



Managing the geotechnical and mining issues surrounding the extraction of small pillars at shallow depths at Xstrata Coal South Africa

by S.Z. Pethö*, C. Selai*, D. Mashiya*, and J.N. van der Merwe*

Synopsis

Pillar extraction at shallow depths with small pillars that were not originally intended for secondary extraction can provide a huge benefit to the coal mining industry in those areas where a significant percentage of the remaining coal reserves are locked up in small pillars at shallow depths and where opencast mining methods are simply not as cost-effective and practical to implement. A system considering all of the pertinent geotechnical and mining aspects for the safe and efficient pillar extraction of small pillars at shallow depths at Xstrata Coal South Africa (XCSA) has been further developed and implemented as part of an ongoing improvement process addressing all of the relevant legal and associated risk aspects. This work follows on from the previous pillar extraction work carried out at the ATC, Boschmans, and Spitzkop Collieries.

The process involved a number of in-house workshops and sessions arranged with all key personnel from Tavistock Colliery, and also included Professor Nielen van der Merwe of the University of the Witwatersrand, a world renowned authority on pillar extraction, towards reviewing and developing the Modified NEVID pillar extraction system employed previously at Boschmans Colliery.

The system is currently being employed at Tavistock Colliery with success and no major accidents, with around 655 000 t of coal having been successfully extracted from the pillar extraction panels.

Keywords

pillar extraction, small pillars at shallow depths, goafing, numerical modelling, instrumentation, mining and geotechnical considerations.

Introduction

Tavistock Colliery was first registered in 1936, and in 1960 Tavistock Colliery also acquired the South Witbank Coal Mine (SWCM), which was originally registered in 1945. It was during 1975 that JCI acquired an interest in Tavistock Colliery and SWCM, and subsequently in 1998 Duiker Mining acquired Tavistock Colliery from JCI. In 2000 Glencore bought Duiker Mining from Lonmin, and finally in 2002 Xstrata Coal South Africa (XCSA) acquired the mining interests of Duiker Mining.

The first coal was produced at Tavistock Colliery in 1948. Tavistock Colliery has the mining rights for the No. 2, 4, and 5 Seams in

the mine lease area. Both the No. 2 and 5 Seam have previously been mined, and there is still a small portion of No. 2 Seam reserves of approximately 3.2 Mt of run-of-mine (ROM) coal that has been excluded from any future plans, owing to the low yields and adverse geological conditions. All mining is currently concentrated on the No. 4 Seam, comprising one pillar extraction and three development sections with a total output of around 280 000 t/month.

The available coal reserves have dwindled over time, and the majority of the coal is now locked up in the remaining safety pillars. The pillar extraction project was initiated by this reality and the necessity to extend the life of mine in line with the entire Southstock complex which comprises, the South Witbank, No. 5 Seam, and Tavistock Collieries. To date around 655 000 t of coal has been safely extracted from the pillar extraction panels, as indicated on the Tavistock Colliery underground plan in Figure 1. The in-house process developed and implemented towards achieving this in a safe and efficient manner will be discussed.

Mining methods at Tavistock Colliery

Historically, the mining of the available coal reserves was never carried out with the intention to conduct pillar extraction on retreat, and hence the original pillar design was usually based on the maximum percentage extraction to be achieved during the primary development mining phase⁶. Bord

* Xstrata Coal South Africa.

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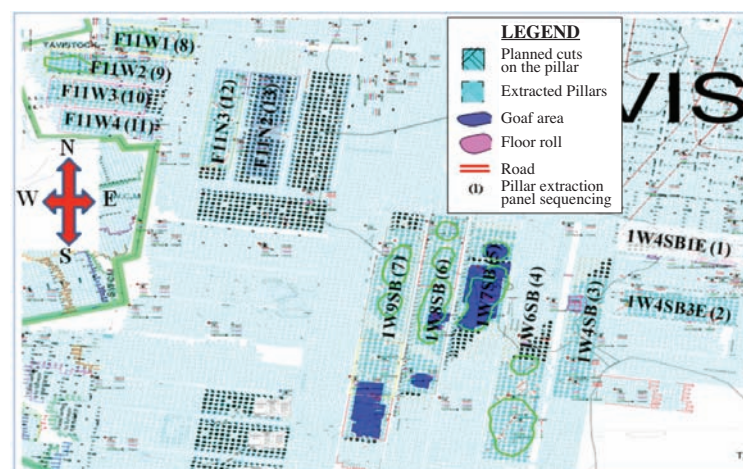


Figure 1—Underground plan showing the location and extent of the 13 panels where pillar extraction has been carried out at Tavistock Colliery

and pillar mining has been the prime method employed for coal extraction since production commenced at Tavistock Colliery. At first, mining was carried out entirely by conventional methods (drill and blast) until the introduction of mechanized mining using a continuous miner (CM) during 2004.

Pillar extraction experience at XCSA

Pillar extraction was initially carried out making use of a total pillar extraction mining method at the Arthur Taylor Colliery (ATC), with goafing occurring concurrent with the mining. Although no fatal accidents were recorded, there were at least two recorded cases of a CM burial and one major windblast accident during this period. This was formally addressed through the re-design of the pillar extraction method to mitigate any CM burials and windblast accidents. The group rock engineer at the time, Mr B. Vorster, employed a Modified NEVID method based on the pillar extraction mining method developed by Sasol Mining.¹⁰ This method of pillar extraction was then carried out at Spitzkop Colliery, ATC, and also later at Boschmans Colliery, with no recorded cases of a CM burial or any windblast accidents.

It must, however, also be pointed out that the method was not effectively designed for goafing to occur concurrent with the mining operation. There are at least three recorded cases of surface subsidences having occurred at Boschmans Colliery after the pillar extraction operations had formally ceased. There is no recorded case of any surface subsidence at Spitzkop Colliery where pillar extraction operations were carried out.

Pillar extraction at ATC was carried out on only the No. 4 Seam with no pillar extraction carried out on the No. 2 Seam. Interestingly enough, pillar extraction was also carried out on the No. 4 Seam in areas where the No. 2 Seam had previously been mined out below, in addition to those areas where the No. 2 Seam was not mined out previously. The modified NEVID method employed at ATC and Boschmans consisted of taking only three cuts per pillar where possible, which will be discussed later.

