Ground Control in South African Coal Mines–A U.S. Perspective

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ABSTRACT

After the United States and Australia, South Africa has the largest, modern underground coal mining industry in the world. Historically, South Africa has been the cradle of many innovations in ground control, particularly in the area of pillar design. Today, South African mines are grappling with many of the same issues faced by their U.S. counterparts, including safety during pillar retreat operations, selecting the proper roof support, and maintaining long-term pillar stability.

The author recently visited seven underground mines in the Mpumalanga, Free State, and KwaZulu-Natal provinces. Mining methods included longwall, room-and-pillar with continuous miners, and drill-and-blast. The mines represented a cross-section of geology and ground support practices. At each mine, evaluations were made of the Coal Mine Roof Rating (CMRR), roof support practices, pillar design methods, and general ground control experience.

The coal seams observed were generally thick (2-5 m), the depths of cover moderate (less than 200 m), and the roof rocks relatively strong (CMRR greater than 45). Unfortunately, the South African roof fall fatality rate is approximately three times greater than in U.S., perhaps in part because roof bolts seem to be more widely spaced in most South African mines. Roof bolting equipment was generally outdated, and the quality of bolt installation was a major concern. Pillar design, on the other hand, is quite advanced, and pillar failures are rare. Several novel partial pillaring techniques are employed, including "checkerboard" mining in which every other pillar is removed, 3-cut systems, and high-extraction mining where engineered final stumps are left by design. The paper also offers observations on ground control management techniques (including recently introduced Codes of Practice), the role of the mine inspectorate, and the status of the research community.

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INTRODUCTION

South Africa is the third largest coal exporting nation, after the U.S. and Australia. In 1996, nearly 106 million clean tonnes were produced from underground mines that employed approximately 28,000 workers (*1, 2*).

The mines are located primarily in the northeastern portion of the country (figure 1). The oldest mining areas are in KwaZulu-Natal, but today most production comes from the Witbank-Highveld area in Mpumalanga Province about 100 km east of Johannesburg. The three large mining "houses" (companies) of Amcoal, Ingwe, and Sasol together account for 80% of all coal production. A total of just 22 large mines account for nearly 90% of all production (*3*). Many of these are captive to power plants or the giant SASOL chemical works.

While the number of underground miners is approximately half of what it was just 10 years ago, underground production has nearly doubled, and productivity has increased by a factor of 3.6. Labor costs per tonne have been essentially constant, however, reflecting sharply higher wages and greater investments in human capital (3).

In 1996, 23 South African miners lost their lives in ground falls, about 50% of all underground fatalities (*2*). In recent years, the groundfall fatality rate has averaged about 0.6 per 1.000

underground employees, a rate about 3 times greater than in the U.S (figure 2). Canbulat and Jack (*2*) present data showing that 35% of these fatalities occurred in the older KwaZulu-Natal coalfields which account for less than 10% of underground production (figure 3). The mining method was drill-and-blast in 67% of all South African ground control fatalities.

The most modern mining methods are found in Mpumalanga province, which accounted for 80% of underground production but just 40% of the groundfall fatalities. Kritzinger's (*4*) detailed analysis of Mpumalanga accident statistics found that between 1997 and 1998, 50% of fatalities occurred under supported roof, 77% occurred in the face area, and 77% occurred on continuous miner sections. Injuries to roof support personnel (roof bolt machine operators, rock drill crews, and pinch bar users) accounted for 32% of serious groundfall injuries. Another 25% of injuries were to continuous miner operators, and 14% were to operators of coal cutting or loading machines on conventional sections.

Nationwide, approximately 40% of the fatalities occur during the process of pillar extraction, though only about 25% of underground production is from "stooping" sections. Also, the thickness of the rock was less than 0.5 m in 63% of the fatal accidents, and less than 1.0m in 81% of the accidents. Sandstone, shale, and coal roofs were each cited in approximately equal frequency in the fatalities where reports were available (*2*).

