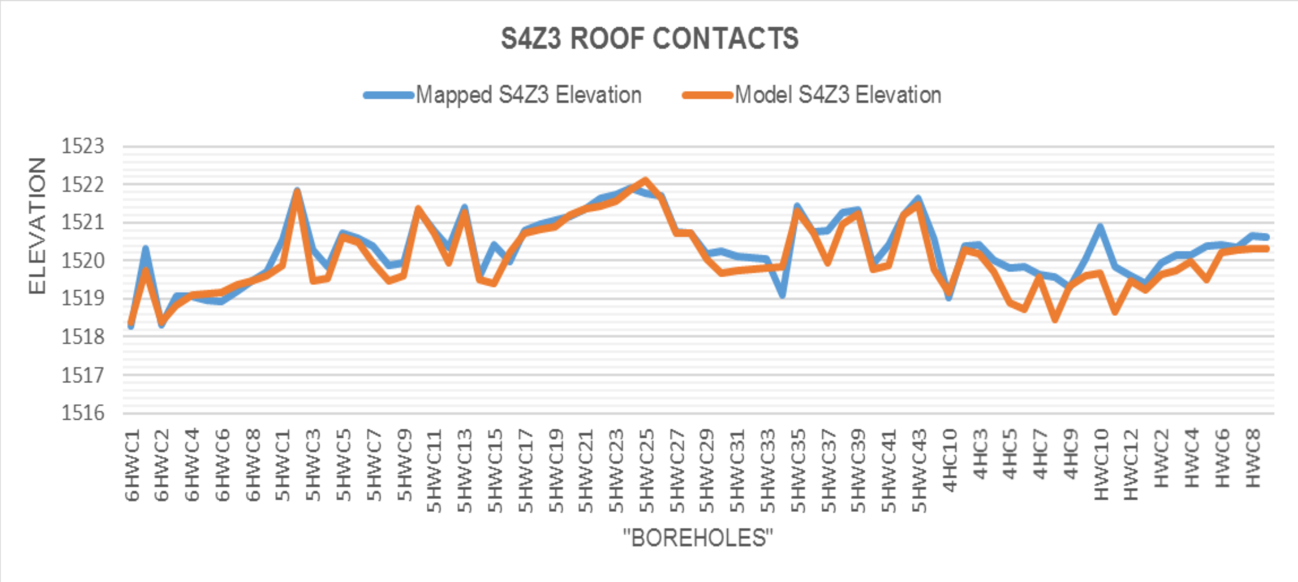


Figure 5.3.6 4-seam Short-term versus Resource Model (Ramp S4 to S5)

(By author)

The 4-seam roof contacts are consistent with the exploration boreholes intersections, this is true because of good core recovery and drilling accuracy.

The next Strip 18 was mapped using highwall flyover with a Phantom 4 drone between S5 ramp and S6 ramp (the same area as mapped and illustrated in Figure 5.3.6) in a demonstration by Vidblast. Four dummy boreholes were used to validate the accuracy of drone highwall flyover photogrammetry technique in this strip. The position of the dummy boreholes (from survey total station) is illustrated in figure 5.3.7.

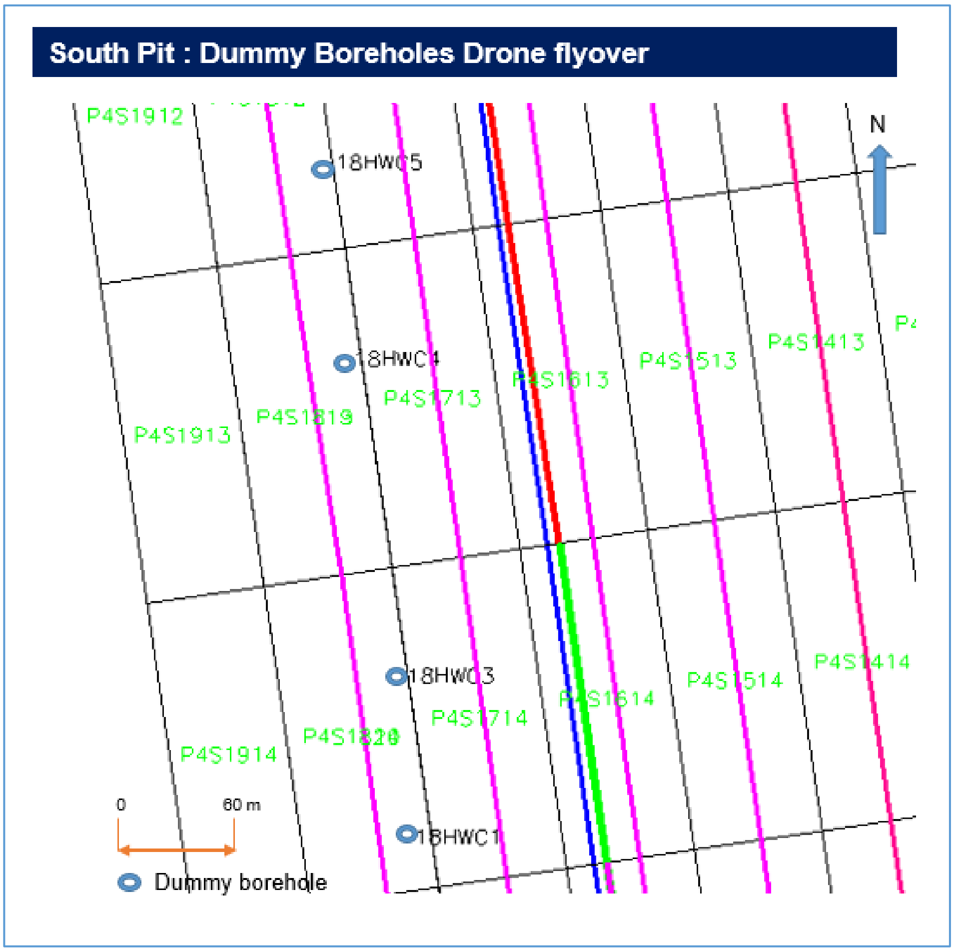


Figure 5.3.7 Dummy borehole positions in Strip 18

(By author)

The 4-seam top contact from the flyover (digital photogrammetry) was then compared with the geological model at the same point in space and is shown in figure 5.3.8.

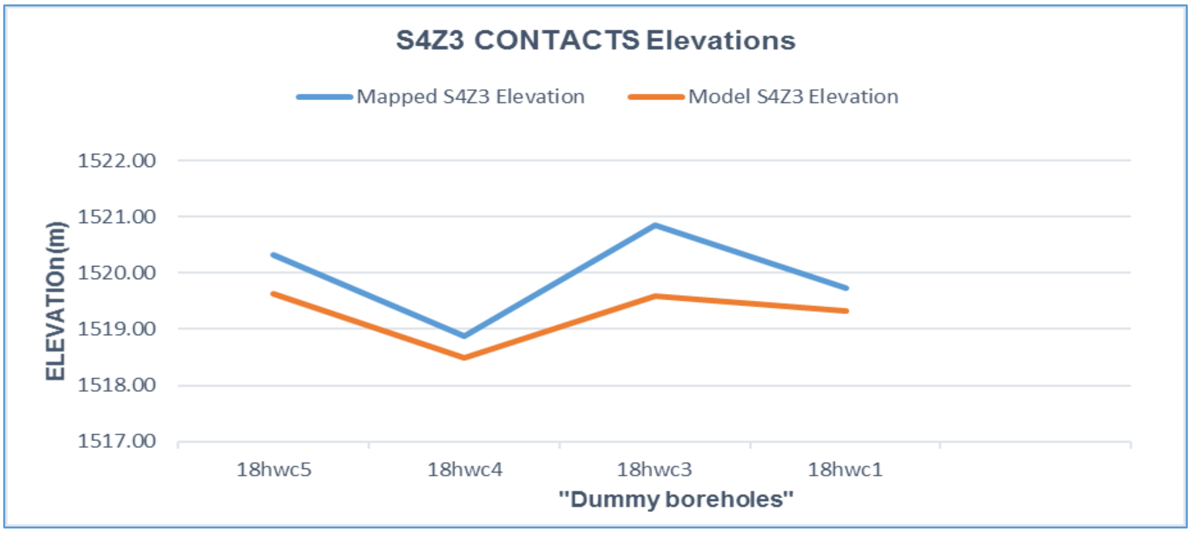


Figure 5.3.8 4-seam contacts Short-term vs Resource Model

(By author)

There is good correlation between the model contacts and the results from drone flyover. The method is faster in generating data for short-term modelling as compared to the survey total station method highwall mapping process.

Drone flyover mapping of the 4-seam roof in the next strip 18 showed good correlation as shown in figure 5.3.9.

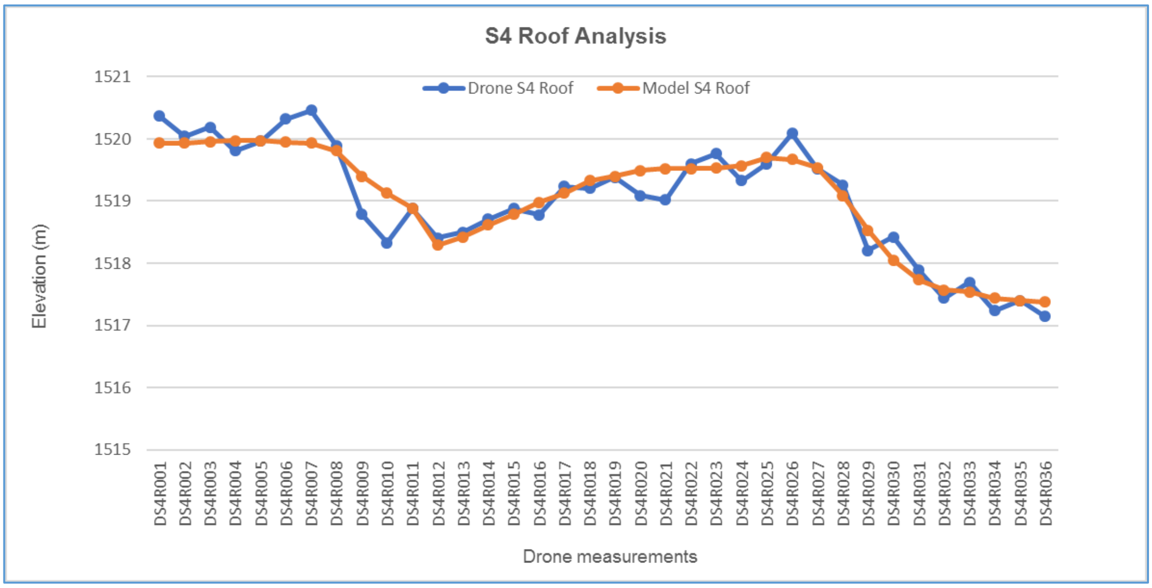


Figure 5.3.9 Strip 18: 4-seam roof Drone vs Resource Model

(By author)

The information extrapolated from the drone flyover data has more detail due to the choice of closely spaced data points for greater accuracy. The reality on the ground was well represented by drone information as compared to physical mapping as well as the resource model based on widely spaced boreholes (100m x 60m grid for Isibonelo). The blue line shows the 4-seam roof contact in Strip18 (the study area). The drone measurements shown above and compared with the geological model's elevations, shows good 4-seam correlation between the two. The average variance in elevation between the two models in the entire section is 0.14m, which is negligible. However, the research exercise also proved that the current borehole data with respect to the coal intersection is true and correct, hence the current resource model has been relied upon over the years for mine planning. The nature of the coal seam at Isibonelo is that it shows very minimal variation on the roof contact, such that it is generally flat. The drone data set was also compared against the top of coal seam survey elevations after dragline exposure in Strip 18. The information was analysed using histograms to show the spread of data and the two show a similar trend. The average elevation for the roof of 4-seam is 1519.39m. The two histograms are shown in figure 5.3.10 (Survey data) and figure 5.3.11(Drone data).

m

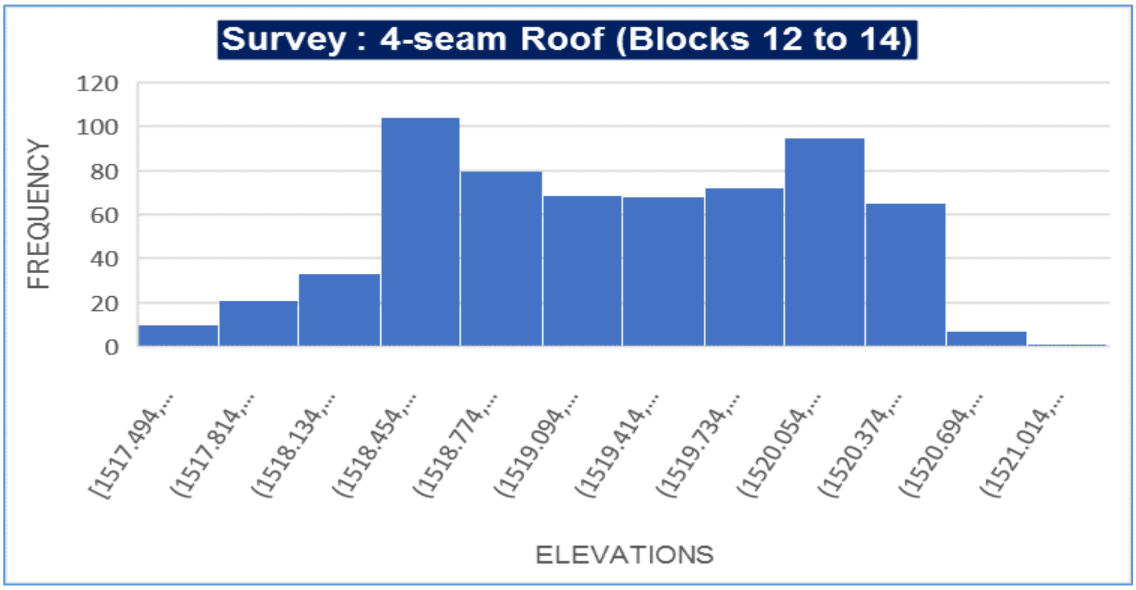


Figure 5.3.10 Survey 4-Seam Roof Elevations

(By author)