Mining process adopted for the safe and effective pillar extraction at Tavistock Colliery

A formal process for evaluating the viability of pillar extraction mining, including all of the key stakeholders, was initiated towards gaining a better understanding of the process. In this regard a number of workshops, sessions, and also mine visits were carried out, in which the following factors were identified for consideration. For simplicity, these factors can be effectively grouped into the Mining and Geotechnical aspects, which will be discussed in the following sections:

Mining considerations

These were addressed by identifying the key activities and allocating resources and personnel to ensure that these were effectively managed.

Mining restrictions (pillar extraction panels available)

Surface and underground

The first challenge confronting Tavistock Colliery was the availability of panels originally earmarked for pillar extraction, owing to the restrictions imposed by various surface structures including public and private roads, buildings, and dams (Figure 2).

Based on the analysis carried out, approximately 30% of the original panels earmarked for pillar extraction had to be scrapped due to further expansion plans for water storage facilities on surface, which were to be extended and in the process would encroach into the mineable and targeted pillar extraction areas. In addition to this, there were also the adverse effects associated with combined floor rolls, paleo-highs, hydraulic pressure conditions, and panel orientations, resulting in further panels having to be removed from the pillar extraction schedule.

External and internal stakeholders

Farmers likely to be affected during this process were consulted well in advance. Fences were erected around the

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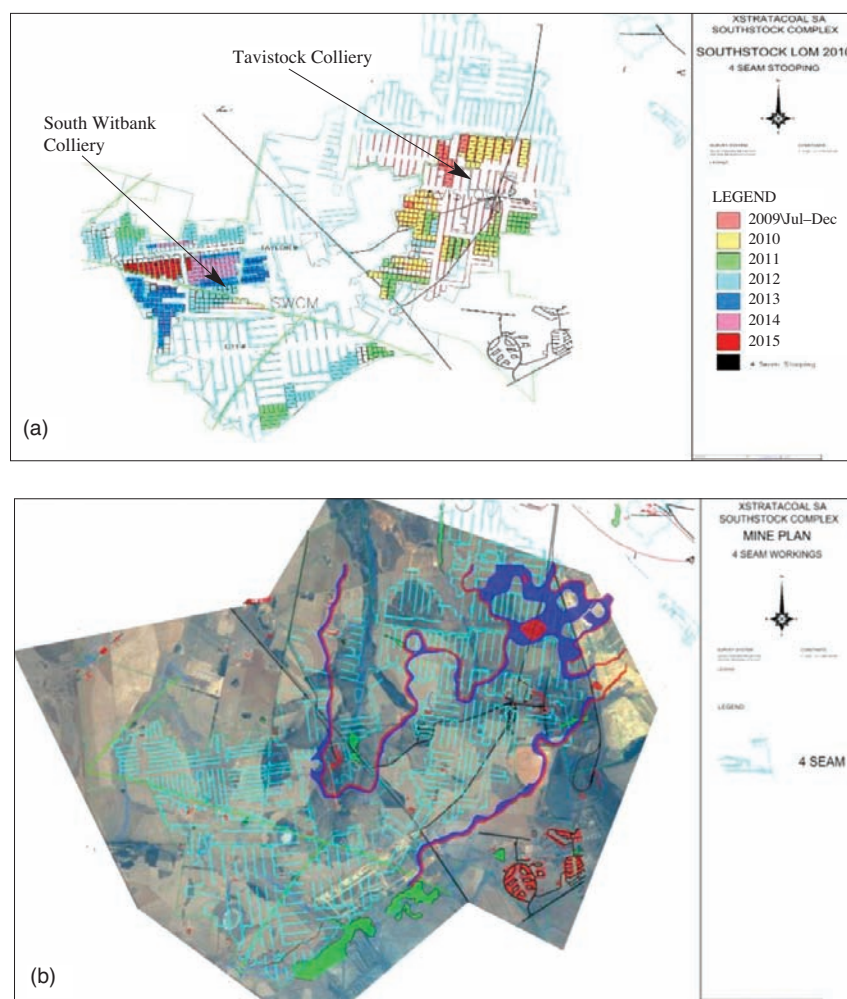


Figure 2—Plan view showing (a) the location and extent of the Tavistock No. 4 Seam pillar extraction and (b) the mining restrictions on surface

planned pillar extraction panels in order to prevent inadvertent access to the surface areas where subsidence could occur. Prior to the commencement of the pillar extraction mining there was already a project underway to relocate affected communities in informal settlements. The trade unions representing the workforce were also duly informed about the pending pillar extraction operations and involved throughout the process. No major complaints were received from any of the abovementioned stakeholders during the pillar extraction operations.

Mine planning

A detailed mine design utilizing the available coal resources and pillar extraction panels indicated that the Tavistock underground operation will be able to continue until December 2011. The development is expected to continue with two sections and the pillar extraction with the other two sections until the end of the year. At the time of publication Tavistock Colliery has just been closed with the last mining taking place on the day shift of the 30th of January 2012.

Cost and production

Based on the comprehensive mining exercise carried out on the available pillar extraction panels, the pillar extraction

method was deemed a viable option due to its positive NPV contribution and minimal capital input required. The ROM production was originally forecast at 55 000 t/month for a three month period with the intention to ramp up to 80 000 t/month. Production commenced in March 2010, and was stopped for two weeks due to a fall of ground that necessitated the panel to be relocated following an extensive analysis on the failure mechanism carried out by various rock engineering experts, as discussed later. It was in November 2010 that Tavistock finally achieved 86 000 t/month from the pillar extraction section for the first time.

Availability of equipment

A strategic decision was taken to gradually phase out all single-pass continuous miners in preparation for mining remnants and pillar extraction. Two ABM30 and one ABM12 continuous miners were decommissioned and replaced with three HM31 continuous miners. Provision was also made in the budget to replace the existing RHAM single boom with RHAM twin-boom roof bolters in order to match the roof support requirements. A machine extractor 'tande-trekker' was also purchased to be on standby in the event that the CM becomes stuck or buried by the goaf.

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The scrubber fan on the CM was initially removed as part of modifications carried out, but at a later stage it was realized that it was not necessary provided that the fan could be switched off. The scrubber fan is required for use in all planned holings or developing prior to the pillar extraction that is carried out on retreat.