GEOLOGY

South Africa is blessed with excellent mining conditions. Coal seams are almost always at least 2 m thick, and often 4-5 m thick. The depth of cover is less than 300 m, and the coal ribs are usually strong and relatively uncleated. The floor is usually competent and the seams are level. The roof is typically comprised of quite competent sandstone or siltstone as well. I found the Coal Mine Roof Rating (*5*) greater than 65 in 5 mines (3 in the Highveld and 2 in KwaZulu-Natal), and greater than 50 in 3 other Highveld observations. The weakest roof observed was in the 3 Seam in the Sasolburg area, in the Free State. Here the CMRR was still about 45 (in the U.S., weak roof is often CMRR=35 to 40). Where the roof is a weaker shale, the mines often leave 0.5 m of the strong coal in the top. Other mines leave 10 cm of top coal to reduce frictional ignitions. There seemed to be a reasonable correlation between the CMRR and the entry width (figure 4).

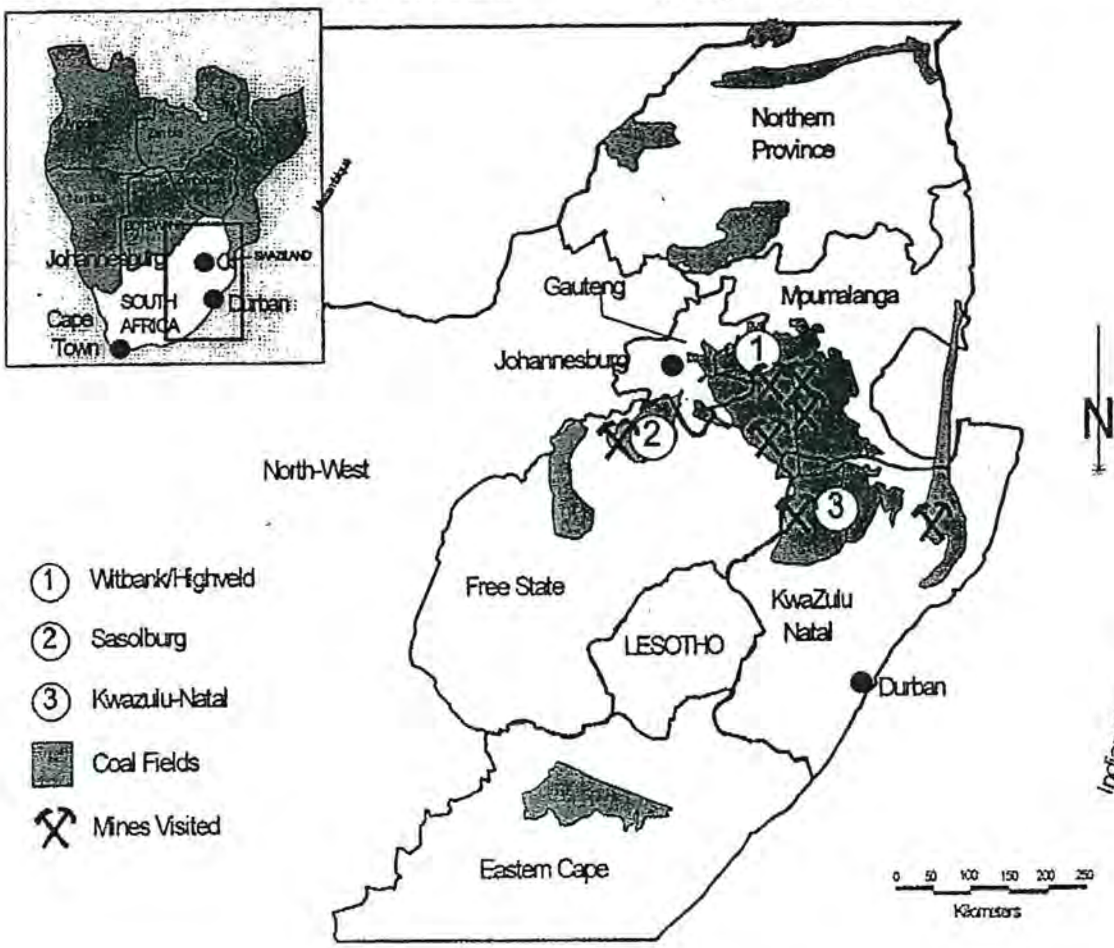

Figure 1. Location of the South African coalfields and the mines visited for this report.