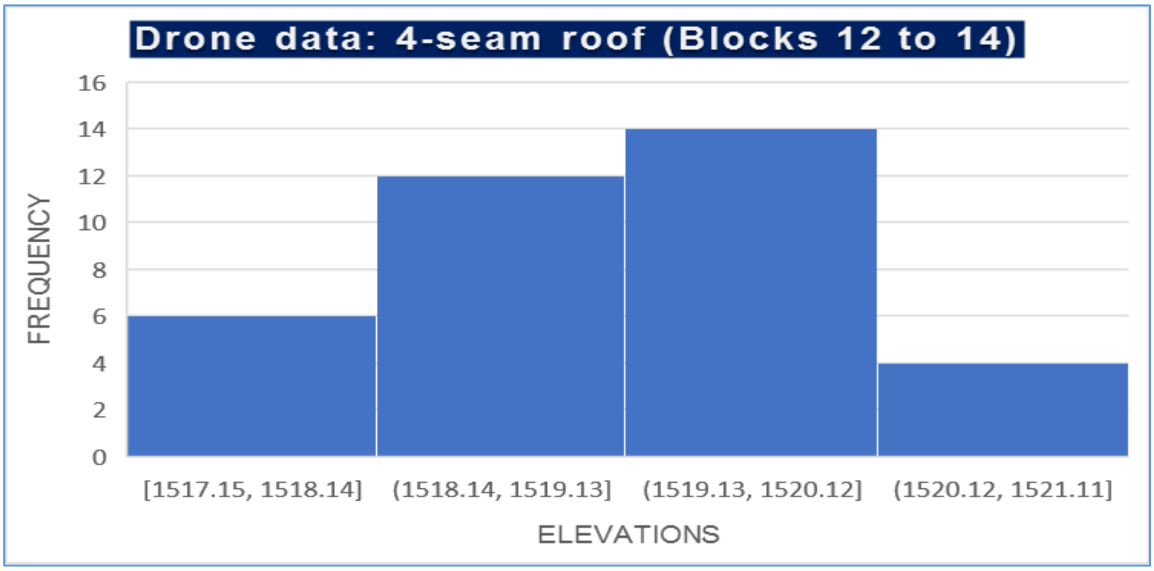


Figure 5.3.11 Drone 4-Seam Roof Elevations

(By author)

The survey histogram has a lot more data points (from the entire 60m wide cut) as compared to the drone data (which is limited to the highwall contact only.

The short-term model information generated in Strip 18 was projected into the next Strip 17 (which was planned to be mined in early July 2018) and then compared with resource model predicted roof and floor contacts. Figure 5.3.12 shows a plot of both the roof and floor elevations on section in Strip 18. The floor elevations also showed good correlation.

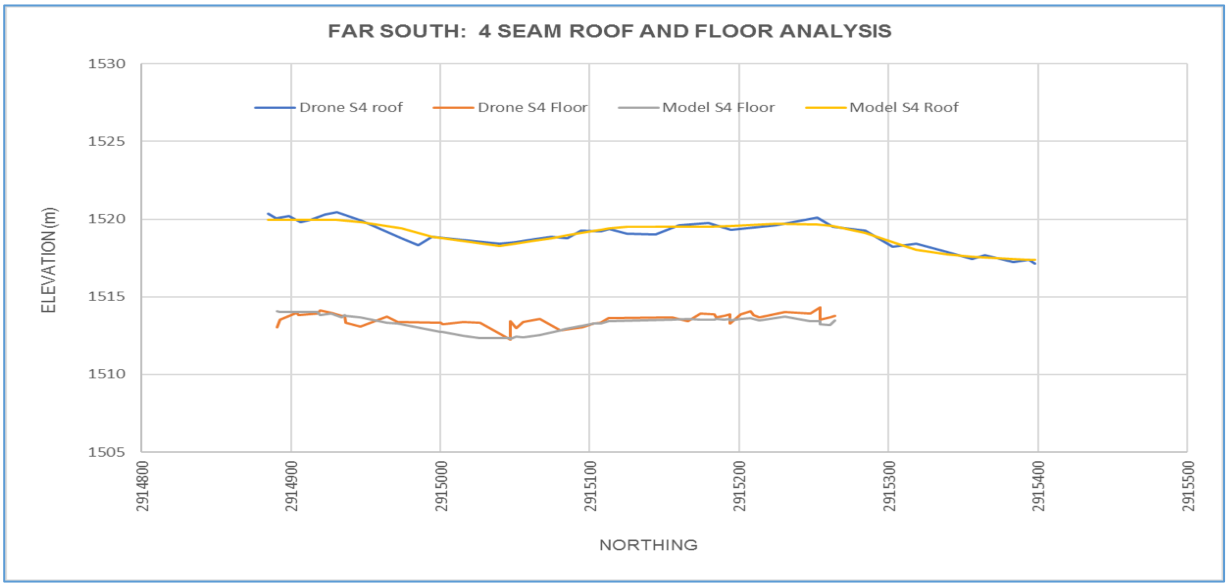


Figure 5.3.12 Far South Strip 18 4-seam roof and floor elevation

(By author)

The same data in figure 5.3.12 was also plotted on plan to show the how the coal was exposed in Strip 18. The floor points showed a scattering pattern due to the nature of the toe of the highwall when the coal is mined out (it is not straight) and the effect of water accumulations on the floor. Figure 5.3.13 illustrates the variances in elevation per block when the resource model was compared against the short-term model projected contacts in strip 17.

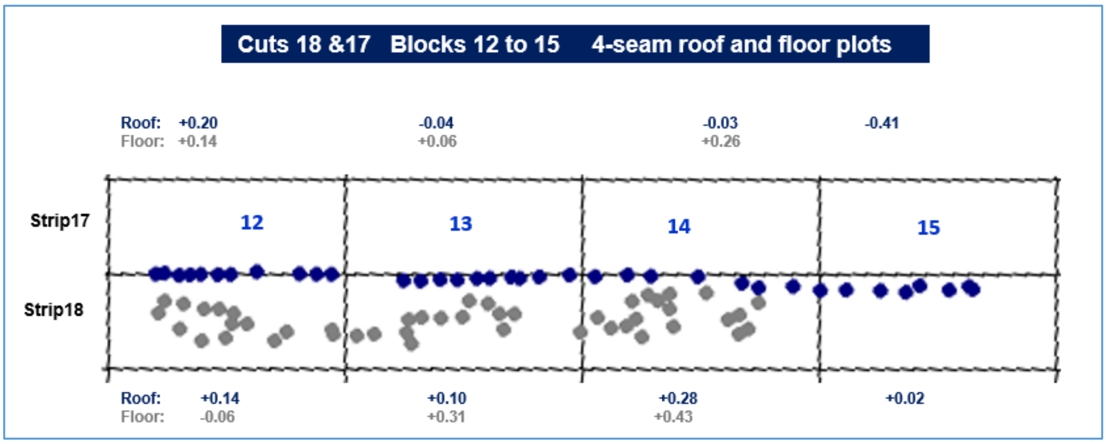


Figure 5.3.13 4-seam roof and floor plots on plan

(By author)

The 4-seam roof contacts measurements are in blue while the floor is in grey in figure 5.3.13. The variances between the short-term model and resource model are shown per block in both Strip 17 and 18. They show that in the projected elevations in Strip 17 there is very good correlation and with the resource model. Hence drone highwall mapping proved that it can improve short-term planning significantly with provision of the most up-to-date roof and floor contact of the 4-seam. The drill design of the next bench in Strip 17 was based on the new data (short-term model).

5.4 Drill and blast Analysis

5.4.1 Status

Drilling and blast design requires accurate geological information to ensure proper extraction of the coal. The current practice at Isibonelo is that the mine activity engineer for drill and blast works with the mine surveyor to produce a drill plan. The geological cross section of the strip to be drilled and blasted is currently derived from the resource model. The blast hole collar elevations are based on the survey of the drill bench after the removal of “softs” overburden and the drill depths are then determined from the provided geological cross section of the area.

Drilling accuracy is one aspect that makes or breaks the mine. There are instances where capping on top of coal results from inaccurate drilled depths. One of the causes of this is the failure to follow the drill plan or an assumption that all the holes on the drill bench must be drilled to the same depths. In areas where the seam undulates, the result is capping (lows) or over drilling into highs leading to serious coal loss during blasting. The drill and blast section has introduced the DPS 900 Drill System by Sitech, on the mine to improve drilling accuracy through automated hole positioning. The drill plan is loaded onto the system on the machine and then the operator reads on the screen and trams the machine navigating to the next hole position. The screen in the operator’s cabin is illustrated in figure 5.4.1

Figure 5.4.1 Example of automation on production drill rig

(De Lange, 2018)

5.4.2 Impact of Short-term Model

The more accurate the geological information is, the better is the drill design. Information from the resource model (with boreholes at 100m apart) may not show seam undulations between the holes. With short-term modelling, the coal seam structure is mapped in detail and the information is added into the model to improve design accuracy. Highwall mapping, as covered in section 5.3.4 provided closely spaced data points to accurately delineate the coal seam roof and floor contacts. The information was used to design the next Strip 17 in the study area.

Blast designing also requires detail of the different rock types in the overburden hence highwall mapping helped to give more detail which allowed the drill and blast engineer to choose the correct explosives for the rock type.

Drone data from highwall mapping was tested in conjunction with alternative software called Winprof. The software allows the importation of the drone data points and then separate the data into face, bench and crest line; the software generates a full bench profile. With the bench profile in place, a full drill bench design, including the charging, is designed automatically. Isibonelo has now embarked on testing this new programme which is compatible with drone generated data for short-term modelling.

The following diagram (Figure 5.4.2) illustrates a bench profile with hole design and consequences of poor profiles.

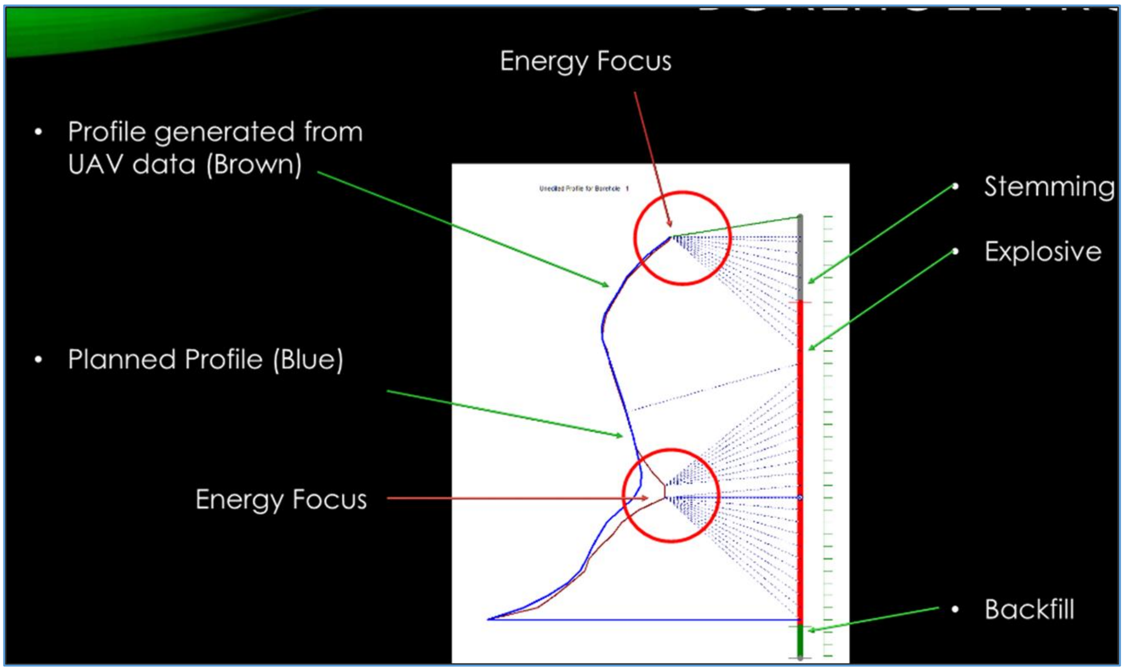


Figure 5.4.2 Borehole profile

(De Bruyn, 2018)

5.5 Summary of the findings

5.5.1 Highwall Mapping Techniques

The friable weathering horizon is not properly highlighted by exploration boreholes. It became clear from the variance shown in the mapped softs highwall that the surfaces show a consistent variance between the resource model and the geological model (see figures 5.3.5 and 5.3.6).

