DESIGN GUIDELINES FOR PILLAR AND RIB PILLAR EXTRACTION IN SOUTH AFRICAN COLLIERIES

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A dissertation submitted to the Faculty of Engineering, University of the Witwatersrand, Johannesburg, in fulfilment of the requirements for the degree of Master of Science in Engineering

Johannesburg, 1992

DECLARATION

I declare that this dissertation is my own, unaided work. It is being submitted for the degree of Master of Science in Engineering in the University of the Witwatersrand, Johannesburg. It has not been submitted before for any degree or examination in any other University.

J S Beukes

this sixth day of March 1992

ABSTRACT

Pillar extraction using 'handgot' methods has been practised in South African collieries for many years. During the late Sixties pillar extraction with mechanized conventional equipment commenced, and approximately a decade later, continuous miners were introduced into pillar and rib pillar extraction panels. During the years that these mining methods were practised, a vast amount of experience was gained on the various collieries. Problems were experienced by various mines and the management of these mines made numerous alterations to the mining methods with varied degrees of success. Research was also conducted by COMRO and by various mines and mining houses.

Apart from the recommendations of Salamon and Oravecz (1976) on pillar design in stooping sections, little information has been published and, thus, little is generally available to mine managers, planners and operators to assist them in the layout and design for pillar and rib pillar extraction.

A survey of all the pillar and rib pillar practises, past and present, has been conducted for collieries in South Africa and abroad and the successes, failures, problems experienced, changes made to the mining methods and the results of these changes have been documented.

The problems and successes experienced, the similarities and difference between mines and mining methods, and the research findings have been assessed and evaluated. Design guidelines relevant to the various methods of pillar and rib pillar extraction have been established to improve the safety and performance of pillar extraction operations.

These guidelines are not intended to be prescriptive but are designed more to bring to the attention of the mine manager, planner and operator those factors which should be taken into consideration during the planning and operation of a pillar or rib pillar extraction panel.

In addition to the strata related factors, the economics of the mining method is important to determine if it is beneficial to do secondary extraction, and also to assist in optimising the secondary extraction. The design principles were therefore applied to different panel layouts, pillar sizes and extraction sequences to determine the effect on the production costs.

This dissertation is dedicated
to my wife
Suzette

ACKNOWLEDGEMENTS

The Chamber of Mines of South Africa Research Organization and the Coal Mining Research Controlling Committee for the use of facilities and resources and permission to publish this data.

My promotor, Mr Gys Landman from the University of the Witwatersrand, for his valuable assistance and encouragement. Special thanks to Professor H R Phillips for his expert advice and inspiration.

The support and assistance of the mine management and staff of all the collieries discussed in this dissertation.

The general support received from my colleagues and the management of COMRO. Special thanks to Messrs Dave Hardman and Murray Macgregor and for the editing and expert advice.

Finally, the support and encouragement of my wife, Suzette, and my children, Johann and Ilze, during the preparation and documentation of this study.

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CHAPTER 1

INTRODUCTION

It is estimated that approximately 90 per cent of the world's reserves of fossil fuels occur in solid form, mainly as coal. This is especially true for South Africa where only limited quantities of oil and gas reserves have been discovered to date. Coal, therefore, is the main source of of power, fuel and chemicals, for which the demand is likely to increase rapidly in future. This growing demand for coal will inevitably lead to a more rapid depletion of the coal reserves which is a non-renewable natural resource. Various estimates of the South African coal reserves have been made in the past, the most important of which Bredell (1991) has summarised in Table 1.1.

Table 1.1 Estimates of South African Coal "Reserves" (Bredell, 1991)

YEAR	REPORTED BY	IN SITU (Mt)	RECOVERABLE (Mt)
1913	Department of Mines	56 245	
1928	W J Wybergh	205 723	
1948	Coal Commission		11 086
1952	F A Venter	67 922	
1959	Mineral Resources	72 467	
1967	D W Bishopp		9 071
1969	W C J van Rensburg et al	33 879	18 881
1975	Petrick Commission	82 018	25 290
1983	F S J de Jager	115 530	58 404

Bredell (1991) states that one should not be too critical of any of these figures that differ so vastly as each was calculated under a different set of circumstances, using different criteria, different classification systems and different raw data. He further states that it is important to recognise and accept national ore-resource figures of any kind for what they are - estimates; estimates based on wide range of assumptions and largely unpredictable parameters. A remarkable fact about the *in situ resources* is that it is estimated that the Waterberg Coalfield, exploited by only one opencast mine at present, contains almost 46 per cent of the total in situ coal resources.

Although these figures indicate that South Africa's coal reserves appear to be fairly substantial, only a small percentage was extracted by underground mining methods prior to the late Sixties, because the main mining method employed was conventional bord and pillar mining. On some mines where multiple coal seams occur, the total percentage volumetric extraction was as low as eleven per cent. As the demand increased, it became essential for the South African coal mining industry to investigate alternative underground mining methods for increasing the total percentage extraction. These mining methods included longwalling, pillar extraction and rib pillar extraction.

Pillar extraction using 'handgot' methods have been practised in South African collieries for many years. During the late Sixties pillar extraction with mechanized conventional equipment commenced. The first experiments with pillar extraction using mechanised conventional equipment proved successful on some collieries and unsuccessful on others. At Sigma Colliery conventional stooping proved hazardous due to the friable roof conditions and the presence of a thick dolerite sill in the overlaying strata.

The first longwall trials were started in 1964, but it was not until the mid Seventies that longwall mining was introduced to any large extent. Due to the frequency of geological discontinuities, especially dolerite dykes, and the varying thickness of the seams in most of the South African coalfields, longwall mining can only be practised in selected portions of the total reserves. The limited application of longwalling therefore made it necessary to investigate other mining methods to improve the overall extraction percentage of the total coal reserves.

Approximately a decade after pillar extraction with mechanized conventional equipment commenced, continuous miners were introduced into pillar and rib pillar extraction panels. During the years that these mining methods, conventional and mechanised, were practised, a vast amount of experience was gained on the various collieries. Problems were experienced by various mines and they made numerous alterations to the mining methods with varied degrees of success.

However, apart from the recommendations of Salamon and Oravecz (1976) on pillar design in stooping sections, little information has been published and is generally available to mine managers, planners and operators to assist them in the layout and design for pillar and rib pillar extraction. In order to assist the mining industry to optimise the pillar extraction methods, with regard to safety, increased extraction of reserves and productivity, the formulation of guidelines for pillar and rib pillar extraction became important.

A survey of all the pillar and rib pillar practises, past and present, were conducted for collieries in South Africa. The successes, failures, problems experienced, changes made to the mining methods and the results of these changes were documented. The problems and successes experienced, the similarities and difference between mines and mining methods, and the research findings have been assessed and evaluated.

Design guidelines relevant to the various methods of pillar and rib pillar extraction have been established to improve the safety and performance of pillar extraction operations.

The geological composition of the coal bearing strata and the behaviour of this strata also have a major influence on the pillar dimensions and mining method. Attention was therefore given to the geology of the different coalfields and the strata control theories for coal mining. In addition to mining parameters and local experience, these factors were also carefully considered during the formulation of the design guidelines.

The vast difference in the geological composition and behaviour of the coal bearing strata, the mining depth and mining equipment used make it impossible to design a specific set of guidelines applicable to all the collieries. The guidelines have thus been formulated in such a way that it is not prescriptive as to the mining method, support or other relevant factors, but rather as a guide to all the factors that must be taken into consideration when designing panels for pillar and rib pillar extraction.

These guidelines must therefore be used in conjunction with information such as the local geology, strata behaviour and other relevant mining parameters, and local experience.

In addition to these strata related factors, the economics of the mining method is important to determine if it is beneficial to do secondary extraction, and also to assist in optimising the secondary extraction. Quite often pillars and panels are designed without considering the economic impact of such designs. The design guidelines were applied in different mining scenarios to demonstrate the effect of pillar size, panel width and the sequence of extraction on productivity and production costs.

The COMSIM computer simulation program was u   d to simulate the potential production for different panel widths and pillar sizes during the initial development and during pillar extraction.

The average estimated present value of the total mining cost in Rand/ton for the various continuous miner mining methods were determined and used in these examples. These are average costs of collieries which have practised both pillar and rib pillar extraction, and are not necessary representative of the total mining industry.

CHAPTER 2

GEOLOGY OF THE SOUTH AFRICAN COALFIELDS

2.1 Overview

The major coal-bearing strata in the South Africa occur in the Ecca Group (Karoo Supergroup of rocks) of Permian age. Other minor occurrences of coal are found in the younger Beaufort and Stormberg sequences of late Permian and Triassic age respectively (see Figure 2.1). The rank of the most economical resources rank from bituminous to anthracite although relatively insignificant lignite reserves are known from the Cretaceous and Tertiary strata (de Jager, 1976).

Anderson and Anderson (1985) state that in terms of climate, the most significant feature in Karoo times was the early Karoo (Dwyka) glaciation. At its greatest extent, the Dwyka glaciation achieved very wide continental proportions. At the close of this long period, glaciation appears to have moved rapidly through several closing phases of glacial advances and retreats from local ice cap centres (Figure 2.2). The continents are then considered to have drifted into progressively lower latitudes, with the South Pole moving from approximately the position of the Transvaal during Carboniferous times, to Antarctica by Upper Permian and Triassic times. During the coal-forming times, the South pole moved, relatively to Gondwanaland from Central to Southern Africa and then eastwards to Antarctica, which at the time lay adjacent to the the east coast of Southern Africa.

As the South Pole moved eastwards, the ice age began to decline, glaciers reduced in size, and swamps began to form around glacial lakes, in valleys, along river banks, on deltas, and in coastal back-swamps. Numerous rivers, bearing fine sediments from melting glaciers and local highlands, meandered through the peat swamps. As the climate became more temperate, plants evolved and flourished whilst established species on the fringes of Gondwanaland migrated inward. The growth of the plant matter in the cold conditions was slow, and possibly seasonal, resulting in coal rich in oxidised plant remains and often high in mineral matter content (Falcon, 1986).

FORMER MAIN CHRONOSTRATIGRAPHIC UNIT			NEW PROPOSED LITHOSTRATIGRAPHIC SUBDIVISION					
Era	Series	System	Supergroup Sequence	Group	Subgroup	Formation	Chronostratigraphic unit	Time x10⁶yrs
CAINOZOIC		QUATERNARY TERTIARY		Various Groups and Formations			QUATERNARY TERTIARY	2 65
MESOZOIC		CRETACEOUS		UITENHAGE ZULULAND ZUURBERG	Various		CRETACEOUS	140
			KAROO	LEBOMBO		Various	JURASSIC	
				DRAKENSBERG		Several		195
	Stormberg	KAROO				Clarens	TRIASSIC	
						Elliot		230
						Molteno	PERMIAN	
PALAEOZOIC	Beaufort			BEAUFORT	Tarkastad	Various		
					Adelaide	Various		
	Ecca			ECCA		Various		280
	Dwyka					Dwyka	CARBONIFEROUS	
	Witteberg Bokkeveld Table Mountain	CAPE	CAPE	NATAL WITTEBERG BOKKEVELD TABLE MOUNTAIN		Various	DEVONIAN SILURIAN ORDOVICIAN CAMBRIAN	345 395 435 500
	Klipheuwel Formation		Cape Granite					570
PRECAMBRIAN		NAMA/DAMARA	DAMARA	NAMA/MALMESBURY GARIEP, NOSSIB	Various	Various	NAMIBIAN	
		KOSSIB		KORAS		Various		1180
	Koras Formation	WATERBERG		SOUTPANSBERG/ WATERBERG	Kransberg Matlabas Nylstroom	Various	MOKOLIAN	
		BUSHVELD IGNEOUS COMPLEX	Bushveld Complex			Wilgenhoutdrif		
				KHEIS		Kaing Marydale		2070
	Pretoria Dolomite Black Reef	TRANSVAAL	TRANSVAAL/ GRIQUALAND WEST	ROOIBERG			VAALIAN	
				OLIFANTSHOEK PRETORIA/ POSTMASBURG CHUNIESPOORT/ CAMPBELL/ GRIQUATOWN	Malmani	Various		
						Black Reef/ Vryburg		
				WOLKBERG				2630
		VENTERSDORP	VENTERSDORP	PNIEL PLATBERG KLIPRIVIERSBERG		Various	RANDIAN	
	Kimberly-Elsburg Main-Bird Jeppestown Government Reef Hospital Hill	WITWATERSRAND	WITWATERSRAND	CENTRAL RAND	Turffontein Johannesburg	Various		
				WEST RAND	Jeppestown Government Hospital Hill			
		DOMINION REEF	Usushwana Complex	DOMINION		Various		
				LIMPOPO	Messina Shanzi			3090
	Mozaan Insuzi	PONGOLO		MACUVILLE			SWAZIAN	
				PONGOLA	Mozaan Insuze			
		MOODIES	SWAZILAND	MOODIES FIGTREE		Various		
	Figtree Onverwacht	SWAZILAND/ KHEIS		ONVERWACHT	Geluk Tjakastad			3750

Figure 2.1 South African lithostratigraphic column (Macgregor (unpublished), 1991)

Contrary to the coal in the Southern Hemisphere which was formed during the Permian period, the coal in the Northern Hemisphere was formed during the Carboniferous period which was typically tropical to subtropical with regular rainfall and continuous plant growth (de Jager, 1976). The coal was thus formed from rapidly growing plants in the waterlogged swamps on the shore-lines of warm equatorial seas (Falcon, 1986).

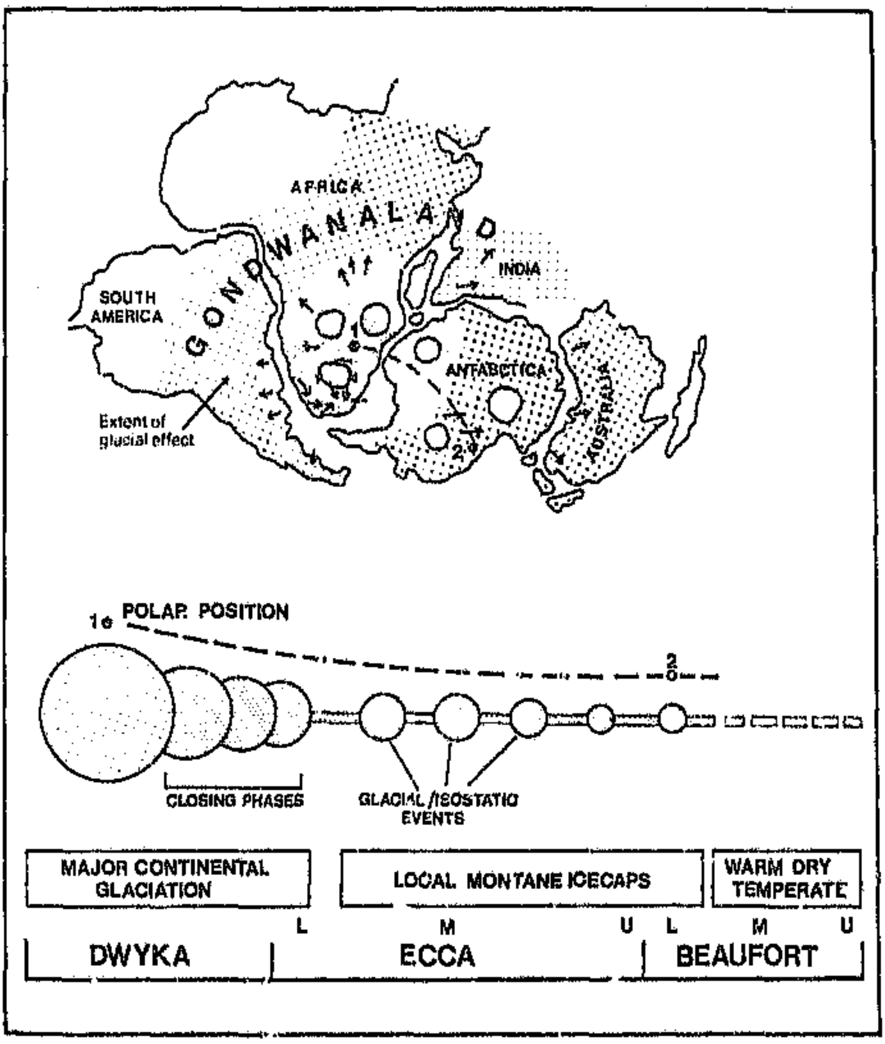


Figure 2.2 **Gondwanaland in relation to polar movement and glacial extent during Permian times (Falcon, 1986)**

As the paleaoclimatic conditions and topography influenced the growth and deposition of the plants during the period coal was formed, the chemical composition of the coal was therefore also indirectly influenced by these factors. The major climatic and floral events during Karoo times are depicted in Figure 2.3.

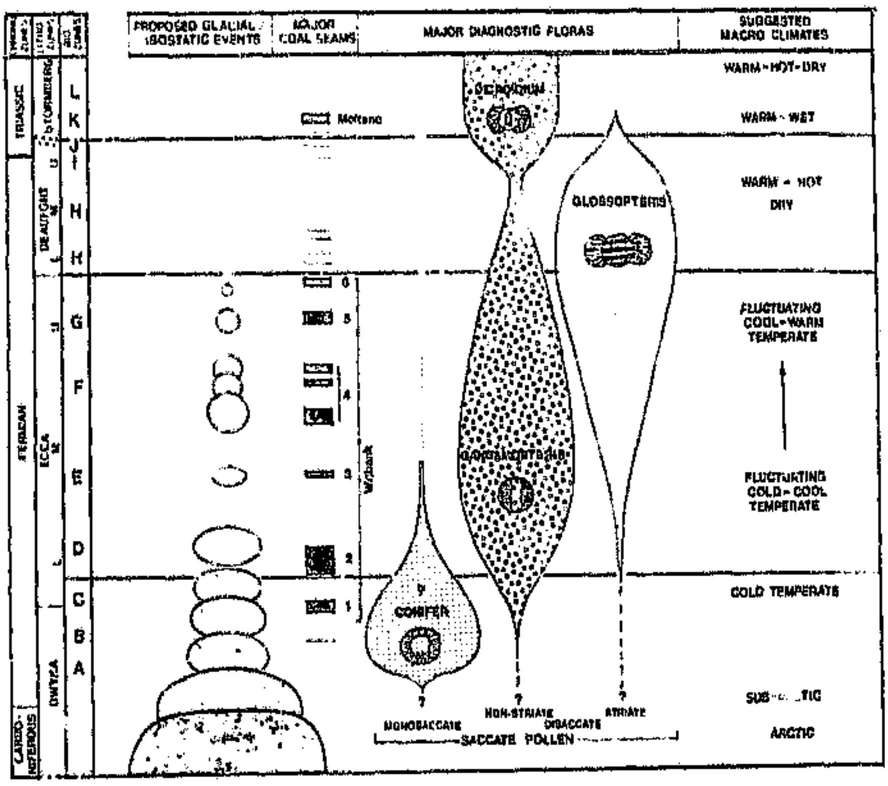


Figure 2.3 Major climatic and floral events during Karoo times (Falcon, 1986)

2.1.1 Chemical composition of the coal in Southern Africa

Coal is composed of a number of microscopic organic constituents (macerals) and inorganic constituents (minerals) which forms microscopic bands (microlithotypes). A series of these bands forms macroscopic bands known as lithotypes. Macerals are divided into three groups, namely vitrinite, exinite and inertinite. Minerals occur as sedimentary rocks (siltstones, shales and sandstones) and as mineral grains within the organic matrix of a seam (quartz, clays, carbonates, sulphides and various oxides). The compressive strength of coal depends on the composition of the lithotypes. The strength of each lithotype is determined by the microlithotypes which in turn depends on their maceral composition. Homogeneous microlithotypes are lower in strength than those rich in minerals. The highest strength is found in the highly mixed, mineral-rich sapropelic coals and the lowest in vitrinites because of the high frequency of fissures and in fusites because of their pronounced friability. The hardness (resistance to penetration) of coal varies according to rank and composition. The hardness of vitrinite-rich coals are at a maximum between low-rank and medium-rank bituminous coals and decreases to a minimum at the boundary between low-rank bituminous and semi-anthracite coal. It then increases again in the anthracite levels due to the elastic behaviour of the vitrinite in the anthracite. The hardness of the inertinite-rich coals, however, does not appear to be affected by rank. In terms of the macerals in the composition, the inertinite group possesses the highest hardness, vitrinite intermediate values, and exinites the lowest (Falcon et al, 1987).

In addition to the differences in the chemical composition, the South African coals are generally hard and uncleated, which makes them much more difficult to cut that the European coals. Macgregor (1983) summarises the major differences between the South African and European coals in Table 2.1.

Table 2.1 Major Differences Between South African and European Coals (Macgregor, 1983)

South African	European
1. Deposited in a cool to cold climate.	Subtropical climate
2. High proportion of inertinite and detrital minerals (clay, quartz). Tougher and more abrasive than United Kingdom coals.	High proportion of vitrinite and exinite.
3. Coal is jointed (little evidence of cleat).	Well cleated.
4. Shallow seams.	Deep seams with accompanying stress and a high cleat frequency makes cutting easier than South African coals.

2.1.2 Stratigraphy

The major coal deposits in South Africa occur within the Main Karoo Basin. The coal is found in the Vryheid Formation, formerly classified as part of the Middle Ecca Series, of the Karoo Supergroup. This formation is only developed in the northern part of the Main Karoo Basin, in general north of latitude 29° (Erasmus et al, 1981), while the 26th meridian forms its western boundary (de Jager, 1976). The Vryheid Formation is a sedimentary sequence of rocks commonly comprising alternating units of sandstone and shale, the sandstone being the most dominant lithology. The coal seams are well-defined bands of coal with well defined roof and floor contacts.

The main Karoo Basin is a large basin situated on the southern and eastern flanks, or South thereof, of the Kaapvaal Craton (Figure 2.4).

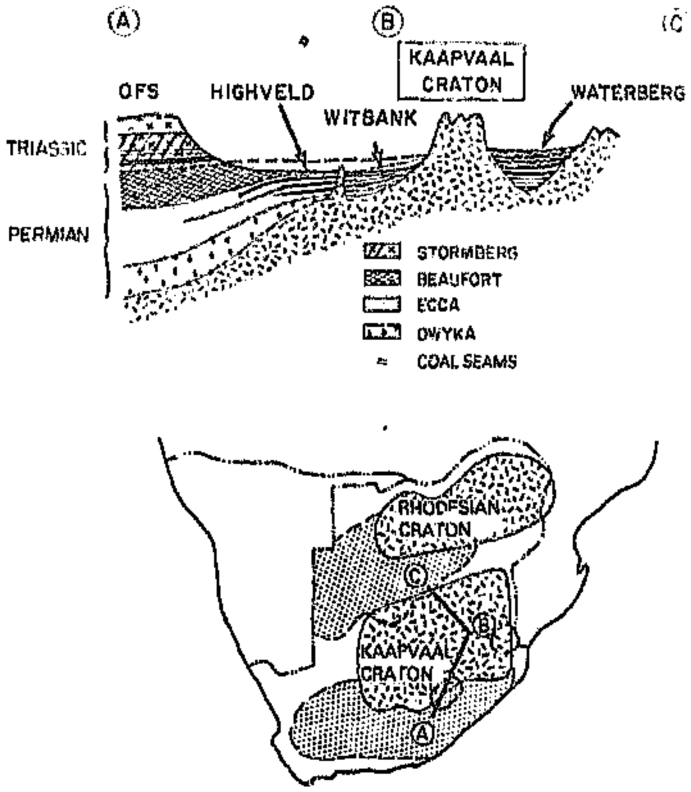


Figure 2.4 The development and ages of coal seams in various Karoo basins in South Africa (Falcon, 1986)

Sedimentation occurred on a stable shelf in the northern sector of the craton, and in a deep, rapidly subsiding part of the basin to the South, which developed over an unstable, mobile belt terrain (Falcon, 1986).

Smaller sedimentary basins occur outside the Main Karoo Basin in which the coal is also gene·ally found in the Vryheid Formation. The main feature of these basins, however, is the development of coal in the overlying formation, which is regarded as the equivalent of the Volksrust Formation in the Main Karoo Basin (Erasmus et al, 1981). This formation, which was formerly classified as part of the Upper Ecca Series, has now been named the Volksr... Formation. Although the Volksrust Formation reaches considerable thicknesses, it is always ... with shale bands which are intimately associated with the coal bands (Erasmus

2.1.3 De... itional sequences

Leeder (1982) states that the broadest pos..ble classification of environments is into *continental, coastal, shelf* and *deep marine.* These can be further subdivided into environmental facies (Table 2.2). The term environmental facies in this context refers to the the whole set of attributes possessed by the deposited sediment laid down in a particular environment.

The difference in the genetic sequences in the various coal bearing areas in South Africa is the result of different dep... ...al s..quences and depends to a large extent on the palaeoenvironment. Winter (1985) recognised continental (glacial and fluvial), coastal (deltaic and barrier) and shelf depositional sequences in the Highveld Co..lfield, and he developed a coal depositional model for the northern part of the Highveld Coalfield (Figure 2.5). These depositional sequences are valid for the majority of the South African coalfields.

Glacial sequences are usually formed during the retreat of valley glaciers and are normally represented by the diamictite and, in most cases, a smaller component of interlaminated siltstone-mudstone deposits. The other sequences, namely the fluvial, deltaic and coastal followed after the glacial period, and the bottom coal seam genetic sequences are normally deposited on or near this diamictite which forms a good floor.

Table 2.2 Summary (not exhaustive) of the Environments of Deposition on the Earth's Surface (Leeder, 1982)

Environmental Association	Environment	Sub-environments or environmental variants
Continental	Desert	Erg, wadi, erg apron, interdune, playa, duricrust
	Alluvial fan	Fanhead channel, proximal fan, distal fan, suprafan lobe
	Alluvial plain and riverine cone	Braided channel, meandering channel, levee, crevasse splay, floodbasin, lake
	Lake	(Saline, temperate stratified, tropical stratified, glacial, delta plain) lake terrace, shoreline, slope, basin, delta
	Glacial and periglacial	Supraglacial (flow till), subglacial (lodgement till), intraglacial (melt out till), morainic complex, outwash fan, glacial lake, esker (also glaciomarine)
Coastal-shelf	Delta	Distributary channel, tidal channel, backswamp, bay, mouth bar, prodelta
	Estuary	Estuarine channel, marginal flats, flood tidal delta
	Linear clastic shorelines	Beach, nearshore, offshore, barrier, lagoon, tidal flat, tidal delta, tidal inlet, coastal aeolian dunes
	Carbonate-evaporite shorelines shelfs and basins	Sabkha algal marsh, tidal flat, beach, lagoon, tidal delta, platform margin, marginal buildups, deep basin, evaporite basin
	Clastic shelf	(Tide dominated, weather dominated) various tidal bedforms, sand ribbons, linear tidal ridges, sandwaves, shoal retreat massifs, buried channels, scarps (also glaciomarine)
Oceanic	Passive margin	Continental slope, continental rise, abyssal plain, submarine fan, submarine channel
	Active margin	Trench, subduction complex, perched basin, fore-arc basin, back-arc basin, fan
	Oceanic pelagic	Mid-ocean ridge, ridge flank, abyssal plain (hyper-saline ocean, euxinic ocean)

Fluvial sequences, such as the sandy braided river and anastomised (stable banks) river deposits of the Highveld Coalfield, are upward fining from coarse conglomerate and sandstone at the bottom to siltstone at the top. The sandy braided river deposits are characterised by thick conglomerate and sandstone units, sporadically interbedded with thin carbonaceous siltstone units.

Deltaic sequences are gradationally upward-coarsening, from siltstone at the base to sandstone at the top. The continuous and regular sheet sandstones found in the Highveld Coalfield is typical of high constructive lobate deltas.

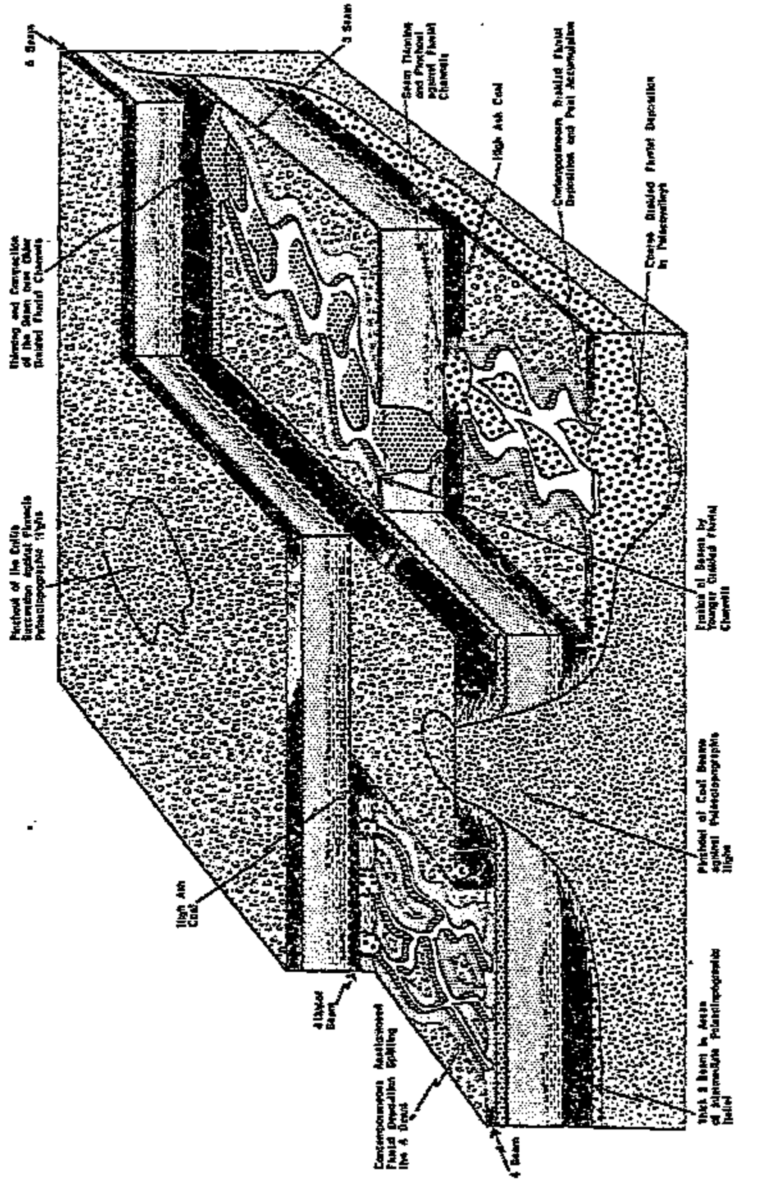


Figure 2.5 Depositional Model for the northern Highveld Coalfield (Winter, 1985)

Transgressive (barrier-island) sequences are characterised by a broadly upward-coarsening grain-size mode and consist of a basal siltstone which passes into interlaminated sandstone-siltstone and then sandstone. It is often capped by thin, discontinuous coal seams.

2.1.4 Classification of coal reserves

Reserves are defined as the known amounts of a mineral that can be profitably produced at current prices using current technology. The two basic concepts of *resources* and *reserves* often cause misunderstanding. The "McKelvey diagram" (see Figure 2.6), used by the U.S. Geological Survey and the U.S. Bureau of Mines, shows the relationship between reserves and other measures of resource stocks (Dorian et al, 1984).

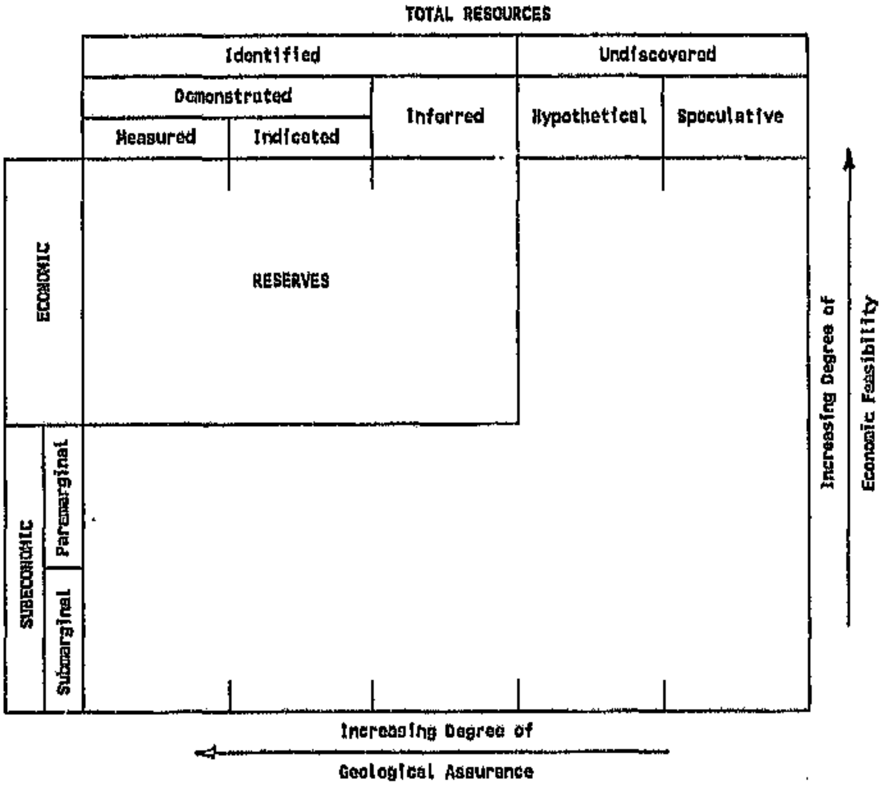


Figure 2.6 Classification of Mineral Resources (U.S.Bureau of Mines, 1975)

This diagram classifies resources according to two parameters:

(i) The degree of geological assurance or confidence.

