Mining through areas affected by abnormal stress conditions at Syferfontein Colliery

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Synopsis

This paper investigates the conditions leading to the indefinite termination of production in four critical primary panels at an underground coal mining operation, the observed shortcomings in the mining approach, and the proposed strategy to mine through the affected panels. Initial assessment of the abandoned panel conditions indicated time-dependent strata failure, (*i.e.* bolted roof failure overrunning intersections), which occurred from mere minutes to up to four weeks post-production, with and without prior warning of failure. This prompted the constant re-supporting of back areas, which raised safety and productivity concerns. Investigation of the initial mining conditions revealed that the failures were due to a critical combination of factors, the chief of which was isolated horizontal stress. Other factors that were initially overlooked by the mine (*i.e.* influence of hydraulic stress, misinterpretation of borehole data), resulted in the conditions being described as abnormal. Remedial actions were determined, and in so doing, a new strategic approach was formulated to thoroughly address all failure concerns. The four panels were explicitly planned to serve as the main intake and return airways for the recently commissioned secondary ventilation shaft, as well as providing access to millions of tons in proven coal reserves. It is thus imperative to mine the panels. A feasibility study showed that the proposed strategy set for implementation would be financially viable.

Keywords

critical primary panels, time-dependent strata failure, horizontal stress, proven reserves.

Introduction

Syferfontein Colliery is an underground coal mining operation situated in Trichardt, Mpumalanga Province, within the Highveld coalfields. At an average depth of 90 m below surface, the mine exploits the 4-Lower coal seam. The bord and pillar method used is fully mechanized, producing on average 2100 t per continuous miner (CM) per shift. Mine expansion required the sinking of a secondary ventilation shaft, the commissioning of which was synchronized with the mining of the four primary panels. The primary panels, once intersected (Figure 1), would serve as the main intake and return airways serving the new ventilation shaft. The panels would also serve as access to millions of tons in proven reserves located in the upper eastern block (Figure 2). Commissioning of the ventilation was completed, but mining through the panels was halted due to abnormal stress conditions. The nature of the conditions required investigation in order to formulate a strategy to realign the mine with its planned objectives.

The long-term mine plans were based on numerous factors, chiefly geological in nature. Syferfontein is riddled with large geological structures including dykes, sills, burnt coal, jointed zones, paleo-lows, and downthrow faults. One such structure is the 13 m wide dolerite dyke that separates the mine's Riversdale and Weltervreden operations. The focus of this study is on Riversdale.

Study focus

Events surrounding the termination of production in the primary panels

Both sections were mining concurrently in their respective panels. Section 3 was mining to the north, while section 6 was mining to the east. Mining parameters were aligned with the standard of 24 m × 24 m pillar centres, 4.1 m mining height, a 7.2 m road width, and advancing 15 m before installing permanent roof support. The factor of safety was determined as 2.28. Omitting the effect of vertical loading, however, a potential high k-ratio above 2.5 was thought likely (Steenkamp, 2013).

Investigation of the conditions that led to the halt in production within all four primary panels yielded the following results.

Section 3

- Extensive guttering between pillars, varying in thickness from minor skinning to 45 cm thick chunks, both in supported and unsupported areas within the section, was first observed in panel R31 North Intake, where bolting density was increased from the standard four bolts per row to six, with the row spacing reduced from 2 m to 1 m
- The cutting distance prior to installation of roof support was reduced (sometimes