Mine design of the "softs" removal with volumes from the resource model need short-term model data, due to the variance between the two models with respect to overburden "softs". The mine activity engineers, have over time found it sometimes is a challenge to reconcile the planned volumes and the actual mined volumes. This was one of the triggers of this project to close that gap. It is a trigger of short-term modelling from a mine planning perspective, and this was confirmed by opencut mining excellence department. This is a department of mine planning specialists who give guidance to opencast operations in the group.

Current highwall mapping practice with assistance of the mine survey method has challenges, due to manpower constraints from the mine survey department. There are not enough mine surveyors on the mine with the current workload to dedicate to this work. Geologists are not trained to use, the total station. There is an opportunity to train geologists to use the total station and to carry out mapping on their own, only if that does not contravene the Mine Health and Safety Act (1996) Chapter 17 regulations. However, with current practice, there is a chance of missing the correct contact being mapped by the surveyor since the geologist can only point to a target since no-one can get close to the highwall due to safety reasons. The highwall mapping practice has not been carried out for a long time, hence there has not been much continuity, and it is being done on an ad hoc basis.

The use of drone for highwall mapping attracted a lot of interest from the stakeholders during the research project. The project recommendation to use drones for highwall mapping will be adopted by mine management after this project presentation is completed. The accuracy of the photogrammetry technique by the drone is highly recommended as it eliminates human error on mapping the lithological contacts. The zones are very clear and the coordinates of the contacts are accurate, in the correct format(xyz). Drone flyovers generate data within minutes over a very large area whereas a mine surveyor would take days to complete the work. The turnaround time of results, including a 3-D model of the flown highwall area, is quick (less than 48hours) and is good in allowing decision making.

There is scope for zooming into a problem area and extracting as much information as possible using a drone without compromising safety. This is not possible with conventional mapping as well as the failure to access other areas (drone can capture everything).

5.5.2 Other opportunities

The drone highwall flyover data generated can be analysed for many other purposes such as reconciliation, measuring structural features such as faults and dykes with great accuracy. The information generated is all geotechnical short-term modelling requires to be compliant and to pass the next OMS audit. The other opportunities include stockpile measures, design verifications (see Figure 5.5.1), drill and blast designs and monitoring the pit vehicle management plans (haul roads, intersections, parking areas and many other in pit traffic related issues).

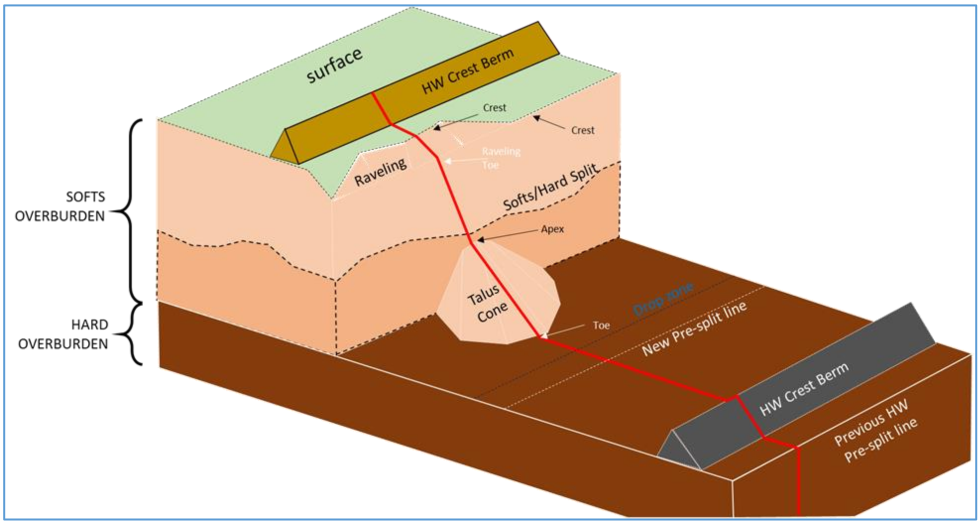


Figure 5.5.1 Typical design verification at Isibonelo

(Matabane, 2018)

5.5.3 Geological Software package

The current Stratmodel software package does not model lithology(except for coal) and only covers surfaces hence the critical sandstone is missed out leading to an extra unplanned activity on pre-strip. “Sandstone drill and blast” has become an extra activity over the years which the mine does not have enough capacity to handle. With short-term modelling in place, improved geological cross sections can be generated which highlight the “missing” sandstone band

The current operations geologists are not trained to update a geological model (author found a lot of learnings through this project research going through the steps with the Resource Geology Specialist). Introduction of short-term modelling is vital for the operation geologist to continuously update the model.

5.5.4 Automatic data flow

Currently mine planning is not using Minescape to carry out mine designs, hence there is no automation of the process at present. The designs are done in a separate package called 3-D Dig and although it is compatible with Stratmodel, the current process is not seamless. If the designs were done in Minescape, the data flow would be automatic (sitting in the same database). There is no central database where information will flow and be used by different stakeholders, as and when required. The current position is that each stakeholder requests information independent of others.

5.5.5 Change management

Change management is still a challenge since OMS was introduced to move from the "old way" to adopting the new requirements and has taken time. Through interaction with many stakeholders, some still feel the short-term modelling process does not add value since the coal seams are generally flat. The sentiment is different from the operations personnel who are in dire need to plan accurately with up to date information generated from the open faces.

5.6 Conclusion

Highwall mapping accuracy with detailed coverage is the solution to short-term geological modelling which will feed into short-term planning. The availability of new technology such as drone flyovers coupled with various software to process data, has improved the speed and accuracy of data acquisition and interpretation. Isibonelo Colliery is ready to adopt the new technology to improve short-term mine planning.

6 CONCLUSION

Short-term geological modelling is an iterative process and data should be constantly generated as mining opens new highwall faces through mapping. The data is processed into various formats for use by the stakeholders, mainly mine planning and rock engineering. Therefore, highwall mapping is the key process to short-term geological modelling to mimic the next mining strip with the currently exposed one. There are various methods of highwall mapping which are summarised below.

6.1 Highwall mapping

Highwall mapping using the latest technology of drone flyover and digital photogrammetry is the best solution because it is accurate (no human judgement errors). It is fast, and it takes less than one hour to capture a 2km long highwall's data using a drone. The drone captures moment in time data which is readily available for processing using various software such as Agisoft and 3DRippler amongst others. The digital images are a very good reference during 3-D modelling. The in-pit manual highwall mapping does not allow personnel to get close to the highwall to scrutinise lithology or take measurements due to safety reasons. A compulsory 10 metre standoff rule applies (the drop zone is a no-go area), hence the naked eye at such a distance can only observe large structures. The drone eliminates this risk for the safety of personnel while at the same it captures detailed data from areas where people cannot access (where there is water, bad highwall hang ups, and unstable spoils).

6.2 Software

The software programmes such as 3DM Analyst have proved useful in the Australian mining industry. This mining analysis software has many advantages which Isibonelo Colliery can benefit from. They include, low cost survey data collection, shorter time frame from capture to data delivery. They can provide denser data wherever it is required, geological data can easily be extracted using this system (drawing lithological contacts is easy), the data can be exported in compatible formats such as .dxf which make it is easier for planners to readily use. The system can work with any range of digital cameras. Short-term geological modelling is all about generating raw data from the field, validating it and using it to update the model, then provide mine planning with up-to-date geological information.

Other highwall mapping methods such as the use of hand held instrumentation with built in software applications, have limitations in terms of time required to map long highwalls against the current staffing levels of the operations. However, they can still be used as an alternative to drone flying. The FieldMove Clino method used at Sishen, an iron ore operation in the Northern Cape, South Africa will be suitable for mapping structural features that are a requisite for input into the geotechnical short-term requirements and thus close the current gap for rock engineering OMS key performance indicators (KPIs).

6.3 Training

There is an opportunity to train geologists to use the total station and reduce the constraint currently due to survey manpower. In Australia, geologists use the total station to map features along the highwall, hence it is possible for South African operations. The data integrity, however will have to be checked and validated by the mine surveyors. The element of mapping the wrong contacts will be eliminated. There is an opportunity to also train the surveyors or geologists as drone pilots and save costs on outsourcing the service, the mine can purchase its own drone.

6.4 Reconciliation

The “softs” volumes are a challenge to reconcile with use of the resource model. The weathering horizons, as depicted in the resource model show some variation with what is in the ground, and exploration boreholes that were logged by different geologists over the years, show variability as well. The current resource model is built after thorough validation of the borehole data hence they are fit for purpose. The introduction of short-term modelling improves the short-term mine planning activity using to update to geological information. The improved mine planning designs shown during the research and trial period from September 2017 up to April 2018, resulted in improved correlation of the dragline dig volumes between planned and actual volumes. Two strips were mined during the research period and the strip volume reconciliation is illustrated in figure 6.4.1. Over the seven-month period, the pit design volumes improved from a variance of 3% down to as low as 0.5% in the last four months.

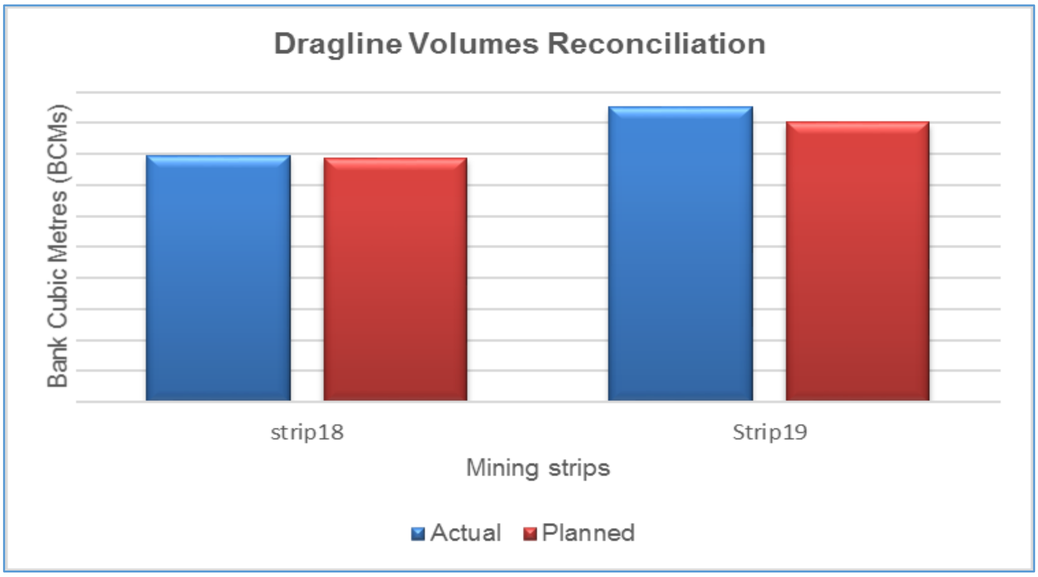


Figure 6.4.1 Dragline volumes reconciliation

(By author)

Coal seam roof contact reconciliation showed very good correlation between resource and short-term models. The coal seam contact in exploration boreholes and the collar elevations form the cornerstone of data validation. In the research project, the 4-seam roof and floor contacts were consistent between resource and short-term models.

6.5 XPAC model update

The XPAC model updating requires the input data in a very simple format. The data is required per each mining block and this includes the block area, top and bottom elevation of each stratigraphic unit in the block, and the thickness is calculated in the software. This research project resulted in the mine's geology department to generate such information from the drone highwall mapping.

6.6 Wireline logging

Down the hole wireline logging of the pre-split production holes proved, in other mining houses, that they generate the most up to date data for short-term modelling. Klipspruit Colliery, for example produces excellent short-term models that enhance accurate drill bench designs. The hole depths designed are very accurate and that improves blasting and coal recovery. Isibonelo Colliery could also incorporate this into their mining activity just such as Optimum Colliery and Klipspruit Colliery who are getting quality pit designs from the wireline logging data.

6.7 Production and Coal recovery

There was significant focus on production and coal recovery as result of improved geological information available for mine planning. The figures 6.7.1 and 6.7.2 illustrate an upward trend in coal recovery and production respectively over the seven month period between October 2017 to March 2018. Improved pit designs through short term planning showed coal recovery increase by 2.1% between October 2017 and April 2018.

Coal production shows an increase of 1.2% between October 2017 and April 2018 despite the low production because of one major equipment outage in November and December 2017(mine operated at half capacity). Coal recovery surpassed the budget in two of the last three months of the research period (February to April 2018), testimony of improved pit designs and compliance to plan among other initiatives on the mine.