(ii) The degree of economic recoverability by mining (Bredel, 1990).

2.1.5 The South African Coalfields

The coal deposits of the Main Karoo Basin have been subdivided into different coalfields, shown in Figure 2.7, based on differences in lithology, numbering, thickness and quality.

Seven of the collieries practising pillar or rib pillar extraction are situated in the Northern Natal coalfields, six in the Highveld Coalfield, three in the Eastern Transvaal Coalfield and one each in the Springs-Witbank, Vereeniging-Sasolburg, South Rand and Zululand Coalfields. The structure and lithology of only these coalfields will thus be described briefly.

Although the coal seams in the different coalfields are numbered or named differently, de Jager (1976) suggested the following correlation between the coal seams in the different coalfields (Table 2.3):

Table 2.3 Suggested Correlation of the Seams of some Middle Ecca Stage Coal Provinces (de Jager, 1976)

Witbank Coalfield	Highveld Coalfield		Carolina-Wakkerstroom Coalfield				Utrecht Coalfield	Vryheid-Paulpietersburg Coalfield	Newcastle-Dundee Coalfield	Colenso-Ladysmith Coalfield
	South & Central Sector	North & Eastern Sector	Carolina-Breyten Sector	Ermelo Sector	Glenfillen Sector	Wakkerstroom Sector				
No. 5	No. 5	No. 5	A	A						
+	+	+	Fritz *	Fritz *	Fritz *	Fritz *	Fritz *	Fritz	Leader	Fritz *
No. 4A	No. 4A	No. 4A	B	B	Alfred	Alfred	Hose	Alfred	Top	Top
No. 4U	No. 4U	No. 4U	C	C	Gus	Gus	Main	Gus	Bottom	Bottom *
+	+	+	+	+	Upper	+	+	Upper	Lower	+
					Dundas #			Dundas	Leader #	
No. 4L	No. 4L	No. 4L	C Lower	C Lower	Dundas	Dundas	Yard	Dundas	+ ?	Dundas #
No. 3	No. 3	No. 3	D	D	Coking	Coking	Coking	Coking	+	Coking *
No. 2	No. 2	No. 2	+	E	Targas	Targas	+	Targas	+	Targas *
No. 1	No. 1	No. 1	+	+	+	+	+	+	+	+

+ Absent.

* Represented by carbonaceous shale.

Intermittent or locally developed.

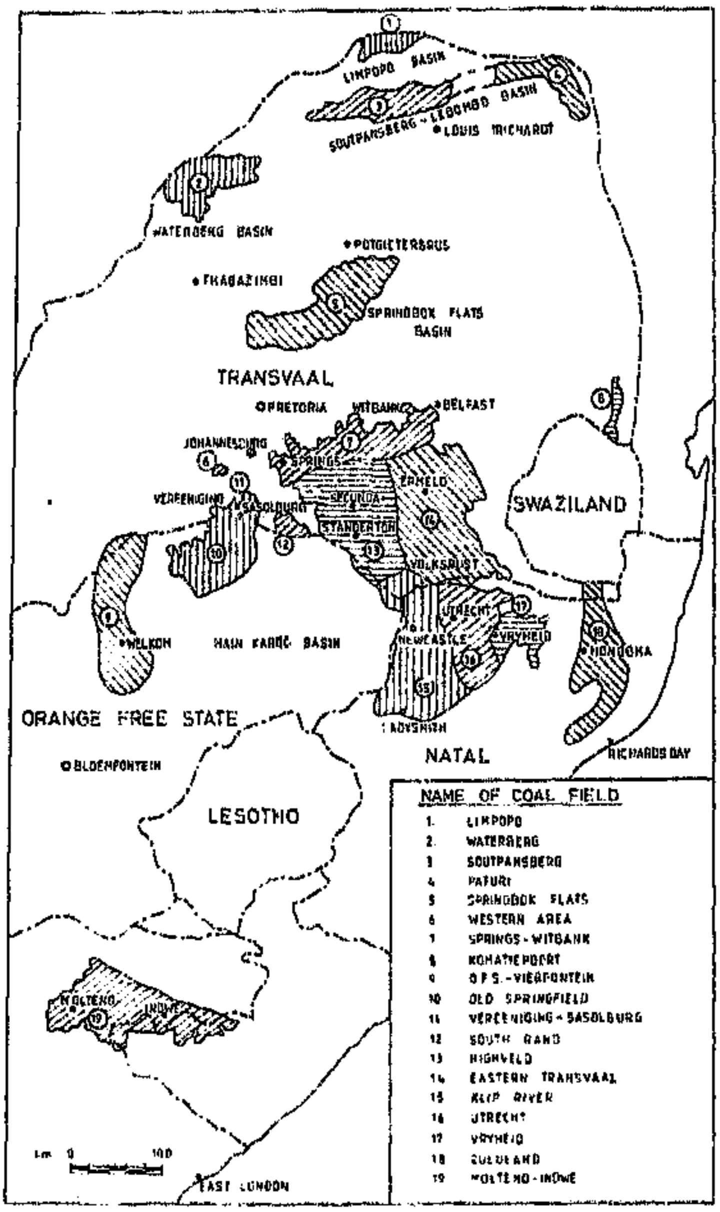


Figure 2.7 **South African Coalfields**

2.2 The Highveld Coalfield

2.2.1 General

The Highveld Coalfield, which covers approximately 7 000 square kilometres, is situated in the south-eastern Transvaal. The following collieries, practising pillar or rib pillar extraction, are situated in this coalfield: Matla, Kriel, Bosjesspruit, Twistdraai, Middelbult, Brandspruit and New Denmark. It is the major coal producing coalfield in South Africa.

The Highveld Coalfield contains sedimentary rocks of the Dwyka Formation and the Ecca Group of the Karoo Sequence. North-West to South-East trending pre-Karoo glacial valleys controlled the deposition of plant material along the northern and western boundaries, and steep slopes are envisaged to occur along the rim of these valleys. The coal in the South and East, however, was deposited on slightly undulating wide valleys and ridges (Erasmus et al, 1981 and Jordaan, 1986). Cadle and Hobday (1977) identified three phases of sedimentation: a lower delta-dominated phase, a fluvially dominated coal zone, and an upper deltaic succession. Sand-dominated facies types in the Highveld Coalfield (see Figure 2.8) form extremely laterally continuous and regular sheet sandstones. This continuity of the sandstone is typical of high constructive lobate deltas (Winter, 1985).

At the majority of the collieries, the strata overlaying the No. 4 Seam (which is the major seam of economic importance at all the collieries) consists of thick competent sandstone which generally forms a good roof. This competent sandstone roof, however, does not cave readily during pillar extraction, especially in narrow panels. This causes stress increases on the pillars being extracted and can cause premature failure of the partially extracted pillars or goaf overruns of the pillars and breakerlines when the roof does goaf during pillar extraction.

2.2.2 Stratigraphy and structure

Dolerite Intrusions

Intrusives of the Drakensberg Formation, in the form of dolerite sills and dykes, covers large areas of the coalfield. The older dolerite sill is non-porphyritic, generally coarse-grained and heavily jointed. It generally occurs at or near the surface and weathers relatively easily. This dolerite sill, which may correlate with the Matshongololo sill in Natal, attains a thickness of up to 90 m and consists of composite sills or a series of splits. These splits can be up to 40 m thick. The younger sill is porphyritic and similar to the Utrecht dolerite in Natal. It varies from 5 m to 80 m in thickness and is finer grained than the older sill. In the Standerton area, this sill intrudes the older non-porphyritic sill (Jordaan, 1986). These sills have been observed to transgress the coal horizon in various places, resulting in the formation of burnt coal and the displacement of coal seams, especially in the central and southern parts where the coal seams have been intensely disturbed.

Numerous dolerite dykes, varying in thickness from a few centimetres to several metres, have been encountered in the coalfield. They have a major influence on mine layouts and the type of mining methods that can be used cost effectively.

The Coal Seams

All the coal seams of the Witbank Coalfield, namely No's. 1, 2, 3, 4 and 5, are present in the coalfield, but only the No. 4 Seam is currently economically extractable throughout the coalfield. The No's. 1 and 3 Seams are thin and discontinuous throughout the coalfield. The No. 2 Seam is currently economically extractable at Matla, Kriel and Middelbult Collieries, and the No. 5 Seam, only at Matla and Kriel Collieries in the northern part of the coalfield. The general stratigraphic sequence of the Highveld Coalfield is shown in Figure 2.8.

The *Nos. 1 and 3 Seams* are thin and discontinuous throughout the coalfield and is currently not considered mineable.

The *No. 2 Seam* is thick and laterally continuous in local basins and valleys in the northern and western parts of the coalfield where it attains a thickness of up to 8 m. The immediate roof is variable and can consist of sandstone, siltstone or mudstone. The sandstone forms a good roof, but the other strata normally require systematic roof support. The variation in the floor strata is similar to that of the roof strata. The sandstone forms a good floor, but the other rock types break up under heavy mining equipment, especially in the presence of water (Jordaan, 1986).

The *No. 4 Seam* is split into No. 4 Upper and 4 Lower Seams by a parting which increases in thickness from 2 m in the North to approximately 15 m in the South. The No. 4 Upper Seam only attains mineable thickness in limited areas in the western part of the coalfield.

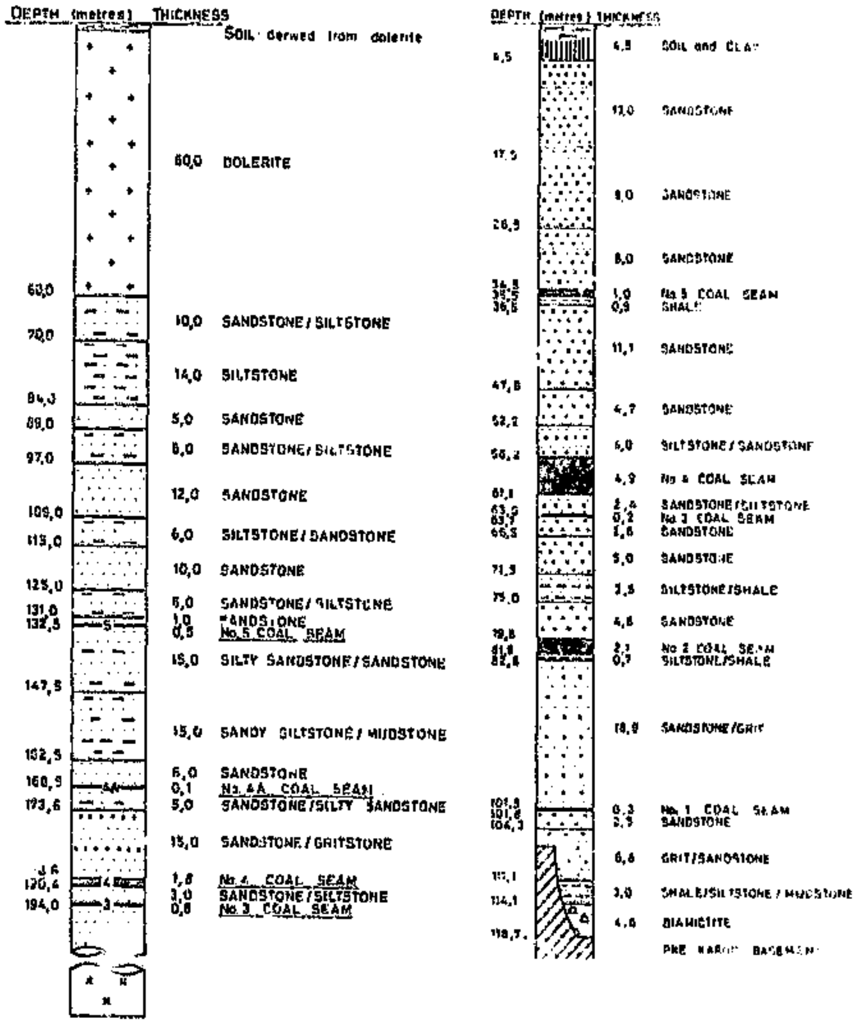


Figure 2.3 General stratigraphic sequence of the Highveld Coalfield

The *No. 4 Lower Seam*, which is well developed over large areas, with an average mineable thickness of approximately 4 m, is the main seam of economic importance and is mined by all the collieries in the coalfield. De Jager (1976) states that the No. 4 Lower Seam is of great importance to the country, as it occurs in the Highveld Coalfield which, with the exception of the Waterberg Coalfield, is the only coalfield that can readily satisfy a large future demand. The roof of the No. 4 Lower Seam also varies considerably and can consist of grit, coarse to fine-grained sandstone, inter-laminated sandstone and siltstone, shale or coal. In the South-East the sandstone roof can be up to 25 m thick. The sandstone provides a good roof, but the other strata normally require systematic support after mining. The floor consist of fine to medium-grained sandstones which result in fair to good conditions.

The *No. 5 Seam* is developed over the entire area, but the average thickness is less than 1 m except in the North where a maximum thickness of more than 3 m have been recorded. The roof of the No. 5 Seam consists of a medium to coarse-grained sandstone which results in a good roof. The soft, highly micaceous siltstone, which becomes slippery and friable on exposure, causing serious problems in the floor of the No. 5 Seam.

2.3 The Eastern Transvaal Coalfield

2.3.1 General

This coalfield extends from Carolina in the North to Volksrust and Wakkerstroom in the South and covers an area of approximately 11 000 square kilometres. The three collieries practising pillar extraction in this coalfield, are Ermelo Mines and Usutu Colliery in the North, and Savmore Colliery in the South.

The coal seams of this coalfield are relatively flat with gentle undulations. Very little folding of the strata occurs, but faulting is common. These faults are generally associated with intrusions of Karoo dolerites of Jurassic age (Greenshields, 1986).

Two major sills, and splits of these sills, are present in Ermelo area of the coalfield. These often transgress the coal seams, dividing the area into a number of reserve blocks (see Figure 2.9) and result in zones of devolatilised coal.

2.3.2 Stratigraphy and structure

Dolerite Intrusions

As many as ten ages of dolerite sills, varying from 10 m to 230 m in thickness and increasing in number in a southerly direction, have been identified in the coalfield. Vast quantities of coal have been burnt or devolatilised and the coal reserves have been cut up into blocks varying in shape and size, with associated elevation differences between the blocks (Erasmus et al, 1981).

Numerous dolerite dykes, varying from 1,0 m to 10,0 m in thickness, occur in the coalfield, increasing in intensity from North to South.

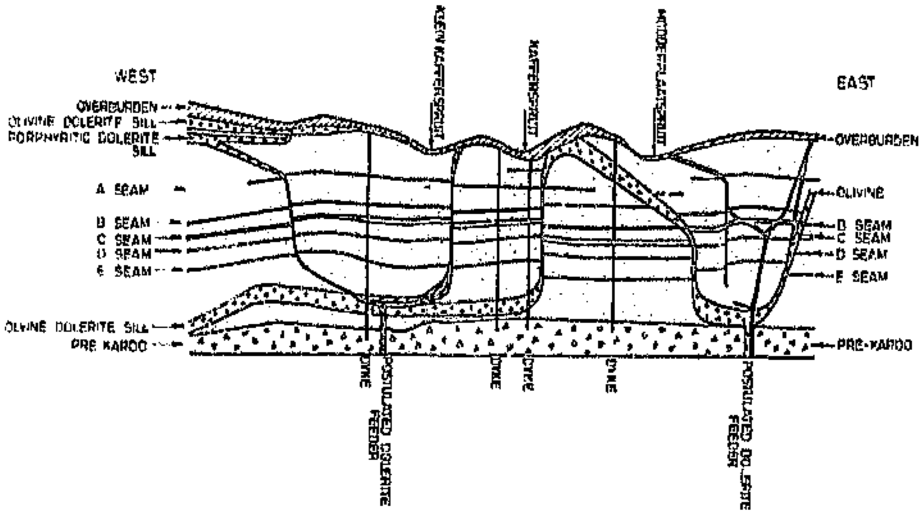


Figure 2.9 Geological section across the Ermelo Mining Area

The Coal Seams

All five major coal seams in the Vryheid Formation have been identified in the coalfield, but only three have attained currently economically mineable thicknesses throughout the coalfield. The coal seams in the northern half of the coalfield have been numbered differently to those in the southern half, but can be correlated with the coal seams in the adjacent coalfields (Table 2.4).

The currently mineable coal seams in the northern area are the B, C-Upper, C-Lower and E Seams. The B, C-Upper and C-Lower Seams seams can be correlated with the mineable seams in the southern area, namely the Alfred, Dundas, and Gus Seams.

Table 2.4 Suggested Coal Seam Correlation (Greenshields, 1986)

Highveld Coalfield	Eastern Transvaal Coalfield		Utrecht Coalfield
	Northern Half	Southern Half	
No. 5	A	Eland	Eland
No. 4A	B	Alfred	Alfred
No. 4 Upper	C	Gus	Gus
No. 4 Lower	C Lower	Dundas	Dundas
No. 3	D	Coking	Coking
No.2	E	Targas	Targas

The thickness of the parting between the Alfred, Dundas, and Gus Seams vary widely throughout the northern part of the coalfield and this has a major influence on the viability of multi-seam mining. The general stratigraphic sequence of the northern and southern parts of the coalfield is shown in Figure 2.10.

The *E Seam* is well developed in the northern part of the coalfield and attains a maximum thickness of over 3 m at depths ranging from surface to 100 m. The roof and floor of this seam are generally composed of competent sandstone and do not require intensive systematic support.

The *D Seam* is usually too thin to be mined by present underground mining methods. It may thicken in local areas where, when considered in conjunction with other seams, it may have opencast potential.

The *C Seam* is the most complex and is usually split into several plies by partings varying in thickness. It is traditionally subdivided into the C Upper and C Lower seams (Greenshields, 1986).

The *C Lower Seam* is usually thin in the northern part of the coalfield, but attains a thickness of up to 2,0 m in the southern part. The floor of the seam usually consists of a sandstone which forms a good floor, whilst the roof generally consists of carbonaceous shale which requires systematic support.

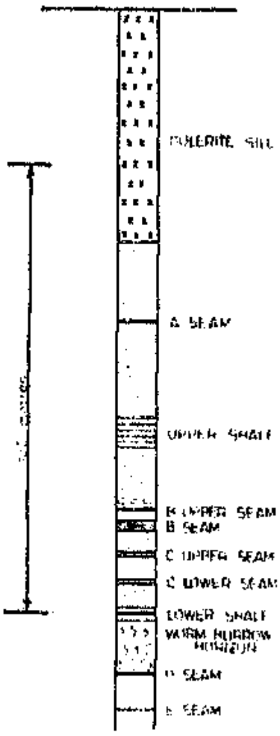


Figure 2.10 General stratigraphic sequence of the Eastern Transvaal Coalfield (Erasmus et al, 1981).

The *C Upper Seam* is well developed over the entire coalfield, but it is often split by in-seam sandstones, siltstones or mudstones which vary in thickness and lateral extent. The floor normally consists of a competent sandstone. The roof also consists of sandstone and does normally not require intensive support.

The *B Seam* is also developed in the entire coalfield and varies in thickness from 1,0 m to 3,0 m. The the northern and central areas the seam may be locally split by in-seam bands.

The roof and floor generally consist of competent sandstone which forms a good floor and does not require intensive roof support.

The *A Seam* occurs as isolated outliers in the northern and central parts of the coalfield. In the southern part it varies from a shaly unit to a seam of 1,0 m thick. It is of poor to medium quality and it has no economic importance (Greenshields, 1986).

2.4 The Vereeniging-Sasolburg Coalfield

2.4.1 General

This coalfield extends from Vereeniging in the North to Koppies in the South, and from Vredefort in the West to the Vaal Dam in the East. Since the closure of Cornelia and Coalbrook, Sigma is the only working colliery in the coalfield.

The coal in this coalfield was deposited by southerly propagated fluvio-deltaic complexes which filled the pre-existing glacial valleys. These glacial valleys are North-South trending in the eastern part of the coalfield, but in the western part the trends are North-West to South-East.

The thick dolerite sills above the coal horizon and the relatively weak roof strata have a major influence on pillar extraction in the coalfield. At Sigma Colliery these geological conditions and the behaviour of the strata makes pillar extraction with conventional equipment a hazardous operation.

2.4.2 Stratigraphy and structure

Dolerite Intrusions

Dolerite sills up to 120 m thick occur in the area. Where these sills are in close proximity to the coal seams, they have a profound influence on the volatile content of the coal. The thick, competent sills also cause significant caving problems for high extraction mining methods.

Numerous dolerite dykes, faults and slips are encounter in the coalfield. The dykes seldom exceed 1,0 m in thickness and do not have a significant thermal influence on the coal.

The Coal Seams

Three mineable coal seams occur in this coalfield (Figure 2.11) and are contained in within a zone that is up to 40 m thick.

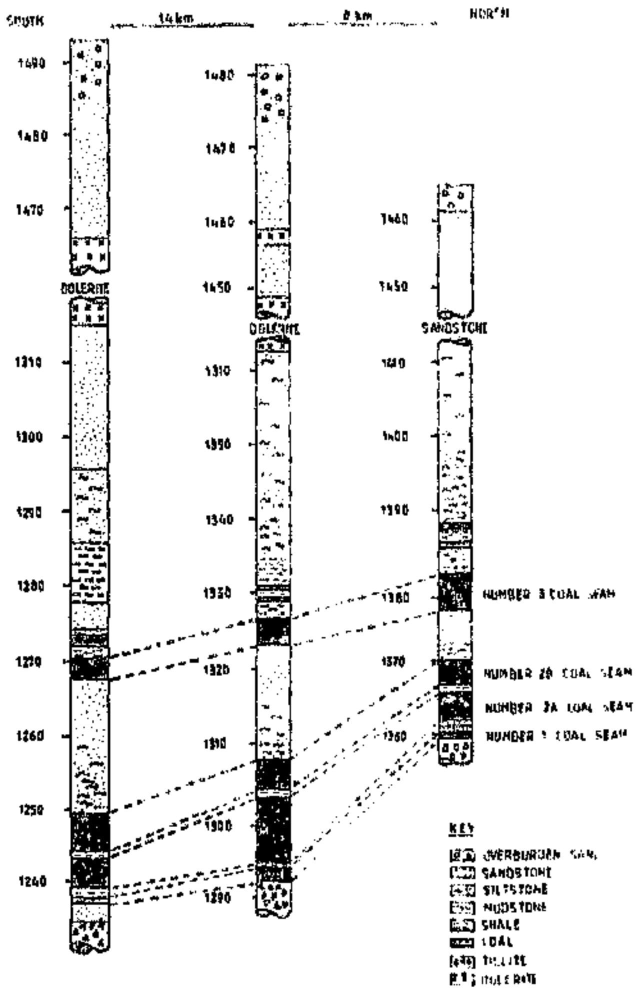


Figure 2.11 General stratigraphic sequence of the Vereeniging-Sasolburg Coalfield

The *No. 1 Seam* is usually only locally developed in the deeper parts of the basin, mainly in the eastern part of the coalfield where it attains a thickness of up to 5 m. In some areas the seam is split into three different units by partings up to 3,5 m thick. The roof consists of upward fining sandstone, grit and conglomerate which generally forms a good roof. The coal seam is deposited on or near the Dwyka diamictite which forms a good floor.

The *No. 2 Seam* is normally divided into the No. 2A and No. 2B Seams which are separated by a mudstone band which can be up to 2 m thick. The combined thickness of the No. 2 Seam can be in excess of 10 m, but due to the thin shale parting, only one of the two seams have been mined to date.

The roof of the No. 2B Seam consists of a sequence of shale, sandstone and mudstone layers. Roof problems are experienced as a result of the laminated and cross-laminated nature of these layers. The mudstone parting between the No. 2A and No. 2B Seams forms the relatively poor floor of the No. 2B Seam. This mudstone parting thus forms the roof of the No. 2A Seam. It forms a poor roof that requires intensive roof support. The floor consists of the upward fining sandstone, grit and conglomerate, which forms the roof of the No. 1 Seam, and good floor conditions are experienced.

The *No. 3 Seam* has a average mineable thickness of approximately 4 m, but reaches a maximum thickness of 10 m in some areas. The roof of this seam consists of mudstone and shale which forms an extremely poor roof requiring intensive roof support because of the tendency of the mudstone to expand on exposure to air and water (Steyn et al, 198[illegible]). The floor, which consists of shale, sandstone and mudstone layers, tends to break up under traffic, especially when exposed to water.

2.5 The Springs-Witbank Coalfield

2.5.1 General

The coalfield extends 180 km in a East-West direction, from Springs to Belfast, and approximately 40 km in a North-South direction.

Because of the relatively shallow depth of the coal seams, a high percentage of the coal production from this coalfield is by opencast methods while the bulk of the underground production is achieved by conventional bord and pillar mining. This is mainly due to the four superimposed mineable coal seams, varying in nature and quality, that occur in the coalfield. The variable marketing restraints makes scheduling and sequencing of total extraction, which has to start from the top seam downwards, extremely difficult. Pillar extraction is presently only practised on Greenside Colliery.

2.5.2 Stratigraphy and structure

Dolerite Intrusions

Dolerite sills, commonly 50 m thick, occur throughout the coalfield and, where they transgress the coal seams, have resulted in large scale displacements of the seams. Where the sills transgress or occur in close proximity of the coal seams, they have resulted in large areas of burnt coal.

The Ogies Dyke, up to 15 m thick, is the most prominent dyke in the area and has resulted in an accompanying burnt zone of up to 300 m wide. Offshoots of this dyke are common in the coalfield, but their frequency appears to be less to the North of this dyke. Only a limited number of dykes occur in the Springs area and the eastern part of the Witbank Coalfield.

The coal seams in this coalfield are generally not affected by folding or severe faulting, except where associated with dolerite intrusions. Small faults with displacements of less than one metre are rare.

The Coal Seams

All five major coal seams in the Vryheid Formation have been identified in the coalfield, and are also number No. 1 to No. 5 from the bottom upwards (Figure 2.12). All the seams, except the No. 3 Seam (which is thin and sporadically developed), are mineable by current underground methods (Smith et al, 1986).

The *No. 1 Seam* is usually 1,5 to 2,0 m thick and is currently mainly mined by opencast methods. However, the competent grit roof and hard sandstone floor result in good underground mining conditions.

The *No. 2 Seam* has an average thickness of 6,5 m and contains the bulk of the reserves (approximately 69%) in the coalfield. The roof consists of shale which forms a poor to fair roof when exposed, but roof conditions are generally good where 1 m to 2 m of coal is left in the roof. Floor conditions are normally good as the floor consists of hard sandstone or grit.

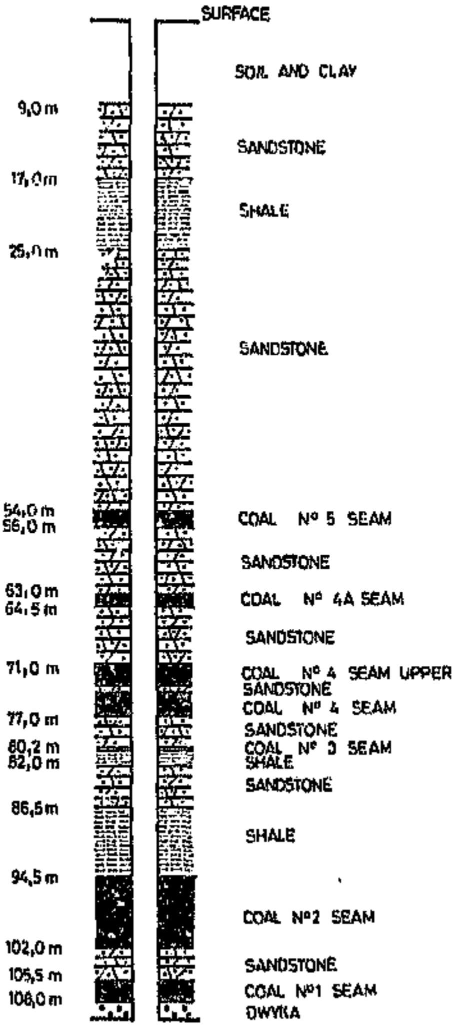


Figure 2.12 General stratigraphic sequence of the Springs-Witbank Coalfield

The *No. 4 Seam* is 2,5 to 5,0 m thick, except in the western part of the coalfield where it reaches a thickness of more than 6 m. The parting to the No. 2 Seam is 15 to 20 m and consists mainly of shale formations. Mining is normally restricted to the lower 3,5 m of the coal seam because of the poor quality in the upper part of the seam and the bad roof conditions if the shale is exposed.

The *No. 5 Seam* has an average thickness of 1,5 to 2,0 m and occurs about 25 m above the No. 4 Seam. It occurs at an average depth of approximately 30 m below surface and has been eroded in the higher areas. The laminated sandstone forms a poor roof that requires intensive roof support, and the laminated micaceous sandstone floor presents heaving problems in localised areas (Erasmus et al, 1981).

2.6 The Utrecht Coalfield of Northern Natal

2.6.1 General

The Northern Natal coalfields have been subdivided into three separate coalfields, namely the Klip River, Utrecht and Vryheid Coalfields. The Natal coalfields, including the Zululand Coalfield, are the only producers of high-grade anthracite in South Africa and also produces some of the best quality coking coal. The Utrecht Coalfield covers an area of approximately 5 000 square kilometres and is situated in the Utrecht and Paulpietersburg districts. Two collieries, namely Longridge Colliery and Welgedacht Exploration Company Limited, are practising pillar extraction in this coalfield.

The two factors which have a major influence on the mining in the Northern Natal coalfields are the large number of dolerite sills overlying the coal zone and the large variance in the depth as a result of the mountainous terrain. The latter has a major effect on pillar and panel sizes and layouts. The varying depth under the mountains often results in frequent changes in the size of the pillars, which affect the panel width, within the main, secondary and panel development. This leads to different stooping practices, often in close proximity to each other. The often multiple, thick dolerite sills result in increased stresses on the pillars, especially during pillar extraction.

2.6.2 Stratigraphy and structure

Dolerite Intrusions

Five major dolerite sills are present in the Utrecht Coalfield. These dolerite sills, in order of decreasing age are the Zuinguin, "B", Utrecht, Ingogo, and No. 10 sills. Of these sills the Zuinguin is the most persistent and attains a thickness of up to 150 m. Major displacements of the coal bearing strata have been caused by these transgressive dolerite sills and faults.

Although vast quantities of coal were burnt or devolatilised during these volcanic events, the thermal effect al led to the formation of the good quality anthracite and coking coals.

Dolerite dykes, with thicknesses varying from 1 m to 10 m, are common in the coalfield, but faulting is not normally associated with the dykes.

Major faults within the coalfields are caused by the dolerite sheets transgressing the coal zone, and faults with displacements of up to 150 m, associated with the Zuinguin Sill, have been encountered in the Utrecht Coalfield (Spurr et al, 1986).

The Coal Seams

Only four of the coal seams in the coalfield, correlated in Table 2.3, are economically mineable with present technology, namely the Alfred, Gus, Dundas and Coking (Figure 2.13).

The *Coking Seam* is generally thin with an average thickness of 0,9 m and a maximum thickness of 1,5 m. The seam is unaffected by the dolerites and yields a moderately good coking coal. The roof and floor rocks consist of sandstone and are normally competent.

The *Dundas Seam* occurs approximately 15 m above the Coking Seam and attains a thickness of up to 2 m. The roof consists of sandstone which forms a good roof, but the floor consists of incompetent shales which breaks up under traffic.

The *Gus Seam* occurs approximately 17 m above the Dundas Seam. The Gus Seam can attain a thickness of more than 1,0 m in the southern area up to 3,3 m in the northern area, and has been the most extensively mined seam in this coalfield. The roof in the Utrecht area consists of sandstone and is fairly competent. In the Kempslust area, however, the thinly-laminated sandstone form an extremely incompetent roof (Spurr et al, 1986). The floor consists of sandstone and is fairly competent.

The *Alfred Seam* occurs approximately 14 m above the Gus Seam. The seam is best developed in a downfaulted block South of Utrecht where it attains a total thickness of nearly 4 m with a mineable thickness of 3 m. In the northern area the seam reaches a total thickness of 3,0 m of which the bottom 1,5 m is currently considered to be economically mineable. The roof and floor consist of sandstone. The roof is reported to be moderately competent while the sandstone forms a good floor (Spurr et al, 1986).