Support and rehabilitation of the pillar extraction panels

It was decided to outsource the re-support of those panels identified for pillar extraction services to a secondary support contractor using hand-held machines, due to the versatility of the equipment and easy access to these old workings. A detailed pillar extraction panel support assessment was also carried out¹⁵, documented, and signed off by the rock engineering department together with the mining department and project-managed through an independent company towards ensuring that this aspect did not become an issue on the project critical path. In order to keep up with frequent panel relocations, there would need to be at least two pillar extraction panels prepared in advance at all times. Preparation in this regards also involved the pumping of any water, rehabilitating the ventilation infrastructure, sweeping/cleaning, construction of travelling ways and conveyor belts, as well as the power and water supply to the working place. All belt roads and travelling ways would be supported from the beginning of the panel right up to the faces, and this also included the installation of systematic roofbolt breaker lines⁵. Breaker line support (Figure 3) consisted of two rows of 1.8 m long \times 20 mm diameter full-column resin-grouted roofbolts installed 1 m apart with five bolts installed per support row, across the width of a bord specifically to:

- Arrest the planned displacement of the roof strata at that point
- Prevent any roof failures from spreading
- Delineate and maintain a clear demarcation between the goaf and the working area.

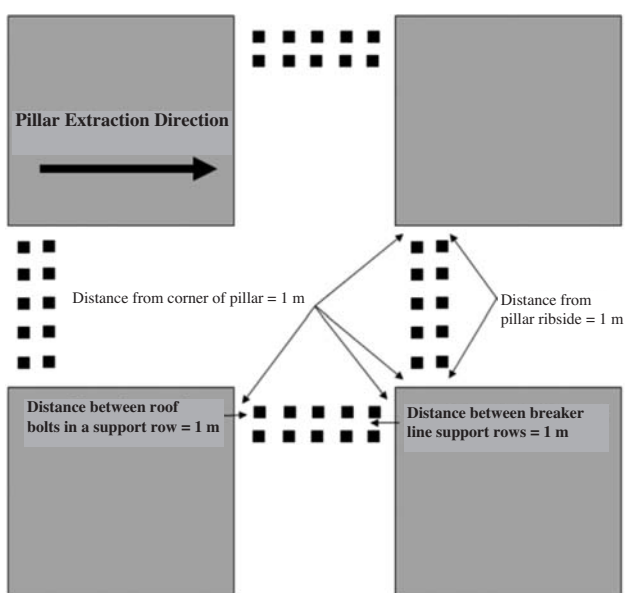


Figure 3—Plan view showing the location of the breaker line support installed

This system has been proven to be very successful in past pillar extraction projects at XCSA. Mining in a panel could commence and continue after four rows of splits from the face had been re-supported to the required standard.

Labour issues and challenges

Some challenges with regard to the compensation for machine operators demanded by the labour unions were overcome through a process of constant engagement. It is understandable that pillar extraction involves hazards that are different to those of development, but these are effectively managed and mitigated through the risk assessment process adopted.

Availability of competent skills and training

Following the closure of the ATC and Phoenix underground operations, key employees were identified and transferred to other operations, and during this process a number were also transferred to Tavistock Colliery. All mining personnel such as shift bosses and miners and CM operators who had prior working knowledge of pillar extraction from ATC were identified and included in the labour planning. A formal training programme was also initiated and carried out by the rock engineering department with the mining crews towards ensuring that the relevant strata control issues and training on the critical controls were provided to the mining personnel, on issues such as the trigger action response plan (TARP), daily inspection checklist, and the marking and cutting of the pillars.

Risk management process (risk assessment)

An issue-based risk assessment¹⁶ for producing coal in a pillar extraction section was developed on the mine with the objective of assessing the availability, adequacy, and effectiveness of the hard barriers (these are physical barriers, such as lockouts and no-entry barricades, as opposed to soft barriers such as procedures and discussions), and to identify required procedures and standards in order to address the high risk/critical tasks. During this process the following key issues were identified, and a schedule with accountabilities established and tracked:

- Ensure fit-for-purpose equipment—modifications needed to be carried out to existing equipment
- Compile a procedure for extracting the CM in the event that the machine is stuck and/or becomes inoperable¹⁸
- Draw up a pillar extraction code of practice,⁷ dealing with issues such as the required support pattern, 'no go' zones and the demarcation thereof, and the designated operator positions with each cut
- To train all relevant personnel on the procedures and standards and issue licenses where applicable.

Panel pre-emptive document

Prior to pillar extraction taking place in a specified panel, the various affected stakeholders (departments) come together in a formal manner to identify all the possible hazards and the likely related risks anticipated during the pillar extraction process, and through this consultative process define the

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controls required in order to reduce the risks to the underground personnel (Figure 4). The process is carried out by critically considering and assessing the following key issues:

- The geological features and structures, as well as the influence on the roof and pillar conditions
- Geometry of the panel (panel length, mining heights, bord width, and the panel width)
- Primary method of mining and age of workings
- Type of support installed during the mining process
- The prevailing roof, pillar, floor, and support conditions
- The existing surface restrictions
- Technical data relating to the panel (the actual safety factor, width-to-height ratio of the pillars, minimum span of the panel, regional and local stress effects, percentage of sandstone constituting the overburden)
- Previous mining in the area either as overlying or underlying mining panels
- The recommended method of goaf and subsidence monitoring, as well as the ventilation structures and layout required.

At the conclusion of the meeting the completed pillar extraction panel pre-emptive document is duly signed off by all parties and a permit to mine signed and issued by the operations manager.

Daily inspections

In order to ensure full compliance to the standards set for safe pillar extraction, inspections are carried out on a daily basis by the miners and shift bosses as well as the mine overseer. These are carried out by means of a pre-shift checklist that encompasses, amongst others, the following key aspects (Figure 5):

- Pillar cutting discipline
- Demarcation of the geological discontinuities and re-supporting where necessary
- Roof and pillar conditions at the critical positions (CM operator's position and the travelling road)
- Access control into the section (the miner needs to have an updated register for all the personnel working in the section)
- Installation of the required monitoring devices in the section
- Availability of the CM extractor and also that it is in a good working condition.

Trigger action response plan (TARP)


A TARP was also developed for the pillar extraction towards managing the various critical aspects that would affect the extraction operations and was included as part of the training process provided to the mining personnel, (Figure 6).