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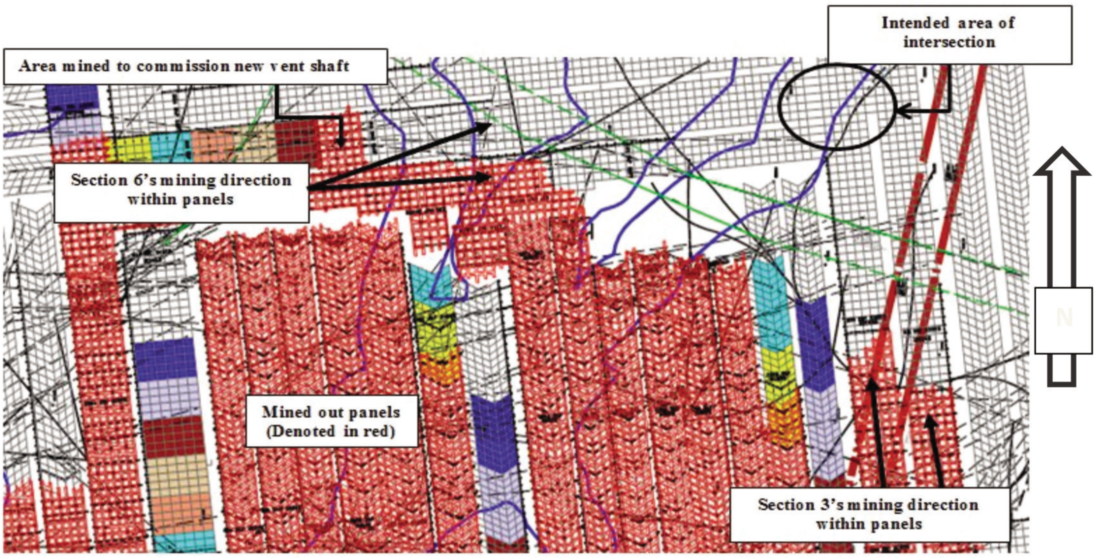

Figure 1 – Detailed locality of panels on mine plan [scale 1:100 000]. Source: Syferfontein survey department (2013)

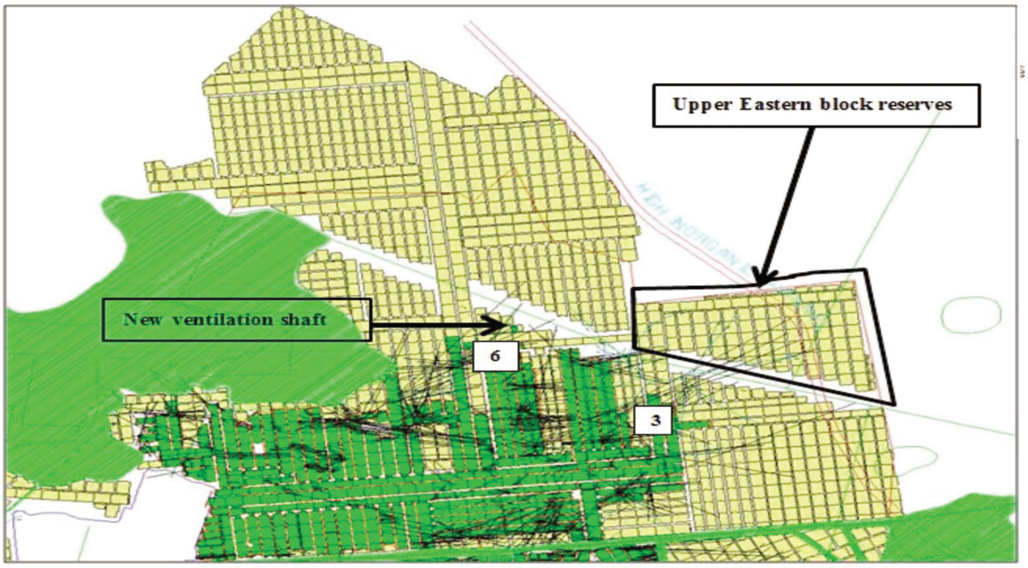

Figure 2 – Areas of interest (Riversdale): green indicates mined-out and unmineable areas [scale: 1:100 000]. Source: Syferfontein survey department (2013)

to less than 5 m)

- Large volumes of strata water entered the working face, even with the drilled drainage holes
- Observed roof failures were time-dependent, occurring during production and up to four weeks post-production, driving the need to re-support back areas with wire mesh plus additional roofbolts. This had an adverse impact on planned rates of productivity
- Production was first halted in this panel due to the resulting reduction in productivity
- The section moved to the adjacent R30 North Return panel (Figure 3). Similar conditions were anticipated and the increased support strategy was implemented from the onset. Similar failure conditions as in the adjacent panel persisted, but were more serious. These included bolted roof failures that overran intersections, falls of ground within splits, and increased guttering between bolts
- As indicated in Figure 3, the nature of the failure conditions drove the section to minimize the number of mining roads from seven to three. This became unproductive and posed further strata and ventilation challenges
- Production in this panel advanced only 250 m from the adjacent panel before it was abandoned due to low productivity and safety concerns.