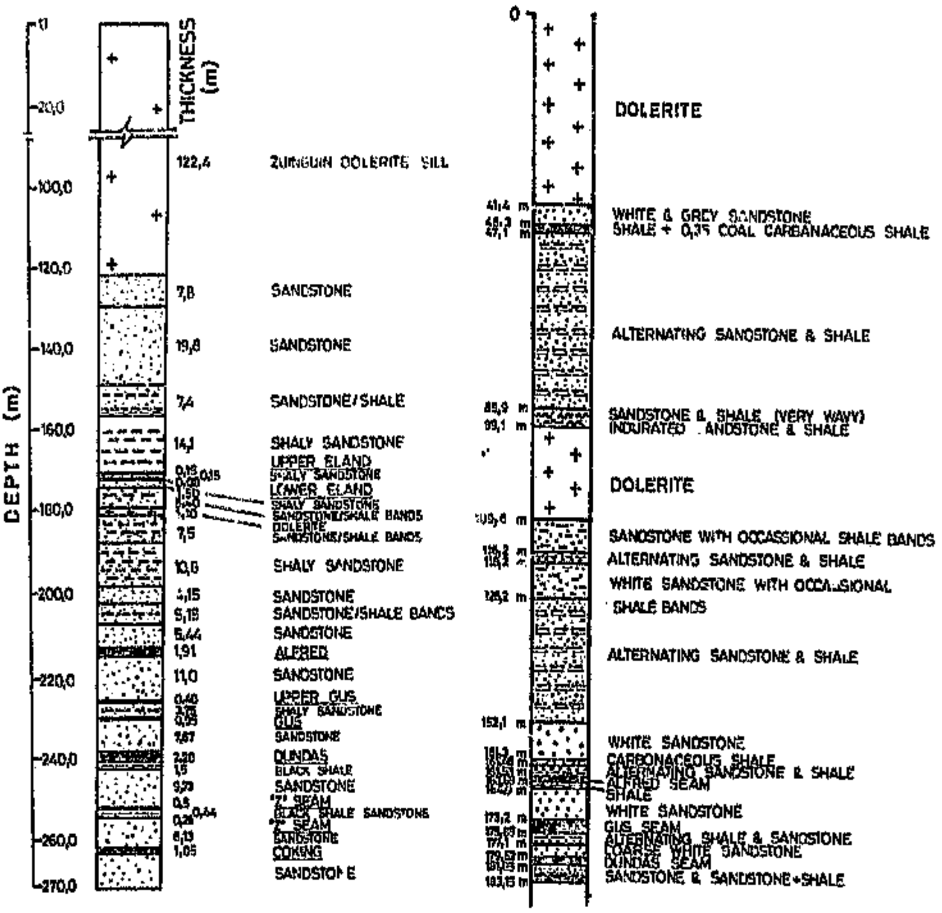


Figure 2.13 General stratigraphic sequence of the Utrecht Coalfield

2.7 The Vryheid Coalfield of Northern Natal

2.7.1 General

The Vryheid Coalfield lies to the East of the Utrecht Coalfield in the districts of Vryheid and Ngotshe, and covers an area of approximately 2 500 square kilometres. The collieries practising pillar extraction in this coalfield are: Vryheid Coronation Colliery, Hlobane Colliery and Alpha Anthracite Colliery.

Similar to the Utrecht Coalfield, the two factors which influences mining most are the large number of dolerite sills overlying the coal ... and the large variance in the depth as a result of the mountainous terrain.

In addition to this, the floor conditions also vary considerably, depending on the seam being mined. Apart from weak and laminated floor disintegrating due to tramming, the combination of depth below surface, competent overlying roof strata and weaker floor strata also lead to floor heave or 'creep'. The phenomenon of floor heave is the result of pressure and stresses within the mining area being transmitted through the surrounding strata to such an extent that the strata in the floor break down under these pressures, resulting in the floor lifting towards the roof (see Chapter 4, Figure 4.4).

2.7.2 Stratigraphy and structure

Dolerite Intrusions

Five major dolerite sills have been identified in the coalfield. In order of descending age, these are the Zuinguin, Ngwibi, Matshongololo, Nyembi and Enyati sills.

The older intrusions, particularity the Zuinguin Sill, are fairly consistent while the younger intrusions, like the Enyati Sill, are typically erratic and commonly dyke-like.

The sill phase was followed by a a period of dyke intrusions, up to 10 m thick, which is associated with limited faulting only (Bell and Spurr, 1986).

The Coal Seams

As many as nine seams have bee identified within the coal zone of the Vryheid Coalfield. The most outstanding feature of this coalfield is the change in the character of the seams, and the associated roof and floor strata, over short distances. Inter-seam partings are discontinuous over short distances and often makes seam identification and correlation very complicated (Bell and Spurr, 1986).

Four of the seams in this coalfield are currently economically exploitable with underground mining methods, namely the Coking, Dundas, Gus and Alfred Seams. Apart from these seams, only the Fritz has economic potential. The typical stratigraphy of this coalfield is shown in Figure 2.14

The *Coking Seam* seldom attains a thickness of more that 1,0 m and has to date not been exploited over the entire coalfield. It has not been effected by dolerite intrusions and yields a good coking coal. The roof strata consist of competent sandstone which forms a good roof. The floor usually consists of fine-grained, micaceous sandstone which grades to a grey shale. This strata form a poor floor which tends to break up under the weight of mining machinery.

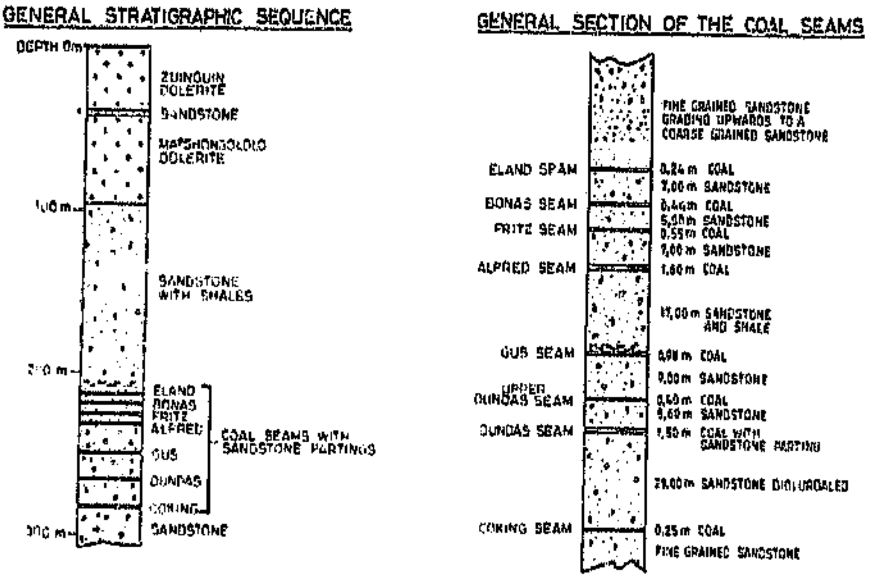


Figure 2.14 General stratigraphic sequence of the Vryheid Coalfield

The *Dundas Seam* is commonly split into two and occur as two separate seams in the northern and central parts of the coalfield. In the southern part, however, the upper portion of the seam is often replaced by a carbonaceous mudstone.

The *Lower Dundas Seam* varies in thickness from 0,2 m to a maximum of 2,5 m. It often has a thin sandstone and shale parting in the top portion of the seam which can reach a thickness of up to 1,0 m and can present problems when mining the seam. The roof and floor conditions are highly variable and are generally poor. The roof strata consist of shaly sandstones, often with a thin mudstone band on the coal contact. The floor generally consists of a micaceous mudstone or laminated sandstone which tends to break up under mining machinery.

The *Upper Dundas Seam* generally occurs 1,5 m to 6,5 m above the Lower Dundas Seam. The thickness of the seam over most of the coalfield varies between 0,15 m and 0,5 m, but in the Vryheid Coronation area, it attains a thickness of 1,0 m to 1,2 m. The roof and floor strata consist of generally incompetent, micaceous sandstones and roof and floor conditions are relatively poor. The occurrence of floor heave can make the mining of this seam extremely difficult.

The *Gus Seam* is the most extensively mined seam in this coalfield and varies in thickness from 0,5 m to 2,0 m. In the eastern part of the coalfield, however, the Gus Seam appears to have been replaced by a carbonaceous shale. The roof normally comprises a coarse-grained sandstone which forms a competent roof. The floor strata consists of sandstone, often interbedded with shale bands, and can cause problems when using mechanised mining equipment.

The *Alfred Seam* attains a thickness of up to 2,2 m in the Vryheid area and has not been as extensively mined as the other seams in the coalfield. Roof conditions are generally poor, because mudstone and lower quality coal are left in the roof to maintain a better quality product. The floor consists of sandstone and is fairly competent.

2.8 The Klip River Coalfield of Northern Natal

2.8.1 General

The Klip River Coalfield is roughly triangular in shape with it's apex in the North beyond Newcastle, stretching South to Ladysmith and then South-East to Dundee. It covers a total area of approximately 6 000 square kilometres of which about 50 per cent is considered potentially coal bearing (Bell and Spurr, 1986). The two collieries practising pillar extraction in this coalfield are: Kilbarchan Colliery and Durban Navigation Collieries.

2.8.2 Stratigraphy and structure

Dolerite Intrusions

All tectonic disturbances, apart from minor faulting, can be ascribed to dolerite sill intrusions. The maximum displacement reported within the coalfield is 137 m. Nine types of dolerite sills have been recognised in the area. The four major sills, from oldest to youngest, are: Zuinguin, Utrecht, Ingogo and Talana.

Dykes, ranging in thickness from a few centimetres to tens of metres are common and seem to be concentrated in certain areas. Their composition is similar to that of the sills, and they are often associated with small displacements. Burning and devolatilization of the coal are also often associated with these dykes (Bell and Spurr, 1986).

The Coal Seams

Only two coal seams, namely the Top and Bottom Seams (Figure 2.15), have been exploited commercially. Although correlation of the coal seams in this coalfield and the adjacent Vryheid Coalfield is uncertain, it is generally accepted that the Top Seam correlates with the Alfred Seam and the Bottom Seam, with the Gus Seam.

The two coal seams are separated by a parting, varying from a few centimetres to 1,1 m in thickness, consisting of sandstones and carbonaceous mudstones. Where this parting is less than 0,5 m, these two seams are often mined in one lift.

The *Top Seam* has an average thickness of 1,10 m and frequently contains minor shale partings. The roof strata comprises micaceous sandy shales which generally do not form a good roof. The floor consists of micaceous or sandy shale which can be very slippery when wet and can break up under the weight of mechanised mining equipment.

The *Bottom Seam* is often split into two or three seams separated by thin sandstones, shales and carbonaceous shales. The roof, comprising the bottom of the sandstone parting between the two seams, are normally competent. The floor consists of micaceous or sandy shale which can break up under the weight of mechanised mining equipment. The floor of both seams can in some specific cases also be prone to floor heave.

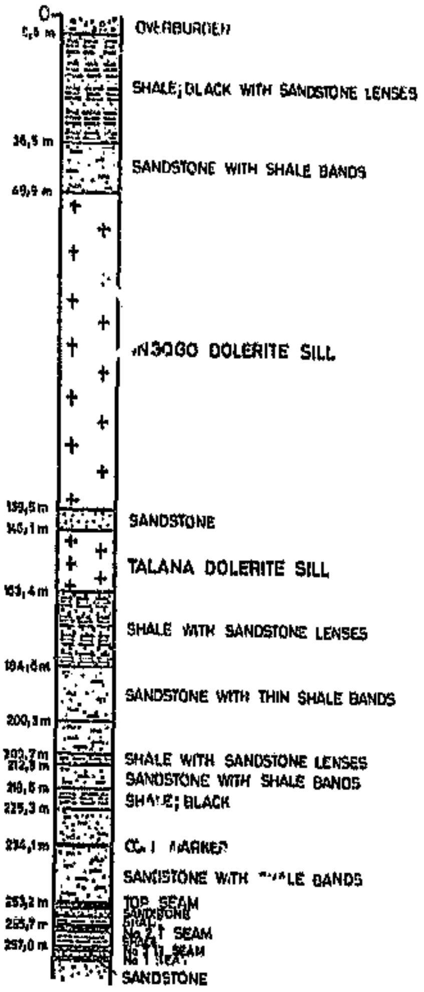


Figure 2.15 General stratigraphic sequence of the Klip River Coalfield

2.9 The Zululand Coalfield

2.9.1 General

This coalfield stretches from Durban in the South to the Swaziland border in the North. The coal-bearing area extends through Swaziland joining up with the Komatipoort Coalfield to the North. The reserves are found in the Nongoma Basin which is preserved within a graben along the eastern edge of the Kaapvaal Craton. Much of the coal in this basin is too lean or has been either eroded, burnt or extensively faulted and intruded. However, in certain distinct blocks the anthracite rese[illegible]s have been preserved, often exhibiting a remarkable consistent quality over large are[illegible].

The only producing colliery in this coalfield is Zululand Anthracite Colliery which employs both conventional equipment and a roadheader in pillar extraction.

2.9.2 Stratigraphy and structure

This is structurally a complicated coalfield. In the vicinity of Nongoma the strata lie virtually horizontal, but towards the Lebombo Range, where dips of up to 45° have been recorded, it start dipping in an easterly direction.

Major rifting in the area was associated with the onset of plate tectonics during later Karoo times. This resulted in a series of North-South striking faults that separated the coal zone into North-South trending blocks (Figure 2.16) which are further subdivided by NW/SE striking transverse faults.

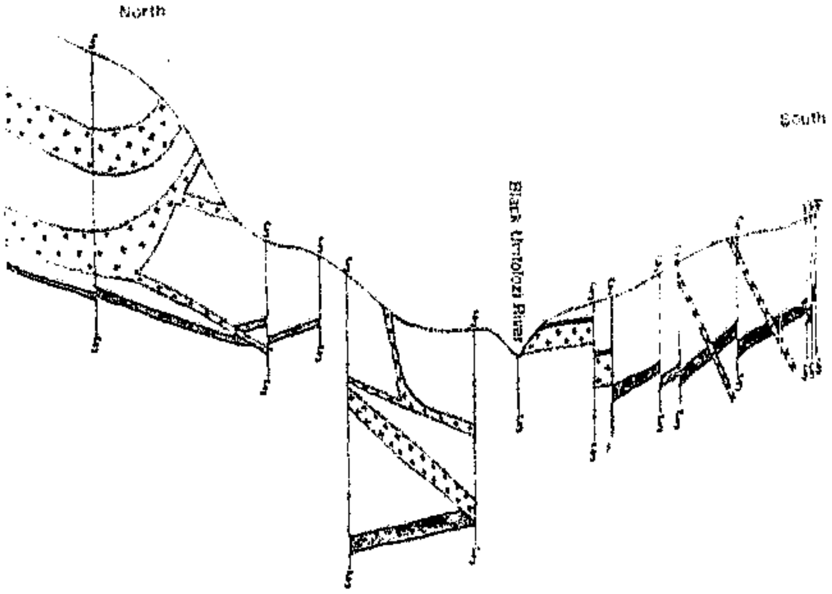


Figure 2.16 Section across the mining area showing geological structures

Local faulting in the area is predominantly of the wrench (scissor) type which arises as a result of the rotational movement between the fault blocks. The distinctive feature of such faulting is that displacements along strike can vary from a few centimetres to several metres over relatively short distances.

Numerous dolerite sills and dykes occur in the coalfield. A number of phases of dolerite intrusions in the form of both dykes and sills were associated with the faulting (Oldroyd et al, 1988). The general stratigraphic sequence of the Zululand Coalfield is shown in Figure 2.17.

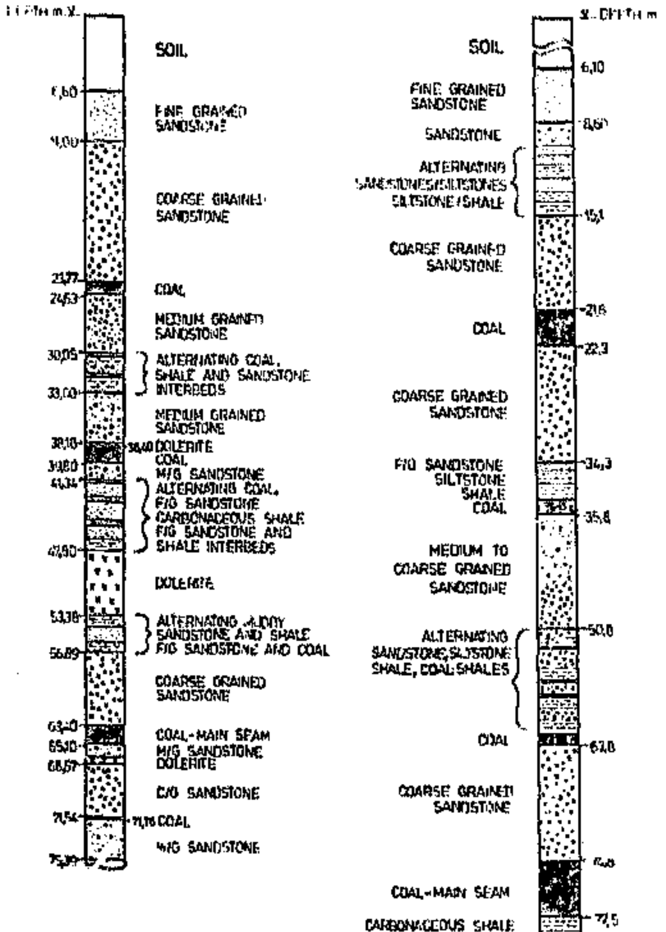


Figure 2.17 **General stratigraphic sequence of the Zululand Coalfield (Oldroyd et al, 1988)**

The Coal Seams

Although the coal seams of the Vryheid Formation have been intersected in the Nongoma area, they are much thinner and often split into a number of seams. The only workable seam in the area is known as the Main Seam, and three well defined markers overlie this seam (Figure 2.17).

The *Main Seam* dips between 1,5 and 15 degrees towards the East and is structurally very weak. In the Zululand Anthracite area, the seam occurs at a depth of 0 to 280 m and the seam height ranges between 1,5 m and 3,2 m, averaging 2,7 m.

The roof consists of a competent, massive feldspathic sandstone. Jointing of the roof is rarely visible and is usually associated with dolerite intrusions. The floor consists of layers of siltstones, fine to medium grained micaceous sandstones and carbonaceous shales with occasional coal stringers.

2.10 Closing Remark

The geological composition and strata behaviour in every situation is unique. However, there are also many similarities, if not in the composition, then in the behaviour of the strata when exposed by mining. These similarities make it possible to formulate design guidelines that can be applied in the industry.

CHAPTER 3

STRATA CONTROL THEORIES IN COAL MINING

3.1 Safety Factors for Pillars in Bord and Pillar Mining

The design of bord and pillar workings in South Africa are based on a procedure proposed by Salamon in 1967. Salamon and Munro (1967) conducted a statistical analysis of 27 collapsed and 98 intact pillar geometries from collieries in the Transvaal and Orange Free State. The pillar strength formula, developed by Salamon and Munro in 1967, was derived from this analysis and forms the key element in this design procedure, commonly referred to as the safety factor formula.

The safety factor formula is given by:

$$\text{Safety Factor} = \frac{\sigma p}{L} = \frac{Pillar\,Strength}{Pillar\,Load} \qquad (1)$$

where:

$$\text{Pillar strength} = 7.2\ \frac{w^{0.46}}{h^{0.66}}\ MPa \qquad (2)$$

$$\text{Pillar load} = 0.025H\ \frac{(w+b)^2}{w^2}\ MPa \qquad (3)$$

Legend: H = Depth to the floor of the seam, (m)
h = Mining height, (m)
w = Width of the pillar, (m)
b = Bord width, (m)

This safety factor formula has been successfully used since 1967 to design coal pillars.

On the strength of this study and analysis, Salamon and Munro (1967) concluded that an acceptable safety factor for pillars in production panels in most mining conditions is 1,6. They emphasised, however, that local experience may permit the reduction of this value to 1,5, or geological disturbances or other unfavourable features may require a safety factor of 1,7. A safety factor of 1,8 to 2,0 is normally used in main and secondary development for long term stability. It must be noted that the safety factor formula is a statement of the stability of the pillar and not of the bord.

Salamon and Oravecz (1976) stated that the safety factor formula probably underestimates the pillar strength when the width to height ratio exceeds 5 or 6, and that the pillar would be indestructible at a width to height ratio of 10.

Many people applied the pillar strength formula well outside the range of parameters for which is was derived. Salamon himself recognised the shortcomings of the design formula and in 1982 he proposed an extension to the formula to account for the increase in pillar strength beyond the critical width to height ratio as suggested by many tests on small laboratory specimens (Madden and Wagner, 1991).

Salamon proposed the following extensions to the original pillar strength formula of 1967:

The original pillar strength formula

$$\text{Pillar strength} = 7176 \frac{w^{0.46}}{h^{0.66}} \; MPa \qquad (2)$$

can be expressed in the following form

$$\text{Pillar strength} = 7176 \frac{R^{0.5933}}{V^{0.0667}} \; MPa \qquad (4)$$

where: R = width to height ratio, and

V = the pillar volume

Based on practical experience, model tests and theoretical considerations, Salamon suggested that when $R > R_0$ the strength can be expressed more accurately by the following formula (Madden and Wagner, 1991):

$$\text{Squat pillar strength} = 7.2 \frac{R_0^{0.5933}}{V^{0.0667}} \left\{ \frac{0.5933}{\epsilon} \left[\left(\frac{R}{R_0} \right)^{\epsilon} - 1 \right] + 1 \right\} MPa \qquad (5)$$

where: R_0 = the critical width to height ratio, and

ϵ = the rate of strength increase

Based on the fact that no pillar with a width to height ratio greater than 3,75 has collapsed, Salamon and Wagner (1985) suggested that for the squat pillar formula R_0 be taken as 5,0 and, although more difficult to make a realistic estimate, that ϵ be taken as 2,5. Model tests on sandstone specimens ranging from R = 1,0 to R = 8,0 suggested that the value of 2,5 was a conservative estimate (Madden, 1991).

This suggests that when the width to height ratio of a pillar is greater than 5, irrespective of the mining depth, the squat pillar formula is the more suitable formula to use as it prevents locking up coal reserves in pillars designed unnecessary large.

The safety factor of a pillar, using the squat pillar formula, is:

$$\text{Safety factor} = \frac{\sigma p}{L} = \frac{Squat\,Pillar\,Strength}{Pillar\,Load} \qquad (6)$$

The squat pillar formula thus takes into account the increase in strength of a pillar as its width to height ratio increases. A comparison of the pillar strength calculated by the squat pillar and Salamon formula is depicted in Figure 3.1.

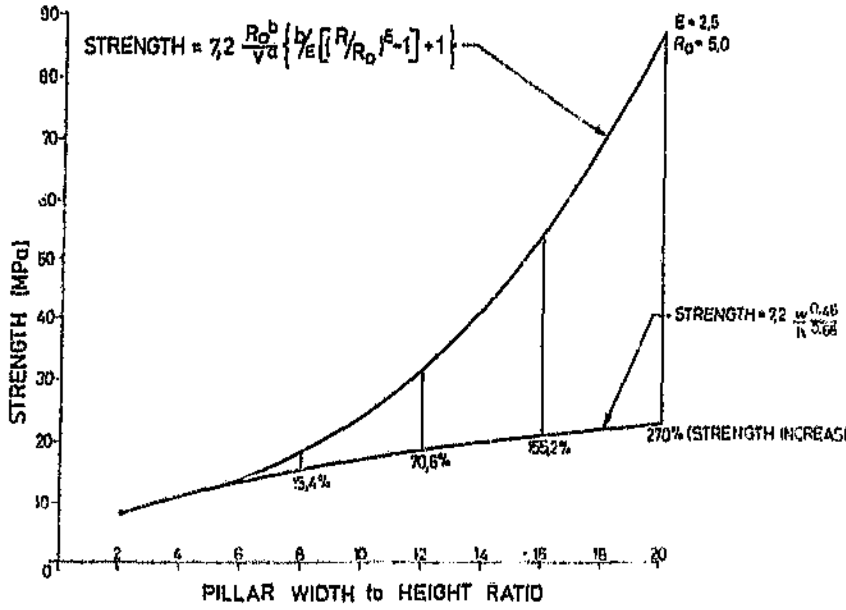


Figure 3.1 Pillar Strength Calculated by the Squat Pillar Formula and the Salamon Pillar Strength Equation (Madden, 1989)

These formulae were developed using the tributary area theory to determine the load on the pillars in a static situation, where the load on the pillar is calculated assuming that each pillar supports the weight of the strata immediately above it (see Figure 3.2). It can be assumed that the whole weight of the overburden is shared equally by the pillars if the panel size is greater than the area of a circle drawn with a radius 0,75 to 1,0 times the depth below surface (Salamon and Oravecz, 1976).

It is important to note the following comment made by Salamon and Oravecz regarding these safety factors:

"It is necessary to point out that the many concrete recommendations made, for example, values of safety factor, are intended only as a general guide. It is always dangerous to generalise in mining, where geological and other conditions vary widely. The recommendations should always, therefore, be reasserted in terms of local experience."

As the pillars created in bord and pillar mining remain static, except for some scaling, the safety factor does not change. The safety factor is thus determined by the load borne by the pillar and the strength of the pillar. Figure 3.2 depicts the typical load supported by a pillar under the mining conditions described in the Model 3.1.

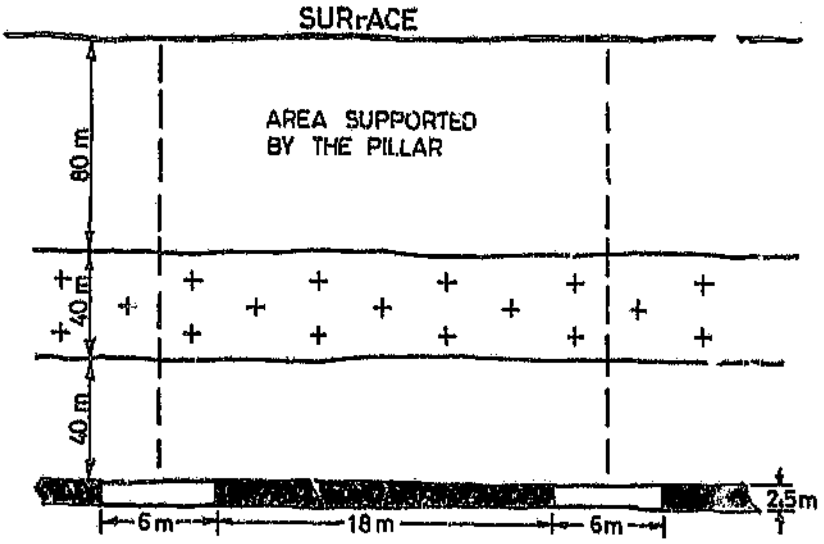


Figure 3.2 Load Supported by a Pillar in Bord and Pillar Mining (Beukes, 1990)

The following example (Model 3.1) will be used to explain and determine the safety factor of the pillars using the different formulae, and the influence of a dolerite sill on the panel widths:

Model 3.1

Assume a coal seam 160 m below surface (to the roof of the seam) overlain by a 40 m thick dolerite sill. The base of the dolerite sill is 40 m above the upper contact of the coal seam. The mining height is 2,5 m, the bord width is 6 m and the pillars are 18 m square. The first subsidence on surface, and thus the first break of the dolerite sill, occurs 150 m after commencing stooping, assuming that the panel is wide enough to cause the sill to break. The angle of fracture is 15° (measured from the vertical).

3.1.1 Calculating the safety factor of the pillars by using the Salamon formula:

Safety Factor $= \frac{\sigma p}{L} = \frac{Pillar\,Strength}{Pillar\,Load}$ (1)

where:

Pillar strength $= 7.2\ \frac{w^{0.46}}{h^{0.66}}\ MPa$ (2)

Pillar load $= 0.025H\ \frac{(w+b)^2}{w^2}\ MPa$ (3)

Legend: H = Depth of mining to the floor of the seam, m
h = Mining height, m
w = Width of pillar, m
b = Bord width, m

If the figures in Model 3.1 are used, the safety factor of the pillars is:

Pillar strength $= 7.2\ \frac{18^{0.46}}{2.5^{0.66}}\ Mpa$

$= 14.86\ MPa$

Pillar load $= 0.025 \times 162,5\ \frac{(18+6)^2}{18^2}\ MPa$

$= 7.22\ MPa$

Safety Factor $= \frac{14.86}{7.22}$

$= 2.06$

3.1.2 Calculating the safety factor of the pillars by using the Squat pillar formula:

Safety Factor $= \frac{\sigma p}{L} = \frac{Squat\,Pillar\,Strength}{Pillar\,Load}$ (4)

where:

Squat pillar strength $= 7.2\ \frac{R_0^{0.5933}}{V^{0.0667}} \left\{ \frac{0.5933}{\epsilon} \left[\left(\frac{R}{R_0} \right)^{\epsilon} - 1 \right] + 1 \right\} MPa$ (5)

Pillar load $= 0.025H\ \frac{(w+b)^2}{w^2}\ MPa$ (3)

Legend: R = Pillar width to height ratio

Ro = Critical width to height ratio (assumed to be 5)

V = Pillar volume (m^3)

ϵ = Measure of accelerated increase in strength (assumed to be 2,5)

If the figures in Model 3.1 are used, the safety factor of the pillars is:

Pillar strength $= 7.2\ \frac{5^{0.5933}}{(18^2 \times 2.5)^{0.0667}} \left\{ \frac{0.5933}{2.5} \left[\left(\frac{7.2}{5} \right)^{2.5} - 1 \right] + 1 \right\}\ MPa$

$= 16.20\ MPa$

Pillar load $= 0.025 \times 162,5\ \frac{(18+6)^2}{18^2}\ MPa$

$= 7.22\ MPa$

Safety Factor $= \frac{16.20}{7.22}$

$= 2.24$

As can be seen from these calculations, the squat pillar formula shows a higher safety factor, because the width to height ratio of the pillars, being 7,2, is greater than the critical width to height ratio, R_o, of five. This is significant because the pillar size can be reduced and still comply with the minimum safety factor required. If, in the example above, a safety factor of 2 is required, the pillar size can be reduced from 18 m square to 16,5 m square. Apart from the other advantages that ensue from this reduction, the the primary extraction is increased by 1,3%.

As the width to height ratio increases, the difference in pillar size determined by the two formula is even more pronounced, as indicated by the following two examples.

(a) If, for example, the mining height in the example above is reduced to 1,0 m, the pillar size calculated by Salamon's formula is 9,9 m for a safety factor of 2. If the squat pillar formula is used, the pillar size is reduced to 8,5 m which means that the primary extraction is increased by 4,4%.

(b) If the mining height remains 2,5 m, but the depth is increased to 300 m, the pillar size for a safety factor of 2, using the Salamon formula, is 36,0 m. If the squat pillar formula is used, the pillar size is reduced to 24,5 m and the primary extraction increases by 9,0%.

3.1.3 Pillars at shallow depths of less than 40 metres

When the mining depth is less than 40 m, the safety factor alone is not sufficient to ensure pillar stability, and other factors such as the integrity of the roof, competent roof layers, weathering and geological discontinuities need to be considered to ensure pillar stability. Investigations have shown that pillars with widths of less than 4 m, where the percentage extraction exceeds 75 per cent, are prone to pillar collapse even with safety factors in excess of 1,6 (Madden, 1989). However, no pillar collapses have been recorded where the width to height ratio exceeded 3,75.

Recent investigations (Madden, 1989) resulted in the following recommendations for designing pillars at shallow depths:

(a) The pillar width should preferably exceed 5 m.

(b) The width to height ratio should be in excess of 2.

(c) The safety factor should be in excess of 1,6.

3.2 The Panel Width Necessary to Induce Complete Failure of the Overburden Strata

3.2.1 Incompetent roof strata (shale or weak sandstone layers)

When the roof strata is relatively weak and incompetent, the high compressive stresses in the vicinity of the abutments are sufficient to cause shear failure of the roof strata. The stress-induced fractures that develop as a result of these stresses are near vertical in this strata. As the lower roof strata in the mined out area is in tension, gravity causes the highly fractured roof strata to cave readily. Because there are no competent roof layers, caving of the roof is continuous and extends to surface.

The critical mining span L, at which the maximum compressive stresses at the abutments are reached, can be estimated by the following simple relationship (Galvin et al, 1982):

$$L = 2H\cot\beta \qquad (7)$$

Legend: H = Depth of mining below surface
β = Average dip angle of face-induced fractures,
and $\cot\beta = \tan(90 - \beta)$

Limited local experience has indicated that the angle of face-induced fractures, β, varies from about 75^0 for highly laminated weak shale bands to 60^0 for competent sandstone beds (Galvin et. al., 1982). The relationship between the critical mining span and the depth below surface is illustrated in Figure 3.3.