Panel and geological/structural parameters


Item	Description	Risk			Resp. Person/s	Comments	Signature
		H	M	L			
1.1	Dip of coal seam/floor conditions				RE		
Risk categories:							
High	Section floor conditions poor, geological floor rolls present, badly cut floor horizon with visible steps present, floor dipping at steep angles throughout the section				MO		
Medium	Section floor conditions moderate, minor geological floor rolls present, few steps present with small elevation difference, floor dipping slightly at some areas						
Low	Section floor conditions good, no visible rolls or steps present, floor at flat angle, competent material						
Item	Description	H	M	L	Resp. Person/s	Comments	Signature
1.2	Presence and affect of geological disturbances				RE		
Risk categories:							
High	Multiple slips present at more than one area in section, faults with displacement present, dykes/sills/slips/cracks present and visible in rib sides or dissect intersection areas, geological structures intersect each other at unfavourable angles						
Medium	Some areas exist where geological disturbances are present - isolated however, slips/cracks/faults present with no sign of movement or visible weakness, majority of geological disturbance not visible in pillar sidewalls						
Low	Good roof conditions exist with very little/no geological disturbances, disturbances only in straight roadways and not intersections, disturbances visible in roof only, visible disturbances (if any) consist of minor isolated hairline cracks, tightly closed with no signs of movement						

Figure 4—Example sheet showing the panel and geological/structural parameters considered in the pillar extraction panel pre-emptive document

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Xstrata Coal South Africa
Southstock Complex
Tavistock Underground Operation
Pillar Extraction Section Daily Checklist



** Note: This document must be completed at the start of each shift in conjunction with the Firemans report*

	Checked	Not checked	Responsible	Sign	Comments
01 Pillar lifts / cuts direction Lines					
Starting position and direction of lines checked to be correct			Miner		
Direction lines marked three pillars in advance			Miner		
Fenders / snooks measured off and demarcated to correct size			Miner		
Pillar cuts / lifts sequence indicated and demarcated on sidewall			Miner		
Pillar cuts / lifts adapted to suit pillar sizes (small pillars)			Shiftboss		
02 Geological features (joints, slips, brows, etc.)					
All features in section identified and demarcated			Miner		
All features supported to standard			Miner		
Geology taken into account with amount of cuts to be taken from pillar			Shiftboss		
03 Roof and sidewall conditions at critical positions					
C/M Operator	Roof & sides made safe and joints / overhangs ID & treated		Miner		
Cable handler	Roof & sides made safe and joints / overhangs ID & treated		Miner		
Next cut positions	Roof & sides made safe and joints / overhangs ID & treated		Shiftboss		
Tramming routes	Tramming route of CM relocation inspected & treated		Shiftboss		
04 Access control					
All persons in section accounted for and known at start of shift			Miner		
No Go areas explained and demarcated			Miner		
Visitors received induction prior to entering the section			Shiftboss		
05 Cutting sequence agreed upon and communicated					
a) In panel (all pillars numbered sequentially on plan)			Shiftboss		
b) In pillar			Miner		
c) In cut			Miner		
06 Monitoring devices					
Correct amount of goaf tell tales installed			Miner		
Goaf tell tales installed in correct position			Miner		
Adequate number of goaf tell tales available to cater for current and next shift			Shiftboss		
Roofbolt Breaker lines	Correct position		Miner		
	Correct length		Miner		
	Correct amount		Miner		
	Correct installation quality		Miner		
	Installed one row of pillars ahead		Shiftboss		

Figure 5—Example sheet showing the pre-shift checklist used for the daily inspection

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Tavistock Colliery
Stooping trigger levels and action response plan

CONDITION	LEVEL 1 Trigger	LEVEL 2 Trigger	LEVEL 3 Trigger
ROOF CONDITION DESCRIPTION	* No scaling / Guttering observed.	* Normal guttering - noted on pillar edges.	* Excessive scaling on one or two rows of pillars behind the goaf line.
	* No cracking.	* Scaling on snooks and or pillars.	
	* No hanging of goaf.	* Timber bending and or cracking.	* Goaf hang distance > critical mining span
	* No timber bending or cracking.	* Coal falling from the roof.	* Stress observed on the snooks and timber.
	* No excessive stress on the snooks.	* Hear strata breaking / bumping.	* Strata breaking or bumping.
	* All goaf tell tales installed one row in from the goaf line indicating white.	* Excessive boards and intersections.	* Multiple slips, excessive boards and intersections.
		* Slips and deviation from sequence.	
		* All goaf tell tales installed one row in from the goaf line showing white.	* Goaf tell tales installed one row in from the goaf line showing yellow and some red.
MINIMUM SUPPORT (Immediate Response)		* Some goaf tell tales installed further back in from the goaf line, showing yellow.	* Goaf tell tales installed further back in from the goaf line, showing yellow and red.
	* Systematic.	* Support as per normal.	* All Roadways where any yellow goaf tell tales are observed one row in from the goaf line, must have at least 2 rows of 5 mine poles installed as additional breaker lines.
	* Breaker lines installed as per the COP.	* Slips, excessive boards, intersections - install additional support as required in pre-emptive assessment.	
	* Stoop as per layout and panel pre-emptive risk assessment. Miner to have copy and to be conversant with content.	* If deviation from sequence - revise issue base risk assessment with relevant persons.	
	* Continuous monitoring of the roof and pillar conditions.	* Remove cars to a safe position.	* Multiple slips - area coverage and as required in pre-emptive assessment.
	* Continuous monitoring of timber, snooks and support elements.	* Withdraw the CM behind the breaker lines at least one Split back.	* If goaf is about to occur response as per Level one.
	* Ensure all loose material is stored between splits.	* Withdraw all people to the waiting place.	* If no sign of goafing report to Mine Overseer for further instructions.
	* Report all defects on machinery.	* Ensure all loose material is stored between Splits.	* Ensure stone dusting is up to standard.
	* Ensure extractor is in place as well as extraction equipment.	* Wait for the impending goaf.	* Mine Overseer to notify the Rock Engineer. Manager, Mine Overseer and Rock Engineer to examine working place and issue further instructions.
			* Only relevant persons to be allowed behind waiting place / No visitors allowed.
			* The Miner to increase frequency of inspections carried out.
			* Ensure sufficient equipment available such as ventilation brattices, timber poles, etc
CREW COMMUNICATION	* Normal toolbox talk.	* As per normal and crew to react as trained in stooping conditions.	* Comply with all instructions received from the MO / SM and or Rock Engineer.
	* Specific issues as relevant.		
	* Fireman's report output by Miner.	* Miner to account for all people in the section.	* SLAM.
	* Daily SO inspections.		* SEEP.
	* Crew training in stooping hazards.	* Notify official on duty.	* Crew and service people trained in potential hazards
AUTHORITY LEVEL CHANGE UP	* Experienced Miner / Operator.	* Miner / Shift Overseer.	* Mine Overseer / Section Manager / Operations Manager

Figure 6—Pillar extraction Trigger Action Response Plan (TARP) developed

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Recovery of an inoperable continuous miner in a pillar extraction section

A procedure was developed with the main objective to ensure that the continuous miner could be extracted and/or recovered from a position where it has become inoperable. This position can be expected to occur beyond the roofbolt breaker line support, and in essence means that the machine has become inoperable in a deemed no-go zone.¹⁸

Pillar cutting sequence in a pillar extraction section

A procedure was developed with the main objective to ensure that a standard cutting sequence is adhered to in a pillar extraction section that will define the sequence in which each identified pillar in a row must be cut, the amount and sequence in which individual lifts/cuts from a single pillar must be taken, and importantly indicate the position that the CM operator and his assistant must take in order to ensure that they do not enter into a 'no-go' zone while cutting¹⁷ (Figure 7).