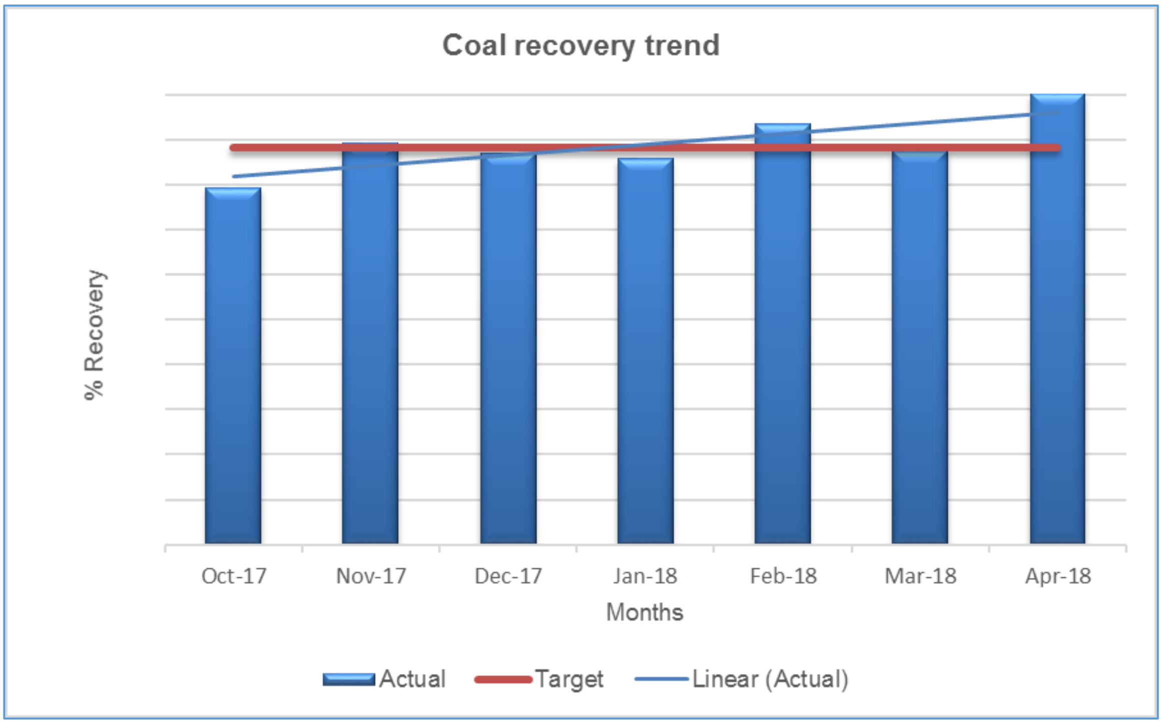


Figure 6.7.1 Isibonelo Colliery coal recovery trend

(By author)

There was an improvement in the turnaround of mine designs because of available latest geological information. Production showed an upward trend after a temporary dip during the November to December period as illustrated in figure 6.7.2.

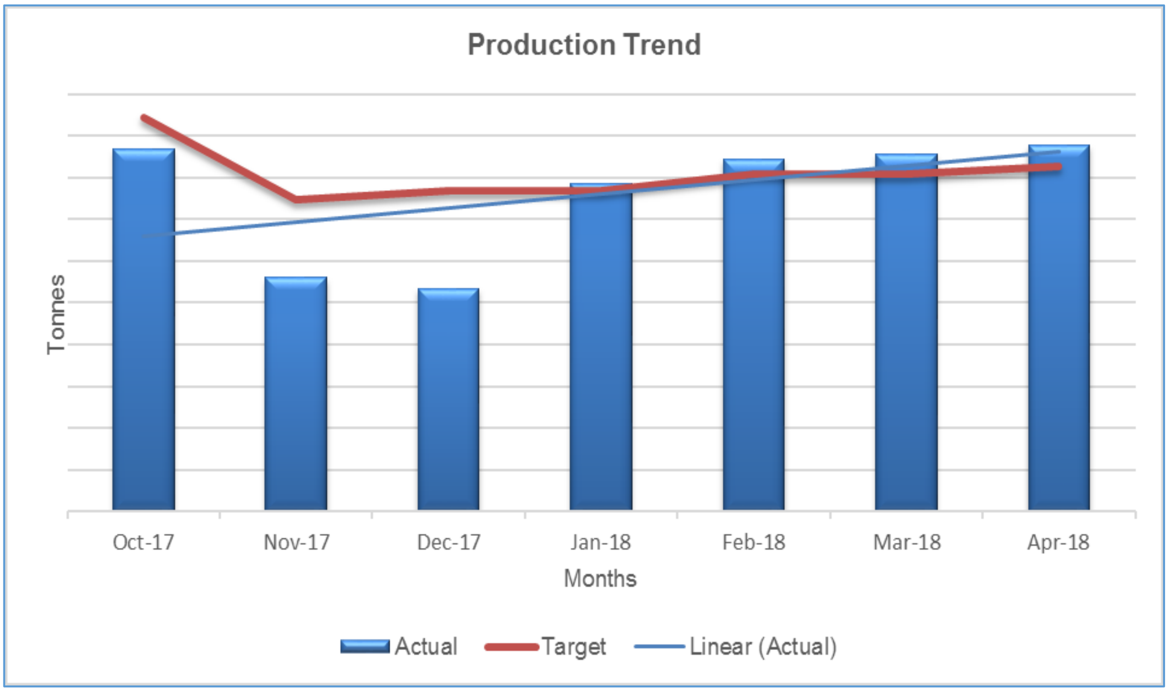


Figure 6.7.2 Isibonelo Colliery production trend

(By author)

6.8 Value Add

Short-term geological modelling adds more value to short-term mine planning process, because of the readily available updated geological information. During the research period, there was increased collaboration between geology department personnel, mine planning, survey, resource evaluation and mining. The interaction between various departments ensures practical mine designs are produced and the execution of the plans result in minimal deviations from plan. Drone flyover highwall mapping not only add value to geological data gathering process but also bring improvement to drill and blast activity. Quality drill and blast add more value to the integrity of the highwalls in the pit.

7 RECOMMENDATIONS

The way forward from the research project findings is detailed below after it generated much interest from some of the key stakeholders. The use of the drone to map highwall to generate data for updating short-term model proved a major innovation for Isibonelo Colliery, hence the presentation at the Anglo American Geoscience Innovation Colloquium held in Johannesburg on 11 May 2018 (presentation is shown in Appendix 10.19).

7.1 Drone highwall mapping

The drone highwall face mapping that uses the digital photogrammetry technique, should be adopted as best practice for use at Isibonelo Colliery and the rest of the ACSA opencast operations. The mapping process produces very accurate results in a very short space of time. The 3-D model generated from the drone data can be used to show many other geological areas of interest. Figure 7.1.1 shows the 3-D Model of the Far South pit (the study area).

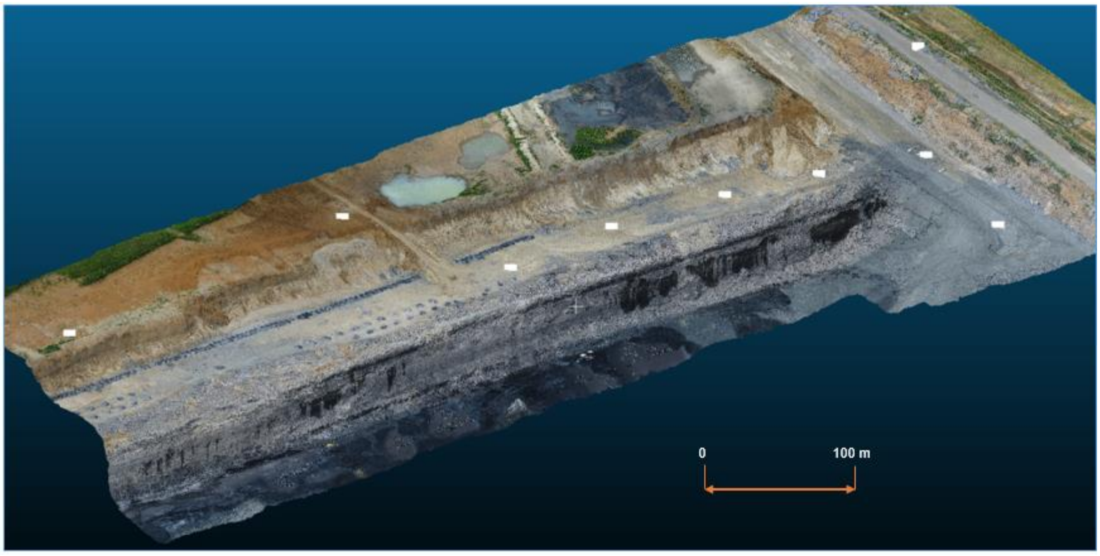


Figure 7.1.1 South Pit: Drone Flyover view

(De Bruyn, 2018)

The 3-D model generated can also be used by mine planning and rock engineering to reconcile design from actual excavation. The slope angles and cut width can be measured and cross sections drawn for comparison with designs (design verification). Currently, handheld laser instruments are being used to take measurements for design verification and the degree of accuracy is person dependent, in the author's opinion; this 3-D model can provide the required information.

7.2 In-house implementation of drone data manipulation

Geologists should be equipped with knowledge of the latest technology to be able to generate as much data as possible for short-term modelling. The drone flyover highwall data model building should be the focus of geologists spending more time interpreting geology and updating short-term models with the latest information. Isibonelo Colliery should invest in the software and training of geologists to be able to build the models in-house and use the information to update the geological models.

The current drones on the market such as the Phantom 4, cost less than R100 000, so to save costs on hiring contractors, geologists or surveyors can be trained and licenced to fly the drone (in-house equipment) and generate data as and when required. The drone will not only generate information for geology alone but also for other disciplines such as survey, planning, rock engineering and or engineering.

The basics of highwall mapping using a total station should be in place as a stop gap measure should all other technologies not be available or implemented. The training of geologists on the basics of surveying points using a total station is highly recommended, provided the provisions of the Mine Health Safety Act (1996) Chapter 17, allow it, hence it will also be recommended to investigate further this process.

7.3 Other techniques

It is also recommended that geologists be exposed to many other mapping techniques such as use of Sirovision (as used in Australia), digital photogrammetry using own digital cameras and processing the data using software such as 3DM analysist. The mine can purchase the relevant software and geologists get trained to run on their own to save costs from outsourcing the services. Further research should be undertaken to investigate how the data from highwall mapping when extrapolated can be integrated into one data base to allow automatic feed into mine planning.

7.4 Wireline logging

The author, from the research finding recommends the use of downhole wireline logging at Isibonelo Colliery to bring more accuracy to drill designs especially regarding the interburden. The mine should have a contract with a reputable service provider and regularly have the pre-split wireline logged (selected holes), and the information incorporated into the short-term geological model. The experience shared with Klipspruit Colliery (see section 2.9) is good testimony that wireline logging has many benefits in terms of drill and blast design accuracy and subsequent improved coal recovery.

7.5 Short-term model process

On completion of the research report, it is the author's recommendation that a workshop on short-term geological modelling be held for Anglo American Coal South Africa operations geologists, mine planners and rock engineering and resource evaluation geologists to map the way forward for the group with learnings from this report. The proposed procedure for short-term modelling resulting from the research project is detailed below for discussion and adoption with amendments by the different stakeholders.

The first step is to identify the highwall to be mapped/or the drill bench where pre-split holes are ready for wireline logging. Such area includes any new strip or new box cut or any working face that has been exposed inclusive of in-pit and "softs" highwall and the responsibility lie with the colliery geology section.

The second step is to check availability of the highwall both in-pit and softs to be mapped, then arrange appropriate date and time with the service provider for the drone flyover and or wire logging. Mining personnel play an important role for ensuring access to the area is safe for both men and equipment. On every flyover, the production geologist and the mine surveyor are to accompany the service provider to assist with access as well as checking if control points are adequate (on the part of survey) and ensure the correct area is flown.

The third step involves data processing by the service provider which is done off site. In the case of drone data, the model will be available in five days after flyover and wireline logging results can be availed in less than two days after completing fieldwork.

When the 3-D Model is received from the service provider it is then imported into the appropriate software for geological extrapolation and produce information in the format required for input into short-term mine planning. The general format is comma separated values (.csv files) and cross sections accompanied by tabulated mine block data.

Management of the database is the responsibility of the geology department; however, a copy of the same data base will be forwarded to Anglo American Geological Services(ACGS) Resource Evaluation Department where the resource model is generated and archived. The data may then be incorporated into the annual resource model updates where appropriate. Meanwhile the colliery geology section will keep the short-term model live at the colliery with regular updates as mining progresses and provide mine planning with the latest information.

There is a proposed procedure template for the short-term modelling process, attached in Appendix 10.20 for adoption with modification to make it colliery specific depending on the conditions.