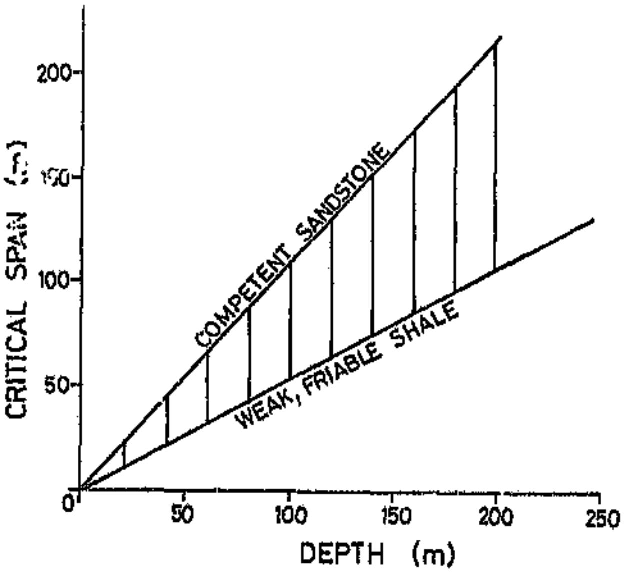


Figure 3.3 Relationship between Depth of Mining, Type of Roof Strata and Critical Mining Span (Galvin, 1982)

3.2.2 Competent roof strata (one or more thick dolerite sills or massive beds of competent sandstone)

The composition of the overburden strata is one of the critical factors affecting the formation of a goaf during stooping. Competent strata layers, such as thick dolerite sills or massive, competent sandstone, can result in the temporary arrest of caving at the base of these competent layers.

Dolerite sills in particular bridge over the goaf and deflect elastically (Salamon et al, 1972). However, when the free span at the base of the sill exceeds the critical span dimensions, it leads to the structural but non-violent failure of the sill (Galvin, 1982). This has been observed above various longwall panels in South Africa (Schumann, 1989).

Salamon et al (1972) found that the strength and elastic modulus of massive dolerite sills, in excess of 30 m thick, which overlie the South African coal bearing strata are an order of magnitude greater than that of the other overlying stratum. The typical range of these two parameters for shale, sandstone, coal and dolerite is shown in Table 3.1.

Table 3.1 Typical Range in Strength and Elastic Modulus of South African Coal Measure Rocks (Galvin, 1981)

Stratum	Strength (MPa)		Elastic Modulus (GPa)	
	Range	Typical	Range	Typical
Shale	60 - 80	70	0,5 - 13,0	3
Sandstone	40 - 100	70	4,0 - 15,2	7
Coal	15 - 40	30	0,4 - 4,1	2
Dolerite	250 - 390	300	50,0 - 98,5	70

Salamon et al (1972) formulated a mathematical model of dolerite behaviour based on investigations at Durban Navigation Collieries. This elastic thin plate model was formulated on the basis of the behaviour of a 70 m thick dolerite sill overlying a longwall panel at Durban Navigation Collieries. Based on observations of a further 11 longwall panels, Wagner and Galvin (1977) modified the elastic thin plate model by determining the relationship between the critical stress and the depth:thickness ratio and substituting it in the model. During 1980 the lack of success in determining the minimum panel dimensions necessary the break the dolerite sill at the Secunda Collieries raised serious doubts about the validity of the model. Galvin (1981) undertook further research and re-analysed the elastic thin plate model. He found that the behaviour of the dolerite sill is significantly influenced by the caving angle, β, and the parting thickness, t_p, of the strata between a coal seam and a dolerite sill (Figure 3.3). He concluded that the effective span, S_{eff}, over which an unfailed sill bridges is not equal to the panel dimension, S, but is defined by the equation:

$$S_{eff} = S - 2t_p \mathrm{Tan}(\beta - 90) \ \ (m) \qquad (6)$$

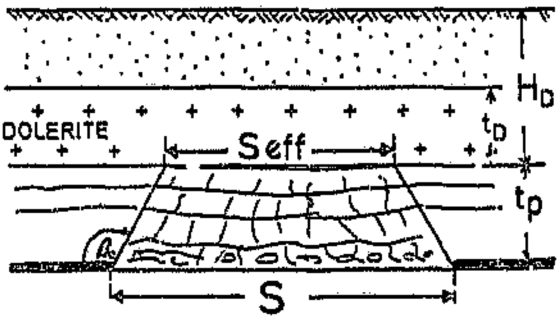


Figure 3.4 **Influence of caving angle, β, and parting thickness, t_p, on unsupported dolerite span, S_{eff} (Galvin, 1981)**

Taking th... findings into account, he modified the refined elastic thin plate model and derived the well known 'Effective Span Thin Plate Model' for determining the minimum panel dimension:

$$L = \sqrt{1165t - \frac{(935t^2)}{d}} + 2p\tan\alpha \qquad (7)$$

Legend: t = th..kness of sill

d = depth to base of sill

p = parting thickness between sill and coal

α = angle of break (caving angle - measured from the vertical)

This equation, however, has yet to be verified for sills thicker than 75 m and for depths to the base of the sill exceeding 140 m (Galvin, 1982).

If the figures in Model 3.1 are u d, the width of the panel necessary to cause the dolerite sill to fail will be:

$$L = \sqrt{(1165 \times 40) - \frac{(935 \times 40^2)}{120}} + 2 \times 40 \times \tan 15°$$

$$= 205 \ \ metres$$

When contemplating any form of total extraction, the effect on the surface environment must be taken into account. If a dolerite sill overlays the coal seams, two options are available:

(a) Designing the panels wide enough to ensure that the dolerite sill does fail. This is desirable to avoid any excessive load on the pillars being extracted. This will also result in the maximum surface subsidence.

(b) Designing the panels narrow enough to ensure that the dolerite sill does not fail. This will cause the sill to bend without failing and will cause less surface subsidence than when the sill fails.

It must be noted that the extraction of several adjacent, subcritical panels will result in additional load on the interpanel or barrier pillars as well as the pillars in the adjacent panels. It is important to determine the stress situation in such a mining layout prior to mining to prevent unsafe working conditions and loss of reserves due to high stresses. The interpanel pillars must be designed with a large enough width to height ratio to ensure long-term stability.

This system of mining subcritical panels to reduce surface subsidence has been practised for more than a decade on some Australian collieries with massive, competent sandstone or conglomerate roof strata (McKendry and Simes, 1988).

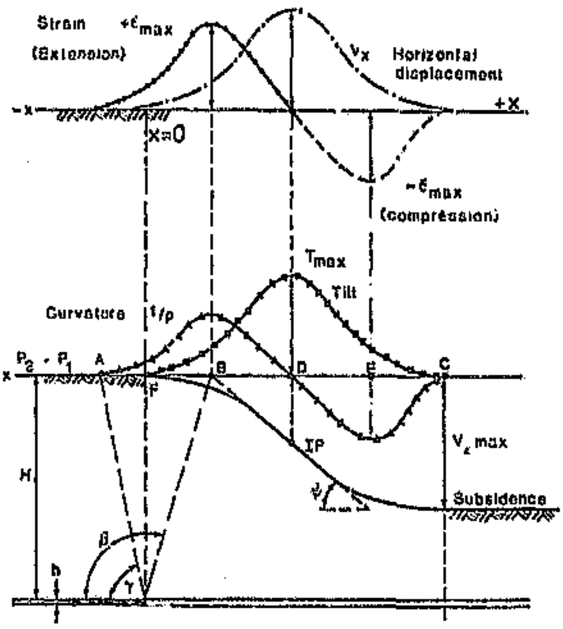
3.3 Surface Subsidence

The composition and behaviour of the coal bearing strata in the South African coalfields, including dolerite sills and massive sandstone layers, influence the surface subsidence that develops above total extraction panels. The relatively shallow depth of the majority of the total extraction panels under competent strata not only present problems with the initiation of caving, but also results in substantial surface subsidence, provided the span is wide enough.

When the width of a total extraction panel under competent strata, such as a competent dolerite sill or massive sandstone, is subcritical, the caving does not reach the surface and the magnitude of the subsidence is governed by the deflection of such competent strata (Schumann, 1988a). As the panel width is increased to the critical mining span, L, the sill will fail structurally and the caving will extend to surface.

The caving process is thus governed by the geomechanical properties and deformation characteristics of the superincumbent strata as well as the magnitude and distribution of stresses which depend on the mining depth and panel width.

The term 'surface subsidence' is generally associated with the lowering of the ground surface, but surface subsidence involves more than just vertical displacements. It also consists of differential displacements across the surface which result in changes in the gradient and in horizontal elongation or contraction of the ground surface (Schumann, 1987a). These differential displacements consisting of the tilt, T; the horizontal strain, ε, and the horizontal displacement are depicted in Figure 3.5 (Schumann, 1988b).



Legend:
- A Trough limit
- B Point of maximum tensile strain
- C Subsidence complete
- D Transition point IP
- E Point of maximum compression
- F Face position
- γ Influence angle or angle of draw (limit angle)
- β Angle of break (caving angle)
- ψ Tangent angle

Figure 3.5 Schematic Model of the Various Elements of Mining Induced Ground Movements (Schumann, 1988b)

The vertical displacement does not generally cause damage to surface structures, but it can have some negative effects on agricultural land (e.g. drainage of surface water).

Differential movement can cause damage to surface structures. In the case of dwellings, the extent of this damage will depend on the foundation, the shape of the plan layout, the number, size and span of the openings for doors and windows and the interaction between the foundation and the soil. The tilt, which is the slope of the subsidence curve, may cause damage to structures if such structures are situated such that part of the structure falls inside the subsidence zone and part over the solid or inter-panel pillar. Excessive tensile strains can cause cracks in pipes, roads and brickwork, while compressive strains can result in the buckling of structures such as pipes and rails, and compressive failure of brickwork or the sub-base of roads.

3.3.1 Single seam extraction

The critical panel width necessary to cause failure of competent overburden strata depends mainly on the depth of mining and the thickness of the competent strata. On relatively deep collieries and in cases where the panels are too narrow to cause the overburden strata to fail, the vertical subsidence will be the direct result of the bending of such strata. In such cases the amount of subsidence is relatively small in comparison to the thickness of the coal extracted.

The effect dolerite sills have on the surface subsidence above high extraction panels can be seen in Figure 3.6, which compares local subsidence with the subsidence model developed by the National Coal Board (NCB) in Great Britain (Schumann, 1988a, b). From this figure it can be seen that the panel widths in South Africa have to be much greater that in Britain for significant subsidence to occur. In addition to this, the maximum amount of surface subsidence is only approximately two thirds of that observed on British Collieries. The reason for these differences are entirely related to differences in the respective geological conditions (Wagner and Schumann, 1991).

When the panel width exceeds the critical width, the goaf will extend to the surface and the surface subsidence can vary between 35% and 65% (and even higher for shallow mining operations) of the total extraction height.

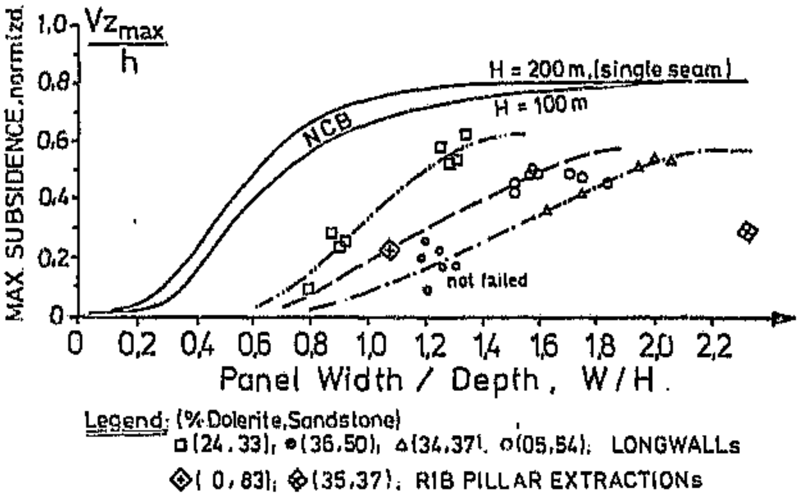


Figure 3.6 Maximum Subsidence vs Panel Width to Depth Ratio for Sigma, Brandspruit and Coalbrook Collieries (Wagner and Schumann, 1991)

Massive, competent sandstone beds in the overlying strata have a similar effect as massive dolerite sills on surface subsidence. Because of the lower strength of the sandstone beds, however, the differences are less pronounced in quantitative terms (Wagner and Schumann, 1991).

The bulking of the caved material, which gradually fills the void created by mining, is another important aspect in the caving process. Once the voids have been filled, the caved material starts exerting some resistance to further strata movement which increases rapidly as the material becomes increasingly compressed by the weight of the overlying strata. The greater the depth, the more the compression and subsequently, the surface subsidence (Wagner and Schumann, 1991). This process is described by Salamon (1966) in his model of strata reconsolidation. In this model the initial caving height, h_c, is given by:

$$h_c = \frac{P_c}{k_l \cdot \gamma} \cdot [\exp \frac{k_l \gamma \cdot h}{P_c (k_l - 1)} - 1] \tag{8}$$

where: P_c = a factor describing the compressibility of the caved material,

k_l = the bulking factor,

γ = the specific weight of the material, and

h = the extracted seam height.

Another critical factor for the mode of surface subsidence is the ratio of the extraction height, h, to the depth of mining, H. Based on the value of the h/H ratio, Salamon and Oravecz (1976) have defined three distinctly different modes of subsidence:

(a) Discontinuous subsidence ($h/H > 0{,}1$). Discontinuous subsidence with major surface cracks and in some cases, pronounced surface steps near the edge of the panel, is possible in the case of thick shallow seams.

(b) Subsidence with surface cracks ($0{,}1 > h/H > 0{,}01$). When the seam thickness is more than two metres and the depth below surface less than 300 metres, subsidence with surface cracks is common. The majority of the South African coal reserves fall into this category.

(c) Smooth subsidence ($h/H < 0{,}01$). Surface subsidence becomes less pronounced as the ratio of h/H decreases (thin seams at depth). Damage to surface structures resulting from subsidence in the deep gold mines is virtually unknown (Wagner and Schumann, 1991).

When the mining span increases such that the competent strata break and caving progresses upwards, an initial V-shaped subsidence trough results (Figure 3.7). This non-uniform subsidence is referred to as 'First Break' and has been observed above supercritical panels, to a depth of 160 m, where the h/H ratio was in excess of 0,02. Subsidence above the remainder of the panel is reduced to approximately 70 to 80 per cent of the initial peak subsidence (see Figure 3.7). The pronounced 'First Break' does not occur above deep workings with small extraction heights (Schumann, 1988a).

3.3.2 Multi-seam extraction

The surface subsidence resulting from 'second seam' extraction is significantly more than for 'first seam' extraction. The results obtained above 'second seam' extraction indicate that the surface subsidence can vary between 64% and 96% of the total extraction height of the second seam (Schumann , 1987b). These larger subsidence factors are mainly the result of the re-compaction of the overlying goaf and the reduced bulking when broken material caves. The transverse troughs which resulted from multi-seam extraction at Sigma Colliery are shown in Figure 3.8.

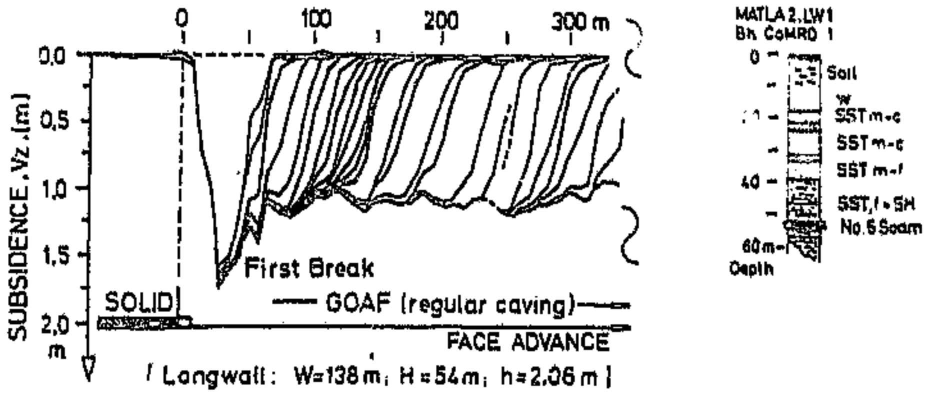


Figure 3.7 Longitudinal Section of 'First Break' and Trough at Matla Colliery (Schumann, 1988a)

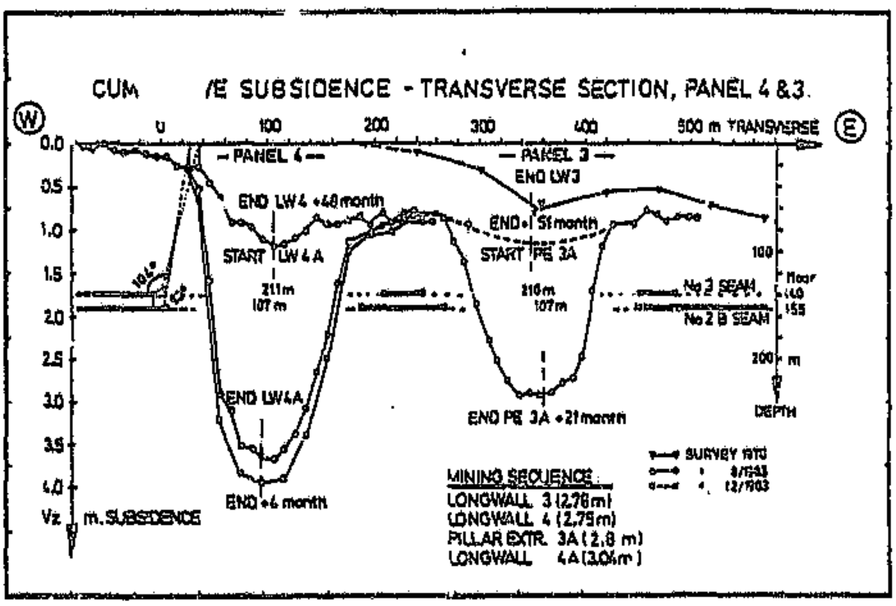


Figure 3.8 Transverse Trough Sections at Sigma Colliery, Showing the Result of Multi-Seam Mining (Schumann, 1987b)

3.3.3 Subsidence prediction

Until recently the use of simple semi-empirical relationships was the only practical means of predicting subsidence above high extraction panels. The presence of the competent beds in the overlying strata and the relatively shallow mining depth could not be handled by subsidence models developed overseas. Attempts to develop numerical models were also met with limited success. Schumann and Hamenstadt (1989) overcame these problems by adopting a two-step approach to simulate surface subsidence above high extraction panels. The principles of this approach are shown in Figure 3.9.

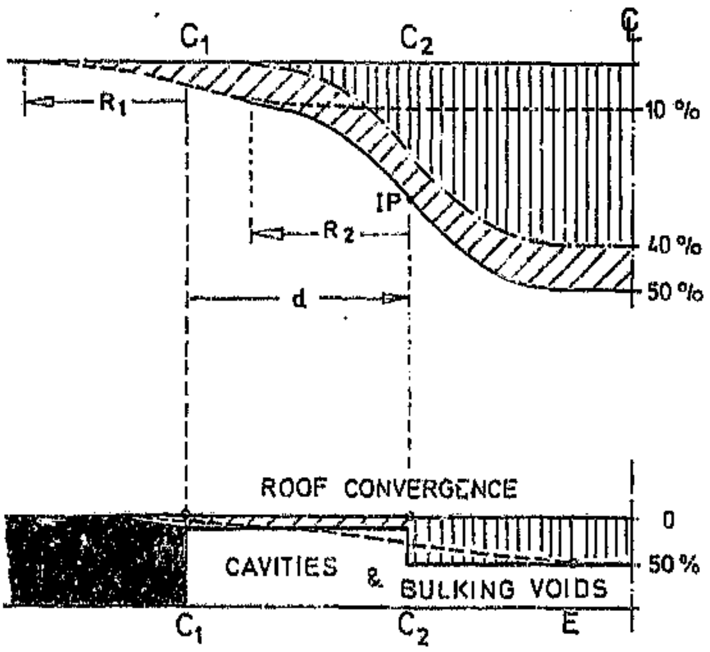


Figure 3.9 Two-step Subsidence Simulation due to Incomplete Closure of the Edge Zone and Larger Closure in the Central Zone (Wagner and Schumann, 1991)

The first step in this approach consists of modelling the effects of the strong competent beds. These competent beds tend to overhang the extraction area thus preventing or minimising strata caving along the edges of the panel. The second step in the approach is the modelling of subsidence in the central part of the panel. The effects of the two simulations are then added to form a composite subsidence trough.

3.3.4 Monitoring of surface subsidence

The purpose of subsidence monitoring surveys is the determination of spatial positions (x,y,z) of a large number of points situated above and adjacent to the vertical projection of an underground extraction panel at certain time intervals (Schumann, 1989). The results of subsequent surveys are compared to the initial survey in order to compute horizontal and vertical displacements and derive tilts and strains.

Schumann (1987a) recommends that one longitudinal and several transverse lines of monitoring pegs be set out above the panel. These lines should extend beyond the projection of the panel area by a distance ranging from approximately 30 m to 60 m (0,5 to 0,7 times the depth). A peg spacing of 10 m is recommended for a mining depth of more than 100 m and 7,5 m for a mining depth of less than 100 m. The details of subsidence monitoring, including standard deviations, error limits and computation, is described by Schumann (1989).

3.4 Application of the Models/Theory in practice

The validity and applicability of the theory can only be determined by analysing experiences in the real production situation.

In the following three chapters the application of pillar and rib pillar extraction on the various collieries are discussed. In many of the problems and/or successes experienced, the validity of the theory is proved or verified.

By analysing the practical experience of the various mines and combining it with the theory and research findings, design guidelines, which are practical and enhance safety and productivity, are compiled.

CHAPTER 4

CONVENTIONAL PILLAR EXTRACTION

4.1 Introduction

A detailed study was made of the conventional pillar extraction methods practised in South African collieries. Of the eight collieries practising conventional pillar extraction, seven are situated in the Northern Natal coalfields and one in the Eastern Transvaal coalfield. These collieries are:

Savmore Colliery, which is situated in the Eastern Transvaal Coalfield;
Vryheid Coronation Colliery, Alpha Anthracite Colliery and Hlobane Colliery, all situated in the Vryheid Coalfield;
Durban Navigation Collieries and Kilbarchan Colliery, both situated in the Klip River Coalfield;
Welgedacht Exploration Co. Ltd., situated in the Utrecht Coalfield, and
Zululand Anthracite Colliery, which is situated in the Zululand Coalfield.

The objective of this chapter is to discuss the various extraction methods used on the various mines. The extraction methods common to several collieries are discussed as well as the reasons why some collieries deviate from these common practices. The experience gained by the mines during the years of pillar extraction is incorporated in the guidelines in Chapter 7.

In additional to the mining methods, the labour complement, production equipment and ventilation layouts is also described briefly.

4.2 Pillar Extraction with 'Handgot' Methods

Pillar extraction using 'handgot' methods has been practised in South African collieries for many years. Although most of the collieries have mechanised their stooping operations, a few collieries still employ handloading mining methods. The method is presently mainly used in Natal collieries where the thin seams make cost effective mechanisation of stooping operations at present extremely difficult. Handgot pillar extraction is practised by Vryheid Coronation Colliery, Hlobane Colliery, Alpha Anthracite Colliery, Durban Navigation Colliery and Welgedacht Exploration Co. Ltd.

One of the main advantages of handgot pillar extraction, or stooping, is that it can be practised in the seams where floor heave impedes the use of mechanized equipment. Although labour intensive, it is presently still one of the most economic pillar extraction practices employed in thin seams and where floor heave is a problem.

The total annual tonnage produced by underground mining methods in South African coal mines from 1987 to 1990 remained fairly constant, but the tonnage from handgot pillar extraction increased from 455 000 tons to 596 000 tons during the same period, which is 0,8% of the total coal mined by underground mining methods. This is mainly due to the increased demand and export of anthracite.

4.2.1 Floor heave

In general, floor heave (see Figure 4.1) can be attributed to three reasons (Ozan, 1991):

(a) High horizontal stresses, causing the floor to fail in tension. Under high horizontal stresses, the floor typically fails under tension with cracks starting in the floor surface advancing vertically towards the lower layers. This is the main reason for the floor heave experienced in the Natal collieries.

(b) High vertical stresses, causing pillar punching. This occurs when a pillar is relatively small and stiff, the roof strata competent and the floor strata weak. In such cases the stresses transferred by the pillar can exceed the ultimate-bearing-capacity (UBC) of the floor which causes the floor failure and consequently pillar punching.

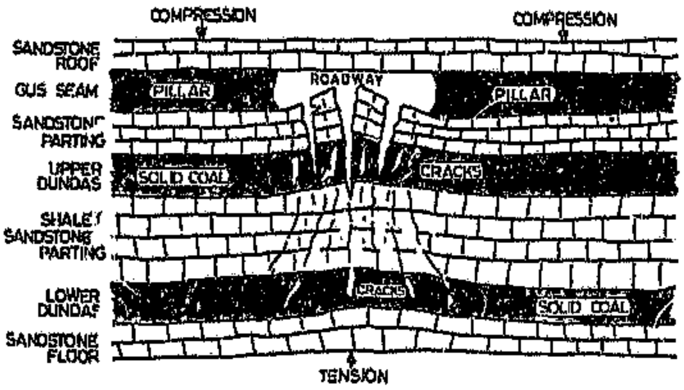


Figure 4.1 Floor Heave or 'Creep'

(c) The existence of swelling rock in the floor strata. Certain clay minerals, particularly the montmorillonite group, expands when exposed to water. When these clays are present in the floor strata, the presence of water causes the clays to swell and this leads to floor heave.

In the Northern Natal collieries, floor heave occurs mainly in the Gus seam, overlain by massive sandstones, at a depth greater than 150 metres. In areas deeper that 200 m, the floor heave is so severe that the floor pushes against the roof. The occurrence of this floor heave in the Gus seam also affects the coal seams below, resulting in poor roof conditions in the Upper Dundas and, to a lesser extent, in the Lower Dundas (Figure 4.1).

4.2.2 Development for pillar extraction with handgot methods

The primary, secondary and panel development on these collieries normally consist of five to nine roadways and the bord widths and pillar sizes vary with depth and local strata conditions and behaviour. The primary, secondary and panel development in the majority of the collieries have been completed many years ago, but the pillars formed by these developments are only being extracted now. As a result of the different pillar sizes, which vary with depth, a number of different pillar extraction methods have to be employed.

4.2.3 Stooping angle and pillar extraction sequence

Different stooping configurations have been tried, but the 45° stooping line method was found to be the most effective and is currently most commonly used (Figure 4.2). A complete row of pillars is extracted at a time.

At the Utrecht Section of Welgedacht Exploration, where the average mining depth is 200 m, the use of the 45° stooping line in the nine-road panels resulted in very long tramming distances. In order to reduce the tramming distance, the stooping line was changed to 30° (Figure 4.3).

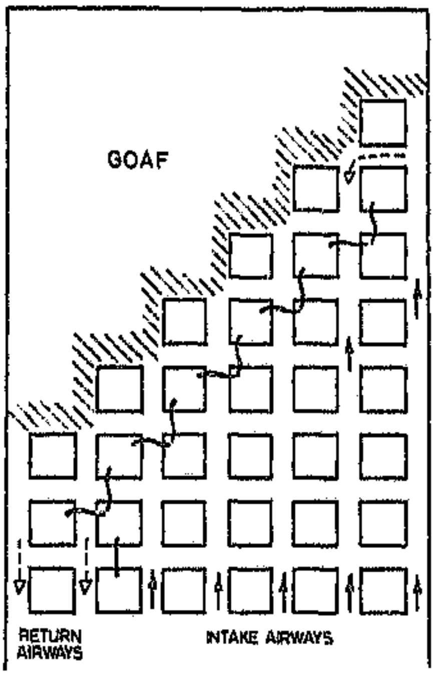


Figure 4.2 The 45° Stooping Line

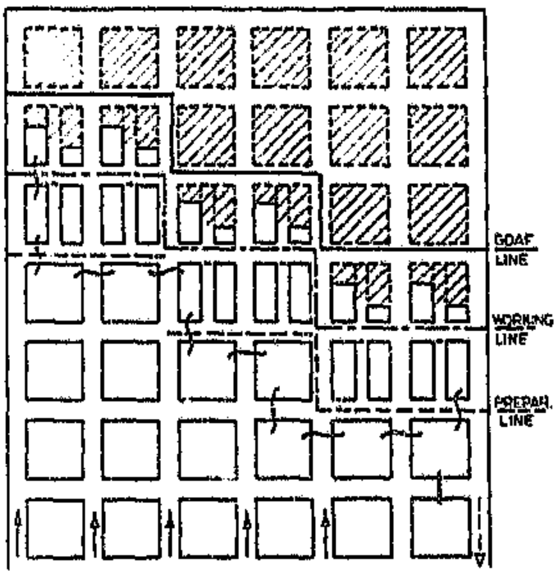


Figure 4.3 The 30° Stooping Line at Welgedacht Exploration

Another exception to the 45° stooping line occurs at Vryheid Coronation Colliery and Hlobane Colliery. At these two collieries the occurrence of floor heave necessitates that the pillars are extracted in a straight line (see 4.2.4 (i)).

4.2.4 Pillar extraction methods

The pillar extraction methods most commonly used in the handgot sections, are the open-end-lift and split and quarter methods. Both square and rectangular pillars are extracted. The sizes of the square pillars vary from 6 to 30 metres, and the rectangular pillars vary from 30 m x 9 m to 30 m x 25 m.

Although the basic concepts of the various extraction methods are the same, the detailed layout and extraction sequence on different mines can vary considerably. A few of the more common extraction methods for square and rectangular pillars will be described. In all the extraction methods, the snooks (pillar remnants) that cannot be extracted are destroyed.

(i) Where floor heave is a problem

When floor heave has occurred in a panel, the open end lift extraction method is used for extracting the pillars. The main travelling road and tramming haulage have to be cleaned out and re-supported where necessary. A skirting is then developed by open end lifting, adjacent to the splits closed by floor heave, to the pillars on the outer limits of the panel (Figure 4.4). This mining method differs from the conventional pillar extraction in that the pillars are extracted in a straight line across the panel and not in a 30° or 45° angle.

Another difference is that all the pillars in a row are not extracted simultaneously (the standard practice in conventional pillar extraction) as the gradual decrease of the pillar size, and the time taken to do this, encourages floor heave to re-occur. Instead, only two pillars are extracted at a time, starting with the two outer pillars and working towards the centre of the panel. The pillars are extracted as fast as possible before floor heave can occur again and impede the extraction.

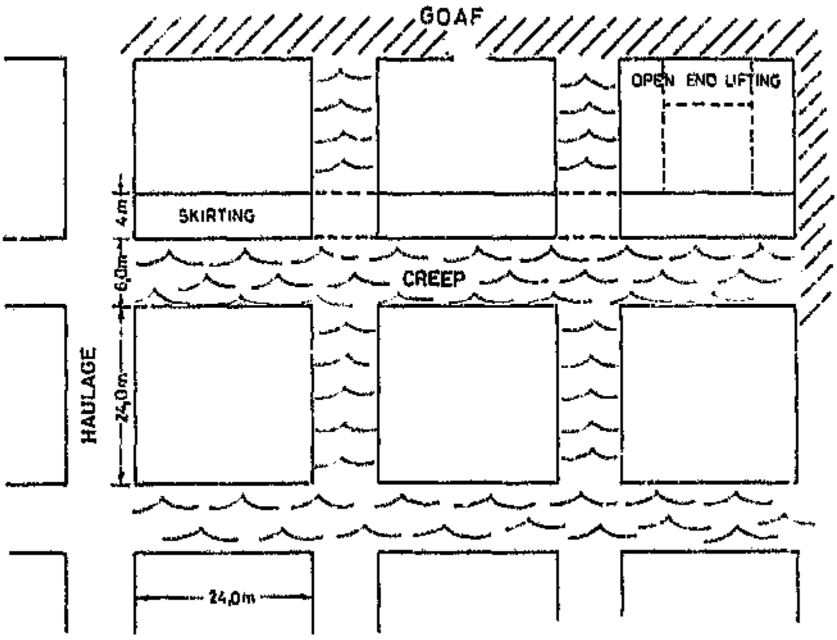


Figure 4.4 Skirting of Pillars where Floor Heave is a Problem

The split and quarter method is not used when extracting these pillars as the creation of the smaller pillars encourages floor heave to form again. Each pillar must be assessed and extracted in the safest possible way. Starting from the skirtings, the open end lift method is used to extract the pillars. The order in which the 4 m wide open end lifts are taken is depicted in Figure 4.5. A 2-row, and on some mines a 3-row, breakerline with headboards, or tapes in poor roof conditions, is installed adjacent to the goaf as the mining progresses. The installation standards are the same as for the other methods. A single row of timber props is installed, 1,0 m apart, along the solid side of the pillar. This is repeated for every lift after which the previous breakerlines are extracted.

The open end lift method is used by Vryheid Coronation Colliery and Hlobane Colliery to extract pillars in the areas where floor heave is experienced.