Geotechnical considerations

The pillar extraction operation at Boschmans Colliery was carried out by means of taking only three cuts per pillar (Figure 8) where practicable, and mining four to seven rows of pillars in this manner, after which two rows of intact

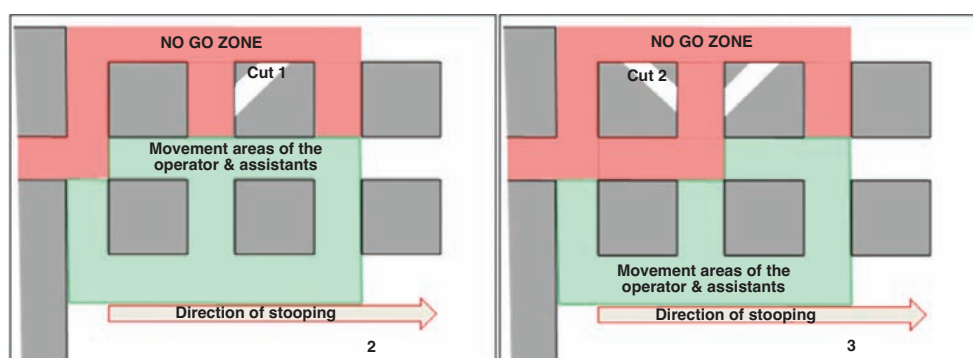
pillars were left as stopper pillars. The intention of the stopper pillars was to mitigate the effects of a windblast. Although this method was found to be a much safer way to carry out pillar extraction, with a very low risk of CM burial and windblast accidents as compared with the earlier total pillar extraction carried out,^{11,12} there was no recorded goaf that occurred concurrent with the pillar extraction mining.

Due to the risks inherent in the non-goafed panels, a meeting was arranged with all stakeholders and experts towards reviewing, and where possible amending, the pillar extraction cutting sequence employed at Boschmans Colliery for implementation at Tavistock Colliery.

The various geotechnical aspects considered are discussed below.

Geotechnical borehole logs

Due to the poor quality of the information available on some of the older geological borehole logs and the lack of adequate geological coverage in the pillar extraction area of interest, it was decided that initially at least two new geotechnical boreholes would be drilled per pillar extraction panel and logged. The geotechnical boreholes would be drilled from surface to a position just above the immediate roof and located in the centre of the pillar extraction panel. The main purposes of these boreholes were firstly to enable the calculation of the minimum spans for the various panels to be



Cut 1 will always be taken on pillar No. 2 first, unless local geological conditions are of such nature that it prohibits the execution of this cut. The No Go zone prohibits any person to enter the indicated area once cutting of the lift/cut starts

When starting cut 2, the operator must position himself in such a way that he is not in the No Go zone, and therefore behind the line of roof bolt breaker line support (and not in the intersection)

Figure 7—Example showing the pillar cutting sequence and no-go zones for the first two cuts taken

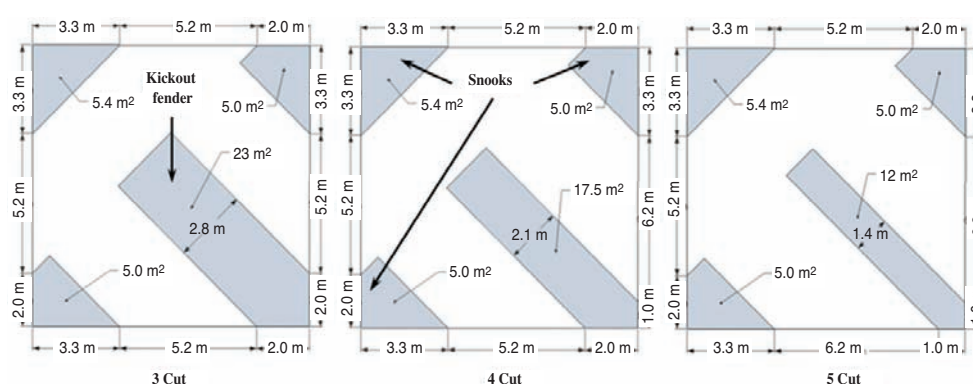


Figure 8—Plan view showing the pillar dimensions for a 10.5 m x 10.5 m pillar for the three different cutting sequences

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carried out, and also to ascertain the general roof composition of the panel in question. A subsequent use identified for these boreholes was for instrumentation, which will be discussed later. A plan, together with a drilling schedule covering all of the pillar extraction panels, was discussed and drawn up in consultation with the Complex geologist, and this was then also effectively project-managed towards ensuring that the required information was always available prior to the pillar extraction taking place in the panel.

Using the available geotechnical information, the minimum spans required for overburden failure to occur were calculated for each panel considering only the strongest sandstone layer and assuming a tensile mode of failure, using the following equation¹:

$$L = t * \sqrt{2 * \frac{\sigma_{tm}}{\gamma}}$$

where, σ_{tm} is the sum of the tensile strength of the beam and the resident horizontal stress, γ is the distributed load on the beam, assuming a unit weight of the overburden strata of 25 kN/m³, t is the thickness of the beam, and L is the minimum span. The results of this analysis are shown in Table I.

Numerical modelling – LAMODEL⁴

For the modelling exercise the LAMODEL numerical modelling software package was used, which is a boundary element program for calculating the stresses and displacements in coal mines or other thin, tabular seams or veins. It can be used fairly easily to investigate and optimize the required pillar sizes and layouts in relation to pillar and multi-seam stresses. LAMODEL simulates the overburden as a stack of homogeneous isotropic layers with frictionless interfaces, and with each layer having the identical elastic modulus, Poisson's ratio, and thickness. LAMODEL was used towards establishing and quantifying the extraction safety factors [ESF] for a representative range of panel spans and depths, together with the number of pillar cuts. The decision was taken to modify the existing NEVID mining method for

the prevailing ground conditions in order to increase the likelihood of goafing in the pillar extraction panels as follows, without increasing the overall risk profile, refer to van der Merwe¹:

- Taking five cuts per pillar instead of only three cuts (Figure 8), where practicably possible (Figure 10)
- Mining of five rows of pillars and leaving only one solid pillar in the centre of the panel of the fifth row, acting as a cushion pillar (compartmentalizes the goaf), instead of mining only four rows of pillars and leaving two complete rows as the stopper rows, in order to reduce the impacts of a windblast.