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10 APPENDICES

10.1 Geological cross section of Strip 32 Blocks 4 to 12 North Pit

10.2 Block data extract from Geological Model

10.3 Typical Highwall showing modelled horizons- South pit (S5-S6)

10.4 Callide Short-Term Modelling Workflow

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10.7 Strip Risk Assessment-Strip 16 South Pit

10.8 BHSO Analysis Table Mapped versus Model

10.9 BHFW Analysis Table Mapped versus Model

10.10 Geology Short-term Modelling Audit template

10.11 Isibonelo Colliery aerial view

10.12 BHSO Boreholes file

10.13 BHFW Boreholes file

10.14 BHWE Boreholes file

10.15 Sandstone Boreholes file

10.16 4-Seam roof contact boreholes file

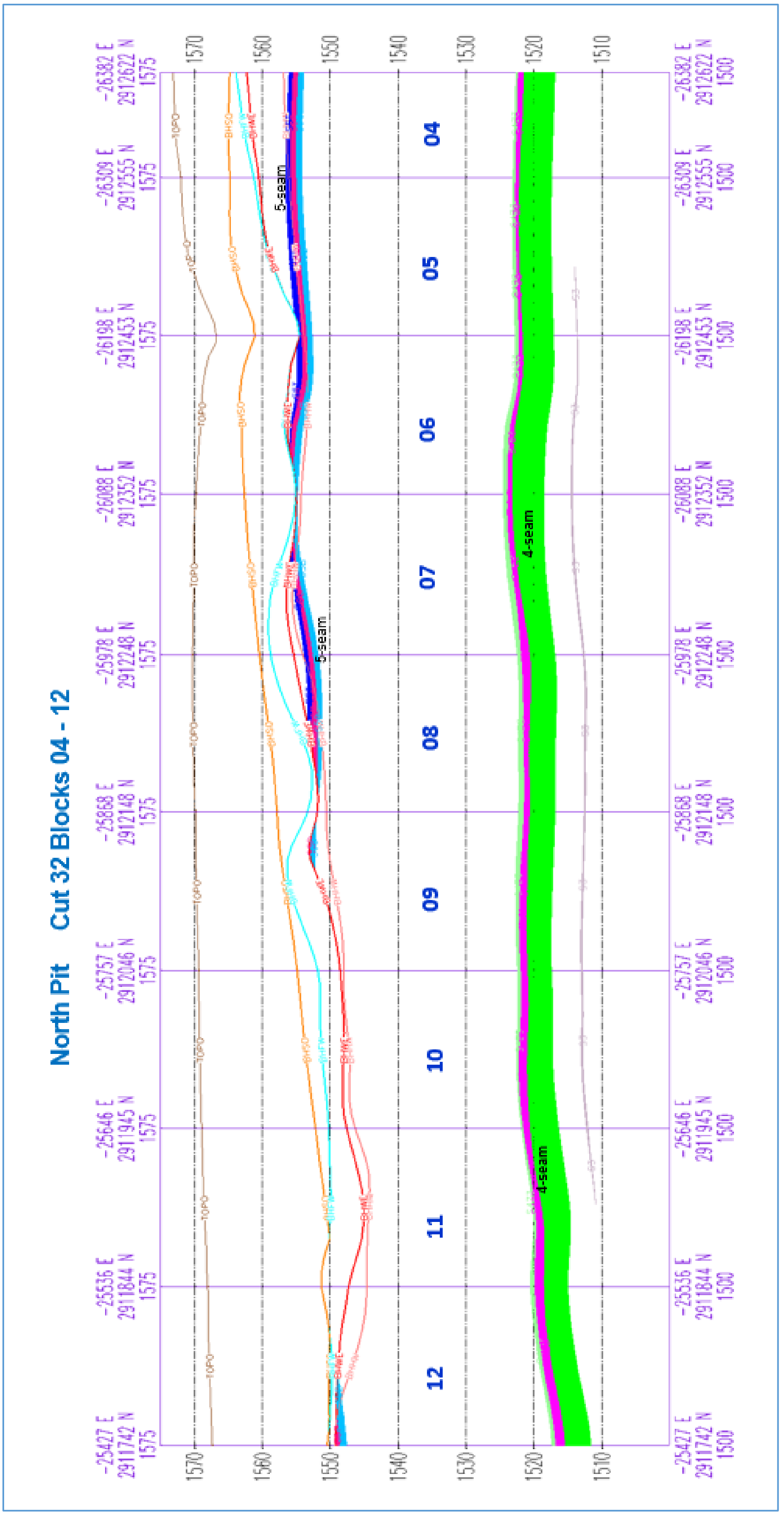
10.17 Sandstone lithology file

10.18 BHFW Lithology File

10.19 Geoscience Colloquium Presentation

10.20 Proposed STM procedure

Appendix 10.1 Geological cross section of Strip 32 Blocks 4 to 12 North Pit



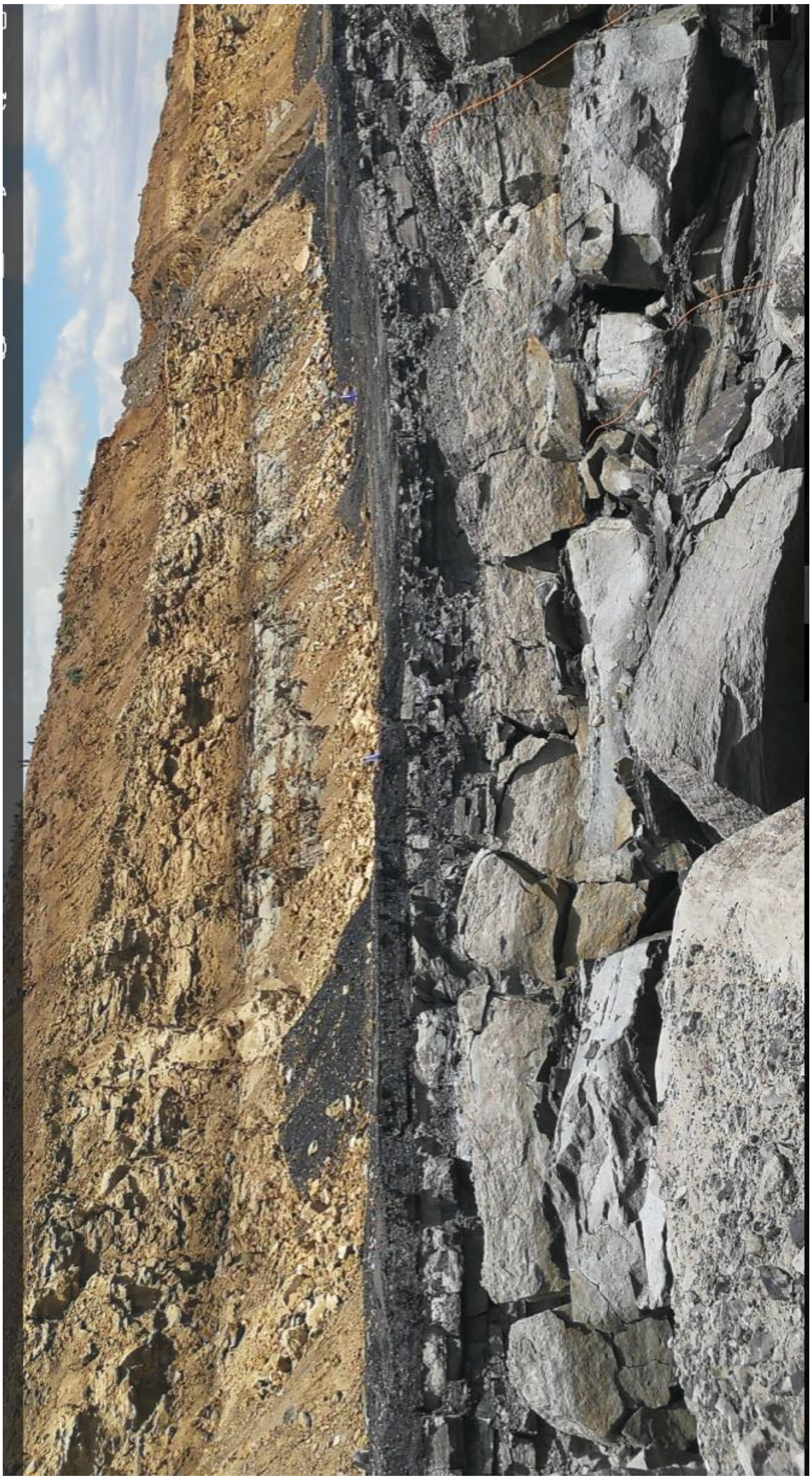
Appendix 10.2 Block data extract from Geological Model

[C:\PROJECTS\C_migisi_f17_audit_131017_CPR\reports\burden_file_isi_m4_0417.rpt] - UltraEdit

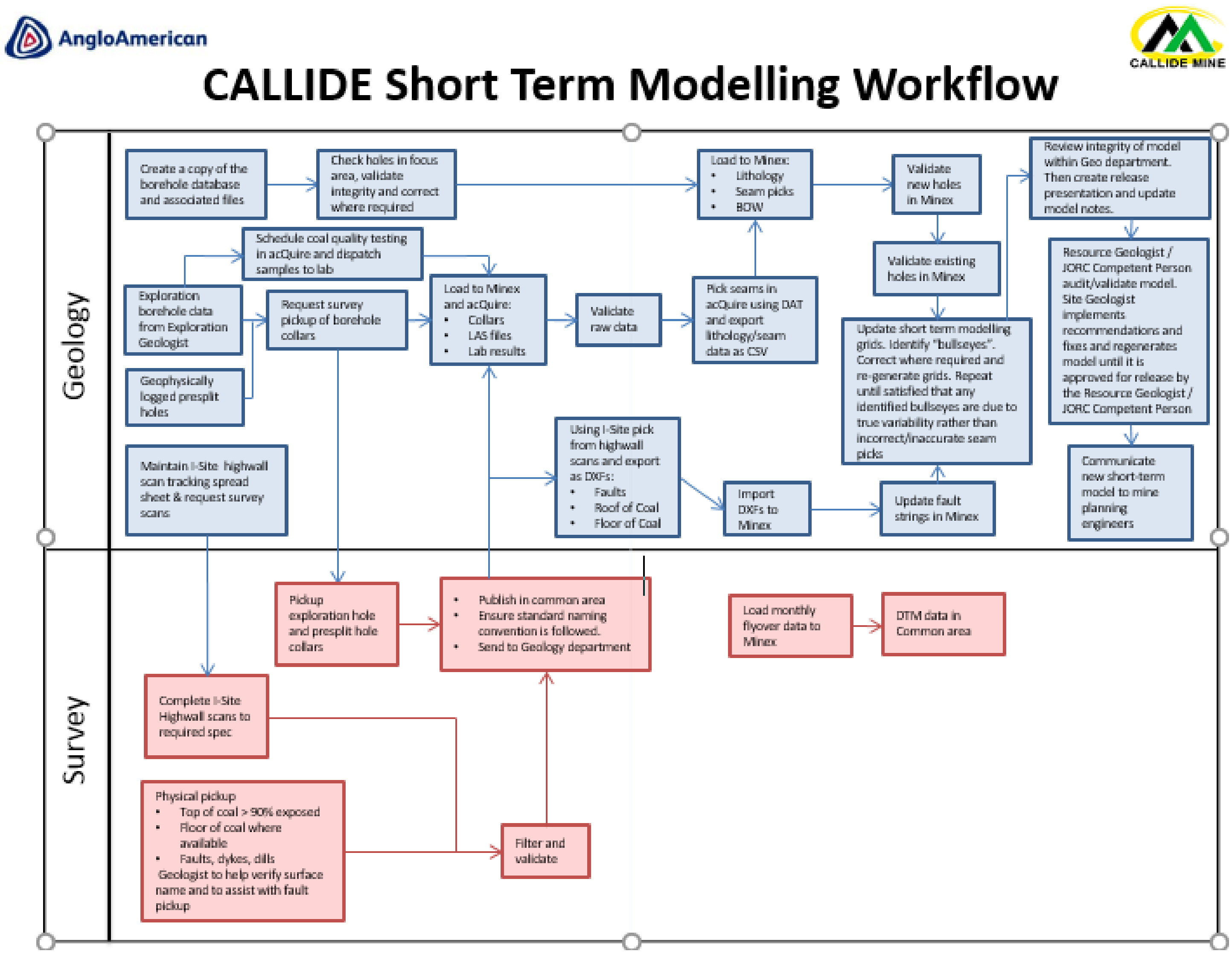
KIC00101	4944	54673	11.06	72891	14.74	127565	25.80
KIC00102	7500	78235	10.43	112425	14.99	190660	25.42
KIC00103	7500	78094	10.41	99073	13.21	177167	23.62
KIC00104	7500	74160	9.89	87125	11.62	161285	21.50
KIC00105	7500	68172	9.09	90652	12.09	158824	21.18
KIC00106	7500	69431	9.26	91271	12.17	160703	21.43
KIC00107	7500	60350	8.05	89057	11.87	149408	19.92
KIC00108	7500	61310	8.17	89211	11.89	150521	20.07
KIC00109	7500	60879	8.12	80170	10.69	141049	18.81
KIC00110	7500	60506	8.07	77621	10.35	138127	18.42
KIC00111	7500	51757	6.90	87209	11.63	138966	18.53
KIC00112	7034	45499	6.47	94769	13.47	140268	19.94
KIC00201	4443	49410	11.12	65622	14.77	115032	25.89
KIC00202	7500	78091	10.41	116422	15.52	194513	25.94
KIC00203	7500	74718	9.96	103532	13.80	178250	23.77
KIC00204	7500	70199	9.36	92460	12.33	162659	21.69
KIC00205	7500	67840	9.05	90330	12.04	158170	21.09
KIC00206	7500	63706	8.49	104248	13.90	167954	22.39
KIC00207	7500	57974	7.73	100129	13.35	158103	21.08
KIC00208	7500	58869	7.85	99184	13.22	158053	21.07
KIC00209	7500	56870	7.58	93718	12.50	150588	20.08
KIC00210	7500	56147	7.49	83118	11.08	139266	18.57
KIC00211	7500	49917	6.66	95845	12.78	145762	19.44
KIC00212	6400	45762	7.15	88051	13.76	133813	20.91
KIC00301	3941	32809	8.33	72482	18.39	105291	26.72
KIC00302	7500	69894	9.32	130108	17.35	200001	26.67
KIC00303	7500	67150	8.95	110790	14.77	177940	23.73
KIC00304	7500	65013	8.67	98574	13.14	163587	21.81
KIC00305	7500	63165	8.42	95205	12.69	158370	21.12
KIC00306	7500	58924	7.86	107297	14.31	166221	22.16
KIC00307	7500	56820	7.58	103518	13.80	160339	21.38
KIC00308	7500	57023	7.60	105396	14.05	162419	21.66
KIC00309	7500	48459	6.46	108782	14.50	157240	20.97
KIC00310	7500	46119	6.15	95757	12.77	141876	18.92
KIC00311	7500	51871	6.92	95698	12.76	147568	19.68
KIC00312	5766	45195	7.84	76963	13.35	122158	21.19
KIC00402	10939	95334	8.72	216075	19.75	311410	28.47