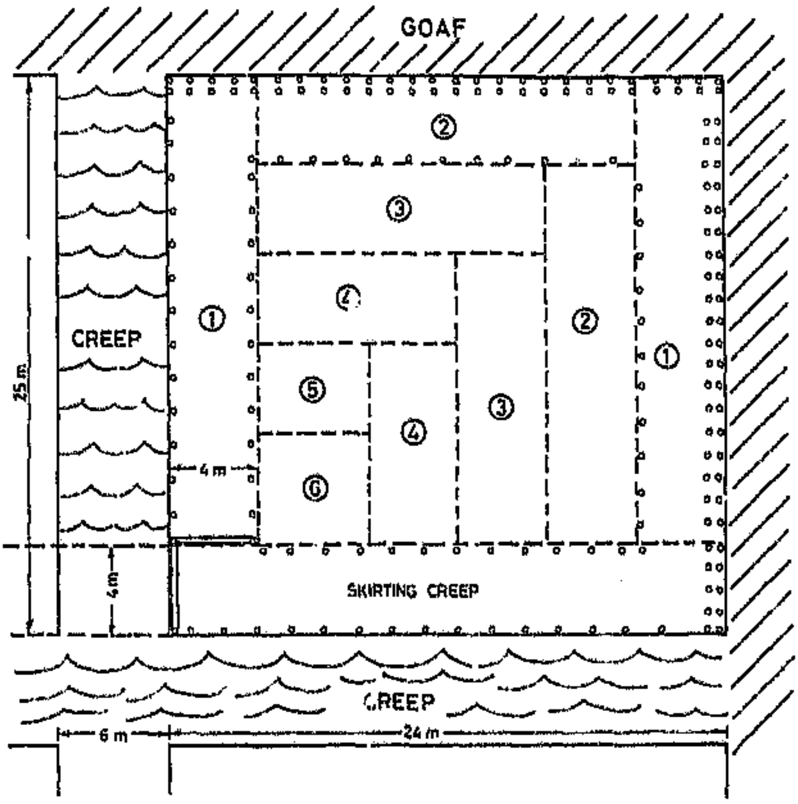


Figure 4.5 Open End Lifting where Floor Heave is a Problem

No snooks must be left. Snooks not only lead to a loss in reserves, but they also can prevent the overlying strata from failing. If the roof strata does not fail, a part of the additional load of this roof strata has to be supported by the pillars on the goaf edge. The higher stress resulting from this, in addition to causing problems during pillar extraction, encourages floor heave to re-occur.

If a snook cannot be extracted with the normal extraction method, it must be destroyed by drilling and blasting to prevent the load being transferred to the remaining pillars.

(ii) Where floor heave is not a problem

(a) Large square pillars

Open end lift

Pillar extraction normally commences at the limits of the panel. The stooping angle may vary from one mine to another, or even from one area to another, and can be 45°, 30° or even an arrow head.

The first open end lift extraction method employed is similar to the method described in Figure 4.5, but without skirting the pillar. This method is normally used where the roof consists of competent roof strata. The method is used by Vryheid Coronation Colliery, Durban Navigation Collieries and Alpha Anthracite Colliery.

In the second open end lift extraction method employed the pillar is split by means of a 4 m to 5 m wide development through the centre of the pillar. When this development breaks through into the goaf, a breakerline consisting of two or three rows of timber props is installed. Open end lifts, starting at the top end of the pillar, are taken back-to-back from this development (Figure 4.6). A 2-row to 3-row breakerline is installed adjacent to the goaf as the lift advances and a single row of timber props, 1,0 m apart, is installed along the solid pillar side. This is repeated for every lift and the previous breakerlines are extracted. This method is often used in areas where roof problems are experienced or where the roof is less competent.

This extraction method is used by Hlobane Colliery, the Utrecht Section of Welgedacht Exploration, and by Alpha Anthracite Colliery under poor roof conditions where the long open end lifts adjacent to the goaf proved to be risky.

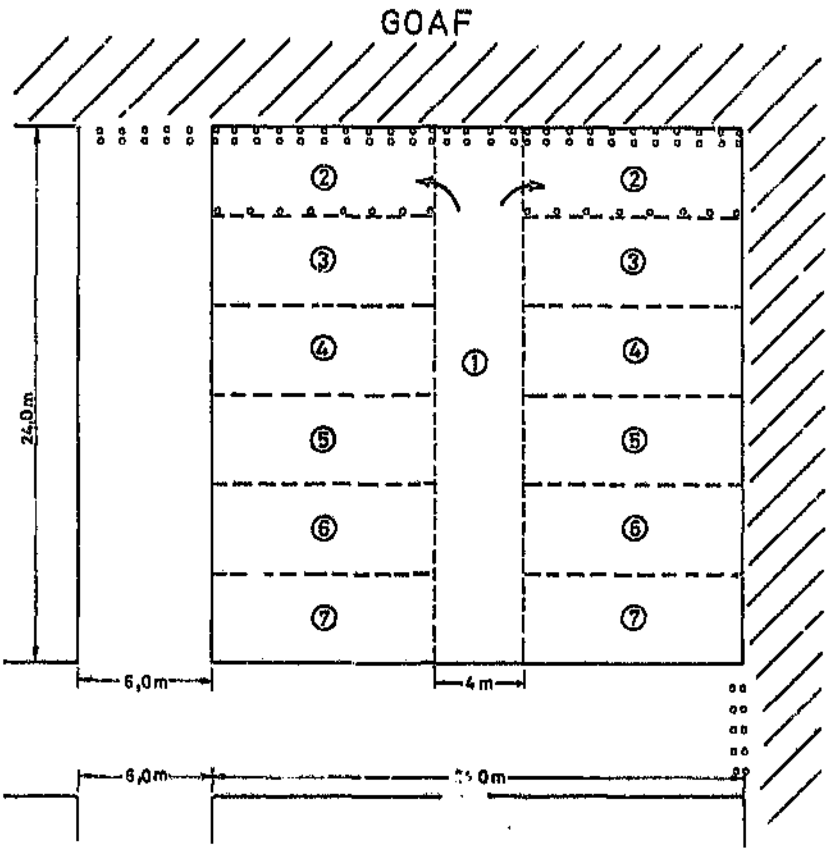


Figure 4.6 Open End Lifting in Large Pillars - Second Method

Split and quarter - open end lift

The pillar is split into four smaller pillars by 4 m wide developments (Figure 4.7). These smaller pillars are then extracted by means of open end lifting from these developments. A typical split and quarter - open end lift is depicted in Figure 4.7, but the sequence in which the lifts are taken vary from mine to mine. The installation of breakerlines is similar to that described in the method above.

This is also one of the extraction methods employed by Durban Navigation Collieries and Vryheid Coronation Colliery.

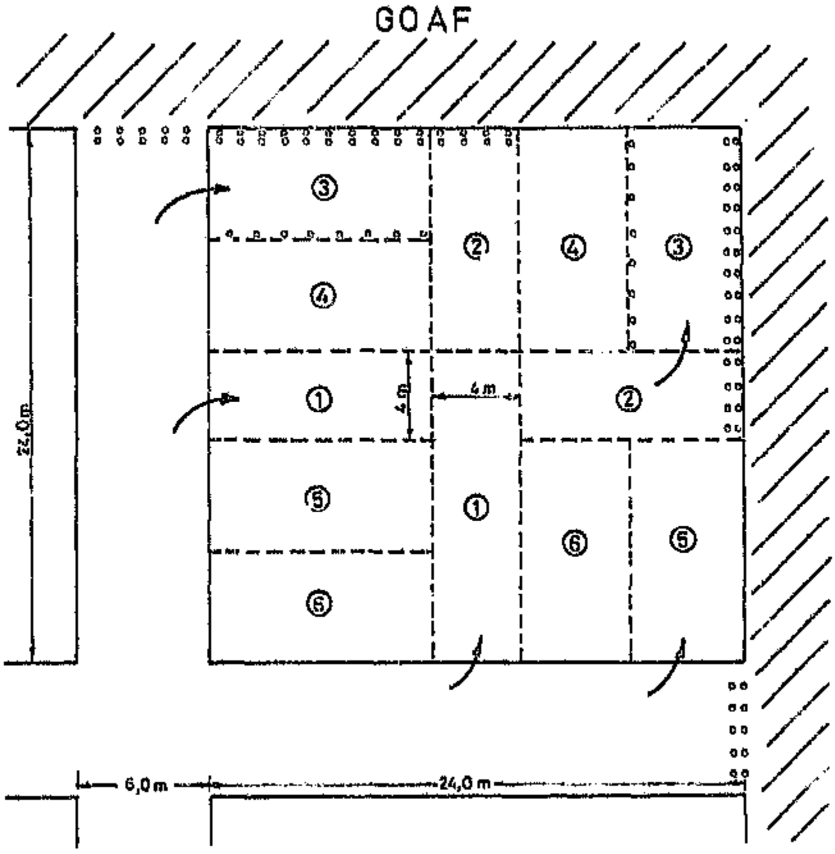


Figure 4.7 Ex...ction of Large Square Pillars by means of Split and Quarter - Open End Lift

Split and fender

The split and fender method (Figure 4.8) is used by Kilbarchan Colliery and by the Utrecht Section of Welgedacht Exploration Co. Ltd. Breakerlines BL1 to BL4 having been installed when the previous pillars were extracted, the pillar is split in two by a 5 m wide development after which breakerline BL5 is installed. The two ribs, approximately 9 m wide, are then extracted in the sequence shown in Figure 4.8. When the various lifts (2, 6, etc. in Figure 4.8) hole through into the goaf, breakerlines are installed. When the last snook (17) has been extracted, breakerlines BL6 and BL7 are installed.

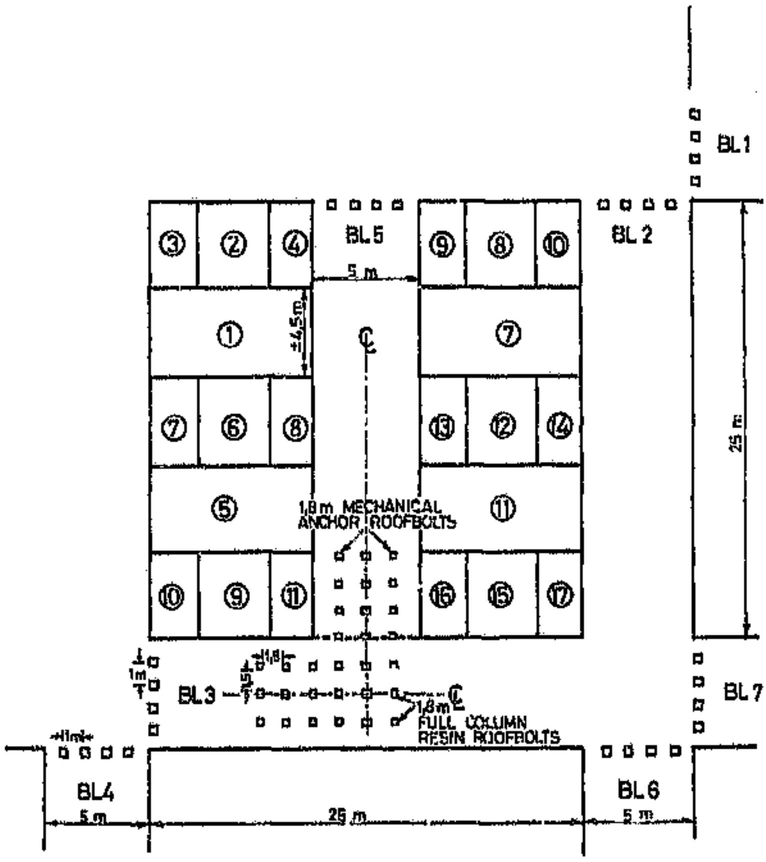


Figure 4.8 **Extraction of Large Square Pillars by means of Split and Fender**

(b) Extraction of small square pillars

The open end lift method used for extracting small square pillars at Vryheid Coronation Colliery is depicted in Figure 4.9. Breakerlines BL1 to BL4 were installed when the previous line of pillars was extracted. The two open end lifts, 1 and 2 in Figure 4.9, are then extracted. Breakerlines are installed adjacent to the goaf and the solid pillar, the method of installation being similar to that described for the large pillars. The final pillar (3) is then extracted and the breakerlines are removed.

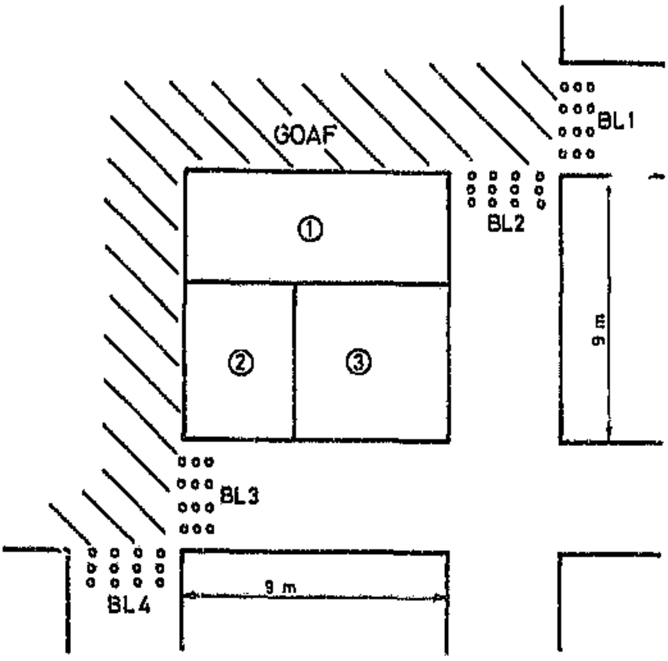


Figure 4.9 Extraction of Small Square Pillars

(c) Extraction of rectangular pillars

The pillars are normally split into two smaller pillars, by a 4 m to 5 m wide development through the centre of the pillars, which are extracted by one of the following two methods:

Split - open end lift

After splitting the rectangular pillar into two smaller pillars, the two smaller pillars are extracted by means of open end lifts. The method used is similar to that depicted for small square pillars in Figure 4.9. This method is used at Durban Navigation Collieries and at Vryheid Coronation Colliery.

Split and fender

The split and fender method used at Vryheid Coronation Colliery when the dimensions of the square pillars after splitting are too large to extract by open end lift as described above, is depicted in Figure 4.10. Breakerlines BL1 to BL4 were installed when the previous line of pillars was extracted. The pillar is split into two fenders by a 4,8 m wide development through the centre of the pillar after which breakerline BL5 is installed. A 4 m wide split (1 in Figure 4.10) is then taken, creating a 3 m wide rib (2 in Figure 4.10) which is extracted next. The remainder of the pillar is then extracted in the sequence shown in Figure 4.10. Breakerlines are installed when the fenders break through into the goaf and the previous breakerline is removed.

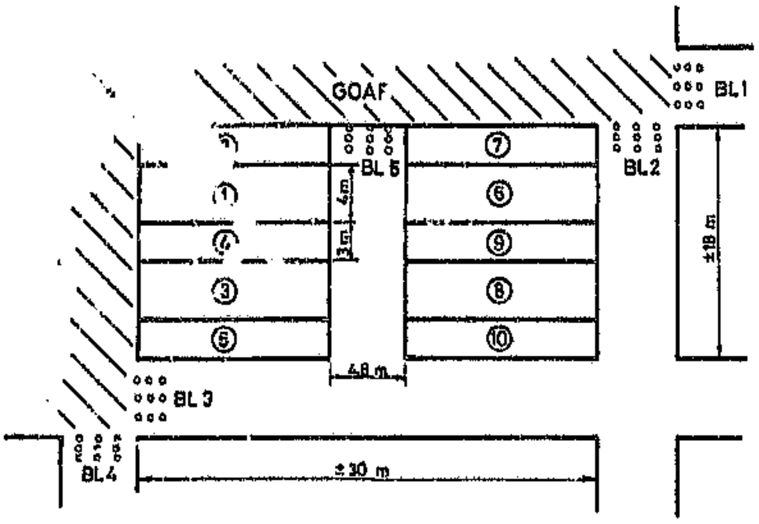


Figure 4.10 Extraction of Rectangular Pillars - Split and Fender

4.2.5 Production equipment

The production equipment for a handloading section consists of coalcutters, electric drills and tubs for tramming the coal. The typical equipment for a handloading section is:

1 x AB 15 Coalcutter
2 x Electric drills
120 x Tubs

4.2.6 Manpower

The number and composition of the operating crews differ significantly from mine to mine. Handgot stooping is a labour intensive method as the coal is loaded by hand into tubs which have to be pushed manually to the endless rope haulages. In addition to this, the large number of timber props that have to be installed also require more labour than in the mechanised sections. The following is a typical operating crew for a handloading section:

Miner	1
Team Leader	1
Electric drill operators	2
Coal cutter operator	1
Timber	10
Loaders (6 span)	12
Trammers	6
Winch operator	1
Track attendants	2
Ventilation	1
Stonedust	1
Miner's assistants	2
TOTAL PER SHIFT	40

4.3 Pillar Extraction with Mechanised Conventional Equipment

Pillar extraction with handgot methods has been practised in South Africa since early in the century, but the first trial with mechanized pillar extraction only took place in the late Sixties. Mechanised conventional pillar extraction has since been practised successfully on many collieries, but unstable or friable roof conditions made it hazardous on some collieries.

The production output from mechanised conventional pillar extraction has increased from 2,23 million tons in 1987 to 3,25 million tons in 1990, which is only 1,8% of the total coal mined by underground mining methods. The increase of one million tons per annum is due to increased anthracite production from the Northern Natal collieries.

The following seven collieries all practice pillar extraction using conventional mechanised equipment: Savmore Colliery, Vryheid Coronation Colliery, Hlobane Colliery, the Durban Navigation Collieries, Kilbarchan Colliery, Welgedacht Exploration Co. Ltd. and Zululand Anthracite Colliery.

4.3.1 Development for pillar extraction with mechanised conventional equipment

The number of roads in the primary development on the different collieries vary between six and nine roads. The bord widths and pillar sizes vary with depth and local strata conditions and behaviour. The development is usually also done by conventional mining methods.

The secondary development also consists of six to nine roadways. The bord widths and pillar sizes also vary with depth and local strata conditions and behaviour. On some collieries, however, the pillar extraction panels are developed directly from the main development.

The number of roads in the pillar extraction panels vary from six to twelve, depending on factors such as the depth below surface, strata conditions, pillar size and the extraction method. The factors affecting the panel layout are discussed in Chapter 7.

4.3.2 Stooping angle and pillar extraction sequence

The majority of the collieries practising pillar extraction with conventional mechanised equipment use the 45° stooping line. At Vryheid Coronation Colliery and Welgedacht Exploration, the use of the 45° stooping line was not successful, and the stooping line was changed to 30°. In the western area of the Vrede Section at Vryheid Coronation Colliery, the weak roof strata resulted in unstable working conditions with the 45° stooping line. These problems were significantly reduced by extracting every second pillar. This gave rise to the 30° stooping line at Vryheid Coronation Colliery (Figure 4.11). At the Utrecht Section of Welgedacht Exploration floor heave was experienced with the 45° stooping line and the angle was also changed to 30° by extracting two adjacent pillars, similar to the handgot method depicted in Figure 4.2. In addition to this change, practical experience at Welgedacht Exploration proved that floor heave decreased when the row of pillars behind the pillars being extracted are pre-split. Although this works in practice at Welgedacht Exploration, it is contrary to the experience on some other mines.

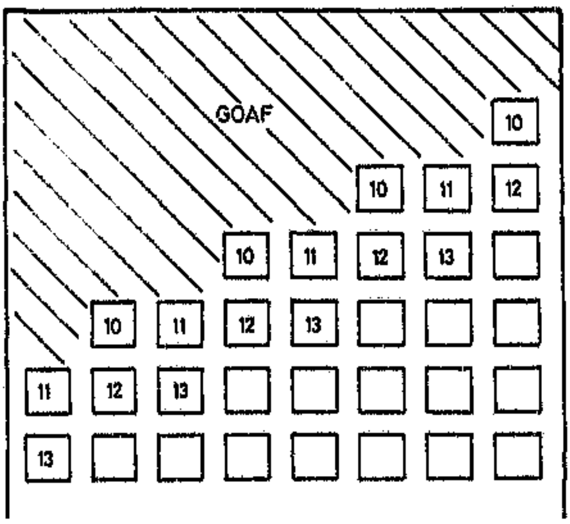


Figure 4.11 The 30° Stooping Line at Vryheid Coronation

At Hlobane Colliery and Alpha Anthracite Colliery an arrov .ead configuratio is used (Figure 4.12). This stooping configuration, however, is not recommended due to the high stresses on the lagging pillars. In all the methods mentioned above, a complete row of pillars is extracted at a time.

Savmore Colliery constitutes one of the exceptions in conventional pillar extraction as a complete row of pillars is extracted in a straight line across the panel (Figure 4.13). This is possibly as a result of the very competent sandstone roof coupled with the extraction method of pillar splitting with fender destruction.

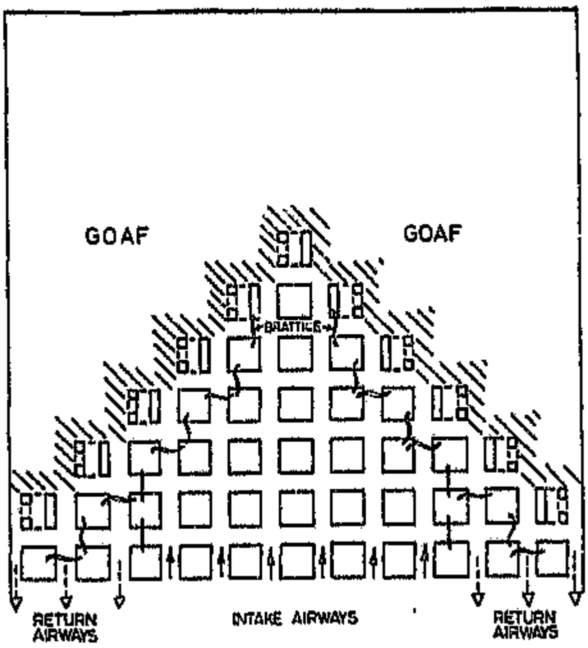


Figure 4.12 The Arrowhead Sequence used at Hlobane Colliery

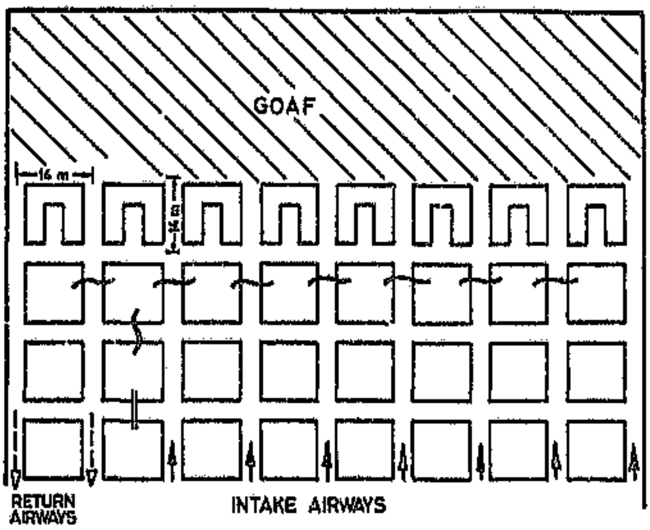


Figure 4.13 Straight Line Extraction at Savmore Colliery

4.3.3 Pillar extraction methods

Apart from the double stall scraper method used at Hlobane Colliery and the pillar splitting with fender destruction method used at Savmore Colliery, the basic concepts of the various extraction methods are very similar. Despite this similarity, the detailed layout and extraction sequence on different mines can vary considerably, depending on the pillar size and shape and the mining method used. The pillar sizes on the different mines vary from 6 m to 25 m square pillars.

In addition to the two exceptions mentioned above, a few of the more common methods used for extracting pillars of different sizes will be discussed briefly.

(i) Extraction method and support for 25 m square pillars

Two basic methods are used for extracting pillars approximately 25 m square. The first method, used at Kilbarchan Colliery, Vryheid Coronation Colliery and Welgedacht Exploration, involves splitting the pillars into two fenders by a 5 m wide development through the centre of the pillar. In the second method, presently used at Durban Navigation Colliery, the pillar is split into three 5 m wide fenders by two 5 m wide developments.

Method One

A modified 'split and fender' system is used to extract the pillars (Figure 4.14). Breakerlines BL1 to BL4 having been installed when the previous row of pillars was extracted, the pillar is then split into two 10 m wide ribs by a 5 m wide development through the centre of the pillar. Breakerline BL5 is installed when this development breaks through into the goaf. The two 10 m wide ribs are then extracted in the sequence shown in Figure 4.14. When the various lifts break through into the goaf, breakerlines are installed and the previous breakerlines are extracted. When the last snook (17) has been extracted, breakerlines BL6 and BL7 are installed and the breakerlines remaining in the pillar are extracted.

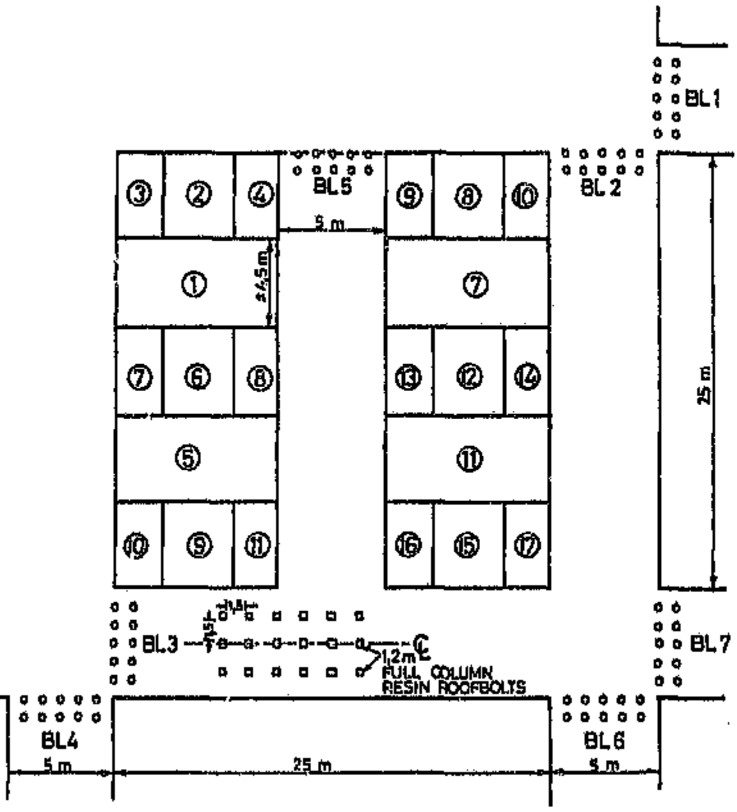


Figure 4.14 Extraction Method for ˜5 m Pillars at Welgedacht Exploration

Method Two

Breakerlines BL1 to BL4 having been installed when the previous line of pillars was extracted (Figure 4.15), the first 5 m development (1) is commenced leaving a 5 m wide rib between this development and the goaf. When this development has progressed approximately half-way into the pillar, the second development is started (2). When the first development breaks through into the goaf, breakerline BL5 is installed. The first development through the rib (3) is then taken, breakerline BL6 is installed and the remaining snook (3A) is blasted and loaded. The second development (4) is then taken and breakerline BL7 is installed. The remaining snooks, 4A and 4B, are then blasted and loaded. The same procedure is then repeated for the rest of the pillar.

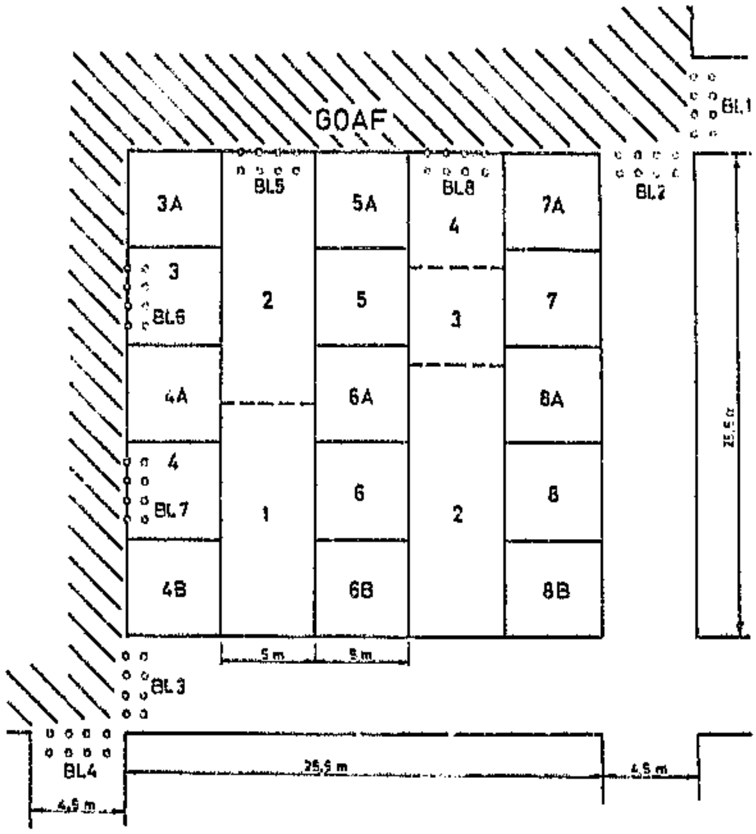


Figure 4.15 Extraction Method for 25 m Pillars at Durban Navigation Collieries

(ii) Extraction method and support for 14 m to 20 m square pillars

Pillar extraction commences when the development of the panel reaches the panel limits. The pillar is split by means of a 5 m or 6 m wide development through the centre of the pillar. The two remaining ribs are then quartered and the remaining snooks are removed (Figure 4.16). Breakerlines BL1 and BL2 having been installed when the previous pillar was removed, the development (1) is then driven through the centre of the pillar and breakerline BL3 is installed. The right hand pillar is then split by a 6 m wide development (2) after which breakerline BL4 is installed. Pillar 3 is then extracted, breakerline BL5 is installed and breakerlines BL3 and BL4 are extracted. After the remaining pillar (4) has been extracted, breakerline BL6 is installed and breakerlines BL2 and BL5 are extracted. The left hand rib is then split (5) from the existing roadway, breakerline BL7 is installed and the two remaining pillars, 6 and 7 are extracted.

Variations of this extraction method are used at Hlobane Colliery and Vryheid Coronation Colliery.

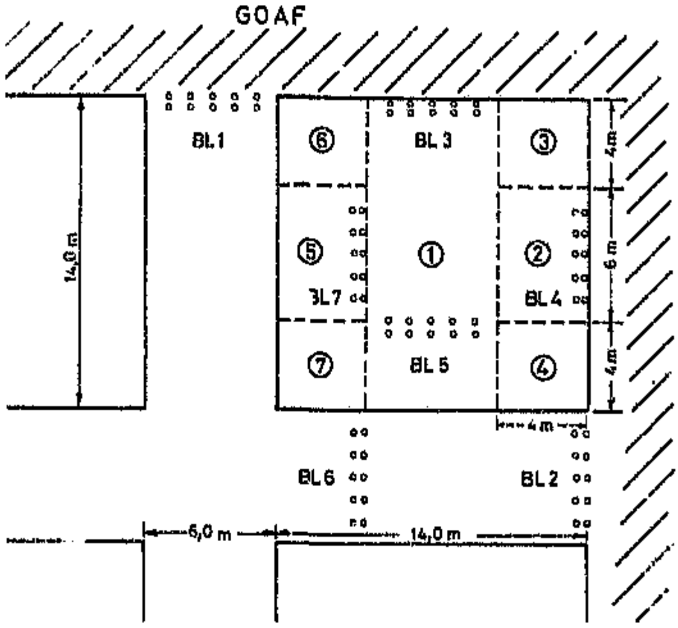


Figure 4.16 Extraction Method for 14 m to 20 m Square Pillars at Hlobane Colliery

At the Leeuneck Section of Vryheid Coronation Colliery, problems are experienced with floor heave if the extraction method described above is practised. This is mainly due to the fact that the pillar is split into two fenders and the first fender is extracted completely before extraction of the second fender commences. When this method was practised, the stress increase on the second fender gave rise to floor heave. Certain alterations were made to the extraction sequence to prevent floor heave. Although the pillar is still split into two fenders, the extraction sequence was altered to reduce the stress build-up in the second fender (Figure 4.17).

The 15 m square pillar is split into two 5 m wide fenders by a 5 m wide development through the centre of the pillar. Instead of splitting and quartering these two fenders as with the previous method, they are extracted as lifts in the sequence shown in Figure 4.17. The installation of the breakerlines is similar to the extraction method discussed above. When a new breakerline is installed, the previous breakerline is removed.

