A Rock Mechanics Perspective on the effects of Hard Rock workings in close proximity to overlying Coal Seams

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Abstract
Mining in the Coalfields has been ongoing for many years, however prior to the discovery of coal, Gold was being mined in the form of the Kimberley Reef. Today it is the coal that has our interest and is the primary mineral being extracted from the ground. This has led to the purpose of this paper which ultimately looks at the effects of historic hard rock workings that are in close proximity to overlying coal seams at the Sasol colliery. Two sections (37 and 49) were monitored to assess the effects that the Kimberley Reef has on the current mining of coal below. The importance of the study was that resultant stress interactions could hinder mining in terms of safety concerns, production losses and additional costs. Underground analysis and monitoring of the area concerned has concluded that additional stresses from the gold mine caused sidewalls in the coal mine to scale and slab. The damage to the roof was evident in terms of ride. This had a negative effect on production, costs and created safety concerns.

Key-words: mining ,rock mechanics, stress, pillars, slabbing

1 Introduction
Sasol colliery is one of five underground collieries owned by Sasol Mining that produce coal that is used in Sasol’s Secunda synfuels plant. Sasol started production in 1982 and currently has three shafts, namely; Main shaft, West shaft and iTemba Lethu shaft. There are nine production and two stonework sections between the three shafts. The mine currently employs 1089 people (excluding contractors) and in the last financial year they produced 8 million tons of coal (Marais, 2008). Sasol colliery is situated in the Highveld coalfield and is mining the number 4C lower coal seam with a mining height of between 3 m to 4 m. The No 4C lower coal seam is between 80 m and 140 m below surface. A lot of geological disturbances such as dolerite intrusions and sills exist in the coal seam being mined by Sasol. One interesting geological feature is that the northern part of Sasol’s reserves overlie the Kimberley gold reef and its sub-outcrops. (Ndlovu, 2008). The principle horizontal stresses in the Sasol area were measured and found to be quite high (k ratio of 2.2:1) and they act in a direction 26˚ west of north (Postma, 2008). The high magnitude of these stresses is due to the large excavation area of the Secunda mining complex. The principle horizontal stresses re-adjust themselves around the mined out area and increased horizontal stresses are present in the Sasol area (Joubert, 2008).

1.1 Geology and formation
Sasol’s coal reserves overlie the Kimberley gold reef. The Kimberley gold reef is at the top of the Winkelhaak Conglomerate formation which is part of the Turffontein Subgroup. The Turffontein Subgroup is part of the Central Rand Group which is part of the Witwatersrand Supergroup. The Kimberley gold reef is the only economic reef in the Evander basin. (Wilson & Anhaeusser, 1998, p330). The reef was formed about 2400 Ma in the Witwatersrand basin. The reef was split into two parts by a normal fault in an extensional environment (Figure 1). Glaciations removed strata from and above the Kimberley gold reef and created two sub-outcrops, namely the southern and the northern part. The sub-outcrops dip in a northern direction at 27˚ (Wilson & Anhaeusser, 1998, p330). The coal formed approximately 310 Ma in the Karoo basin and is 87 m above the sub-outcrop at the nearest points (Figure 1). There are four faults present in the coal seam where it is in close proximity to the northern part of the sub-outcrop. Close proximity defines the area where the coal seam and the Kimberley gold reef’s sub-outcrops are 87 m – 250 m apart. The exact time of the formation of these faults are
unknown but the coal was moved by them, thus they are younger than the coal, which was formed about 310 Ma. There exists a strong possibility that they formed at the break-up of the Gondwana super continent about 170 Ma. These are all normal faults that caused up and down throws of between 0.1 m and 2.7 m in the coal seam (Ndlovu, 2007).

Production of the Kimberley gold reef commenced in 1958 and gold was produced by four mines namely; Kinross, Leslie, Braken and Winkelhaak. These mines are currently operating as Evander gold mines under Harmony gold. Hard rock workings in this case refer to mining of the Kimberley gold bearing reef. The southern part of the reef was mined first and the gold mines developed four levels to mine the Kimberley gold reef. When the northern part of the reef was mined, levels 1 -14 were used. Thus the excavation created in the northern part was much larger than that of the southern part. Coal mining in close proximity to the Kimberley gold reef sub-outcrops has been done extensively over the southern part and to a lesser extent over the northern part. All the gold mining activities in close proximity to the coal seam ended more than 10 years before coal mining began. Thus the mined out stopes had time to reach a state of equilibrium again (Marais, 2007).

Figure 2 shows the historic gold mining activities highlighted in blue and the red are historic coal mining activities. The pink lines are areas where no water storage is allowed in the coal mine and the black are areas of planned coal mining. The two sections that were monitored ;Section 49 and Section 37 are also indicated on the map.