The data shows in columns from left to right: block names, block area, volume from topography to BHFW, depth from topography to BHFW, volume from topography to BHWE, depths from topography to BHWE, volume from topography to 4-seam roof, and depth from topography to 4-seam roof

Appendix 10.3 10.3 Typical Highwall showing modelled horizons- South pit (S5-S6)



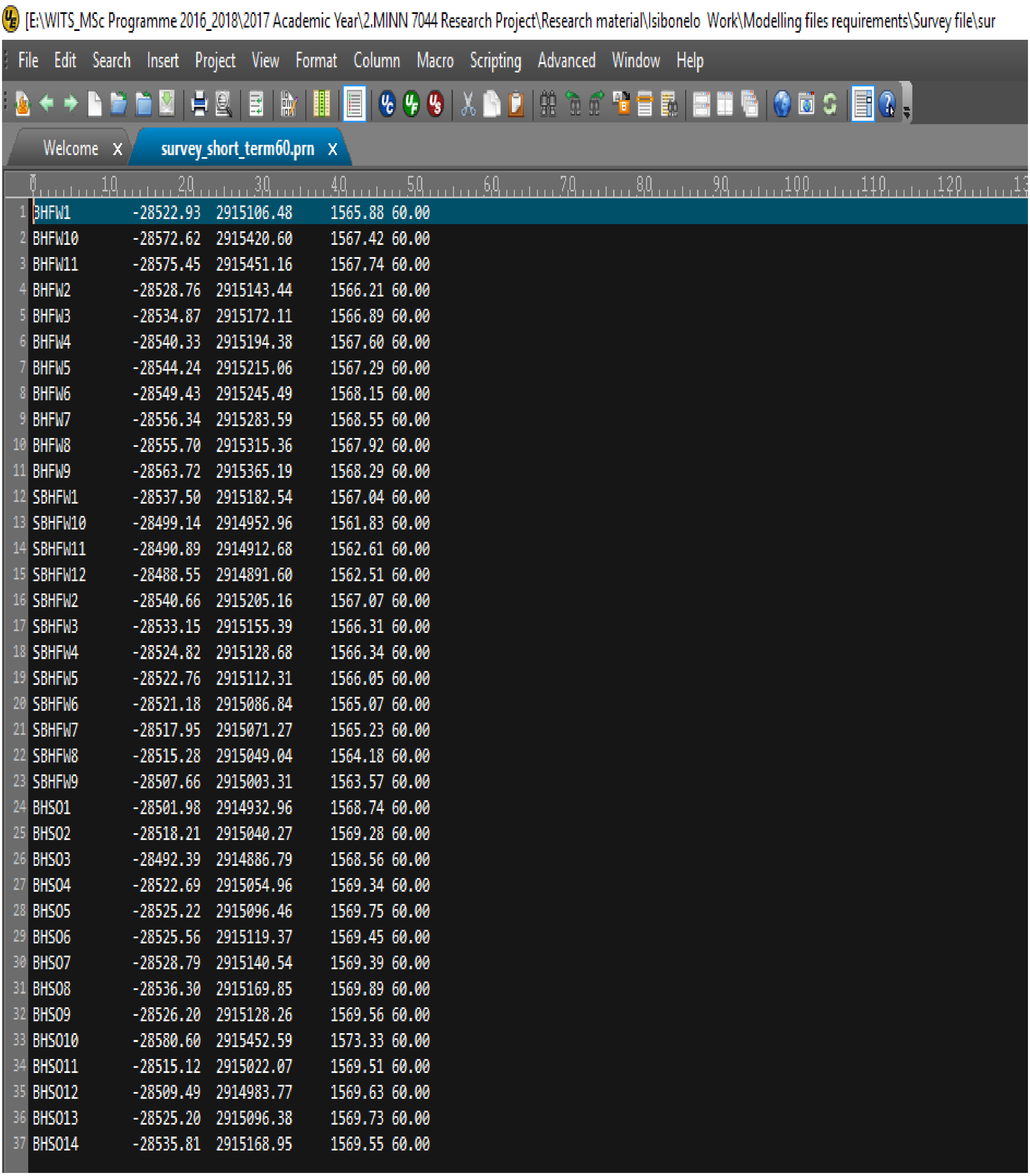
Appendix 10.4 Callide Short-Term Modelling Workflow



Appendix 10.5 Borehole Predictions files

mkaturuza	MINCOM	SOFTWARE												
22-Dec-17	C_MIGISI_	PROJECT	VERSION	4119										
s4_str19a	Page:	1												
____														
Predicted	Hole	ID:	HWC1											
Easting:	-28362.99	Northing:	2914626.8	Collar	:	1569.00								
Schema	:	oc_f17_02	Model	type	:	GRID								
--														
Number	of	intersecti	24											
Depth	Elevation	Thickness	Unit	name	Lith	Type	Intersect	type						
0	1569	0	TOPO	Collar										
12.32	1556.68	12.32	BHSO	Surface										
12.57	1556.43	0.25	BHFW	Surface										
18.23	1550.77	5.66	BHHW	Surface										
18.46	1550.54	0.23	BHWE	Surface										
19.36	1549.64	0.9	S5T	Interval_roof										
19.7	1549.3	0.34	S5T	Interval_floor										
19.7	1549.3	0	S5P	Interval_roof					48.9623	**HWC1**	**S4Z3_ROOF**		**48.9623**	**48.9623**
20.28	1548.73	0.58	S5P	Interval_floor										
20.28	1548.73	0	S5B	Interval_roof										
21.04	1547.96	0.77	S5B	Interval_floor										
49.38	1519.62	28.34	S4Z3	Interval_roof										
50.17	1518.83	0.8	S4Z3	Interval_floor										
50.17	1518.83	0	S4Z2	Interval_roof										
50.99	1518.01	0.82	S4Z2	Interval_floor										
50.99	1518.01	0	S4Z1	Interval_roof										
55.43	1513.57	4.44	S4Z1	Interval_floor										
59.38	1509.62	3.95	S3	Interval_roof										
59.47	1509.53	0.09	S3	Interval_floor										
79.92	1489.09	20.44	S2	Interval_roof										
80.58	1488.43	0.66	S2	Interval_floor										
120.7	1448.3	40.13	THDW	Surface										
120.7	1448.3	0	THDW	Surface										
124.39	1444.61	3.69	THPK	Surface										
mkaturuza	MINCOM	SOFTWARE												
22-Dec-17	C_MIGISI_	PROJECT	VERSION	4119										
s4_str19a	Page:	2												
____														
Predicted	Hole	ID:	HWC10											
Easting:	-28388.3	Northing:	2914817.5	Collar	:	1569.99								
Schema	:	oc_f17_02	Model	type	:	GRID								
--														
Number	of	intersecti	24											
Depth	Elevation	Thickness	Unit	name	Lith	Type	Intersect	type						
0	1569.99	0	TOPO	Collar										
9.24	1560.74	9.24	BHSO	Surface										
10.98	1559	1.74	BHFW	Surface										
13.02	1556.96	2.04	BHWE	Surface										
14.02	1555.96	1	BHHW	Surface										
19.91	1550.08	5.88	S5T	Interval_roof										
20.24	1549.74	0.34	S5T	Interval_floor										
20.24	1549.74	0	S5P	Interval_roof										
21.05	1548.93	0.81	S5P	Interval_floor										
21.05	1548.93	0	S5B	Interval_roof										
21.8	1548.18	0.75	S5B	Interval_floor										
49.74	1520.24	27.94	S4Z3	Interval_roof										
50.31	1519.67	0.57	S4Z3	Interval_floor					49.0977	**HWC10**	**S4Z3_ROOF**		**49.0977**	**49.0977**
50.31	1519.67	0	S4Z2	Interval_roof										
51.36	1518.63	1.05	S4Z2	Interval_floor										
51.36	1518.63	0	S4Z1	Interval_roof										
55.74	1514.24	4.38	S4Z1	Interval_floor										
59.85	1510.13	4.11	S3	Interval_roof										
59.89	1510.09	0.04	S3	Interval_floor										
80.52	1489.46	20.63	S2	Interval_roof										
81.34	1488.65	0.82	S2	Interval_floor										
120.18	1449.8	38.84	THDW	Surface										
120.18	1449.8	0	THDW	Surface										
125.14	1444.84	4.96	THPK	Surface										

Appendix 10.6 Survey File Generated



BHFW1	-28522.93	2915106.48	1565.88	60.00
BHFW10	-28572.62	2915420.60	1567.42	60.00
BHFW11	-28575.45	2915451.16	1567.74	60.00
BHFW2	-28528.76	2915143.44	1566.21	60.00
BHFW3	-28534.87	2915172.11	1566.89	60.00
BHFW4	-28540.33	2915194.38	1567.60	60.00
BHFW5	-28544.24	2915215.06	1567.29	60.00
BHFW6	-28549.43	2915245.49	1568.15	60.00
BHFW7	-28556.34	2915283.59	1568.55	60.00
BHFW8	-28555.70	2915315.36	1567.92	60.00
BHFW9	-28563.72	2915365.19	1568.29	60.00
SBHFW1	-28537.50	2915182.54	1567.04	60.00
SBHFW10	-28499.14	2914952.96	1561.83	60.00
SBHFW11	-28490.89	2914912.68	1562.61	60.00
SBHFW12	-28488.55	2914891.60	1562.51	60.00
SBHFW2	-28540.66	2915205.16	1567.07	60.00
SBHFW3	-28533.15	2915155.39	1566.31	60.00
SBHFW4	-28524.82	2915128.68	1566.34	60.00
SBHFW5	-28522.76	2915112.31	1566.05	60.00
SBHFW6	-28521.18	2915086.84	1565.07	60.00
SBHFW7	-28517.95	2915071.27	1565.23	60.00
SBHFW8	-28515.28	2915049.04	1564.18	60.00
SBHFW9	-28507.66	2915003.31	1563.57	60.00
BHSO1	-28501.98	2914932.96	1568.74	60.00
BHSO2	-28518.21	2915040.27	1569.28	60.00
BHSO3	-28492.39	2914886.79	1568.56	60.00
BHSO4	-28522.69	2915054.96	1569.34	60.00
BHSO5	-28525.22	2915096.46	1569.75	60.00
BHSO6	-28525.56	2915119.37	1569.45	60.00
BHSO7	-28528.79	2915140.54	1569.39	60.00
BHSO8	-28536.30	2915169.85	1569.89	60.00
BHSO9	-28526.20	2915128.26	1569.56	60.00
BHSO10	-28580.60	2915452.59	1573.33	60.00
BHSO11	-28515.12	2915022.07	1569.51	60.00
BHSO12	-28509.49	2914983.77	1569.63	60.00
BHSO13	-28525.20	2915096.38	1569.73	60.00
BHSO14	-28535.81	2915168.95	1569.55	60.00

Appendix 10.7 Strip Risk Assessment-Strip 16 South Pit

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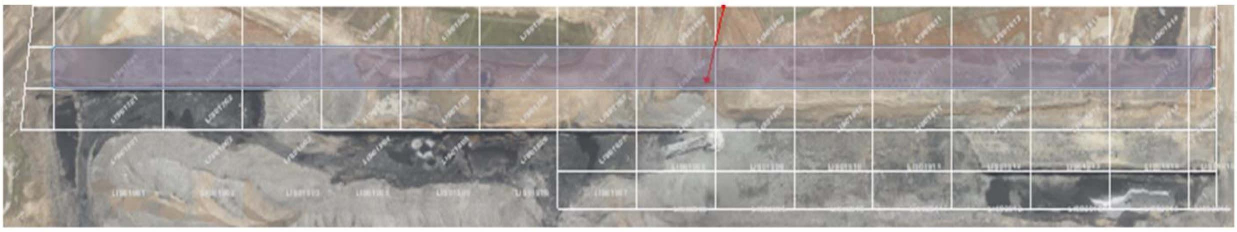
ISIBONELO COLLIERY
STRIP RISK ASSESMENT

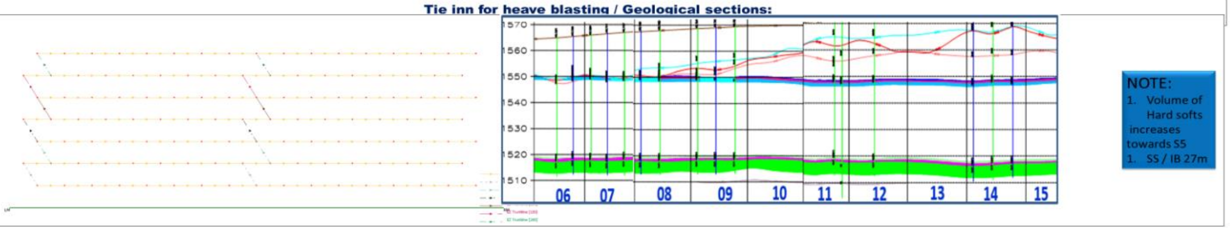
PIT: SOUTH PIT
STRIP: 16
BLOCK: 7 - 15

ACTIVITY: Drilling & Blasting INTERBURDEN
AT Nr: at 215

LOCATION:



Tie inn for heave blasting / Geological sections:



GEOTECH: AT 169 V1

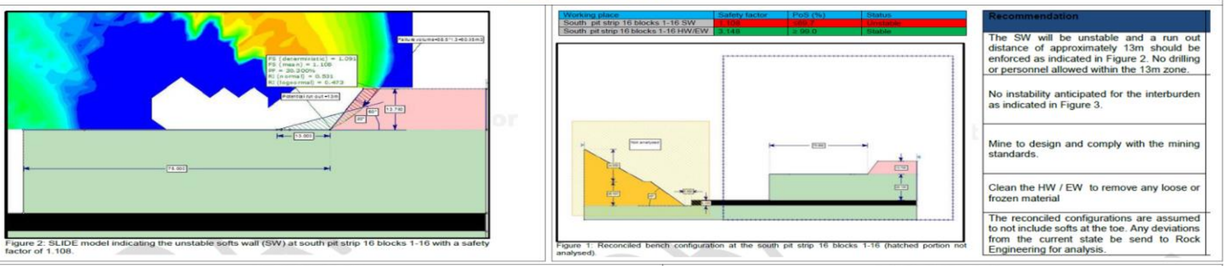


Figure 2: SLIDE model indicating the unstable softs wall (SW) at south pit strip 16 blocks 1-16 with a safety factor of 1.108.