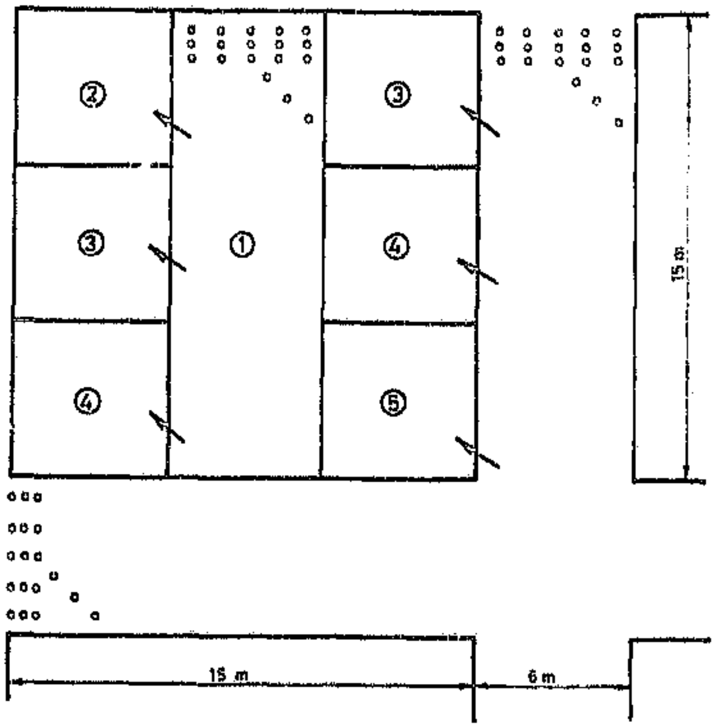


Figure 4.17 Extraction Method for 14 m to 20 m Square Pillars at Vryheid Coronation where Floor Heave is a Problem

(iii) Extraction methods and support for the 9,5 m square pillars at Savmore Colliery

Extraction method in the Alfred Seam

The extraction method is depicted in Figure 4.18. The breakerlines consist of two rows of 1,8 m mechanical anchor roofbolts with headboards, installed a maximum of 1,0 m apart in both directions, and not more that 1,0 m from each ribside. Single timber props are installed between the two rows of roofbolts to act as 'policemen' (see Figure 4.18). A 5,5 m wide split is developed through the centre of the pillar, leaving two 2 m wide snooks on either side of the pillar. Two 1,8 m mechanical anchor roofbolts are installed not more that 1,0 m from each ribside and 2,0 m from the next row. When the split holes through into the goaf, the two 2,0 m wide snooks are destroyed before extraction of the next row of pillars commences.

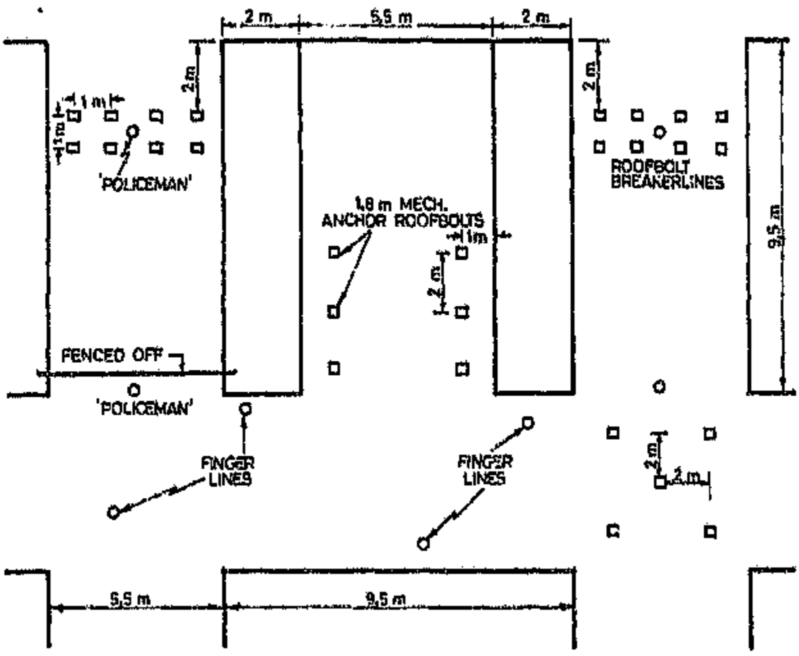


Figure 4.18 Pillar Extraction Method at Savmore Colliery - Alfred Seam

Extraction method in the Dundas Seam

When pillar extraction commenced in the Dundas Seam, it was decided to optimise the percentage of coal extracted from the pillars. As the fenders created in the extraction method described above were too narrow to extract safely, the extraction method was altered to that depicted in Figure 4.19. The breakerlines also consist of two rows of roofbolts installed to the dimensions described above. The 5,5 m wide split is developed from corner to corner, and when the split has been completed, two additional cuts are taken from the two resulting snooks (Figure 4.19), after which the remaining snooks are destroyed. The roofbolts in the split are also installed to the dimensions described above. The use of this extraction method increased the percentage extraction by approximately 10%.

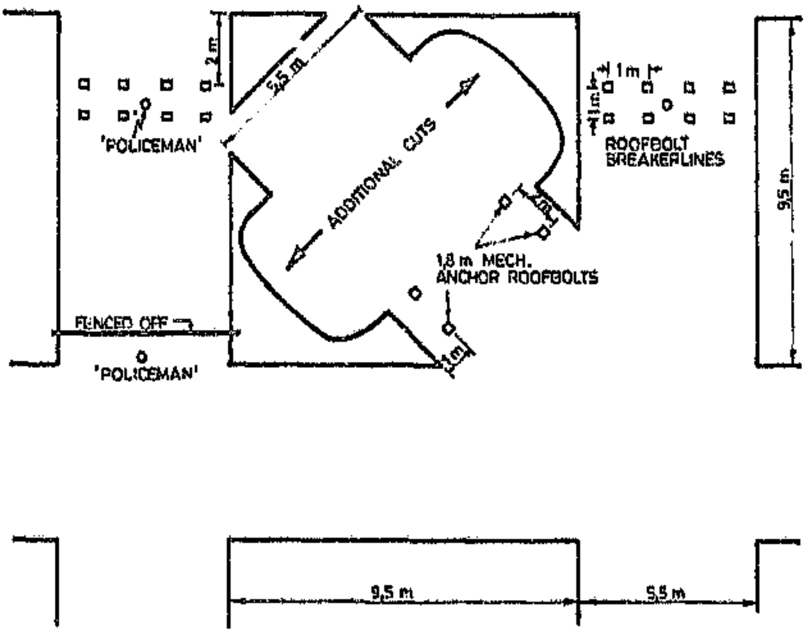


Figure 4.19 Pillar Extraction Method at Savmore Colliery - Dundas Seam

(iv) Double stall scraper method used at Hlobane Colliery

Five double stall scraper sections are employed in the Gus Seam at Hlobane Colliery in seam heights that vary from 0,5 m to 1,1 m. This mining system was developed to extract reserves in the Gus Seam where the seam height was too low to employ other mechanized methods without a fair amount of dilution.

Main panel development

The main panel development consists of three roads, the centre road being the main travelling/belt roadway. This roadway is mined 6 m wide and the roof is brushed to 1,8 m. The two companion roads are mined 5 m wide at seam height. The pillars in this development are mined at 20 m centres. The splits between the main and companion roadways are 6 m wide and are brushed to 1,4 m to accommodate the winches and ramps.

The winch is placed in a split as close as possible to the conveyor tail-end, and tracks are laid as close as practicable to the brushed face (Figure 4.20). The brushing of the main travelling/belt road lags behind the main development to allow for large stone to be hand-packed underground.

Secondary panel development

Double stalls, 10 m wide, are developed on either side of the main panel development at right angles to the main development (Figure 4.20).

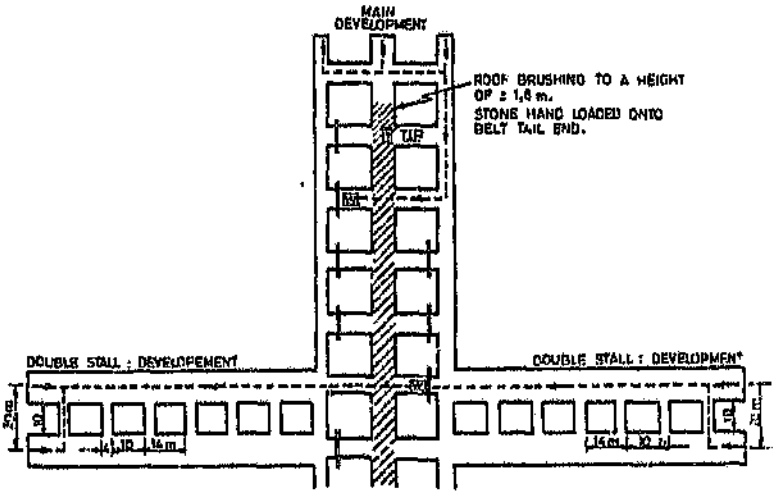


Figure 4.20 Secondary Panel Development - Double Stall Scraper Method at Hlobane Colliery

These stalls are developed at 20 m centres and the splits are developed 4 m wide and at 14 m centres. This results in 10 m square pillars. Ten metre wide barrier pillars are left between the double stall panels.

Mining method

The main difference between this and the normal conventional mining method is the cleaning equipment used. A double-drum winch is used to pull a scraper for cleaning the working faces. The bends are negotiated by means of 'round-the-corner' pulleys, and ramps are built over the conveyor belt for the coal to be scraped onto the belt. A schematic layout of the system is given in Figure 4.21.

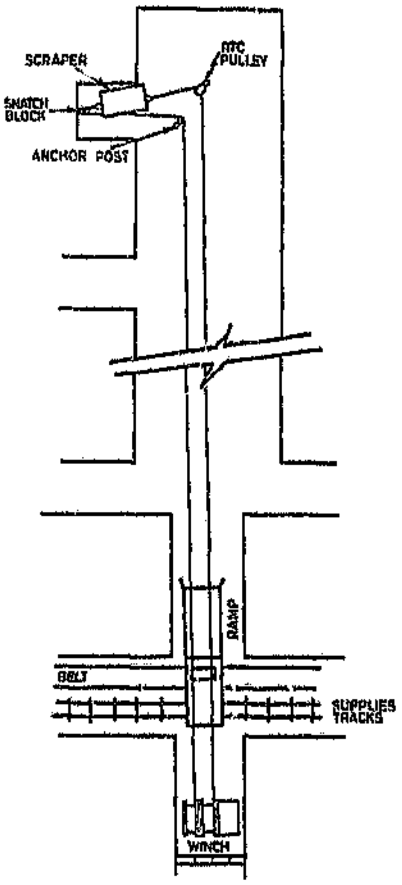


Figure 4.21 Schematic Layout - Double Stall Scraper Met[illegible]d at Hlobane Colliery

Extraction method

Pillar extraction commences when the development of the first double stall reaches the panel limits. The 10 m square pillars are split by 6 m wide roadways, thus leaving 2 m wide crush pillars on either side. As the pillar extraction retreats, the barrier pillar between the stalls is stooped by developing splits 10 m wide, leaving 2 m wide crush pillars on either side (Figure 4.22).

The stalls are thus stooped on an advancing method, leaving the two 10 m pillars adjacent to the main panel development and the pillars in the main development intact. When the stalls have been stooped to the limits of the panel, these centre pillars are stooped on the retreat employing the same mining method.

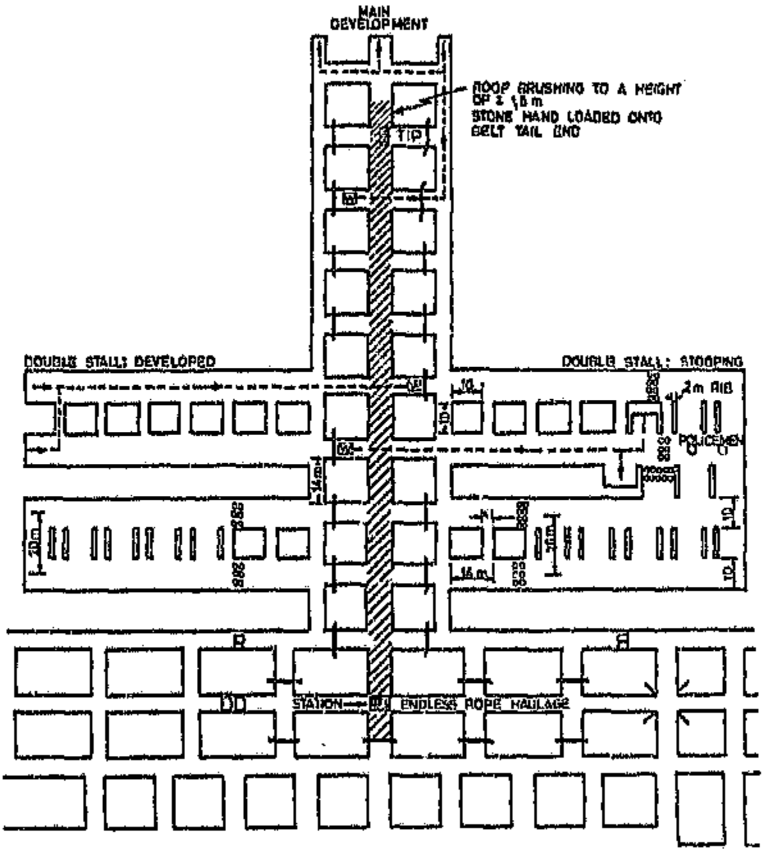


Figure 4.22 Double Stall Scraper Extraction Method at Hlobane Colliery

4.3.4 Production equipment for mechanised pillar extraction

Although the type of equipment varies from mine to mine, the numbers remain fairly constant. The main difference is in the transport equipment, where shuttle cars, scoops or load haul dumpers can be used. The typical production equipment for a section is:

- 3 Scoops - (type S and S 488), <u>or</u>
  Shuttle cars, <u>or</u>
  Load haul dumpers
- 1 Coalcutter
- 1 Roofbolter
- 1 Gathering arm loader (if shuttle cars are used)
- 2 Electric drills
- 1 Feederbreaker or beltfeeder

4.3.5 Manpower

The number and composition of the operating crews differ significantly from mine to mine. The number of men in the crews vary between 22 and 35, but following is a typical operating crew for a conventional pillar extraction section:

Miner	1
Team Leader	1
Loader Operators	2
Coal cutter operators	2
Roofbolt operators	4
Electric drill operators	4
Shuttle car operators	3
Miner's assistants	2
Barring attendant	1
Duff loaders	2
Tally/tip attendant	1
Ventilation attendant	1
Timber	<u>3</u>
TOTAL PER SHIFT	<u>27</u>

4.4 Percentage Extraction

The estimated percentage in-panel extraction on the various collieries differs vastly. It varies from 58% at Savmore, where the pillars are split and the ribs destroyed, to 95% at some of the collieries practising handgot pillar extraction

4.5 Support

4.5.1 Systematic support

The systematic support on the various collieries differs vastly as it depends mainly on the composition, competence and behaviour of the overlying roof strata. On a number of mines the sandstone roof is so competent that no systematic support is installed whilst a dense roofbolt pattern is necessary on others with incompetent shale and mudstone roofs.

4.5.2 Breakerline support

The use of breakerlines and fingerlines differs from one extraction method to the next. The pattern and types are influenced by the extraction method, behaviour of the overburden strata and approved systematic support rules. During open end lifting in handgot pillar extraction, the two or three row breakerlines forms a barrier between the working area and the goaf (Figures 4.6, 4.7 and 4.8). When mechanised conventional equipment is used, the breakerlines prevent the goaf line from entering the working area (Figures 4.15, 4.16 and 4.17). The actual position of the breakerlines can also differ. At most of the collieries, breakerlines placed in line with the pillar edges (see Figure 4.14) have proved to be effective. At Savmore Colliery, however, the breakerlines have to be placed 2 m inside the roadway (see Figure 4.18) to prevent goaf overruns. The two types of breakerlines used in conventional pillar extraction are timber breakerlines and roofbolt breakerlines.

Timber breakerlines

The vast majority of breakerlines consist of timber props. Little use has been made to date of hydraulic props mainly due to the mass of the long props in high seams and the possibility of losing these in the goaf which would prove very costly.

Limited research was done on timber breakerlines by COMRO (Buddery, 1985). The aim of the research was to determine the maximum load carrying capacity of the timbers in breakerlines. Timber props of varying thickness, with and without wedges inserted, were tested in the laboratory. Underground tests were done in pillar extraction sections on two collieries where load cells were installed under a number of timbers in breakerlines and fingerlines.

A satisfactory correlation was found between the actual failure loads of the laboratory and site tests and the failure loads as predicted by the Rankine/Gordon strut formula.

The Rankine/Gordon formula is as follows:

$$P = \frac{Oc.A}{1 + \alpha\left(\frac{l}{k}\right)^2} \qquad (9)$$

Legend: P = crippling load in MPa

Oc = material constant (taken as 35 for timber)

A = cross-sectional area of prop (in metres)

a = constant (taken as 1/3000)

l = length of prop (in metres)

k = the square root of the least radius of gyration (D/4)

The following is a summary of the laboratory and site tests and the application of the formula:

(i) The diameters of individual props were found to vary between 102 mm and 202 mm and the mining height varied between 2,7 m and 3,0 m. If these figures are inserted in the Rankine/Gordon formula, the average load a breakerline of 8 to 10 props can withstand, varies between 89 tons and 308 tons (Buddery, 1985). This correlated well with the loads measured on site and in the laboratory.

(ii) It was found that in practice the load on individual props in the breakerlines seldom exceeded 12 tons before a new breakerline was installed and this breakerline was removed. In the majority of cases the average load was as low as 5 tons when the breakerline was removed. Where individual props were left as 'policemen' when the breakerlines were removed, loads of up to 29,8 tons were recorded before the prop failed.

(iii) The use of wooden wedges resulted in much larger deflection before the maximum load was transmitted to the prop and failure occurred. During laboratory tests, the average deflection before failure for 2,8 m long props was found to be in excess of 50 mm for props with headboards as compared to an average of approximately 24 mm for props without headboards.

(iv) Once the first signs of failure have been recorded, the load bearing capacity rapidly drops to zero.

Roofbolt breakerlines

Roofbolt breakerlines are being used successfully at Savmore Colliery (conventional pillar extraction) and Middelbult Colliery (pillar extraction with continuous miners), both with a competent roof strata and at Kilbarchan Colliery (conventional pillar extraction), which has a laminated, incompetent roof strata. A number of the other collieries using mechanised equipment for pillar extraction is also planning to experiment with roofbolt breakerlines. Although roofbolt breakerlines differ from timber breakerlines as they function according to the suspension or beam formation theory, they have to date been successful in preventing the goaf from extending into the working area in the collieries where they are used.

The main advantages of roofbolt breakerlines are (McCosh et al, 1989):

(i) The quality of installation and its effectiveness are independent of the extraction height.

(ii) The breakerline can be sited to suit strata control requirements.

(iii) The roofbolts provide additional stiffness to the roof.

(iv) The breakerlines can be installed before pillar extraction commences. If it is installed as part of the systematic support system during the development phase, it results in installation time and cost savings.

4.6 Ventilation

The number of roadways utilised as return airways differ from mine to mine and depend on the total number of roads in the panel and the extraction height. The ventilation layout of a typical nine-road section is depicted in Figure 4.23.

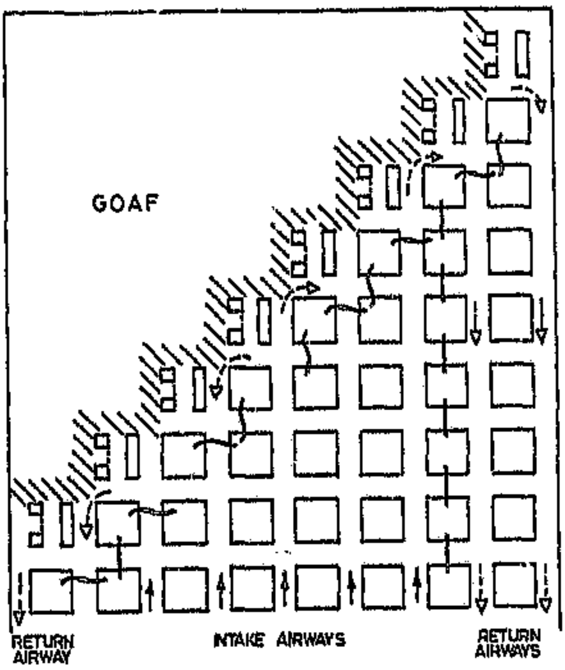


Figure 4.23 Typical ventilation layout - 45° stooping line

On some collieries, where a panel consists of six roads, only one return airway is created on one side of the panel, but where a panel consists of a large number of roads, as many as three roads on either side of the panel are used as return airways. The air enters the section via the intake airways and is coursed along the pillars being extracted to the return airways with the aid of ventilation brattices.

4.7 Conclusions

Although various methods are used under different geological conditions and at various depths, the methods used under comparable conditions are fairly similar.

This similarity, with also verifies the validity of the strata control and mining theories, makes it possible to compile general guidelines that can be applied in practice.

In the next chapter, the experience gained in extraction pillars with continuous miners are discussed and analysed.

CHAPTER 5

PILLAR EXTRACTION WITH CONTINUOUS MINERS

5.1 Introduction

The first experiments with pillar extraction using mechanised conventional equipment proved successful on some collieries and unsuccessful on others. The problems experienced with conventional pillar extraction on Sigma Colliery and Coalbrook Colliery were mainly due to weak roof strata and the presence of thick, competent dolerite sills in the overlaying strata. The first experiment of pillar extraction with continuous miners was conducted at Usutu Colliery in the late Seventies. Since then various mines have been using continuous miners in pillar and rib pillar extraction. The various pillar extraction methods and pillar extraction sequences on all the collieries using continuous miners have been studied. These collieries, situated in all the major coalfields in South Africa being mined at present, are:

Middelbult Colliery, Twistdraai Colliery, Bosjesspruit Colliery, Brandspruit Colliery and New Denmark Colliery, all situated in the Highveld Coalfield;
Usutu Colliery, Savmore Colliery and Ermelo Mines, all situated in the Eastern Transvaal Coalfield;
Longridge Colliery, situated in the Klip River Coalfield;
Greenside Colliery, situated in the Springs-Witbank Coalfield;
Hlobane Colliery, situated in the Vryheid Coalfield;
Zululand Anthracite Colliery, situated in the Zululand Coalfield, and
Sigma Colliery, which is situated in the Vereeniging-Sasolburg Coalfield.

The objective of this chapter is to discuss the various extraction methods and extraction sequences used on the various mines. The extraction methods common to several collieries are discussed as well as the reasons why some collieries deviate from these common practices or use different methods. The experience gained by the mines during the years of pillar extraction is incorporated in the guidelines in Chapter 7.

In additional to the mining methods, the labour complement, production equipment and ventilation layouts are also described briefly.

The annual tonnage produced by pillar extraction with continuous miners increased rapidly in the early Eighties, but flattened off in the latter half of the decade. In 1989 approximately 12,3 million tons, which represents 11% of the total coal mined by underground methods, were produced with this mining method.

5.2 Development for Pillar Extraction with Continuous Miners

The number of roads in the primary development on the collieries practising pillar extraction with continuous miners differ vastly. It varies from double entries, one for intake and one for return ventilation, consisting of six to eight roadways, to single entries consisting of six to thirteen roadways (Beukes, 1989b). The bord widths and pillar sizes vary with depth and local strata conditions and behaviour. The development is done by continuous miner or conventional mining methods.

The secondary development consists of five to thirteen roadways and is done by continuous miner or conventional mining methods. The bord widths and pillar sizes also vary with depth and local strata conditions and behaviour. Wherever practical, the development is positioned such that pillar extraction panels can be developed on both sides of the development.

The number of roads in the pillar extraction panels vary from five to thirteen, depending on factors such as the depth below surface, strata conditions, pillar size and the extraction method. The factors affecting the panel layout are discussed in Chapter 7.

5.3 Stooping Angle and Pillar Extraction Sequence

The angle at which stooping with continuous miners is practised will depend largely on the behaviour of the local strata and may differ from mine to mine. Although the majority of the collieries extract pillars in a straight line, some collieries find it necessary to do so at an angle of 45°.

The reason why pillars can also be extracted in a straight line when using continuous miners is that only one pillar is extracted at a time. The pillar being extracted is thus partially protected by the adjacent pillars (Figure 5.1). As can be seen from Figure 5.1, the pillar being extracted is partially protected by pillars 1 and 2. As the extraction is concentrated on only one pillar at a time, each pillar is extracted in a relatively short time thus preventing it from being exposed to increased stress for long periods.

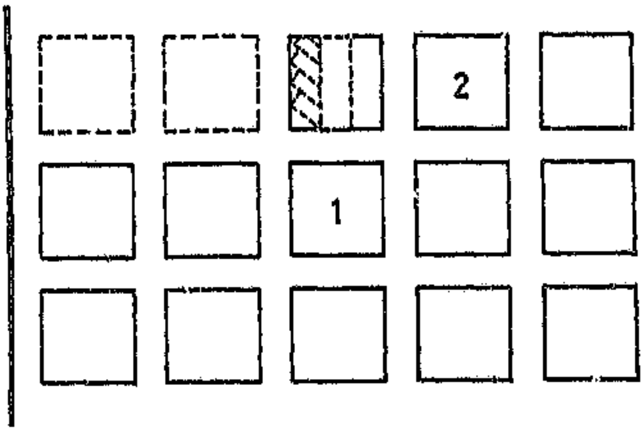


Figure 5.1 Extracting Pillars on a Straight Line Using Continuous Miners

The first stooping panel at Sigma Colliery was started at a 45° angle, but the pressures on the lagging pillars became so high that premature fender and bord failure occurred and this method had to be abandoned. The pillars were then stooped in a straight line which proved to be successful. This is also the method followed by nine of the twelve collieries.

At Greenside Colliery, Usutu Colliery and Ermelo Mines straight line stooping resulted in high stresses on the pillars adjacent to the goaf. This resulted in severe scaling in the roadways and difficulties were experienced when removing the last pillars in the line. It was thus decided to change to a 45° extraction line to overcome these problems. This is similar to the stooping line used in conventional stooping, the only difference being that when extracting pillars with continuous miners, only one pillar is extracted at a time. Greenside Colliery and Usutu Colliery are still using this sequence.

At Ermelo Mines, however, the 45° line across the 11 to 13 road panels resulted in such long tramming distances that the stooping angle was changed to a short 45° line consisting of two to four rows of pill (Figure 5.2) and in adverse geological conditions to a 30° stooping line (Figure 5.3). These proved to be successful and are still being used.

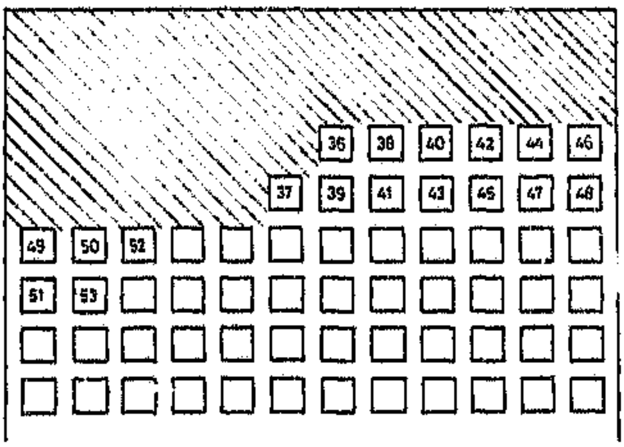


Figure 5.2 45° Stooping Line at Ermelo Mines

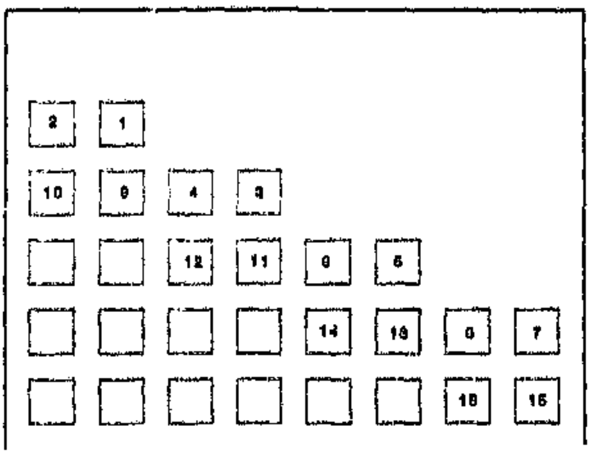


Figure 5.3 30° Stooping Line at Ermelo Mines

The main difference between Ermelo Mines, Usutu Colliery and Greenside Colliery and the other collieries doing pillar extraction with continuous miners, is the number of roads per panel. The number of roads on these three collieries varied between 11 and 13 in comparison with the 5 to 7 roads on the other collieries. The larger the number of roads, the slower the retreat during pillar extraction. The slower retreat can result in the pillars adjacent to the goaf being exposed to the higher stress for prolonged periods, causing pillar and bord deterioration.

In addition to this, the composition and behaviour of the local strata plays a major role in the extraction sequence. Practical experience on collieries such as Ermelo Mines and Zululand Anthracite has proved that an extraction sequence that is effective in one part of a mine can prove hazardous in another part of the same mine.

At Zululand Anthracite Colliery the pillars are normally extracted in a straight line, but a 45^0 stooping line is sometimes followed in adverse geological conditions or when the panel geometries are distorted due to faulting.

5.4 Pillar Extraction Methods

A number of pillar extraction methods are practised on the various collieries. The extraction methods followed are mainly dictated by the pillar size and the composition and behaviour of the local roof strata.

5.4.1 Extraction method and support for pillars of 10 m square and smaller

(a) The extraction method practised at Ermelo Mines and Greenside Colliery is depicted in Figure 5.4.

Breakerlines BL1 and BL2 were installed when the previous pillar was extracted, and fingerlines FL1 and FL2 are installed before extraction commences. Breakerline BL3 and fingerline FL3 are installed when cut 1 has been completed, and fingerline FL4 is installed on completion of .t 2. On completion of cut 3, the continuous miner is trammed to the next pillar, and breakerline BL4 is installed. All the breakerlines and the fingerlines, except BL3 and BL4, are then removed.

(b) At Sigma Colliery, where the roof consists of friable shales and mudstones, the centre cut is taken first. A fingerline is then installed in the centre of the pillar and the two cuts on either side of this fingerline are then taken.

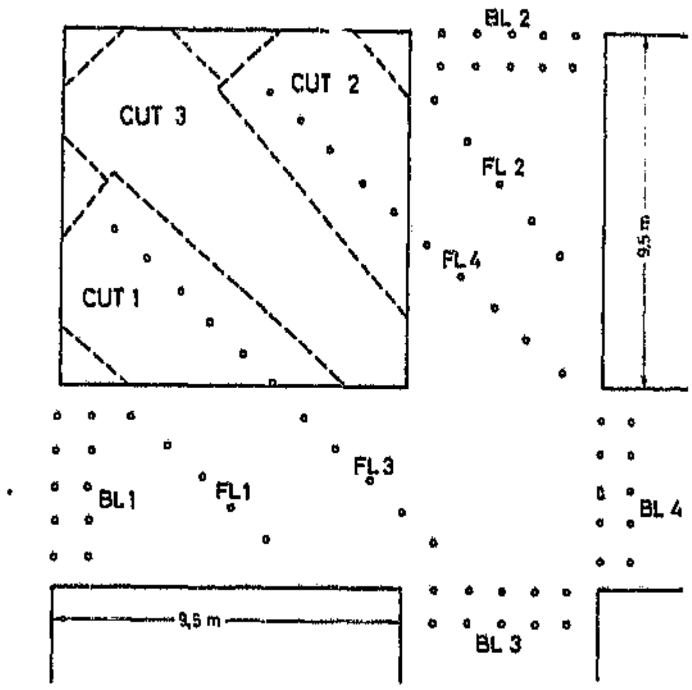


Figure 5.4 Extractio. ?lethod for Pillars smaller than 10 m at Ermelo Mines and Greenside Colliery

5.4.2 Extraction method and support for pillars between 10 m and 14 m square

At Usutu Colliery and Ermelo Mines, where the roof consists of a competent sandstone, the pillars are also split at a 45° angle. Ermelo Mines made further refinements to the cutting sequence which are described in detail by Beukes (1989b).

The extraction method, as well as the support installed during extraction, is shown in Figure 5.5.

Timber breakerlines BL1 and BL2 and fingerlines FL1 and FL2 are already in position as they were installed before the previous pillar was extracted. The first cut is then made and whilst fingerline FL3 is being installed, the second cut is made on the opposite side of the pillar.Cut 3 is then made whilst fingerline FL4 is installed. Cut 4 is then made whilst fingerline FL5 and breakerline BL3 are installed and fingerline FL3 is extended. The continuous miner then has to wait whilst fingerline FL6 is installed and fingerline FL4 is extended before making cut 5. When this cut has been completed, the continuous miner moves to the next pillar to be extracted and breakerline BL4 is installed. All breakerlines and fingerlines, except BL3 and BL4, are then extracted.