Section 6

- Exactly the same failure conditions as in section 3 were observed in section 6. Section 6, however, was mining in an eastern direction more than 1 km from section 3. Adverse conditions became apparent in the K22 B&P

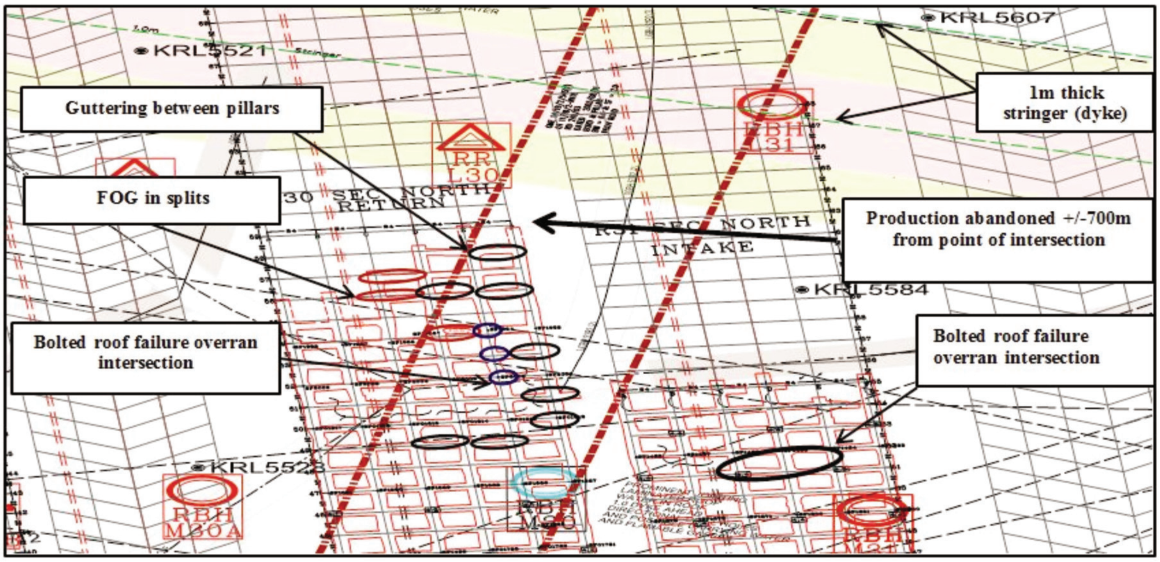

Figure 3 – Map indicating conditions in the section 3 panels leading to abandonment of production

East panel, before the section relocated to the adjacent K23 B&P East panel.

- Water-driven falls of ground resulting from bursts of inrushing water occurred before drainage holes could be drilled. Occurrence was close to the face and before roof support could be installed
- Mining span was also reduced to counteract the falls of ground without increasing the pillar centres.
- Similar to section 3, it was found that the failures in all panels followed a NE-SW direction and were aggravated by reactivated joint planes
- Production was eventually abandoned citing similar reasons as for section 3.

Results

Observed shortcomings in the mining approach

The normal mining approach failed to address the root causes of the abnormal conditions due to the following shortcomings.