Figure 1: Reconciled bench configuration at the south pit strip 16 blocks 1-16 (hatched portion not analysed).

DRILL DESIGN:

1) Strip 16 Blocks 1 – 15 Drilling
2) Average depth 24 - 31 m
3) Burden 9m by Spacing 11m
4) Number of rows 6 on 311mm .
5) Total meters to be drilled 36 754m IB and 4 226m softs from Block 8.
6) Daily observation and recording of Drilled holes to compare and assure compliance to plan.
7) Powder factor of 0.65
8) Cup density of 1.05
9) Hole diameter 311mm .
10) Stemming 6.5 m
11) Heave blast design as DL 1 will be chopping.

TASKS/ACTIONS:

TASK/ACTION	RESPONSIBLE PERSON	DATE
1) Pre stripping to prep the area before drilling can commence.	Liviero / Dragline 1	
2) Accurate Staking out of drilling holes is of utmost importance and should be monitored on a daily basis by Drilling foreman.	C Nkomo / Survey	
3) Bench sign off to be in place in order for drilling to commence.	Dragline foreman / Pre-strip Foreman	
4) Any drilling deviations should be reported to MAE.	C Nkomo / Team / G de Lange	
5) Closing holes after being drilled by means of white hats on top in order to prevent holes collapsing or closing up.	C Nkomo / TEAM / G J de Lange	
6)	C Nkomo / TEAM / G J de Lange	

HAZARD	CONTROLS	ACTIONS
1) Softs High wall.	Drop zone cones and daily inspections.	Should be verified to comply with design.
2) Moving machinery	VMP standard and fundamental parking and barricading.	Should be verified to comply with design.
3) Low wall.	Berms need to be in place on crest.	Should be verified to comply with design.
4) LDV management on drilling benches.	Barricading, signage and two way radio communication with operators.	Should be verified to comply with design.

NAME	DESIGNATION	SIGNATURE	DATE
H Reyneke	Sec Manager		
L Janse van Rensburg	Planning Manager		
G J de Lange	Activity Engineer		
C Nkomo	D & B MO		
M Katuruza	Geology Manager		
J Felix	Rock Engineer		
S Crous	Survey Manager		

HOD SIGN-OFF:

NAME	DESIGNATION	SIGNATURE	DATE
E Carpenter	TSD Manager		
D Miller	General Manager		
T Tamenti	Mining Manager		

Appendix 10.8 BHSO Analysis Table Mapped versus Model

	Mapped BHSO Elevation	Model BHSO Elevation	Variance
BHSO1	1568.74	1559.75	8.99
BHSO2	1569.28	1562.08	7.2
BHSO3	1568.56	1559.3	9.26
BHSO4	1569.34	1562.35	6.99
BHSO5	1569.75	1563.48	6.27
BHSO6	1569.45	1564.02	5.43
BHSO7	1569.39	1564.3	5.09
BHSO8	1569.89	1564.21	5.68
BHSO9	1569.56	1564.18	5.38
BHSO10	1573.33	1564.62	8.71
BHSO11	1569.51	1561.46	8.05
BHSO12	1569.63	1560.38	9.25
BHSO13	1569.73	1563.48	6.25
BHSO14	1569.55	1564.22	5.33
BHSO15	1570.06	1563.96	6.1
BHSO16	1570.25	1563.67	6.58
BHSO17	1570.38	1563.28	7.1
BHSO18	1571.05	1563.23	7.82
BHSO19	1571.28	1565.63	5.65
BHSO20	1572.51	1564.23	8.28
BHSO21	1573.04	1564.37	8.67
7BHS1	1564.16	1554.06	10.1
7BHS2	1564.18	1553.83	10.35
7BHS3	1563.94	1553.59	10.35
7BHS4	1563.27	1553.39	9.88
7BHS5	1563.02	1552.6	10.42
7BHS6	1562.17	1551.9	10.27
7BHS7	1562.55	1551.11	11.44
7BHS8	1561.55	1549.99	11.56
7BHS9	1558.97	1549.92	9.05
7BHS10	1559.35	1549.58	9.77
7BHS11	1562.78	1552.09	10.69
7BHS12	1564.19	1553.64	10.55
7BHSO1	1566.19	1555.7	10.49
7BHSO2	1566.11	1556.16	9.95
7BHSO3	1566.34	1556.79	9.55
7BHSO4	1566.51	1557.36	9.15
7BHSO5	1566.09	1557.84	8.25
7BHSO6	1565.41	1558.11	7.3
7BHSO7	1566.07	1558.1	7.97
7BHSO8	1566.95	1557.73	9.22
7BHSO9	1566.02	1557.56	8.46
7BHSO10	1566.85	1556.91	9.94

7BHSO11	1567.37	1557.78	9.59
7BHSO12	1566.64	1560.12	6.52
7BHSO13	1565.59	1558.2	7.39
7BHSO14	1565.94	1557.5	8.44
BHHSO1	1567.86	1564.18	3.68
BHHSO10	1572.18	1564.62	7.56
BHHSO11	1568.00	1561.46	6.54
BHHSO12	1568.52	1560.38	8.14
BHHSO13	1568.22	1563.48	4.74
BHHSO2	1567.81	1564.22	3.59
BHHSO3	1568.79	1563.96	4.83
BHHSO4	1569.14	1563.67	5.47
BHHSO5	1569.33	1563.28	6.05
BHHSO6	1570.13	1563.23	6.9
BHHSO7	1570.09	1565.63	4.46
BHHSO8	1571.59	1564.23	7.36
BHHSO9	1571.85	1564.37	7.48
BBHSO1	1567.06	1559.75	7.31
BBHSO2	1567.53	1562.08	5.45
BBHSO3	1566.91	1559.3	7.61
BBHSO4	1567.63	1562.35	5.28
BBHSO5	1568.26	1563.48	4.78
BBHSO6	1567.63	1564.02	3.61
BBHSO7	1567.51	1564.3	3.21
BBHSO8	1568.49	1564.21	4.28
Average	**1567.60**	**1560.06**	7.55

Appendix 10.9 BHFW Analysis Table Mapped versus Model

	Mapped BHFW Elevation	Model BHFW Elevation	Variance
BHFW1	1565.88	1563.85	2.03
BHFW10	1567.42	1563.05	4.37
BHFW11	1567.74	1562.64	5.1
BHFW2	1566.21	1564.2	2.01
BHFW3	1566.89	1563.99	2.9
BHFW4	1567.6	1563.7	3.9
BHFW5	1567.29	1562.87	4.42
BHFW6	1568.15	1560.81	7.34
BHFW7	1568.55	1561.51	7.04
BHFW8	1567.92	1564.44	3.48
BHFW9	1568.29	1565.71	2.58
SBHFW1	1567.04	1563.91	3.13
SBHFW10	1561.83	1559.59	2.24
SBHFW11	1562.61	1560.5	2.11
SBHFW12	1562.51	1559.75	2.76
SBHFW2	1567.07	1563.37	3.7
SBHFW3	1566.31	1564.2	2.11
SBHFW4	1566.34	1564.16	2.18
SBHFW5	1566.05	1563.99	2.06
SBHFW6	1565.07	1563.43	1.64
SBHFW7	1565.23	1563.11	2.12
SBHFW8	1564.18	1562.65	1.53
SBHFW9	1563.57	1560.97	2.6
7BHFW1	1560.9	1554.96	5.94
7BHFW2	1560.46	1555.22	5.24
7BHFW3	1560.03	1555.05	4.98
7BHFW4	1560.61	1554.61	6
7BHFW5	1560.83	1554.28	6.55
7BHFW6	1561.62	1554.13	7.49
7BHFW7	1561.02	1554.49	6.53
7BHFW8	1561.78	1555.42	6.36
7BHFW9	1561.62	1550.64	10.98
7BHFW10	1561.72	1551.24	10.48
7BHFW11	1561.55	1551.07	10.48
7BHFW12	1564.21	1556.43	7.78
Average	**1564.46**	**1559.83**	**4.63**

Appendix 10.10 Geology Short-term Modelling Audit template

AngloAmerican

OMS AUDIT SHEETS

CK-23-35-107B - Short Term Modelling

Site:	ISIBONELO
Audit Date:	02-Aug-17
Auditors Names:	
Site Participants:	

ITEM	PROCESS STEP	DEFINITION	NO. OF COMPONENTS	COMPLIANCE	COMPONENT	NUMBER OF COMPLIANCE	SCORE	SITE COMMENTS (EVIDENCE, FEEDBACK AND DETAILS)	AUDIT COMMENTS SUPPORTING DOCUMENTS (EVIDENCE, FEEDBACK, AND		Best Practice	Action Required	By Who	By When	Sign-off
1	Mapping: Sites shall undertake regular mapping.	Data Collection: Regular mapping is undertaken using appropriate mapping styles to meet requirements in terms of timing and quality. Process includes geological and geotechnical mapping as well as field observations.	1	Site has a formal, documented process for mapping new exposures	1	0	67%			yes	1				
		The site must have a process in place to monitor and report on progress towards mapping new exposures as a critical lead indicator in the identification of hazards or conditions that may result in a deviation to plan	2	Mapping of new exposures occurs regularly at timeframes linked to OMS operational planning and control requirements.	1	1				yes	1				
			3	Documented process includes: - Type and content - frequency / timing - QA/QC - Use of interpretations - Presentation formats - Communication of information - storage and versioning - KPIs to be tacked	1	0				yes	1				
			4	Minimum standard includes: O/C - georeferenced and interpreted quality photographs U/G - Georeferenced and interpreted face & development mapping	1	1				yes	1				
			5	Site can demonstrate high level of compliance with documented process (80% - 95%)	1	1				yes	1				
			6	KPIs relating to adherence with the documented process established and tracked	1	1				yes	1				
		Process by which geological / geotechnical mapping / observations and new exploration data is interpreted to convert it into useful information.	1	Site has a formal, documented process for geological interpretation	1	1				yes	1				
		New data may include (In addition to mapping), exploration or operational	2	Documented process includes: - Type and content - frequency / timing - QA/QC - Use of interpretations - Presentation formats	1	1				yes	1				

Appendix 10.11 Isibonelo Colliery aerial view

Appendix 10.12 BHSO Boreholes file

BHSO			
BHSO1	-28501.98	2914932.96	1568.74
BHSO2	-28518.21	2915040.27	1569.28
BHSO3	-28492.39	2914886.79	1568.56
BHSO4	-28522.69	2915054.96	1569.34
BHSO5	-28525.22	2915096.46	1569.75
BHSO6	-28525.56	2915119.37	1569.45
BHSO7	-28528.79	2915140.54	1569.39
BHSO8	-28536.30	2915169.85	1569.89
BHSO9	-28526.20	2915128.26	1569.56
BHSO10	-28580.60	2915452.59	1573.33
BHSO11	-28515.12	2915022.07	1569.51
BHSO12	-28509.49	2914983.77	1569.63
BHSO13	-28525.20	2915096.38	1569.73