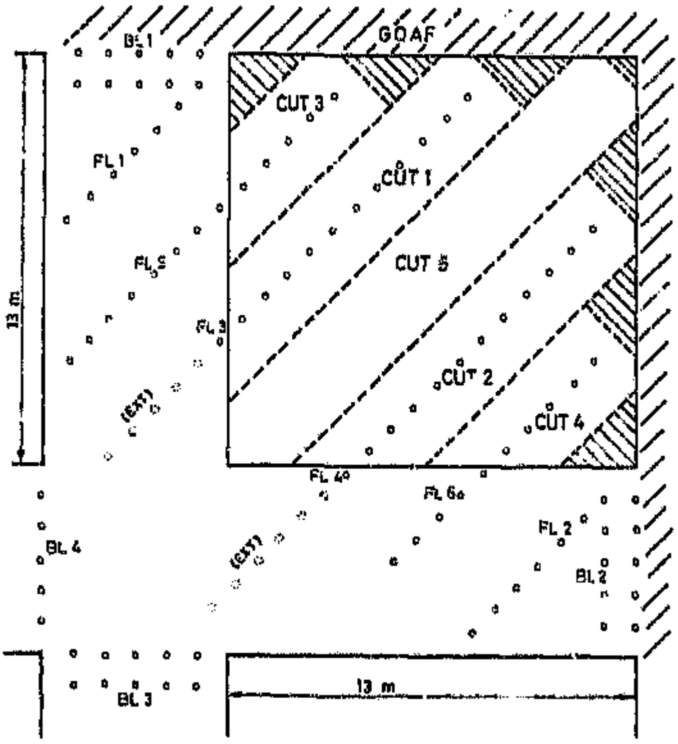


Figure 5.5 Extraction Method for a 13 m Pillar at Usutu Colliery and Ermelo Mines

5.4.3 Extraction method for 18 m square pillars

The pillar size at the majority of the mines practising pillar extraction with continuous miners is 18 m square. Although there are certain minor differences in the support and direction of the cuts, the extraction methods are very similar. This extraction method is practised at Sigma Colliery, Middelbult Colliery, Twistdraai Colliery and Zululand Anthracite Colliery. A typical extraction method is depicted in Figure 5.6.

Breakerlines 1 and 2 were installed when the previous row of pillars was extracted. The pillar is split into two fenders by a 6 m wide development through the centre of the pillar and breakerline 3 is installed. On the completion of cut 3, breakerline 4 is installed and the remainder of the fender is extracted. When cut 6 has been completed, breakerline 5 is installed and breakerlines 2, 3 and 4 are removed before starting the similar extraction of the next fender.

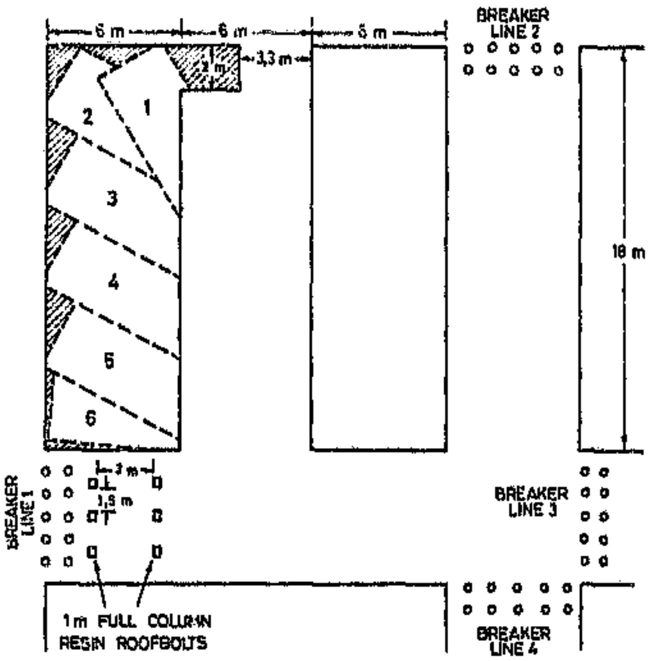


Figure 5.6 Extraction Method for a 18 m Pillar at Sigma, Middelbult and Twistdraai Collieries

5.4.4 Extraction method for 25 m square pillars

The pillar size of the pillars being extracted at Springfield Colliery is 24,5 m square. At Longridge Colliery, mining under a mountain, the pillars near the outcrop are 19 m square. As mining proceeds into the mountain, the pillar size increases to 25 m square, then to 33,5 m, and eventually to 40 m.

(a) The original extraction method at both collieries consisted of splitting the pillar into three 5 m wide fenders by two 5 m wide developments through the pillar (Figure 5.7). As the mining height varies between 2,8 m and 3,5 m, the width/height ratio of these fenders was less than 2 and premature failure occurred.

At Springfield Colliery, various changes were made to the breakerline support and extraction sequence in an attempt to overcome these problems, but it was unsuccessful (Beukes, 1989b).

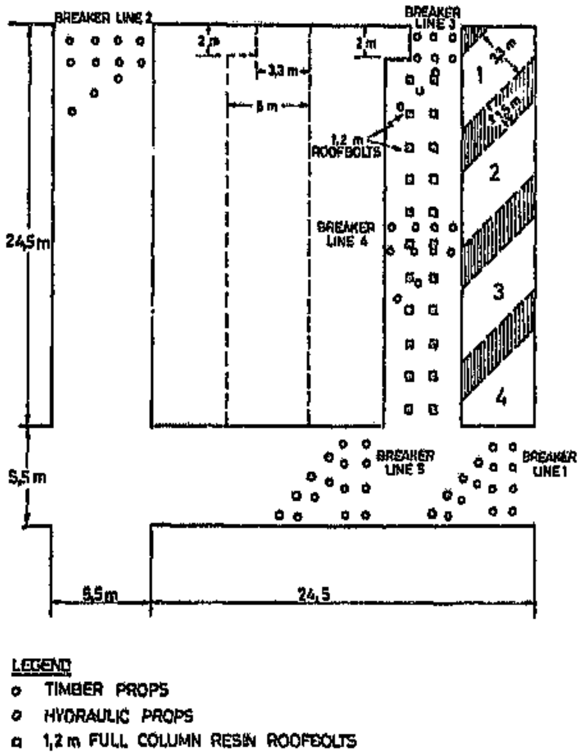


Figure 5.7 Initial Extraction Method for a 25 m Pillar at Springfield Colliery

The extraction method on both collieries was then changed by splitting the pillar into two fenders by a 5 m wide development through the centre of the pillar.

(b) The extraction method and support at Springfield Colliery is depicted in Figure 5.8. The 9,5 m wide ribs are not extracted completely, but a rib of 2-2,5 m wide is left to crush. This change proved to be successful.

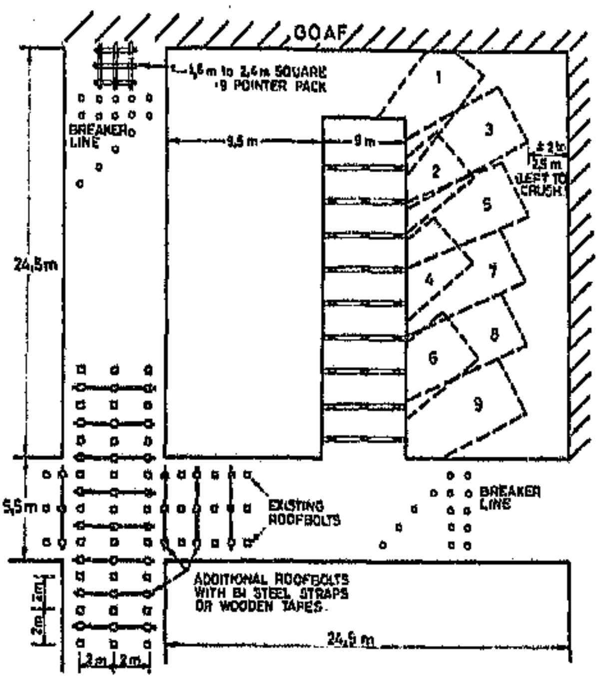


Figure 5.8 Final Extraction Method at Springfield Colliery

(c) At Longridge Colliery the pillars were also split into two fenders, but the cutting sequence differed. The extraction method is depicted in Figure 5.9.

Initially the complete fender was extracted, but the large unsupported area at the intersection when extracting the final cut in the fender resulted in the continuous miner being buried by roof falls on three occasions. It was decided to leave a 3 m wide rib of coal, shown in Figure 5.9, between the two final cuts and no similar incident has occurred since.

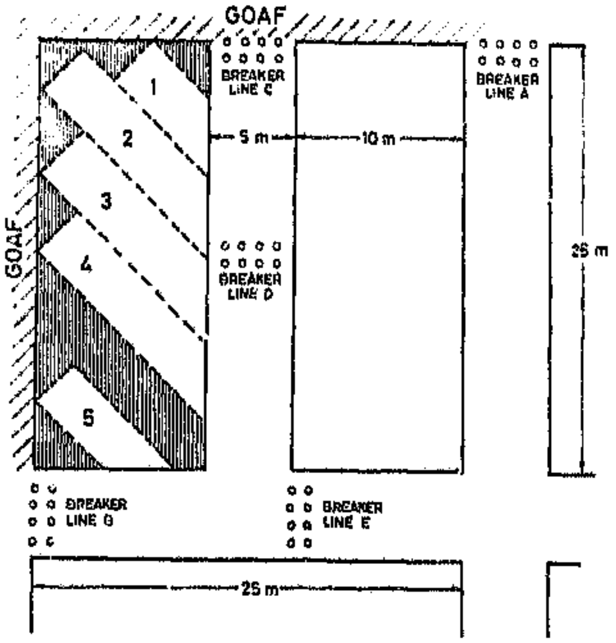


Figure 5.9 Final Extraction Method at Longridge Colliery

5.4.5 Extraction of pillars larger than 25 m square

The large pillars are split and quartered thus dividing them into four smaller pillars. These smaller pillars are then extracted using one of the methods for extracting small pillars described above.

5.5 Ret· Rooming Extraction Method with a Fairchild Wilcox Contin·· s Miner at Hlobane Colliery

The Fairchild Wilcox Mark 21 continuous miner, unlike the crawler-propelled continuous miners, manoeuvres and advances by means of hydraulically powered jacks and rope winches (Figure 5.10). By eliminating crawlers, Fairchild has probably arrived at the lowest and smallest configuration in any continuous miner, being capable of mining to a minimum height of 0,7 m. It has dual forward-pointing augers and advances in slices of 1,2 m by fanning back and forth in a windshield wiper fashion. By fitting different size augers, the Wilcox miner is capable of cutting seam heights ranging from 0,7 m to 1,14 m.

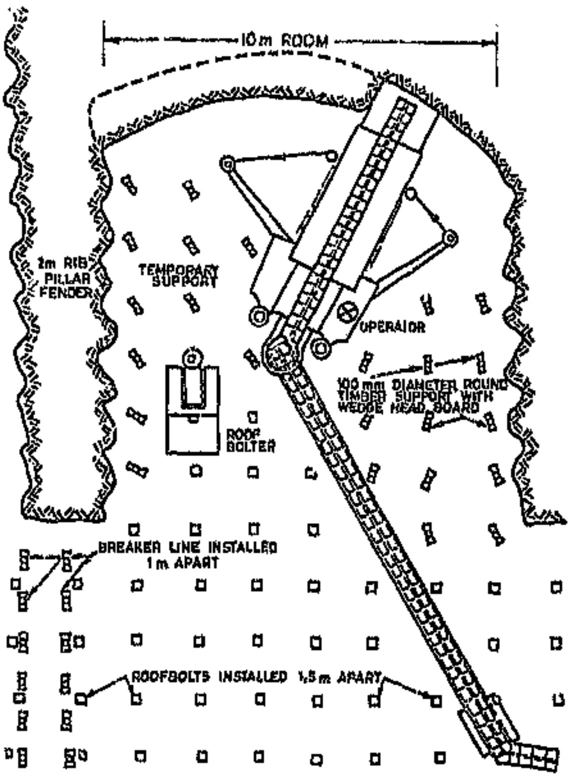


Figure 5.10 Cutting Method of the Fairchild Wilcox Miner at Hlobane Colliery

Main development

The main development consists of 7 roads on average and the pillars are mined at 15 m centres and 30 m centres, depending on the depth below surface. The travelling road is developed at a height of 1,8 m and the bolt road at 1,5 m, irrespective of the seam height.

Secondary development

The secondary development consists of three roads. The bords are mined 8 m wide and the pillars are mined at 18 m centres, thus creating 10 m square pillars.

A number of regulatory restrictions, as well as the capabilities of the low drive conveyor belt, defined the section boundaries as 1 000 m long and 456 m wide. The main access entry development is located such that secondary extraction panels can be mined at an optimum length of 228 m on both sides of this development.

Two road panel development and extraction

When the secondary development reaches the boundaries of the panel, a two road panel development is driven at right angles to the 3-road development to its limit of 230 m, leaving a 26 m to 28 m wide barrier pillar between the development and the previous goaf or the boundary of the panel (Figure 5.11). The bord width of this development is 9 m, and the 9 m wide connecting roads are developed such that 11 m by 3 m pillars are created.

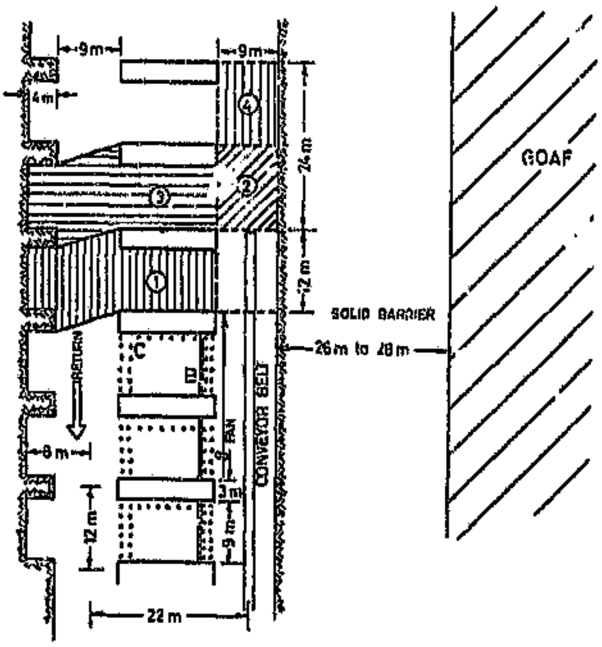


Figure 5.11 Panel Development for Retreat Rooming Extracting Method at Hlobane Colliery

Retreat rooming extraction method

As soon as the secondary development reaches the limit of the panel, retreat rooming commences. This consists of 10 m wide developments driven into the barrier pillar leaving 2 m wide protection pillars (Figure 5.12). During the retreat rooming operation, additional breakerlines are installed. When area 1 has been completed, breakerlines A and B are installed, and on completion of area 2, C and D are installed. The timbers in these breakerlines are 1 m apart in both directions (Figure 5.12).

When this process has been completed on the one side of the three-road development, the process is repeated on the opposite side, and the panel is mined out on a retreat basis.

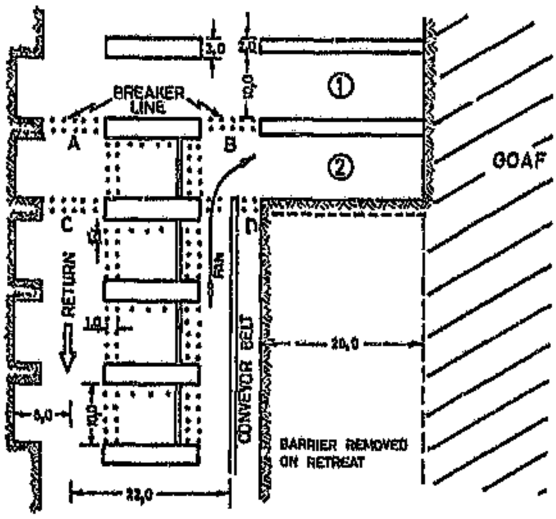


Figure 5.12 Retreat Rooming Extraction Method at Hlobane Colliery

5.6 Support

The support for pillar extraction with continuous miners is similar to that described for conventional pillar extraction in Chapter 4, Section 4.4.

5.7 Percentage Extraction

The in-panel extraction, as estimated by the various collieries, varies between 70 per cent and 90 per cent.

5.8 Manpower

The manning of the sections on various mines differ and also depends on the type and number of equipment used. The following, however, is typical of the manpower in a stooping section using one continuous miner and two shuttle cars. Additional manpower will be required when additional equipment, like Load Haul Dumpers, is used in the section.

Operating crew :	Miner	1
	Team Leader	1
	Continuous miner operator no.1	1
	Continuous miner operator no.2	1
	Cable handlers	1
	Shuttle car operators	3
	Roofbolt operators	2
	Barring attendant	1
	Support and ventilation	3
	Feederbreaker operator	1
	TOTAL PER SHIFT	15

5.9 Production Equipment

Although a wide variety of equipment is used on the various mines, the number of the specific types of equipment is very similar.

The equipment in a typical stooping section will be:

1 . ntinuous miner
3 Shuttle cars (one is normally on stand-by), Tractor-Trailer units or Load-Haul-Dumpers
1-2 Roofbolters (depend'ng on the der. ity of support).
1 Feederbreaker or tipping tailend

5.10 Ventilation

The ventilation layout differs from mine to mine. The number of roadways utilised as return airways varies from one road in the narrower panels with only five roadways, to as many as six roads in panels consisting of thirteen roadways. Ventilation brattices are used to course the air along the pillars being extracted towards the return airways. A certain amount (10% to 15%) of the ventilation leaks through these brattices and flows across the goaf to the return airways.

Figure 5.13 shows a typical ventilation layout for a narrow panel where the pillars are extracted in a straight line and Figure 5.14 a layout for a wider panel with a 45° stooping line.

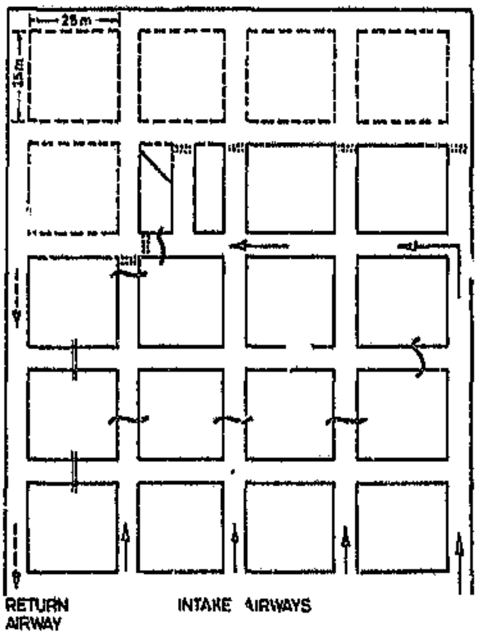


Figure 5.13 Typical Ventilation Layout when Extracting Pillars in a Straight Line

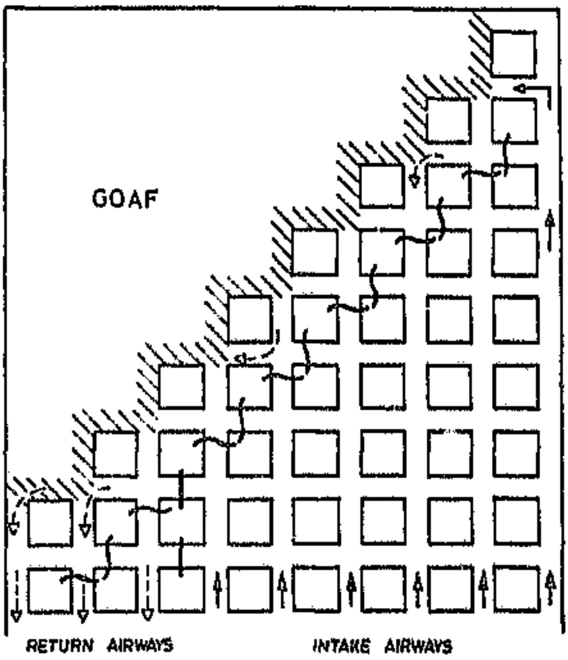


Figure 5.14 Typical Ventilation Layout when Extracting Pillars on a 45^{0} Angle

At the majority of the collieries mentioned above, CH4 and CO monitor heads are installed in the return airways of the pillar extraction sections and alarms are triggered if the pre-determined percentages of gas are exceeded.

5.11 Conclusions

It is actually remarkable how similar the pillar extraction methods used by the various mines for similar size pillars are. The difficulties experienced with certain mining methods and the success of the changes made, verifies the validity of a number of the strata control theories as well as certain research findings.

These facts does not only make the compilation of design guidelines possible, but actually desirable.

In the following chapter, rib pillar extraction, which was derived from the Munmorrah, Wongawilli and Old Ben mining methods practised in Australia, are discussed and evaluated.

CHAPTER 6

RIB PILLAR EXTRACTION

6.1 Introduction

A detailed study was made of the rib pillar extraction methods practised in South African collieries. In this chapter the Australian mining methods, from which the South African rib pillar system originated, the initial rib pillar methods and the evolution of the rib pillar system since 1980 in five South African collieries are discussed.

During the past decade, rib pillar extraction was practised in five collieries. These collieries are:

Middelbult Colliery, Twistdraai Colliery, Kriel Colliery and New Denmark Colliery, all situated in the Highveld Coalfield, and
Sigma Colliery, which is situated in the Vereeniging-Sasolburg Coalfield.

The objective of this chapter is to discuss the various extraction methods and extraction sequences used on the various mines. The initial extraction method is discussed as well as the changes made to this method and the reasons for such changes. The experience gained by the mines during the years of rib pillar extraction is incorporated in the guidelines in Chapter 7.

In additional to the mining methods, the labour complement, production equipment and ventilation layouts is also described briefly.

6.2 Historical Background

Apart from some poorly documented, small-scale attempts at longwall mining, longwall trials in low seams (1 - 1,2 m) were started at Hlobane Colliery in early 1964 and at Durban Navigation Collieries, where it is still practised, in the middle of 1965. Early in 1967 longwall trials were also started at Sigma Colliery in a higher (2,7 m) seam (Salamon, et al, 1972. It was not until the mid Seventies, however, that longwall mining was introduced on a larger scale. During the early Eighties, a total of eight collieries had one or more longwall faces in production. Due to the frequency of geological discontinuities, especially dolerite dykes, and the varying thickness of the seams in most of the South African coalfields, longwall mining can only be practised in selected portions of the total reserves. The limited application of longwalling therefore made it necessary to investigate other mining methods to improve the overall extraction percentage of the total coal reserves.

The first experiments with pillar extraction using mechanised conventional equipment proved successful on some collieries and unsuccessful on others. At Sigma Colliery conventional stooping proved hazardous due to the friable roof conditions and the presence of a thick dolerite sill in the overlaying strata.

During the late Seventies, project teams from Sigma Colliery and Kriel Colliery visited Australia to investigate the stooping methods practised successfully in New South Wales. Legislation in Australia prohibited the mechanised extraction of pillars until the early Fifties when the introduction of continuous miners eliminated the necessity of multiple working places. However, the use of continuous miners resulted in low extraction percentages due to the operator's inability to remove the 'snooks' or to complete the lifts in the 'open-end-lift' method.

The very thick, competent conglomerate overlaying the coal seams caused sudden, unplanned roof falls and a very serious accident during stooping operations in New South Wales triggered an investigation into the development of safer mining methods. Rib pillar extraction mining methods were developed in an attempt to overcome these difficulties.

The three Australian mining methods investigated, namely Munmorrah, Wongawilli and Old Ben, were all rib pillar extraction methods with continuous miners and are briefly described below.

6.2.1 The Wongawilli System

The application of this method varies from colliery to colliery depending on the prevailing geological conditions. Due to the length of the rib pillars, the method resembles a shortwall face.

The layout of the system is shown in Figure 6.1 and the basic concept is as follows:

A panel is created by a secondary development consisting of 3 to 5 roads, leaving a continuous pillar of coal between the development and the previous caved area (Figure 2.1). This pillar of coal is normally between 50 m and 150 m wide and is extracted by developing and extracting 7 m wide ribs in a modified split and lift system. The pillars formed by the development are extracted as the rib extraction retreats.

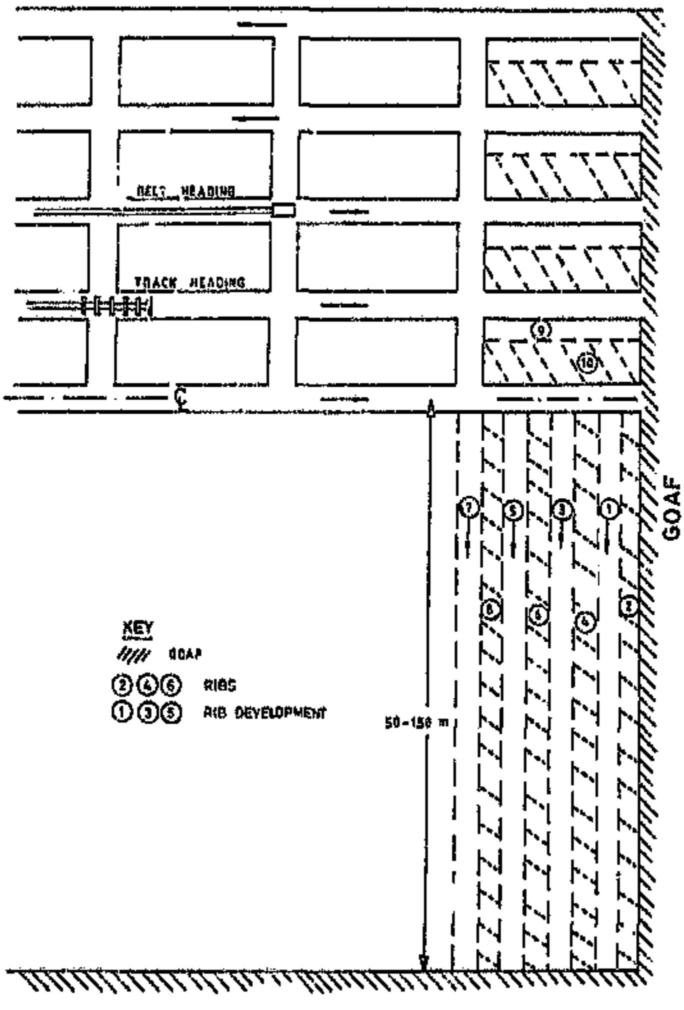


Figure 6.1 Wongawilli System of Pillar Extraction

6.2.2 The Munmorah System

The Munmorah system is also practised in New South Wales at an average depth of 180 m below the surface (Figure 6.2).

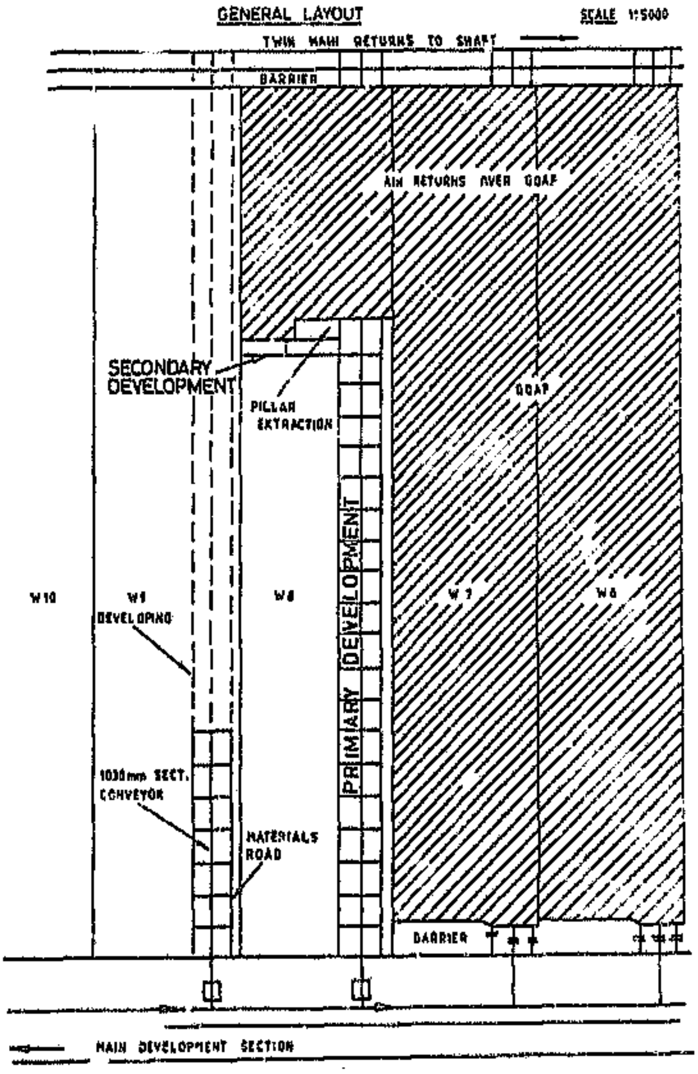


Figure 6.2 Munmorah System of Pillar Extraction

The coal seam at Munmorah Colliery is between 1,8 m and 3,0 m thick and is very hard which makes if difficult to cut with a continuous miner. The floor is composed of soft shales and floor heave often occurs due to the pillars being forced into the soft floor. The rib pillar panels are normally 1 220 m long and 183 m wide, and are developed on either side of the main development. The primary development consists of three roads. The bord width is 5,5 m and the pillar sizes are 26 m x 40 m centres (Figure 6.2).

6.2.3 The Old Ben Method

A further mining method developed was the Old Ben method (Figure 6.3) which is very similar to the Munmorrah system.

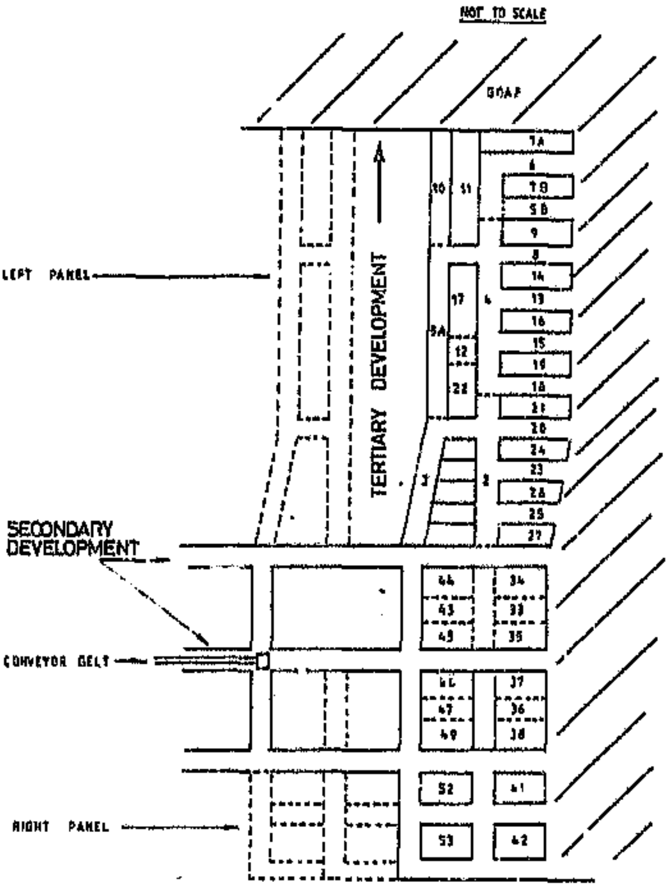


Figure 6.3 The 'Old Ben' Mining Method

The secondary development consists of three roads, leaving reserves for pillar extraction on either side. The total panel width is in excess of 200 m. Tertiary development, consisting of two roads, is developed towards the end of the panel. From this development short fenders are then developed and extracted.

The initial rib pillar extraction methods used in South Africa were based mainly on the Munmorrah system. Although the two teams from Sigma and Kriel Colliery designed their rib pillar extraction methods separately, both mining methods turned out to be very similar. As the various collieries gained experience with the mining method, however, a number of changes were made to the original method to suit local conditions and improve productivity. These changes are discussed in detail below.

6.3 Rib Pillar Panel Development

6.3.1 Primary development

The primary development is used to divide a block of coal into rib pillar panels, the length of which can be up to 1000 m or longer, and the width varying from 150 metres to approximately 220 metres.

A typical layout of the development for a rib pillar panel is depicted in Figure 6.4.

The primary development consists of three to four roadways from the main development to the limits of the panel (Figure 6.4). It is preferably perpendicular to the main development, but it can be altered to suit the geometry of the available reserves.

Because the primary and secondary development is so narrow, the full weight of the overburden is not shared equally by the pillars in the development. Salamon et al (1976) stated that if an area is larger than the area of a circle drawn with a radius 0,75 to 1,0 times the depth below surface, it can be assumed that the whole weight of the overburden is shared equally by the pillars, and consequently the pillar load can be determined from the tributary area theory. The conventional safety factor formulae are thus not valid to determine pillar sizes in the narrow rib pillar development. The geometry of the pillars are therefore designed to suit the planned mining layout with careful consideration of the local strata behaviour.

All services such as stores, the miner's box, maintenance bays, etc., are positioned in this development during the rib pillar extraction phase.