Figure 2. Number of employees and groundfall fatality rate for the South African coal mining industry.

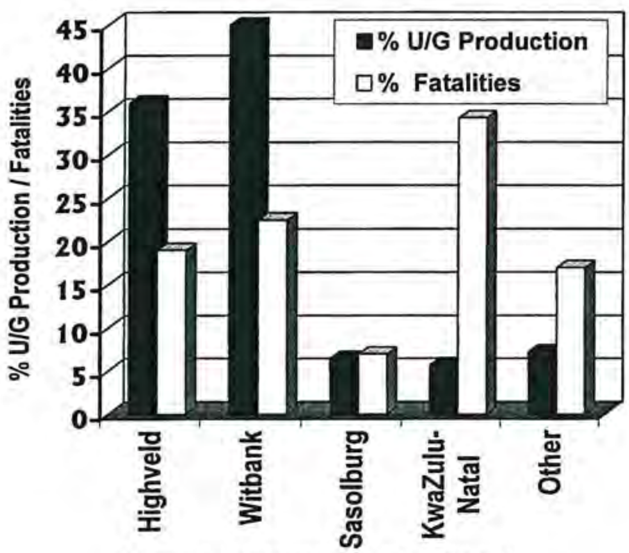

Figure 3. Underground production and groundfall fatalities compared by location.

Horizontal stress was not considered an issue in South Africa until very recently. Clear evidence of horizontal stress could be observed in some of the weaker roof types. A study at the Brandspruit Colliery in the Highveld area also indicated that most of their fatal accidents have occurred beneath stream valleys (*6*). According to the world stress map project, and confirmed by stress measurements in deep hard rock mines, the major principle stress is oriented NNW (*7*). Several of the visited mines reported that EW entries were the most troublesome, which would result from an approximately NS regional principal stress.

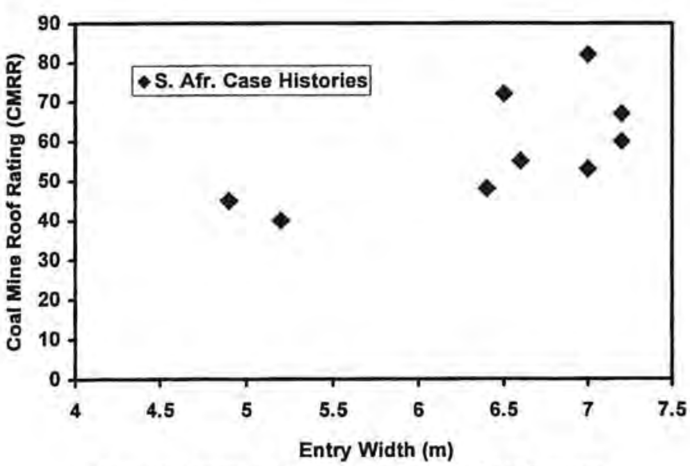

Figure 4. Entry widths and Coal Mine Roof Ratings (CMRR) for mines that were visited.

Igneous dykes appear to be the most significant large-scale geologic features affecting ground stability. The dykes often cut through the coal seam, affecting mine layouts. At Syferfontein Colliery, in the Highveld, the dykes devolatize the coal, weakening it and ruining it as top coal. The shale roof is much more prone to failure without top coal, so the entry widths are reduced from 6.6 to 4.9 m near dykes, and extra support is installed. Faulting is also a significant problem in some mines.

Dolerite sills are another igneous feature that affects ground control in many South African mines. Dolerite is extremely strong, and the sills may be 50 m thick. The loading experienced by pillars in a retreating section can be much higher when the sill is intact and bridges the panel. Therefore, panels are often sized to exceed the "critical width" of the dolerite, so that it will cave and transfer the load to the gob (*8, 9*). Where the required width is excessive, two retreat panels may be worked simultaneously side-by-side.