All geological discontinuities identified during the pillar mapping exercise were incorporated into the designing and positioning of the required cushion pillars as far as practicably possible. Once the goaf in a panel has been initiated and progresses with the subsequent mining, the cushion pillar requirement falls away and the pillar can be mined depending on the outcome of the pillar mapping exercise.

During this exercise a simple and effective process flow was developed for the pillar extraction operation mining at Tavistock Colliery⁸ (Figure 9).

Panel mapping exercise

This entails an assessment of the various geotechnical parameters that can directly affect the behaviour of the pillars and immediate rock mass during the pillar extraction process. During this process, all the underground panels that were planned for pillar extraction were visited, and the following parameters were assessed and the information captured on the survey plans to ensure that the pillar extraction of each panel is carried out in a safe and efficient manner:

- Geological features such as joints, faults, dykes, and paleo-floor or floor rolls
- Indication of the weak and strong side of any geological features observed
- Integrity of the pillars in the panel

Table I

Minimum span, percentage sandstone in the immediate roof, cuts taken, and instrumentation for the pillar extraction panels

Panel name	Depth below surface (m)	Panel span (m)	Panel minimum span (m)	Percentage of sandstone (%)	Number of cuts taken per pillar	Type of surface instrumentation
1W4SB1E	50 - 59	108	70.9 - 87.1	56	5	TDR
1W4SB3E	50 - 58	110	56.3 - 64.5	75.8	5	TDR
1W4SB	46 - 51	108.8	64.5 - 68.0	65.4	5	TDR
1W6SB	50 - 62	144	80	69.6	5	TDR
1W7SB	50 - 60	142	79.5 - 92.0	70.0	5	TDR
1W8SB	51-61	109	81 - 119	50.4	5	None
1W9SB	51 - 60	140	108 - 112	57.1	5	None
F11W1	52	107	96.6	64.2	5	None
F11W2	56	125	106.7	64.2	5	None
F11W3	55	109	107	74.0	4	None
F11W4	54	94	107	74.0	4	None
F11N3	65	91.8	51	29.3	5	None
F11N2	65	143	96.6	48.8	5	None

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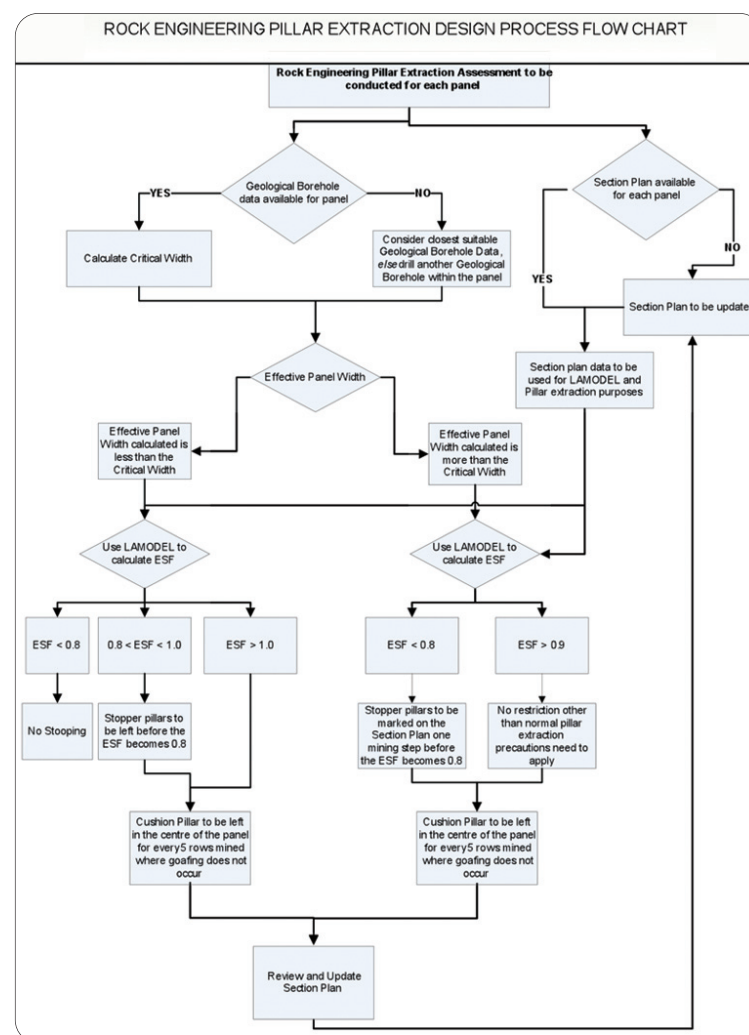


Figure 9—Pillar extraction geotechnical process flow

- The prevailing ground conditions of the roof and floor
- Conditions of the installed roof support units
- Signs of increasing stresses on the pillars, roof, floor and the installed support units
- Indications of any water in the roof, particularly at the intersections, and water in the roadways.

Once the information had been captured, a detailed pillar and risk assessment layout plan was generated which forms part of the pillar extraction pre-emptive risk assessment process. A signed-off copy of the pillar layout plan was then provided to the miners (Figure 10).

Instrumentation

It was decided to carry out a simple instrumentation programme in order to gain a better understanding of the overburden behaviour during the pillar extraction process. In this regards a decision was made to implement the time domain reflectometry (TDR) technology, which is a fairly simple and cost-effective geotechnical monitoring system that is generally used in massive mines to determine the height and profile of the cave above the draw point. TDR works through propagating a radar frequency electromagnetic pulse down a transmission line while monitoring the reflected

signal. As the electromagnetic pulse propagates along the transmission line, it is subject to impedance by the dielectric properties of the media along the transmission line. For a customized mining application solution, the system consists of grouting a specific type of conductive cable with known electrical properties into a surface borehole. A total of five of the geotechnical boreholes were instrumented with the TDR cabling (Table I), consisting of three cables of different thickness in each borehole, with the intention of understanding the overburden behaviour during the pillar extraction. A limited degree of success was achieved with the TDR instrumentation; however, this technique does not lend itself to providing early warning (precursor) information of overburden instability and should rather be used to provide information related to the location, rate, and extent of roof failure that occurs during and after pillar extraction.