1.2 Problems and effects
Numerous problems were experienced when the coal above the northern part of the Kimberley gold reef and sub-outcrop was mined as compared to the southern part. These problems comprised of ride in the roof and scaling and slabbing of the sidewalls occurred. Rock engineers suggested that W- straps and 1.2m roofbolts be installed in sidewalls and pillars where risk and circumstance dictated (Jacobs, 2007). The installation of the roofbolts posed a problem in that it could not grip properly as a result of the scaling and slabbing sidewall making the support obsolete. The area stabilised within the medium term (a few days to two or three weeks) and competent supporting of the sidewalls and pillars were possible. As development of the coal seam progressed further northward, the magnitude and frequency of these problems decreased. This can be attributed to the fact that the development of the coal seam was then more than 250 m above the Kimberley gold reef, thus not in close proximity to the reef anymore.

Of the two sections 37 and 49 that were monitored for this study, the worst conditions were experienced in section 49. Section 49 developed the coal seam in close proximity to the sub-outcrop from July 2007 to August 2007. Section 49 mined a larger area of the coal seam that is in close proximity to the northern part of the sub-outcrop and it overlies a much larger part of the mined out Kimberley gold reef. In 2003 the Mining Division of ISS International Ltd did a seismic hazard assessment of the over mining conducted by Sasol mining over Evander gold mines. A seismic hazard assessment of the area was conducted and a numerical model of the area was done. This seismic assessment gave inconclusive results as no seismic data was available for the shallower parts of the gold.

2 Results
The coal overlying the southern part of Kimberley gold reef and the sub-outcrop was developed from 1995 – 2004. No abnormalities or problems were experienced when mining took place there. When the coal overlying the northern part of the Kimberley gold reef and the sub-outcrop was developed, numerous problems occurred. These problems were mostly associated with the sidewalls and included the following: Scaling of side walls (Fig 3); Slabs falling out of side walls (slabbing) (Fig 4); Joints in side walls; Wedges in side walls; Widespread ride in the roof.

All these effects were observed where the gold mining took place in close proximity to the coal seam. Close proximity means that the parting thickness between the coal and the sub-outcrop is between 87 m – 250 m. The conditions improved as the coal mining progressed north and the parting thickness became larger as the gold reef dips away deeper. Geologically, four faults were present in sections 49 and 37 in the zone of close proximity to the sub-outcrop. These faults formed in geological time after the coal was formed created up-and-down throws of between 0.1 m and 2.7 m of the coal seam. These discontinuities are weak spots in the coal seam and are potentially hazardous as movement can take place on them which could cause falls of ground. The side walls in these sections were supported with w-straps, mesh wire and roof bolts, especially around the faults.

2.1 Impacts on coal mining

Section 49 developed the area that was in close proximity to the northern part of the sub-outcrop using the standard road width of 7 m and pillar widths of 21 m to 28 m. During the mining of the area the road width was revised to 6.6 m. The road width was reduced to create larger pillars, thus increasing the factor of safety. If scaling and slabbing of pillars occur, the pillar will be reduced but will still be large enough to provide the required factor of safety and support. In terms of safety, the active joint zones caused sudden failure of the sidewalls and this caused a major safety concern to all personnel working in the section. All the high risk zones like active joint zones and corners of pillars were highlighted with barricade (chevron) tape. Loose coal was barred down from side walls and where it was possible, the side walls were supported with 1.2 m roof bolts, mesh wire and w-straps. (Jacobs, 2007). All personnel, especially the continuous miner (CM) operator and cable handlers, were advised to stay clear of side walls as far as possible.

Another issue in terms of mining coal was that the trailing cable of the CM had to be placed in the middle of the last through road to avoid damage to it from falling coal caused by scaling and slabbing side walls. It was also suggested that the corners of the pillars should be inspected before a jet fan was placed 0.5 m into the last through road at the corner of a pillar. This was to prevent coal falling on the jet fan and its cable, causing damage to them.