In general, however, ground conditions are relatively benign. In an extensive study reported by Canbulat and Jack (*2*), 8 m long sonic extensometers were installed at 29 sites in 5 collieries. Though the mines represented a variety of geologic environments and mining methods, the maximum total roof movement measured at any intersection site was just 12 mm. In roadways, the maximum deflection was only 3 mm! Apparently, the combination of strong roof, light cover, and moderate horizontal stress mean that massive roof falls are relatively rare.

MINING METHODS

More than 90% of the underground coal is mined using room-and-pillar techniques. In 1992, more coal was still being mined by conventional drill-and-blast than by continuous miners (*10*). All the mines I visited employed continuous miners, except Zululand Anthracite Colliery.

Longwall mining has never been popular in South Africa, due to the faults and dykes, subsidence concerns, and the excellent conditions for room-and-pillar mining (*10*). Longwalls currently account for less than 5% of underground production.

New Denmark Colliery is one of the two large South African longwall mines (Ingwe's Matla Colliery is the other one). Attached to a large power station, it is one of the deepest operating collieries (200 m) and is in a thin seam about 2 m). As many as four longwall faces may be operating at any one time.

Pillar design at New Denmark has been driven by the need for uniform surface subsidence. The first longwalls used a two-entry system, with a 25 m pillar that was reduced to 9 m by the longwall. The blind cut-out was less than satisfactory, and was replaced by a 3-entry system where one pillar was extracted. The mine has now returned to 2-entry gates with 9-12 m "crush pillars." New Denmark also has considerable experience extracting pillars and mid-gates with longwalls (figure 5), with some mixed success (*11*).

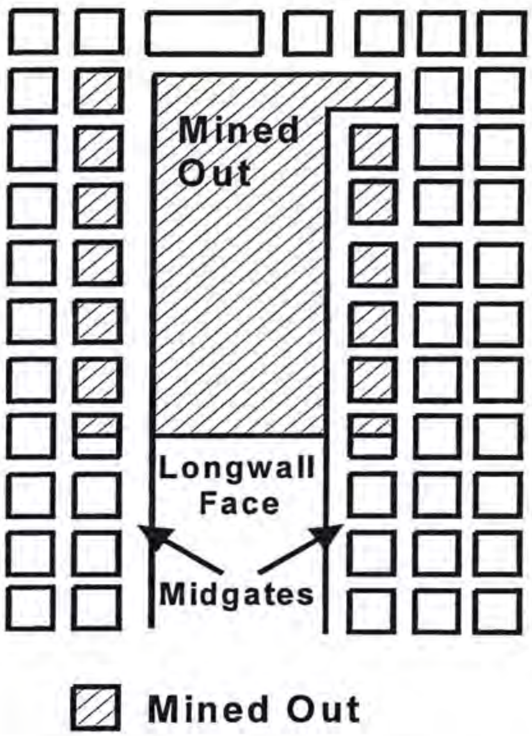

Figure 5. Midgates in a longwall panel at New Denmark Colliery.

New Denmark's roof is a competent sandstone, with a CMRR estimated at 72. No bolts are installed during development. When the longwall face is 60-70 m away, contractors install rows of 3-4 bolts every 1.5-2 m in the 6.5 m wide gate entries. Cable bolts are also installed in the intersections, but no standing support is used in the tailgate.

Another unique mining system was observed at Syferfontein Colliery. There an ABM30 miner-bolter is used in conjunction with a continuous haulage system. Two bolts are installed for each meter of advance in the 4.8 m high entry. The entries are mined on 24 m centers, with the crosscuts angled at 60°. A strong, flat floor is essential to the success of the system, which averages 70 m of advance in a 10-hour shift. Smaller ABM20s are used in the weak roof areas near dykes.

ROOF SUPPORT

One striking feature of South African coal mines is the relative lack of roof bolts. The Primary Support Rating (PSUP) averaged 0.08 for mines with a CMRR between 50 and 70, which is less than half the support that mines in similar conditions in the U.S. would use (*12*). The biggest difference is the bolt density. Where the spacing between bolts in the U.S. is limited to 1.5 m, and 4 bolts per row is standard, in South Africa a typical pattern is 3 bolts every 2-3 m. In fact, 9% of South Africa's collieries use no bolts at all (*2*). Figure 6 shows that PSUP observed in South African mines essentially falls on the lower bound of the U.S. data. Interestingly, the figure also shows that the regression equation derived from Australian data (*13*) basically defines the upper bound of the U.S. data.