GoafWarn

Previous work carried out by Brink *et al.*², and Edwards³ indicated the need for a reliable early warning seismic system indicating major roof instability in a coal mine, considering the significant percentage of reserves tied up in coal pillars. Following this the GoafWarn instrument was developed,

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which is installed approximately 50 m to 100 m from the region where any such roof instability may occur. The device monitors the micro-seismicity associated with the formation and extension of fractures which are the precursors to the larger instability process that follows. The instrument comprises a seismic velocity sensor, analogue-to-digital conversion, and a microprocessor for data processing.

Two of the older generation GoafWarn instruments were obtained to trial from CSIR Miningtek, with the purpose of using them in the pillar extraction section to build up an understanding of how the roof behaves prior to, during, and after the goaf. Unfortunately, no success was achieved with these instruments because of issues with the software and timing, and thus valuable information regarding the actual goafs recorded was lost in the process.

Going forwards, new-generation GoafWarn instruments will be purchased to allow for remote reading and accessing of the data, thereby providing a real-time solution to the challenge at hand of understanding the roof behaviour.

Pillar extraction section performance rating form

As part of the compliance process, a pillar extraction rating form was designed to rate the section performance of the underground mining personnel against the set standards and procedures. The form addresses and assesses, amongst others, the following key factors:

- Marking of the direction lines on the identified pillars to ensure that the operator can take the intended cuts in the required direction
- The presence of a signed copy of the pillar extraction panel pre-emptive risk assessment document and layout plan for that specific panel at the waiting place, and understanding of the contents
- Understanding of the escape route to be followed during the event of a goaf occurring
- Correct positioning of the CM operator and his assistant during the pillar extraction mining process
- Adherence to the cutting sequence and physical cutting direction of the pillars as depicted on the layout plan, to prevent an uncontrolled goaf
- Drilling of the required bleeder holes in order to reduce the buildup of any hydraulic pressure in the roof
- Breaker line and support installation as per requirements.

The performance rating form is compiled during the startup phase of the new pillar extraction panel and during the month, with the results discussed and communicated to the mine overseer.

Implementation phase

Pillar extraction success

The pillar extraction operation at Tavistock Colliery started during April 2010 with the panels situated on the eastern side of the mine, viz. 1W4SB1E and 1W4SB3E (Figure 1). To date the pillar extraction has been effectively carried out on a total of thirteen panels, and there has been goafing in eight of the panels (Table II). A summary of the goafing information for the pillar extraction panels as well as their orientation is provided in Table III.

As stipulated in Table II, only 62% of the pillar extraction panels have goafed while the mining was being carried out. It is pertinent to note that the pillar extraction in three of the non-goafed panels was undertaken by using five cuts on each pillar, whereas the remaining two were extracted using four cuts per pillar. In all of the panels where goafing occurred during mining, the pillar extraction was undertaken by using five cuts on each pillar where practicably possible. It is important to take note of the central remnant portion of a pillar left during pillar extraction (kickout fender) that is created with the three different mining options used on XCSA. In this regard the area of the kickout fender increases from 12 m² (1.4 m thick) to 17.5 m² (2.1 m thick) and to 23 m² (2.8 m thick) for a 5 cuts, 4, to 3 cuts per pillar respec-

Table II

Goaf information for the pillar extraction panels

Total number of pillar extraction panels	13
Total number of pillar extraction panels that have goafed	8
Total number of pillar extraction panels that have not goafed	5
Number of pillar extraction panels orientated in an E-W direction	6
Number of pillar extraction panels orientated in a N-S direction	7
Number of pillar extraction panels orientated in an E-W direction that have goafed	4
Number of pillar extraction panels orientated in a N-S direction that have goafed	4
Percentage of total pillar extraction panels that have goafed (%)	62

Table III

Pillar extraction information relating to the mining cuts and goafing

Panel name	Span/depth ratio		Number of cuts per pillar	Goafing during mining
1W6SB	2.88	2.32	5	Yes
1W7SB	2.84	2.37	5	Yes
1W8SB	2.14	1.79	5	Yes
1W9SB	2.75	2.33	5	Yes
F11W1	2.06		5	Yes
F11W2	2.23		5	Yes
F11N3	1.41		5	Yes, but not to surface
F11N2	2.2		5	Yes, but not to surface
1W4SB1E	2.16	1.83	5	No
1W4SB3E	2.2	1.90	5	No
1W4SB	2.37	2.13	5	No
F11W3	1.98		4	No
F11W4	1.74		4	No

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tively, (Figure 8). From the pillar extraction information gathered to date at XCSA, the relationship of the size and performance of the kickout fender and the roof behaviour is a crucial aspect that needs to be studied in more detail towards garnering a better understanding of the roof failure mechanism for pillar extraction of small pillars at shallow depths. In this regard, the UDEC and FLAC3D numerical modelling packages will be able to provide further clarity and insight.

Challenges experienced and further enhancements

Goaf overrun and fall of ground

There has been one recorded incident of a fall of ground (FOG) and a goaf overrun since the inception of pillar extraction operations at Tavistock Colliery. The FOG occurred in panel 1W4SB1E where the pillar extraction operation commenced (Figure 1). The FOG occurred on the off-shift during cutting of the third row of pillars, and was noticed along the roadway R3 from split 14 to split 19 (Figure 11). The fall progressed up to split 12 located adjacent to the waiting place. All the operations were ceased in this panel for the safety of the underground personnel. An extensive

investigation was conducted by the rock engineering department towards understanding the mechanism of this FOG, and Mr Jaco van Vuuren of Saxum Mining, Professor Nielen van der Merwe, and Mr David Postma the group rock engineer at Sasol Mining were also consulted. The FOG was attributed to the combination of the floor roll, water in the roof, and the stress changes associated with the east-west orientation of the pillar extraction panel.^{9,13,14}

Following this incident it was decided that in addition all floor rolls will be mapped and captured on the survey plan to ensure that this is taken into consideration during the design of the pillar cutting sequence. In addition, deeper bleeder holes (3.9 m in length) will be drilled at the roadway R3, roadway L3, and the belt road for every third split for the draining of any water from the immediate roof, in order to prevent the build up of any hydraulic pressure, which tends to cause strata problems. Intensive monitoring of the ground conditions will also be carried out while mining the panels in the east-west or west-east direction.