- Long development ends (approx. 15 m) prior to installation of roof support, particularly under laminated/layered roofs, allowing parting that compromised strata competency upon installing permanent support, as emphasized by Steenkamp (2013)
- Trapped water in roof (hydraulic pressure) driving falls of ground even in supported and competent roof areas. This was aggravated where strata was laminated, as failure under these conditions is violent
- Strata sag or movement was addressed through the installation of telltales. These were, however, only installed in intersections. Installing telltales after roof layers have parted is ineffective. The section telltales were mechanically activated and with the application of stone dust some would be masked and thus overlooked if activated by further sag or movement in the strata. This made it difficult to control time-dependent failures
- Drainage holes (2 m deep) were drilled only in the intersections, thus the sources of strata water were not properly identified
- Dyke structures have a propensity to concentrate stresses around them (Khumalo, 2012). Both sections were approaching a 1 m thick dolerite dyke, but its influence on the stress conditions was overlooked as both section halted production approximately 250 m away from this dyke (Figure 4). The magnitude of concentrated stress is not necessarily related to the size of the feature but rather to the nature and source energy at deposition, as alluded to by Muaka (2013). This was evident with similar cases around the mine, yielding different conditions
- The impact of isolated horizontal stress was not accounted for in the initial approach. According to Bird *et al.* (2006), the principal horizontal stress direction over the mine region is oriented NW-SE. This conjecture was supported by the observed falls of ground, which were predominantly in a NE-SW direction. Other horizontal stress lead indicators such as buckled bolt plates, reported bumping and spitting in the roof during production, and floor heave (De Clerq, 2013) were noted. The approach to addressing horizontal stress is not always premeditated as the location and size of the stress source varies throughout the mine
- The survey cross-section over the two sections' panels indicated that the immediate strata consisted of competent sandstone. Examination of the rock composition of the failures revealed that the immediate strata in fact consisted of laminated shale and mudstone, which has a major impact on the roof support strategy required
- Instrumentation used at the time to monitor movements in the strata was by means of mechanical telltales. These were seemingly ineffective due to limited visibility when activated, more so after the application of stone dust
- The size of the area affected by these abnormal stress conditions cannot be determined due to a lack of detailed

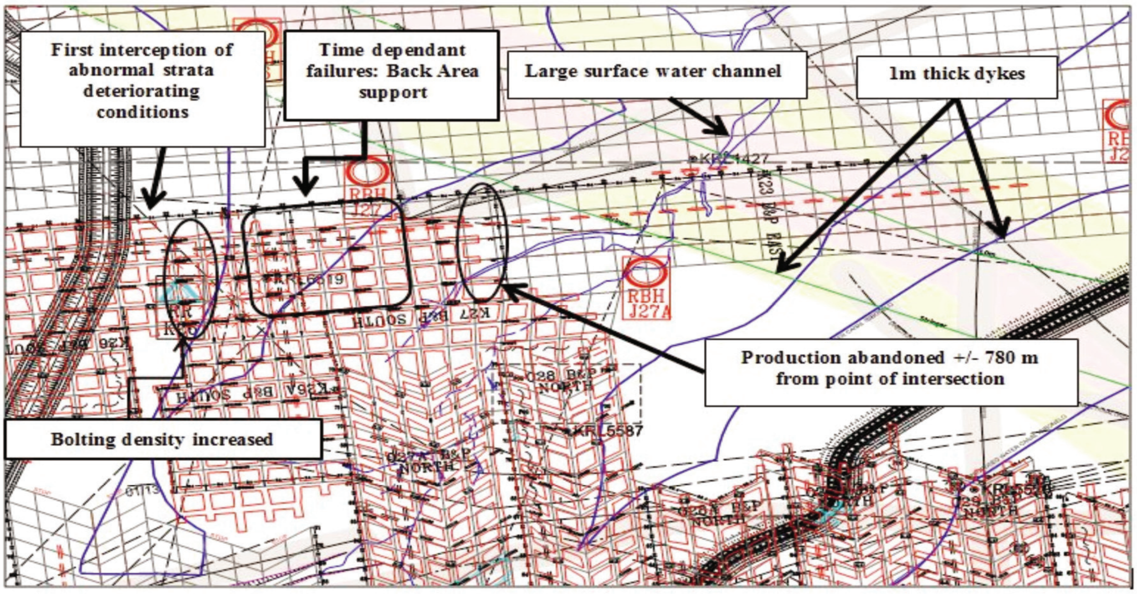

Figure 4 – Map of section 6 highlighting conditions in the panels

geological data required to prepare the mine stress maps (Van der Westhuizen, 2012).

Suggested strategic approach

The strategy formulated addresses the shortcomings initially overlooked and critical elements that did not form part of the mining COP at the time of failure. Safety took precedence, together with uninterrupted productivity such as to avoid delays caused by time-dependent failures.

A staggered approach with similar dimensions to the normal modified approach (Figure 5) was investigated as it would ideally address the predominant failures in the splits. The mining direction cannot be altered. This approach would require the use of battery haulers and a change in cutting sequence, which will pose ventilation constraints.