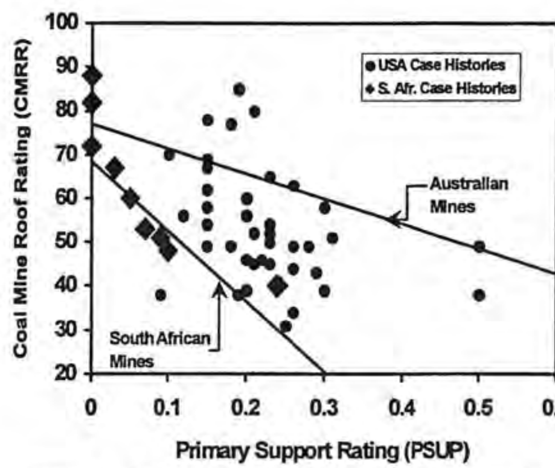

Figure 6. Primary support ratings (PSUP) for South African, U.S. and Australian coal mines.

The South African "Guidelines for Compiling a Mandatory Code of Practice to Combat Rockfall Accidents in Collieries" (*14*) classifies roof into three types:

- *Strong roof* requiring no systematic support;
- *Suspension-type roof* where a thin layer of weak material is overlain by a stronger layer, and;
- *Beam-creation type roof* consisting of a thick layer of weak material.

The Guidelines also mention discontinuities, road width, burnt coal, ribside support, and water/gas pressure, and "the potential for failure between support elements."

While large roof falls do seem to be unusual in South Africa, most of the injuries and fatalities are being caused by relatively small pieces of rock. The wide spacing between bolts may be an important contributing factor. Some South African rock mechanics specialists have argued that installing shorter bolts on a tighter pattern could be effective in preventing these small rock falls. The mines seem reluctant to adopt this approach, and roof bolting equipment may be part of the reason. The roof bolters I saw were all single-boom machines, some with scissors-type drill masts, mounted on small rubber tires. Automated temporary roof support (ATRS) was either inadequate or non-existent, so temporary jacks are required. It is considered a good shift when two men install 50 bolts with this equipment.

The quality of roof bolt installation is also a source of controversy. Studies conducted at the Sasol mines found that between 30 and 70% of the installations were inadequate. Sasol has recently implemented a program where roof bolts, drill rods, and resin cartridges are all color-coded to ensure that they match. Timing lights have been installed on the roof bolters to help the operators time the resin spin cycle. After the improvements were implemented, a follow-up study found that 98% of the installations were good, and the Sasol approach is now spreading through the industry.

There is no equivalent of the ASTM standards for roof support materials that are used in the U.S., so maintaining quality of roof bolt consumables is another problem. Ingwe mines require tight quality specifications in their contracts with roof support manufacturers. Samples from every batch of supports are tested in Ingwe's own rock mechanics lab, and batches that fail are rejected. At Sigma, the Code of Practice requires that roof support materials shall be supplied by ISO 9002 rated companies, with independent quality checks carried out on all support elements (*15*).

PILLAR DESIGN

Pillar design has been a defining issue in South Africa ever since the 1960 Coalbrook disaster in which over 400 miners were killed in a massive pillar collapse. The Salamon-Munro (*16*) formula, which was statistically derived from back-analysis of 125 case histories, is still the basis for most pillar design in the country. The Guidelines for Codes of Practice (*14*) state that "pillars shall be designed to a suitable safety factor using the Salamon-Munro (*16*) formula." The Guidelines allow that "any other formula with proven applicability" may be used, but "deviations from the Salamon-Munro (*16*) formula must be approved by the Chief Inspector."