Pillar cracking

The mining of panel F11W1 was successfully carried out with a goaf occurring as planned, though not up to surface, and with no abnormal pillar and roof conditions observed prior to the commencement of the pillar extraction operation. It was, however, noted during the process of extracting pillars in this panel that the southern barrier pillar started to develop guttering on the right hand side of panel F11W2 (northern side). After completion of the pillar extraction in panel F11W1, preparations were made to commence with the pillar extraction in panel F11W2. The first goaf happened after nine rows of pillars had been extracted, and this also did not progress up to the surface (Figure 12). After mining a further two rows of pillars the next goaf occurred, which triggered all of the uncompleted goafs (the goaf in panel F11W1 and the first goaf in panel F11W2) to progress. The goafing then proceeded to alternate between the two panels for about an hour. Following this it was noted that the pillars extending from the goaf line backwards had developed an interesting tensile crack extending from the top to the bottom of the pillar corner (Figure 12). This was observed in panel F11W2 and also F11W3, the next panel planned for pillar extraction. These tensile cracks were observed on both the eastern and western sides of the pillars, with minor guttering noted on the southern side of the pillars.

It was concluded that the damage to the pillars observed was as a result of lateral displacement, due to the sudden release of horizontal compression accompanying the progression of the goaf in the adjacent panel. The layout plan was altered to leave four rows of pillars to stiffen up the system, and pillar extraction resumed. A special modified cutting sequence was developed for panel F11W3, taking cognisance of the cracks and guttering. In this sequence the planned cuts on the sides of the pillars where the cracks had developed were removed, in order to prevent the already fractured dislodged corners from falling and thereby causing injuries to personnel or damage to the equipment.

In conclusion, pillar extraction of the panels orientated in the east-west or west-east direction, probably coinciding with the direction of maximum horizontal stress, can present challenges that need to be managed.

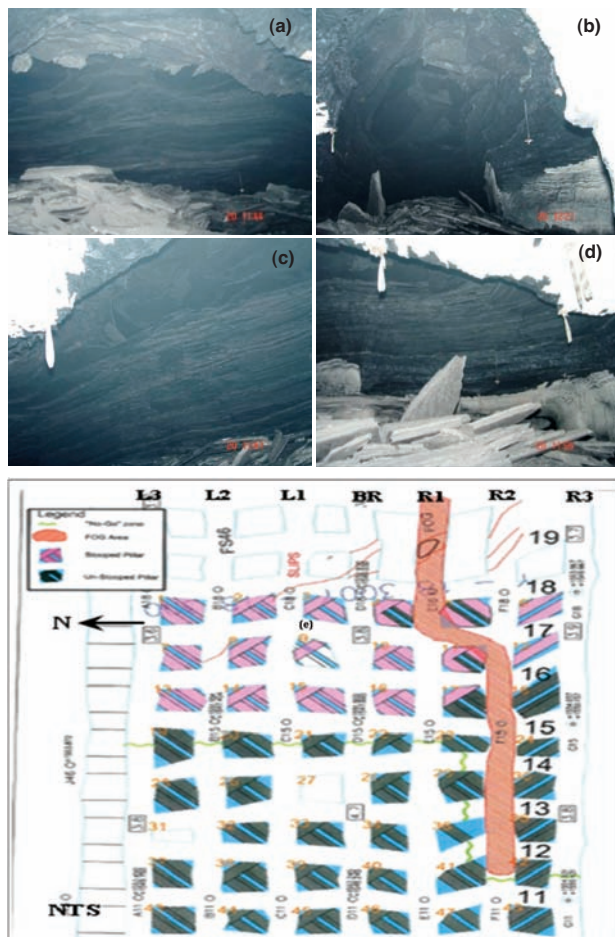


Figure 11 – The FOG and plan view showing the planned and actual pillar extraction cuts taken together with the extent of the falls of ground that occurred in panel 1W4SB1E. The photograph taken in various areas show the laminated nature of the immediate overburden and the height of the falls of ground, and also indicate evidence of some overthrusting

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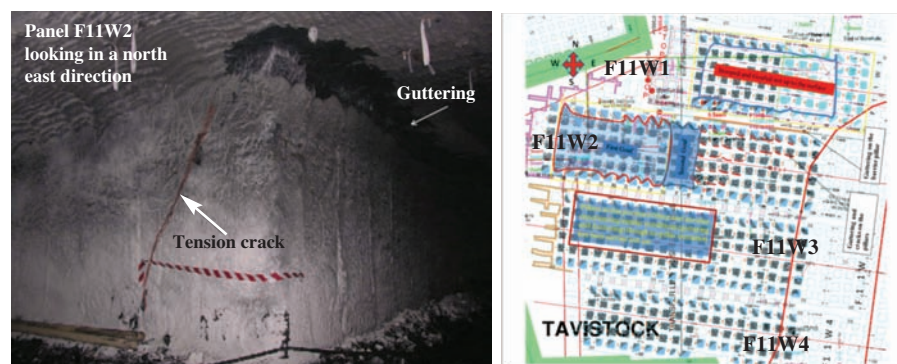


Figure 12—Underground photograph of a pillar and plan showing the panels where cracks and guttering were observed



Figure 13—The corner created by the Voest CM showing the scaling that has taken place

Scaling of pillar corners in areas where the previous mining was carried out using a Voest CM

Scaling occurred during the extraction of pillars that were originally mined using a Voest CM, which tends to create a rounded pillar corner in the roof (Figure 13). This corner tends to scale off with the stress changes associated with the pillar extraction operation. Two incidences were also reported of the Hilti gun causing this fractured piece of rock to become dislodged, resulting in an injury to an employee during the normal installation of brattices required for ventilation control.

Conclusion

The pillar extraction process designed and carried out at Tavistock Colliery has proved to be a success in terms of safety and efficiency, and has enabled a better understanding to be gained of the behaviour of small pillars at shallow depths during pillar extraction. The work has shown that it is possible to extract old, small, shallow pillars that were not originally intended for secondary extraction, provided that detailed prior investigation is done and that the mining is planned in great detail and executed according to plan.

Based on the experience to date, there is still, however, further numerical modelling work that needs to be carried out towards understanding the behaviour and interaction of the kickout fender and the immediate roof response during pillar extraction operations for various panel geometries, stress orientations, and depths towards formulating guidelines.

It is also necessary to improve the understanding of failure mechanisms preceding goafing, which will hopefully be achieved with the implementation of the improved GoafWarn instrument.

Acknowledgements

The authors would like to thank XCSA management for permission to publish this paper, and also acknowledge Mr B. Vorster for all of the earlier pillar extraction work carried out at Boschmans, ATC, and Spitzkop Collieries.

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