Appendix 10.13 BHFW Boreholes file

BHFW			
BHFW1	-28522.93	2915106.48	1565.88
BHFW10	-28572.62	2915420.60	1567.42
BHFW11	-28575.45	2915451.16	1567.74
BHFW2	-28528.76	2915143.44	1566.21
BHFW3	-28534.87	2915172.11	1566.89
BHFW4	-28540.33	2915194.38	1567.6
BHFW5	-28544.24	2915215.06	1567.29
BHFW6	-28549.43	2915245.49	1568.15
BHFW7	-28556.34	2915283.59	1568.55
BHFW8	-28555.70	2915315.36	1567.92
BHFW9	-28563.72	2915365.19	1568.29
SBHFW1	-28537.50	2915182.54	1567.04
SBHFW10	-28499.14	2914952.96	1561.83
SBHFW11	-28490.89	2914912.68	1562.61
SBHFW12	-28488.55	2914891.60	1562.51
SBHFW2	-28540.66	2915205.16	1567.07
SBHFW3	-28533.15	2915155.39	1566.31
SBHFW4	-28524.82	2915128.68	1566.34
SBHFW5	-28522.76	2915112.31	1566.05
SBHFW6	-28521.18	2915086.84	1565.07
SBHFW7	-28517.95	2915071.27	1565.23
SBHFW8	-28515.28	2915049.04	1564.18
SBHFW9	-28507.66	2915003.31	1563.57
7BHFW1	-28426.18	2914463.00	1560.9
7BHFW2	-28429.61	2914495.81	1560.46
7BHFW3	-28433.49	2914522.78	1560.03
7BHFW4	-28436.17	2914544.10	1560.61
7BHFW5	-28438.23	2914562.40	1560.83
7BHFW6	-28442.85	2914578.05	1561.62
7BHFW7	-28445.01	2914595.38	1561.02
7BHFW8	-28447.92	2914620.97	1561.78
7BHFW9	-28451.90	2914643.44	1561.62
7BHFW10	-28455.53	2914672.32	1561.72
7BHFW11	-28460.20	2914705.27	1561.55
7BHFW12	-28482.33	2914795.35	1564.21

Appendix 10.14 BHWE Boreholes file

BHWE			
7BHWE1	-28414.01	2914490.01	1550.09
7BHWE2	-28419.65	2914521.22	1549.72
7BHWE3	-28419.3	2914500.49	1549.98
7BHWE4	-28420.88	2914533.42	1549.5
7BHWE5	-28425.86	2914550.31	1548.77
7BHWE6	-28427.77	2914573.75	1549.27
7BHWE7	-28431.87	2914580.15	1548.81
7BHWE8	-28431.93	2914593.67	1549.22
7BHWE9	-28436.29	2914609.81	1549.04
7BHWE10	-28437.99	2914626.76	1549.12
7BHWE11	-28437.7	2914637.96	1549.22

Appendix 10.15 Sandstone Boreholes file

SANDSTONE/SILTSTONE			
BSSFL1	-28498.09	2914990.94	1550.0052
BSSFL2	-28485.21	2914941.05	1550.9441
BSSFL3	-28477.21	2914886.88	1550.0881
BSSFL4	-28488.65	2914957.93	1549.9992
BSSFLO1	-28535.32	2915179.52	1561.5565
BSSFLO10	-28491.42	2914924.54	1560.3827
BSSFLO11	-28486.01	2914887.92	1560.5649
BSSFLO2	-28529.94	2915150.12	1561.6451
BSSFLO3	-28522.87	2915128.11	1561.6351
BSSFLO4	-28520.95	2915112.54	1560.8791
BSSFLO5	-28521.16	2915099.57	1560.4022
BSSFLO6	-28514.1	2915074.5	1559.559
BSSFLO7	-28510.78	2915035.65	1559.9512
BSSFLO8	-28503.22	2914996.58	1559.5624
BSSFLO9	-28497.73	2914952.74	1559.9438
SSFLO1	-28539.42	2915217.87	1559.4396
SSFLO2	-28537.59	2915210.11	1559.5703
SSFLO3	-28536.4	2915203.83	1560.1627
SSFLO4	-28536.2	2915197.58	1560.1929
SSFLO5	-28535.23	2915192.01	1560.2184
SSTTOP1	-28516.92	2915086.29	1558.4635
SSTTOP10	-28495.24	2914951.78	1558.1594
SSTTOP11	-28488.23	2914916.57	1557.9297
SSTTOP12	-28480.13	2914852.64	1558.0651
SSTTOP2	-28519.09	2915093.99	1558.5137
SSTTOP3	-28520.41	2915107.21	1558.9952
SSTTOP4	-28519.84	2915122.13	1559.8978
SSTTOP5	-28524.66	2915139.64	1559.8628
SSTTOP6	-28529.39	2915155.44	1560.3836
SSTTOP7	-28513.52	2915074	1559.0515
SSTTOP8	-28512.91	2915053.47	1558.5924
SSTTOP9	-28500.53	2914993.59	1557.5985
SSTFLO1	-28521.07	2915141.07	1558.1807
SSTFLO10	-28483.37	2914888.43	1556.2788
SSTFLO2	-28518.66	2915117.34	1557.9887
SSTFLO3	-28518.01	2915099.66	1556.8934
SSTFLO4	-28516.36	2915087.3	1557.035
SSTFLO5	-28512.81	2915067.35	1558.2255
SSTFLO6	-28509.65	2915040.05	1557.0086
SSTFLO7	-28500.11	2914996.65	1556.3535
SSTFLO8	-28492.9	2914951.72	1556.1496
SSTFLO9	-28486.9	2914915.49	1556.3891

7SSFLO1	-28422.06	2914492.5	1552.6885
7SSFLO2	-28410.75	2914450.45	1553.5293
7SSFLO3	-28423.56	2914525.55	1552.1066
7SSFLO4	-28427.65	2914541.76	1551.7848
7SSFLO5	-28433.55	2914567.61	1552.5466
7SSFLO6	-28435.52	2914592.22	1551.7282
7SSFLO7	-28439.12	2914612.69	1551.7438
7SSFLO8	-28440.96	2914631.56	1552.0931
7SSFLO9	-28442.8	2914645.83	1551.8274
7SSFLO10	-28451.65	2914696.92	1552.8793
7SSFLO11	-28454.49	2914731.6	1553.3917
7SSFLO12	-28473.61	2914848.98	1554.01
7SSTOP1	-28413.03	2914451.45	1555.4136
7SSTOP2	-28426.28	2914496.11	1556.2799
7SSTOP3	-28434.13	2914532.4	1558.2362
7SSTOP4	-28436.63	2914559.34	1558.0161
7SSTOP5	-28441.91	2914580.4	1559.1091
7SSTOP6	-28442.12	2914600.71	1558.2716
7SSTOP7	-28444.24	2914616.72	1558.2754
7SSTOP8	-28449.17	2914642.58	1558.3605
7SSTOP9	-28456.92	2914697.61	1557.5921
7SSTOP10	-28476.73	2914813.33	1562.0486
7SSTOP11	-28492.28	2914923.1	1562.5769

Appendix 10.16 4-Seam roof contact boreholes file

S4Z3 (4-seam Roof)			
6HWC1	-28311.49	2914308.93	1518.29
6HWC10	-28366.1	2914659.03	1520.33
6HWC2	-28321.2	2914372.33	1518.31
6HWC3	-28328.86	2914420.63	1519.06
6HWC4	-28336.5	2914466.96	1519.05
6HWC5	-28341.51	2914493.78	1518.97
6HWC6	-28346.87	2914518.82	1518.94
6HWC7	-28352.56	2914555.78	1519.21
6HWC8	-28355.34	2914576.77	1519.47
6HWC9	-28362.6	2914620.38	1519.7
5HWC1	-28298.65	2913373.74	1520.57
5HWC2	-28322.77	2913527.45	1521.83
5HWC3	-28303.08	2913396.82	1520.3
5HWC4	-28282.16	2913333.66	1519.86
5HWC5	-28307.49	2913455.04	1520.74
5HWC6	-28307.05	2913446.73	1520.59
5HWC7	-28299.56	2913380.34	1520.4
5HWC8	-28279.43	2913325.44	1519.89
5HWC9	-28302.39	2913416.08	1519.95
5HWC10	-28318.47	2913504	1521.32
5HWC11	-28309.12	2913463.72	1520.8
5HWC12	-28299.62	2913380.74	1520.35
5HWC13	-28317.72	2913500.11	1521.39
5HWC14	-28281.46	2913331.73	1519.58
5HWC15	-28300.56	2913383.2	1520.42
5HWC16	-28301.81	2913420.12	1519.97
5HWC17	-28309.25	2913464.66	1520.78
5HWC18	-28311.13	2913471.82	1520.96
5HWC19	-28312.44	2913477.45	1521.06
5HWC20	-28316.03	2913494.75	1521.17
5HWC21	-28318.46	2913503.9	1521.38
5HWC22	-28319.1	2913508.82	1521.64
5HWC23	-28319.54	2913514.79	1521.73
5HWC24	-28322.82	2913531.04	1521.9
5HWC25	-28323.76	2913560.09	1521.76
5HWC26	-28331.99	2913607.54	1521.71
5HWC27	-28309.1	2913463.69	1520.77
5HWC28	-28340.2	2913647.33	1520.71
5HWC29	-28343.95	2913678.48	1520.18
5HWC30	-28344.02	2913699.01	1520.24
5HWC31	-28328.47	2913703.28	1520.1

5HWC32	-28313.59	2913706.05	1520.09
5HWC33	-28299.35	2913704.98	1520.06
5HWC34	-28287.33	2913702.18	1519.09
5HWC35	-28317.89	2913501.7	1521.43
5HWC36	-28309.57	2913465.01	1520.75
5HWC37	-28299.31	2913379.21	1520.79
5HWC38	-28312.8	2913479.54	1521.27
5HWC39	-28317.12	2913496.96	1521.33
5HWC40	-28291.11	2913361.31	1519.92
5HWC41	-28297.87	2913370.4	1520.43
5HWC42	-28316.8	2913496.31	1521.19
5HWC43	-28319.06	2913509.21	1521.65
4HC1	-28384.08	2914783.27	1520.58
4HC10	-28348.05	2914526.56	1519.04
4HC2	-28375	2914722.2	1520.38
4HC3	-28372.6	2914697.32	1520.41
4HC4	-28365.53	2914655.67	1520
4HC5	-28364.38	2914633.64	1519.82
4HC6	-28361.68	2914614.94	1519.83
4HC7	-28358.63	2914596.65	1519.65
4HC8	-28355.36	2914575.64	1519.57
4HC9	-28351.83	2914553.16	1519.3
HWC1	-28362.99	2914626.8	1520.04
HWC10	-28388.34	2914817.52	1520.89
HWC11	-28359.65	2914607.71	1519.83
HWC12	-28354.78	2914572.64	1519.62
HWC13	-28349.45	2914536.15	1519.41
HWC2	-28366.48	2914647.98	1519.93
HWC3	-28365.94	2914659.16	1520.14
HWC4	-28368.33	2914676.05	1520.16
HWC5	-28370.11	2914687.39	1520.39
HWC6	-28373.08	2914707.88	1520.41
HWC7	-28375.31	2914728.68	1520.36
HWC8	-28377.09	2914745.21	1520.66
HWC9	-28384.31	2914783.32	1520.61

Appendix 10.17 Sandstone lithology file

LITHOLOGY _SANDSTONE/SILTSTONE				
BSSFL1	SD_FLOOR		20.7848	20.7848
BSSFL1		ST	20.7848	60
BSSFL2	SD_FLOOR		19.5459	19.5459
BSSFL2		ST	19.5459	60
BSSFL3	SD_FLOOR		20.1519	20.1519
BSSFL3		ST	20.1519	60
BSSFL4	SD_FLOOR		20.5808	20.5808
BSSFL4		ST	20.5808	60
BSSFLO	SD_FLOOR		9.7535	9.7535
BSSFLO1		ST	9.7535	60
BSSFLO	SD_FLOOR		10.0073	10.0073
BSSFLO10		ST	10.0073	60
BSSFLO	SD_FLOOR		9.6551	9.6551
BSSFLO11		ST	9.6551	60
BSSFLO	SD_FLOOR		9.6349	9.6349
BSSFLO2		ST	9.6349	60
BSSFLO	SD_FLOOR		9.6349	9.6349
BSSFLO3		ST	9.6349	60
BSSFLO	SD_FLOOR		10.4109	10.4109
BSSFLO4		ST	10.4109	60

Appendix 10.18 BHFW Lithology File

Hole ID	Lithology	Stratigraphic Unit	Top Depth	Base Depth(EOH)
BHFW1	BHFW		5.42	5.42
BHFW1		ST	5.42	60
BHFW10	BHFW		6.39	6.39
BHFW10		ST	6.39	60
BHFW11	BHFW		6.73	6.73
BHFW11		ST	6.73	60
BHFW2	BHFW		5.06	5.06
BHFW2		ST	5.06	60
BHFW3	BHFW		4.41	4.41
BHFW3		ST	4.41	60
BHFW4	BHFW		3.72	3.72
BHFW4		ST	3.72	60
BHFW5	BHFW		4.06	4.06
BHFW5		ST	4.06	60
BHFW6	BHFW		3.27	3.27
BHFW6		ST	3.27	60
BHFW7	BHFW		3.18	3.18
BHFW7		ST	3.18	60
BHFW8	BHFW		4.29	4.29
BHFW8		ST	4.29	60

Appendix 10.19 Geoscience Colloquium Presentation

Separate attachment

Appendix 10.20 Proposed STM procedure

ISIBONELO COLLIERY PROPOSED SHORT TERM MODELLING PROCEDURE

AUTHORISATIONS	NAME	POSITION	SIGNATURE	DATE
Author	Meaker Katuruza	Geology Manager Production		
REVIEWED BY		Operational Geology Specialist		
REVIEWED BY		Technical Services Manager		
APPROVED BY		General Manager		

Separate attachment