A nearly universal "deviation" appears to be the Salamon (*17*) "squat" formula which was developed for pillars with width-to-height (w/h) ratios greater than 5. Typically, main entries are designed to SF=1.6 with the Salamon formulae. Where pillar extraction is anticipated, SF of 1.8-2.0. are used.

Some local adjustments have been necessary. In the Vaal Basin (which includes the Sasolburg Coalfield), experience has shown that the in situ coal strength is 4.5 MPa, not the 7.2 MPa used elsewhere in South Africa (*18*). At Zululand Anthracite Colliery, where the coal is highly sheared, a pillar squeeze occurred despite a SF of 1.7 on development. The SF for all subsequent developments was increased to 2.0.

Madden and Canbulat (*19*) evaluated the case history data and found that 34 pillar collapses have occurred when the SF exceeded 1.6. They determined that nearly all of these failures could be explained by four factors:

- Slender pillars at shallow depth;
- Weak coal in the Vaal Basin;
- Soft floor, and;
- Slips and joints in some KwaZulu-Natal Coals.

They concluded that to prevent failures at shallow depth, w/h ratios should be greater than 2.0, extraction ratios should not exceed 75%, and no pillar should be less than 5 m wide. Most recently, van der Merwe (*20*) re-analyzed the case histories and derived a new pillar strength formula that reduces the strength of slender pillars but predicts greater strength for squat pillars.

PILLAR RECOVERY

Pillar recovery operations account for a disproportionate share of the groundfall fatalities in South Africa. The mines I visited had adopted a variety of techniques to improve upon this record. A common theme seems to be the use of "high extraction" techniques that leave small remnants of pre-determined size in planned positions (*21*). The goal is that the "snooks" (remnants) are large enough to support the roof above the intersection as the pillar is being extracted, yet small enough to fail once they are in the gob (*15*). The "high extraction" concept has largely replaced the older philosophy that emphasized complete pillar recovery (*22, 8*).

Sasol's Middlebult Colliery is reportedly typical of the large mines in Mpumalanga. The roof is quite competent, with a CMRR of 67, and the seam is 3-5 m high. In areas where pillars will be recovered ("stooped"), they are initially sized with an SF of 2.0. A typical pillar is 20 by 20 m. The pillars are then recovered by split-and fender. Only a single row of breaker posts, and no bolts, are employed. However, there is no attempt to recover a pushout. Instead, the final stump, measuring approximately 4 by 6 m, is left for roof support.

Sigma Colliery, in the Free State, is another Sasol operation. The roof is significantly weaker, with the CMRR ranging from 40-50. Under the CMRR=50 roof, a rib pillar technique (similar to the U.S. outside lift, or "Old Ben" technique (*8*)) was quite successful (*23*). In the weaker top, however, roof falls frequently trapped the continuous miner. A partial recovery technique, called "pillar robbing" but similar to our Virginia three-cut, has proved much more successful. One of the advantages of pillar robbing is that it gives the crew more flexibility to respond to changing geologic conditions.

The roof at Zululand Anthracite Colliery (ZAC) is such a competent sandstone that no roof bolts are installed. During full pillar recovery, the roof has a tendency to hang up for tens of meters and then cave suddenly. These large falls could "feather edge" into the working areas with occasionally fatal consequences.

ZAC has now adopted a partial pillaring technique called "checkerboarding." Pillars originally measure approximately 12 m square in the 1.3 m seam. Half the pillars are completely recovered, while every other pillar is reduced to a stump measuring 8 by 8 m (figure 7). The goal is to provide roof support, while at the same time preventing a massive collapse that might occur if smaller stumps (with width-to-height ratios less than three) were left. Worker confidence has so improved with this system that overall coal recovery is said to have remained unchanged. One problem I observed, however, is a tendency to reduce the "checker" pillars too much.