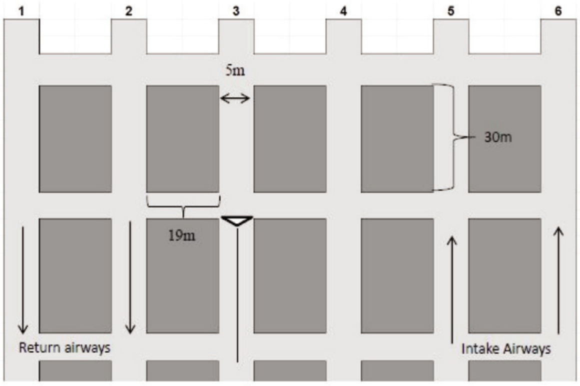

Figure 5 – Mining parameters and layout for proposed strategy

Strategy feasibility

The feasibility of the proposed strategy was determined using a model designed in conjunction with Sasol Mining personnel to determine the productivity and costs to be incurred until the point of intersection. This model has inputs for mining parameters as well as the required mining consumables, maintenance, and labour.Although the model does not account for operational costs such as electricity, it is nevertheless an effective planning tool. The results are as follows, based on the normal-modified strategy parameters.

	Section 3	Section 6
Productivity (tons/shift)	1100	1000
Mining duration until intersection	9 weeks	10 weeks
Extracted coal (tons)	180 000	200 571
Estimated mining OPEX (R mil)	2.59	2.85
*Approx. revenue (R mil)	36.00	40.11
*Avail. working capital (R mil)	33.40	37.21

*Estimated at a selling price of R200 per ton

Table I

Normal-modified layout strategy parameters

	Normal-modified layout strategy
Support requirements	1.8 m long rod, 4 bolts in a row, 1.5 m spacing Breakerline installed around each intersection Rapid installation of support (proactive), wire mesh to act as area support Systematic sidewall support (2 bolts at each pillar corner) W-straps in areas of closely spaced joints , upgrade to electronic 2 m long telltales, proactive drilling of drainage holes 2 m into the roof (not only at intersections as per COP).
Mining parameters	Pillar centres: 24 m × 35 m, bord width 5 m, advance 10 m. Longer pillars in direction of mining, ensure a beam of coal is left beneath the laminated roof (beam to seam height-mining height > 0.6 m minimum). Drill additional inspection holes within roadways during roofbolt installation (not only in intersections) and proactively monitor the strata composition.
Equipment requirements	Refurbished CM with a designated maintenance plan. Two refurbished single-boom roofbolters (addresses high support needs), designated LHD, 3 × 16 t shuttle cars.
Advantages	Adaptable with current cutting sequence, reduced production tempo allows for safer production through adequate time to observe strata behaviour. Ease of ventilation control. Larger pillars account for effects due to horizontal stresses. Strata stability.
Disadvantages	Limited pit room increases equipment congestion thus reducing effective productivity. Rerouting of cables over longer pillars increases relocation time, Routing through ventilation in the LTR will take longer due to reduced advance and longer pillars. Reduced percentage extraction (32.1%) compared to >40% under normal circumstances
Benefits	A reduced road width allows for the creation of stress relief zones, thus less area for stress to act. The creation of two independent teams (possibly from stoneworks teams) will remove the need to use teams and equipment from high-production sections. Improves stability given the panels will be used as main airways. Using refurbished CM and shuttle cars, which are near their scheduled full overhaul, eliminates the need to buy new machinery for both sections.

Conclusion

Production was terminated in four primary panels due to the inability of the mining method to proactively address the abnormal stress conditions, which led to an array of failures. This had a negative impact on productivity, and was further hampered by ineffective monitoring techniques and misinterpretation of geological data. The abnormal conditions were due to a combination of failure factors that were initially overlooked as a whole. All critical factors have been identified and can be addressed using the proposed strategy. Prior to mining the panels a detailed risk assessment will need to be conducted to ensure that safety standards are aligned. At the completion of the study, the strategy had not yet been implemented, although it was being given strong consideration.

Recommendations for further work

The application of the staggered pillar method for similar conditions and parameters, along with its feasibility in small and large panels as well as the proactive use of extensometers, should be investigated.

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