3 Problem Solution

Due to the fact that no stress measurements were made during the coal seam development above the southern and northern part of the Kimberley gold reef and its sub-outcrops or during the development of the coal seam at Sasol Colliery, it was impossible to calculate and compare if there were increased stress levels in Section 49 and 37 when they mined the coal seam over the northern part of the sub-outcrop. It is however possible to analyse effects and the behaviour of the sidewalls and roof that were observed when the development above the northern part of the sub-outcrop was done. When making these comparisons it is important to compare areas which have similar road widths, pillar widths, roof conditions and depths below surface. Three areas, namely area A, area B and area C were identified and was compared to one another. These areas are indicated on Figure 5. Area A is an area where the coal seam does not overlie the Kimberley gold reef or any of its sub-outcrops.
Area B is an area where the coal seam was developed over the southern part of the sub-outcrop. Area C is the area over the northern part of the sub-outcrop where section 49 developed the coal seam. All of these areas used road widths of 7 m and pillar widths of 21 m – 28 m, the road widths in area C was reduced to 6.6 m during the course of mining there. This was done to increase the pillar size and thus increasing the Factor of Safety (FOS). The depth below surface for area A is 105 m, area B is 114 m and area C is 137 m. All the areas have a sandstone roof. Thus the only difference in these three areas is where they were developed in relation to the Kimberley reef and its sub-outcrops. No problems or abnormalities were experienced when the coal seam was developed in area A and although area B also overlies a sub-outcrop, no problems were experienced there as well (Joubert, 2007).

The following section will explain the probable causes of the effects of hard rock workings on overlying coal seams in close proximity and why these effects where only present at the northern part of the sub-outcrop. Before any mining took place, the strata was in a virgin state of stress, as shown in Figure 6.

Then the gold mines developed the Kimberley gold reef and both the sub-outcrops, the gold was extracted and an excavation was created. When an opening is created underground, the stresses around the opening do not disappear, they redistribute themselves. The horizontal stresses (red arrows) redistribute and increase the load and the roof and floor while the vertical stresses (blue arrows) increases the load on the sides of the opening as shown in figure 7. These stresses redistributed around the excavated gold stope as shown in figure 8.

The mined out gold stopes compressed and the stresses were in state of equilibrium again, but now there were additional stresses acting on the under and overlying strata. The highest concentrations of these redistributed stresses acted on the corners of the excavation. Thus there were additional stresses on the coal seam as well, making it like a loaded spring. The extent to which these stresses redistribute themselves depend on the size of the excavation, the larger the excavation, the larger the surrounding area that will be affected by the stresses. The stresses were larger at the northern part of the sub-outcrop due to the larger excavation created there (Postma, 2008). There were also addition shear stresses on the four faults that are present in the close proximity zone induced by the mining of the sub-outcrop.
(shown as an “s” in Figure 8). This additional shear stress caused extra pressure to build up in the faults. There exist two 20 m thick sandstone layers between the coal seam and the sub-outcrop. This rigid sandstone absorbed some of the stresses, but there were still stresses that reached the coal seam.

After the mined out gold stopes compressed and the stresses reached a state of equilibrium again the coal seam was developed and excavations were created. The stresses had to redistribute themselves again around the excavations. At the northern part of the sub-outcrop there was higher than normal concentrations of stresses because of the larger excavation created there by the mined out gold stopes. Thus there was more stress load on the sidewalls, roof and floor than at the southern part of the sub-outcrop (Postma, 2008). The roof and floor are sandstone, which are more competent than coal and have a higher compressive and tensile strength. When the coal excavation took place, it also created room for the faults to move, releasing built-up pressure causing a release of energy. (Prinsloo, 2007) The additional load on the sidewalls, roof and floor and the energy released from the faults were not very large, but they were large enough to activate joints in the coal seam where movement and release of pressure were possible, thus causing scaling of the sidewalls, slabs falling from the sidewall and ride in the roof. The area stabilized in the medium term because pressure was released and the stresses had reached a state of equilibrium again. There is also no water storage allowed over the zones that are in close proximity to the sub-outcrop as these additional stresses and energy releases can cause underground pressure seals to break causing underground dams to leak and fail, causing a flood. No noticeable subsidence occurred in the coal seam that is in close proximity to the sub-outcrops. This is because only a 1 m stope was mined in the Kimberley gold reef and the sub-outcrops and the overlying strata of the gold stopes absorbed the subsidence.

4 Conclusion

Although a previous seismic hazard assessment and numerical modeling of the area gave inconclusive results. The main reason for this is that there was no seismic data available for the shallower parts of the gold mine. From a rock mechanics perspective the effects that the hard rock workings had on the coal seams in close proximity were caused by redistributed stresses which acted on the coal seam and caused scaling and slabbing of the sidewalls as well as ride in the roof (Fig 3& 4). The impact experienced in terms of mining production on coal mining were that the trailing cable of the CM had to be put in the middle of the last through road. This resulted in increased shuttle car travelling time and increased tramming. In terms of ventilation to the mine workings, the jet fans had to be moved further in the last through road, this resulted in a reduction of the maximum cutting depth, thus negatively impacting on the production rates. All of this resulted in a production loss for the months when mining was done over the sub-outcrop. Additional rock engineering cost and production losses resulted in a loss of approximately R 5, 6 million.

References