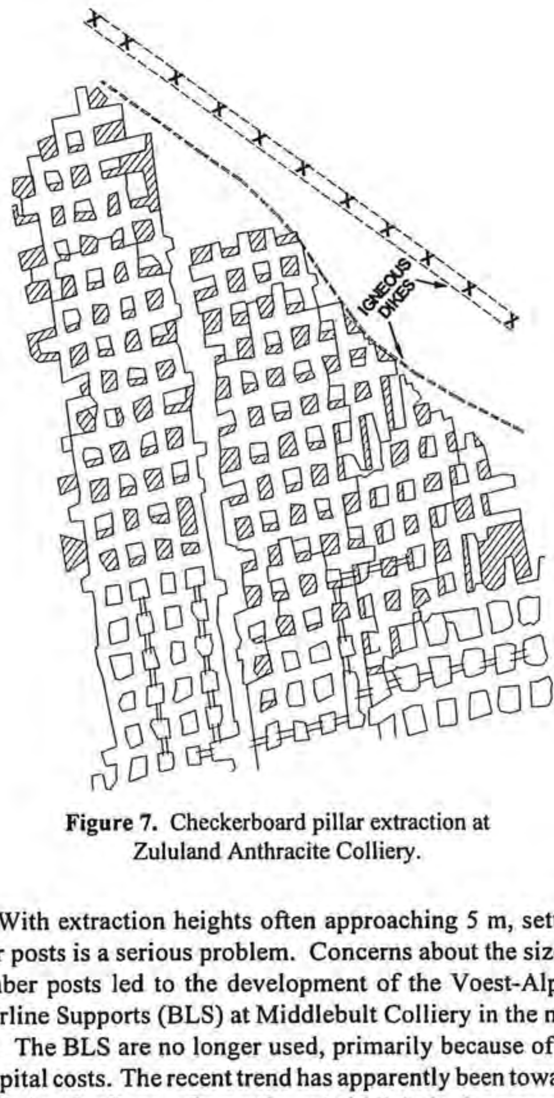

Figure 7. Checkerboard pillar extraction at Zululand Anthracite Colliery.

With extraction heights often approaching 5 m, setting breaker posts is a serious problem. Concerns about the size of the timber posts led to the development of the Voest-Alpine Breakerline Supports (BLS) at Middlebult Colliery in the mid-1980's. The BLS are no longer used, primarily because of the high capital costs. The recent trend has apparently been towards roof bolt breakerlines. Currently at Middlebult, for example, breakerlines consist of a single row of 1.2 m fully-grouted bolts.

INSPECTORATE, CODES OF PRACTICE, AND REGULATORY ISSUES

The role of the mine inspectorate in South Africa is currently evolving. On the one hand, it has much greater responsibility than it did in the past. The resources available to it have not increased proportionately, however. In Mpumalanga province, for example, the Principal Inspector is responsible for 70,000 miners in coal, gold, and chromium mines. He has just 23 inspectors (including specialists) for this huge job. The inspector/worker ratio is about 10 times greater than it is in the U.S.

Three years ago the inspectorate began a major tripartite initiative to reduce groundfalls through Codes of Practice (COP), a concept borrowed from Australia. A COP is drafted by a committee established by the mine manager in consultation with the mine's Health and Safety Committee, and approved by the Chief Inspector. Once approved, it has the status of a legal document and non-compliance is an offense. It is reviewed annually, and covers the geology, five-year historical rockfall analysis, panel design, roof support, and procedures for "special areas" (*14*).

The COP reflects the philosophy that "due to the complexity and variability of conditions at mines pertaining to the design, geometry, and support requirements, rigid and prescriptive guidelines would not be in the interest of safety" (*14*). Instead, the COP attempts to apply general principles combined with local expertise, experience, and knowledge. Indeed, even the COP is a general "strategy" document. For example, Sigma's COP contains statements like "ribside support will be installed where it is required in the opinion of the responsible official" (*15*). The real function of the COP is to guide the formulation of specific mine manager's rules, called the "standards and procedures." These include details like bolt pattern, cut sequences, etc.

The inspectors and rock mechanics specialists I spoke with expressed some disillusion with the COP approach. Apparently, three years on the COPs have not had the desired effect in reducing groundfall accidents. The emphasis is now shifting to implementation, through better training, improved roof support equipment and consumables, and higher quality roof support installations. Hazard recognition is considered a critical training element, in light of the relative inexperience of many roof fall accident victims.

Another controversial issue is accident investigations. Despite significant improvements since the issue was addressed by the Commission of Inquiry into the Safety and Health in the Mining Industry (*24*), there is still a lack of solid technical information on accidents. However, the inspectorate cannot provide the rock mechanics expertise to investigate every groundfall fatality with its small staff. Fortunately, a research project has recently been approved to address this issue.

LABOR ISSUES

Labor issues are important because of the emphasis that is now being placed on "tripartism" to combat rock related accidents (*14*). Many of the labor issues faced by the South African mining community are a legacy of the old apartheid regime. Though black workers made up the big majority of the workforce, they were considered transient migrant laborers, not career coal miners. Black workers were housed in single-sex hostels at the mines, and were not allowed to bring their families. They were also barred from all but the least responsible jobs. Skilled white miners earned ten times as much as their unskilled black co-workers.

Recent years have seen dramatic improvements. Unions were legalized twenty years ago, and the National Union of Mineworkers has won large wage increases for its members. Blacks are now free to live where they please, and mines are increasingly staffed by a permanent, local workforce. Unfortunately, blacks formerly received so little education and training that it will take some time before the professional and management ranks are finally integrated. In the meantime, the racial gap can exacerbate the usual difficulties in labor-management communications.

ROCK MECHANICS COMMUNITY AND RESEARCH

Rock mechanics has a formal and important role in the South African mining industry, perhaps because of its central place in the gold mines. There is a difficult Rock Mechanics Certificate, similar to the U.S. Professional Engineering Certification. In addition, a "suitably qualified rock engineering practitioner" must participate in the development of Codes of Practice, and must approve any plans for "special areas" (*14*). There is some ambiguity about the definition of a "suitably qualified rock engineering practitioner", however.

The coal mining rock mechanics community consists of three parts. The three big mining houses have their own rock mechanics departments, each with a central office and field staff at the mines. There are consultants who carry out rock mechanics duties for the small mining companies and special projects for the large ones. And there is CSIR Miningtek, the government research agency which some years ago merged with the Chamber of Mines research organization. Communication between these three groups is formalized by their active participation in the Coalfields Branch of the South African National Group on Rock Mechanics (SANGORM). Currently there seems to be little involvement from academia in coal mine ground control.

Research is funded by a mechanism similar to the Australian model. As in Australia, a tax is collected from the mining companies, but the levy is based primarily on a company's accident rate rather than its production. The funds are administered by the Safety in Mines Research Advisory Committee (SIMRAC), a tripartite committee. SIMRAC solicits competitive research proposals from all sectors of the mining community, on critical health and safety topics in the gold, coal and other mines. A total of 34 million Rand (about $7 million) was spent on research projects in 1999, with 73% going to gold research and 18% going to coal. CSIR Miningtek performs much of the research. In coal mining, nine projects are addressing the issues of explosions, fires, face ventilation, and frictional ignitions. Another three projects are on rock mechanics topics, two on pillar design and one on roof support. While the emphasis on health is currently increasing, in 1997 there were apparently only two generic health projects for the entire industry, one addressing dust sampling and the other noise hazards.

SIMRAC also places a great emphasis on technology transfer. Symposia are held each year in the mining areas, and final reports are made available over the internet and on CD disk. Future planning is based both on surveillance data and stakeholder input expressed in strategic workshops.

CONCLUSIONS

During the last two decades, coal industries around the world have experienced wrenching changes. In South Africa, the coal industry has had to contend not just with economic dislocation, but with dramatic social and political changes as well. Thus far, the mining community (like South African society as a whole) has demonstrated a remarkable resilience and adaptability.

Much of the South African coal industry today resembles the room-and-pillar segment of the U.S. industry. A continuous miner section in the Highveld already looks much like a Coalburg seam operation in southern West Virginia. The increasing emphasis on health and safety in South Africa will surely increase the similarities.

South Africa has a long tradition of world leadership in mining rock mechanics. With its excellent connections to the industry and strong research orientation, the coal rock mechanics community should continue to deliver innovative solutions. U.S. roof bolting concepts and technology may also have quite a bit to offer South Africa. The coming years should see much valuable interaction.

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