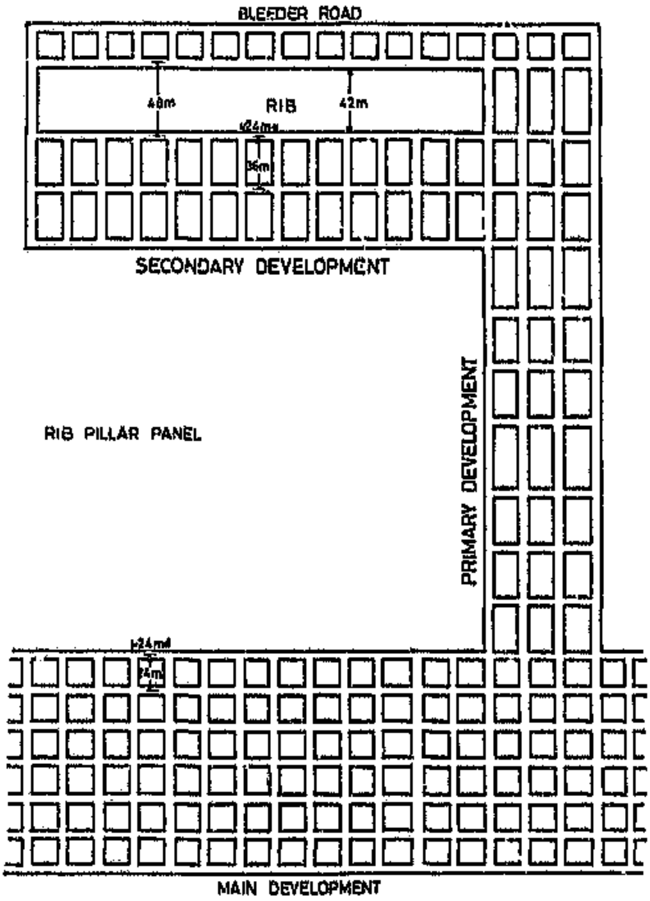


Figure 6.4 Rib Pillar Panel Layout

6.3.2 Secondary development

The secondary development is used to cut the rib pillar panel into blocks or ribs. These blocks, or ribs, are normally 42 metres wide, but one colliery is using 66 metres wide blocks.

The secondary development during the initial phases of rib pillar extraction consisted of two roads, one being an intake airway and one a return. Although Twistdraai Colliery maintained this layout, some collieries experienced a congestion of equipment and services and inadequate ventilation. At Sigma Colliery the two roads were increased to three, and at Middelbult Colliery, it was increased to four roads (Beukes, 1989a). This development is always perpendicular to the primary development (Figure 6.4).

The 6 metre wide fenders are developed and extracted, with the exception of Sigma and Middelbult Colliery, from the secondary development.

6.3.3 Bleeder roads

On the majority of the collieries, twin bleeder roads are developed (Figure 6.4). The pillars between the outside two roads of the primary development are not extracted with the panel as the outside road is used as the bleeder road for the next panel. The pillars left between these two roads are then extracted with the next panel. Twistdraai Colliery uses a single bleeder road and leaves a 6 m wide protecting pillar adjacent to this road when extracting the fenders (see Figure 6.9).

6.4 Pillar Extraction Sequence

6.4.1 The basic method

As soon as the secondary development has reached the limits of the panel, the first 6 m wide fender is developed. When this development breaks through into the bleeder road, this fender is extracted. The pillars in the secondary development is extracted on a retreat basis with this rib. The extraction sequence is shown in Figure 6.5.

When extraction has retreated to the primary development, the pillars in this development are also extracted before the secondary development for the next rib commences.

Due to the lack of suitable roofbolt equipment to install roofbolts without removing the continuous miners from the working face, the continuous miner can only develop a given distance, specified by the systematic support rules or dictated by roof conditions and behaviour, before roofbolts have to be installed. During the development of two or more roads this is not a problem as the continuous miner can be trammed to another roadway whilst the roofbolting is carried out. During fender development, however, this does not apply. In order to prevent the continuous miner from waiting until the roofbolting in the first fender development has been completed, the development of the second fender is started during this period. This results in the second fender being partially, or fully, developed before the first fender is extracted.

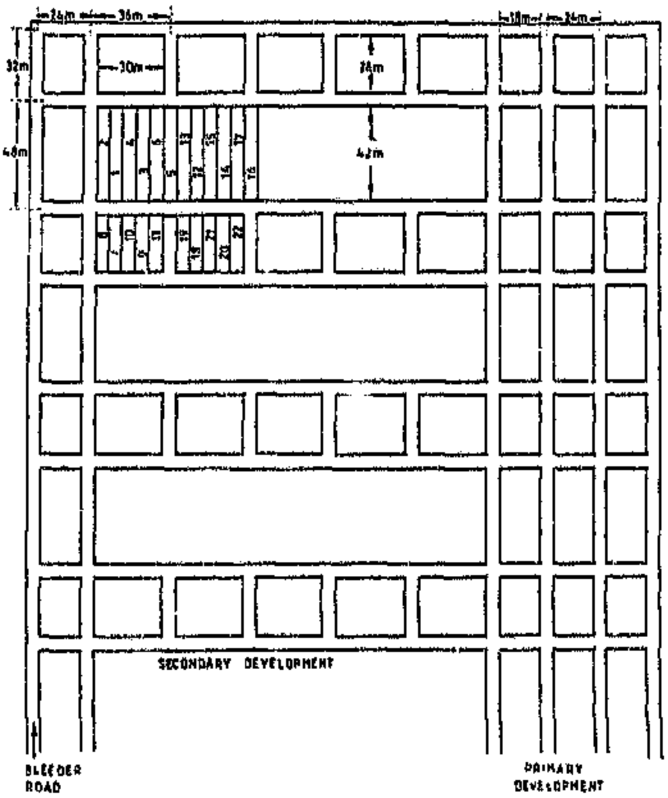


Figure 6.5 The Basic Extraction Sequence

The number of fenders that can be pre-developed safely will depend mainly on the geological conditions and behaviour of the strata, but should be restricted to the practical minimum to prevent premature failure of the fenders and possible goaf overruns. Except when the geological conditions are unfavourable, a certain amount of pre-development is necessary to augment productivity.

6.4.2 Variations to the basic method

On some of the collieries practising rib pillar extraction, a number of problems were experienced and certain changes were made to the basic extraction sequence.

(a) At Sigma Colliery the number of roads in the secondary development was increased from two to three and the pillar size was reduced from 30 m x 18 m rectangular pillars to 9 m square pillars to improve the productivity during the secondary development phase. Unfortunately these small pillars became excessively stressed and they started failing ahead of the working faces. The three road development was maintained, but they reverted back to the proved 30 m x 18 m pillars.

(b) Due to the size of the continuous miners, it is very difficult to develop the fenders perpendicular to the secondary development. Sigma Colliery theretore decided to developed the fenders at 45° to the secondary development (Figure 6.6).

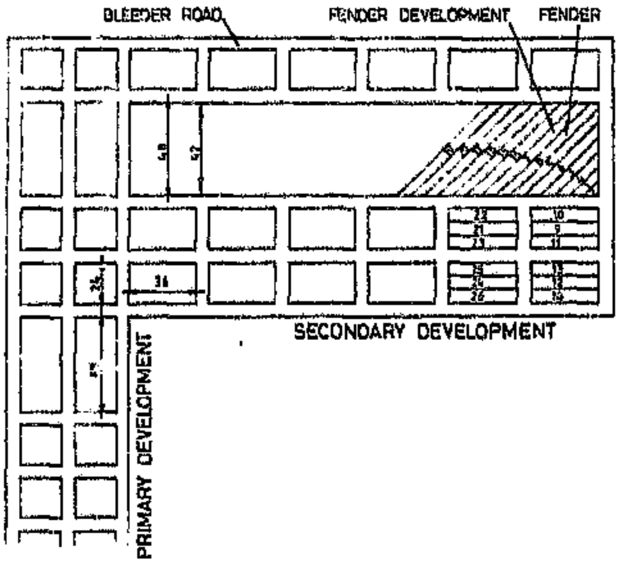


Figure 6.6 Fenders Developed at a 45° Angle at Sigma Colliery

This proved to be totally unsuccessful as the continuous miner operators found it extremely difficult to maintain the 45° direction during fender development which resulted in large fluctuations in the width of the fenders. Considerable coal reserves were lost due to the inability to extract large portions of fenders as a result of this. The mining process also changed continuously due to the triangular geometry of the first and last section of the rib pillar.

(c) Problems were also experienced with the premature failure of the 42 m long fenders at Sigma Colliery, resulting in excessive loss of reserves. A tertiary development was introduced to split the 42 m wide rib into 42 m x 18 m ribs. The fenders were then developed and extracted at right angles to the tertiary development, and are only 18 m long. In addition to this, the direction of the 36 m and 24 m axis of the pillars was turned through 90° (Figure 6.7) to allow for a uniform system of extracting both the fenders and the development pillars, and to decrease the tramming distances. As can be seen from Figure 6.7, this gave rise to a uniform method of extraction for both development- and rib pillars. It made the system and subsequently training and appli ation, much simpler.

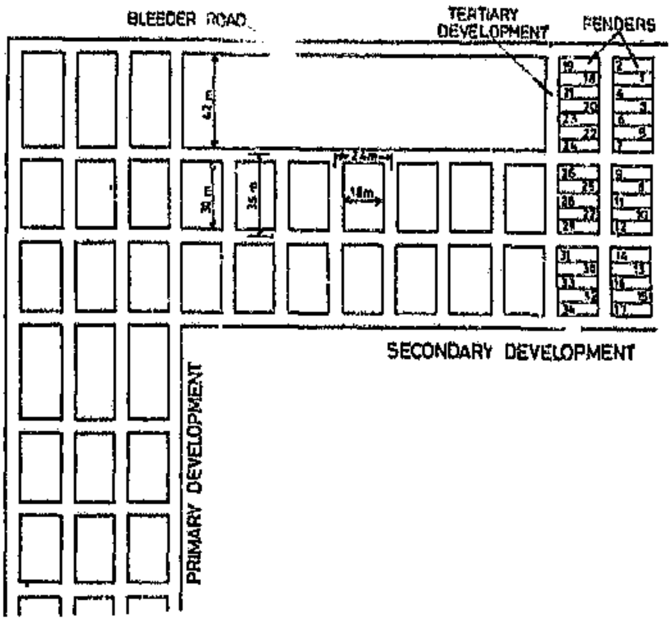


Figure 6.7 Tertiary Development used to Create 18 m Long Fenders at Sigma Colliery

(b) At Middelbult Colliery the number of roads in the secondary development was increased to four to improve the ventilation and the pumping of water. Tertiary development was also used to divide the block into 18 m wide ribs thus resulting in 18 m long fenders, similar to the layout shown in Figure 6.7.

The evolution of rib pillar extraction on these collieries is described in detail by Beukes (1989a).

6.4.3 Rib pillar extraction on an advance and retreat basis.

When doing rib pillar extraction on a retreat basis, the primary development has to be mined to the limits of the panel before secondary development and fender extraction can commence. This results in the continuous miner being confined in the lower production output development phase for a considerable period of time before starting the pillar extraction phase. Secondly, a separate primary development has to be mined for every rib pillar panel.

In order to reduce the amount of development and to start the more productive pillar extraction phase at an earlier stage, Twistdraai Colliery mined a block of coal on an advance and retreat basis.

The three-road primary development was positioned in the centre of the block of coal to be extracted and the bleeder road on the side to be mined on the advance method (Figure 6.8).

The primary development was mined to the position of the first secondary development and stopped. The first secondary development was then completed and the 42 m wide rib extracted. The pillars in the primary development were left intact and were only to be extracted in the retreat phase. In addition, a 6 m wide pillar was left adjacent to the primary roadway for protection (Figure 6.9).

This process continued until the one side of the section was completely mined out. The opposite side of the section, including the pillars in the primary development, were then mined out on the retreat. A bleeder road was created by leaving a 6 m wide rib to protect the end roads of the secondary development, and by connecting the secondary development on the retreat side with a single roadway also protected by a 6 m wide rib (Figure 6.9).

This experimental panel proved to be successful. The floor gradient must be considered carefully during planning as the unplanned inflow of water during pillar extraction can jeopardise the success of this method.

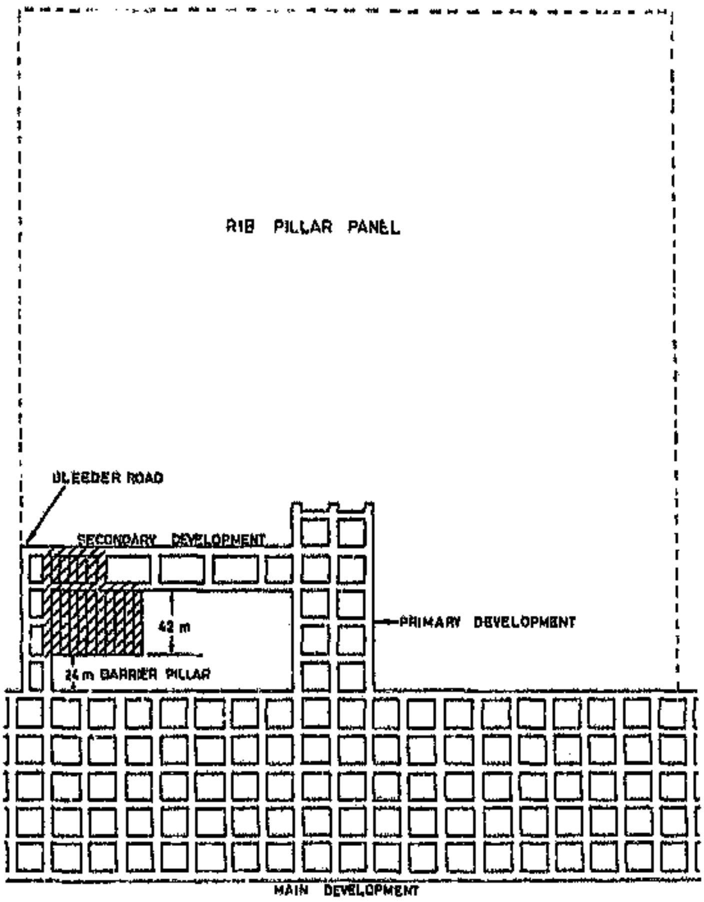


Figure 6.8 Rib Pillar Extraction on the Advance at Twistdraai Colliery

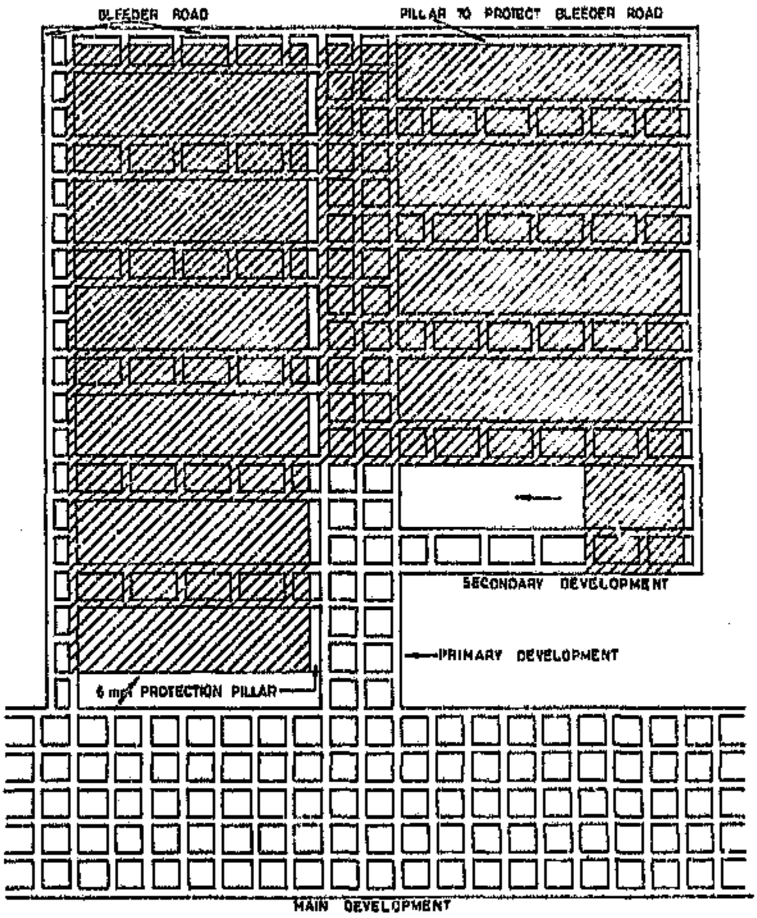


Figure 6.9 Rib Pillar Extraction on the Advance and Retreat at Twistdraai Colliery

6.5 Pillar Extraction Methods

6.5.1 Extraction of 18 m long fenders

The cutting sequence for extracting a 18 m long fender using mobile mechanical breakerlines is shown in Figure 6.10. Mechanical breakerlines 1'A' and 2 are placed in position before extraction of the fender commences. As soon as the first three cuts have been completed, mechanical breakerline 1'A' is moved to position 1'B', and the remainder of the fender is extracted. When the fender has been extracted completely, both mechanical breakerlines are moved into position for extracting the next fender.

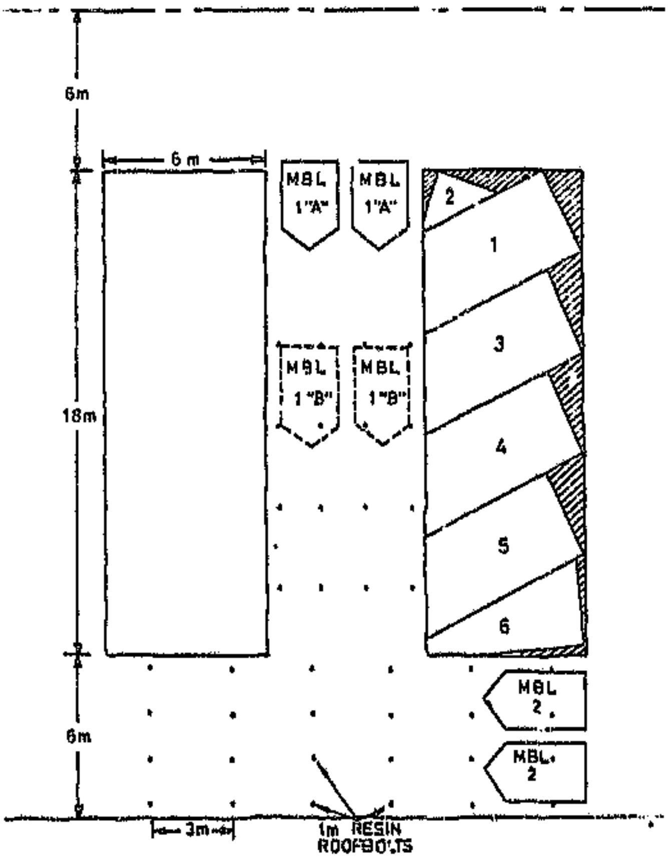


Figure 6.10 Cutting Sequence and Support - 18 m Fender

6.5.2 Extraction of 42 m long fenders

The cutting sequence for extracting the fenders is shown in Figure 6.11. Breakerlines A and B and fingerline A must be installed before extraction of the fender commences. On completion of cut 4, breakerline C is installed and breakerline B is removed by means of a sling, or chain, pulled by a full shuttle car. One timber prop is normally left intact to act as a deflection indicator. This procedure is continued until the fender has been extracted completely after which breakerline A and fingerline A are also removed.

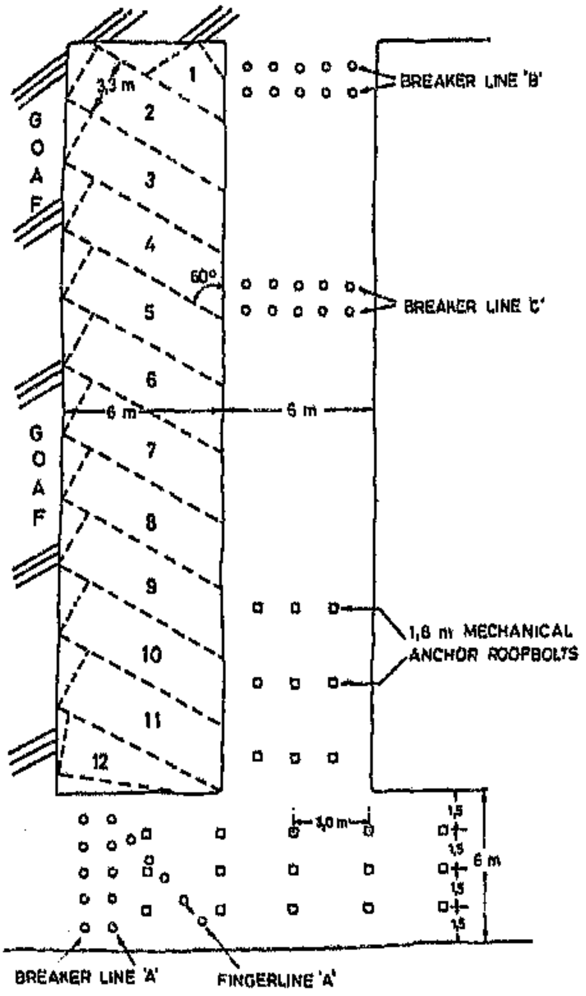


Figure 6.11 Cutting Sequence and Support - 42 m Fender

6.6 Support

In addition to the timber breakerlines described in Chapter 6, mobile mechanical breakerlines have been used at some of the Secunda Collieri. The application of these breakerlines was described in Section 6.5.1 above and depicted in Figure 6.10.

6.6.1 Mobile mechanical breakerlines

The use of mobile mechanical breakerlines (Figure 6.12), which was pioneered in South Africa, has gained ground world wide in pillar and rib pillar extraction. The mechanical breakerlines used by the Sasol mines have proved to be successful in rib pillar extraction. The main problem with these breakerlines is the high initial capital cost.

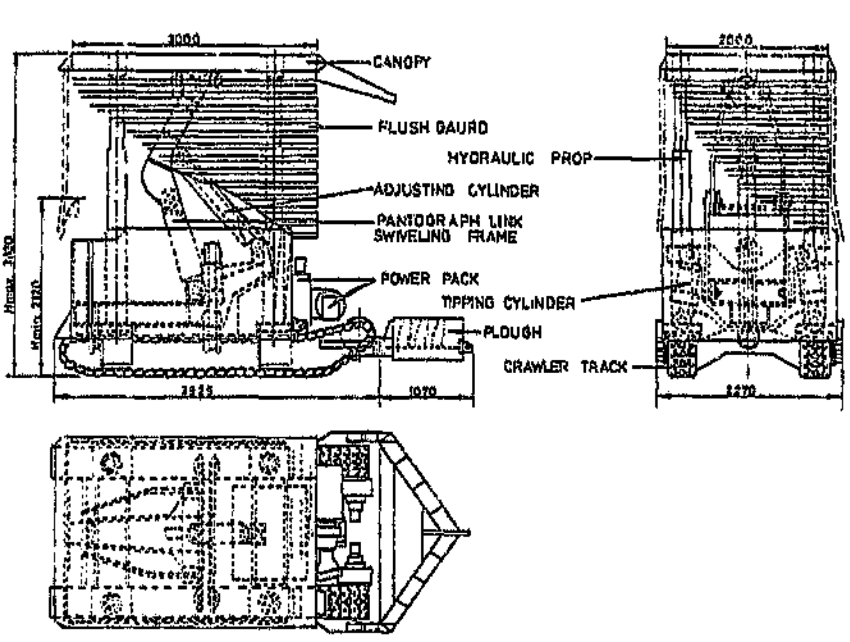


Figure 6.12 Mechanical Breakerline Support - BLS 3800/450

The main advantages of mechanical breakerlines are:

(i) The yield load of the Voest Alpine BLS 3800/450 mobile breakerline, for example, is 540 tons per unit (1080 tons per breakerline) as compared to the support resistance of between 89 tons and 308 tons for a timber breakerline.

(ii) The ease and speed of installation (moving of the units).

(iii) It shields the workers from the goaf.

(iv) It prevents large slabs from the goaf sliding into the work area.

(v) It is safer to withdraw and move forward as it can be done remotely.

6.7 Percentage Extraction

The percentage in-panel extraction achieved with rib pillar extraction is estimated by the various collieries to vary between 70 per cent and 90 per cent in comparison with the 45 per cent to 57 per cent achieved with bord and pillar mining.

6.8 Manpower

Similar to the other extraction methods, the manning of the sections on various mines differ and also depends on the type and number of equipment used. The typical operating crew in a stooping section using one continuous miner and two shuttle cars is as follows:

Operating crew :	Miner	1
	Team leader	1
	Continuous miner operator No. 1	1
	Continuous miner operator No. 2	1
	Cable handler	1
	Shuttle car operators	3
	Roofbolt operator No. 1	1
	Roofbolt operator No. 2	1
	Feederbreaker operator	1
	Support and ventilation	4
	TOTAL PER SHIFT	15

6.9 Production Equipment

A variety of equipment is used on the various mines, the number of the specific types of equipment is very similar. Two of the collieries use a double continuous miner section. The first continuous miner completes the first secondary development and on completion of the development commences with rib pillar extraction. The second continuous miner then starts the following secondary development. This enables the two continuous miners to work in tandem and they leapfrog down the panel. The equipment and manpower for such a double continuous miner will not be discussed further.

The equipment in a typical rib pillar section will be:

1 Continuous miner
3 Shuttle cars (one is normally on stand-by)
1 Roofbolter (depending on the density of support).
1 Feederbreaker

Some of the collieries also use Load Haul Dumpers to assist with cleaning in the sections.

6.10 Ventilation

Bleeder roads are developed for every panel to avoid the necessity of auxiliary ventilation during the pillar extraction phase. The fresh air supplied via the intake airways flows over the goaf thus removing the dust and creating a positive flow (Figure 6.13). It is important to maintain this positive flow over the goaf to prevent gases from entering the section.

During caving, voids are formed in the roof of the goaf which allows a flow of ventilation through the goaf area. In the event of the goaf closing completely, bifurcated fans could be used to return the air to the return airway.

During the development phase, 22 kW to 37 kW force fans are used to ventilate the headings.

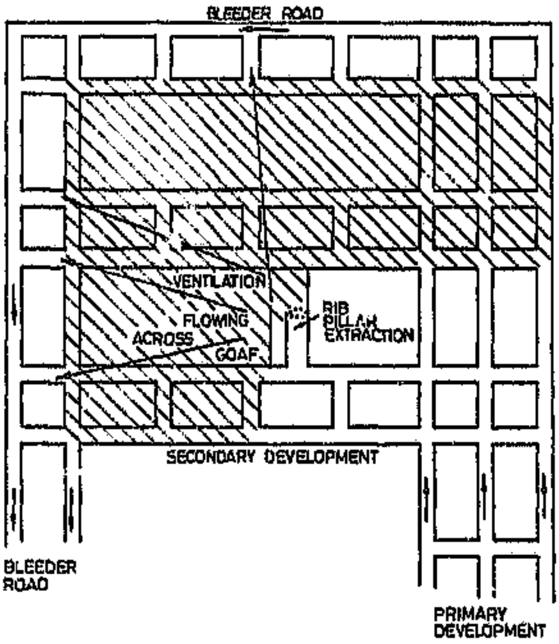


Figure 6.13 Ventilation Layout

6.11 Risk Areas

6.11.1 The final positions of fenders

It has often been observed that during goafing the roof strata do not form acute angles to match the exposed roof area, but tend to form a natural overhang and goaf along gradual curves (Figure 6.14).

This means that the final crook (B) will always be required to support a larger area of roof. This situation is aggravated by the large area of unsupported roof created by the intersection with the secondary or tertiary development.

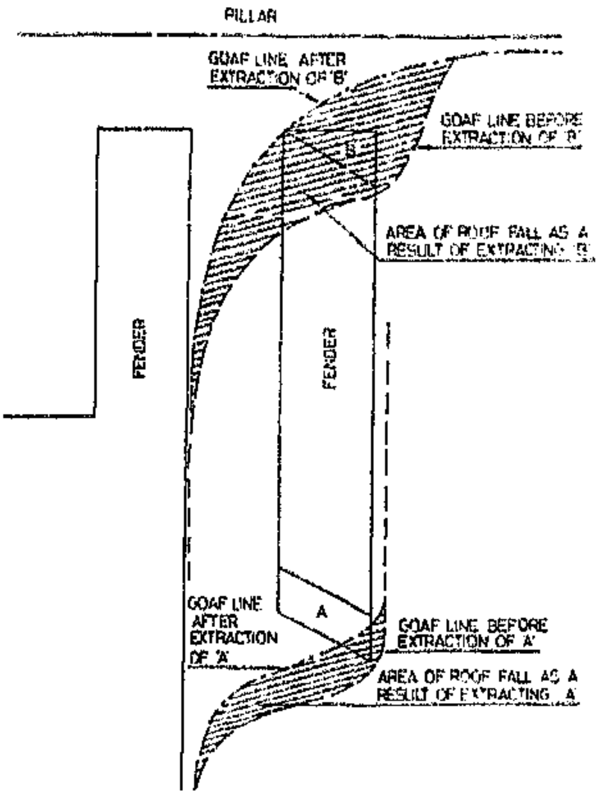


Figure 6.14 Goafing when Extracting the Final Portion of a Fende (Crous et al, 1986)

6.11.2 Gas accumulation

Each continuous miner is equipped with a methanometer which has an audiovisual alarm to warn the operator should inflammable gas be present. Continuous methanometers are normally also situated in the last through road to the return airway to monitor possible methane build-up.

6.11.3 Spontaneous combustion

The coal and carbonaceous shale, mainly from the roof strata, which remains in the goaf creates a risk of spontaneous combustion. CO monitors are installed in the return airways from the section to monitor any heating in the goaf areas.

6.12 Conclusions

Although various changes were made by different collieries, the final product turned out to be very similar. As can be seen from the analyses above, the basic strata control theories and principles were constantly applied and adhered to.

Although the composition and behaviour of the strata plays a major role in the design of rib pillar extraction, the similarities in the mining methods make it possible to formulate applicable design guidelines.

The practical experience gained by all the collieries, the research findings and the strata control principles and theories have been assessed and evaluated, and are used to to establish design guidelines for pillar and rib pillar extraction in the following chapter.

CHAPTER 7

GUIDELINES FOR PILLAR AND RIB PILLAR EXTRACTION

7.1 Introduction

The information compiled during the survey of pillar and rib pillar extraction has been assessed and the important factors to be considered when planning and operating a pillar extraction panel have been identified.

During the years that these mining methods were practised, a vast amount of experience was gained on the various collieries. Problems were experienced by various mines and they made numerous alterations to the mining methods with varied amounts of success. Due to the importance of increasing extraction, and as the application of pillar extraction practices increased, research was conducted by COMRO and by various mines and mining houses.

The problems and successes experienced by the various mines and the research conducted by COMRO, individual mines and mining houses form the basis of these guidelines. These facts are itemised in these guidelines so that improved performance and safety can result from pillar extraction operations.

The vast difference in the geological composition and behaviour of the coal bearing strata, the mining depth and mining equipment used make it difficult to design a specific set of guidelines applicable to all the collieries.

These guidelines have thus been formulated in such a way that it is not prescriptive as to the mining method, support or other relevant factors, but rather as a guide to all the factors that must be taken into consideration when designing panels for pillar and rib pillar extraction.

These guidelines must therefore be used in conjunction with information such as the local geology, strata behaviour and other relevant mining parameters, and local experience.

7.2 Designing Pillars for Pillar Extraction

Although the safety factor of the pillars is important to ensure that the pillar strength is adequate to support the overlying strata, it is only the start of the design process. Other factors that play equally important roles are the mining method to be practised, the equipment to be used and the behaviour of the local strata.

In the past the safety factor was too often the only parameter used to determine the size of the pillars and other critical factors were ignored. The behaviour of the overburden strata is possibly the most critical factor as it also affects the mining method, the type of mining [illegible] that can be used and the support required during development and pillar [illegible] critical factors affecting pillar size are depicted in Figure 7.1.

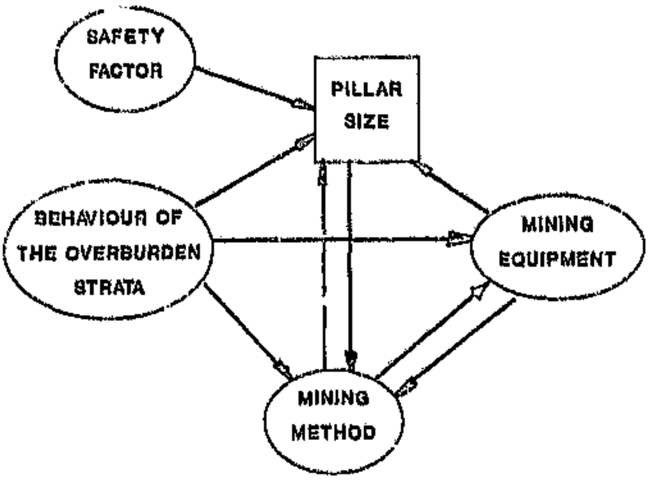


Figure 7.1 Factors Affecting Pillar Size

The mining method should be pre-determined and the pillar should be designed to accommodate this method. The type and size of the mining equipment also have a major influence on the type of mining that can be practised and the pillar dimensions required for safe and effective extraction.

Unlike the pillars in bord and pillar sections, the load on the pillars in pillar extraction sections changes constantly due to the dynamic nature of the mining process. When the coal seam is overlain by a dolerite sill or competent massive sandstone which does not break during initial goafing, the load on the pillars will be higher than after failure of the sill or sandstone. This is due to the additional load that has to be borne by the pillars in the vicinity of the goaf edge to support the overburden spanning the goaf area.

Before the safety factor for these pillars can be determined, the additional load on the pillars has to be determined. The factors that will affect the additional load are the depth below surface, the width of the panel and the composition of the overburden. The additional load may be determined by simulating the mining situation using computer simulation programs such as FLAC, MINLAY and BESOL.

The following example (Model 7.1) will be used to indicate the variation in the stresses on the pillars before and after the failure of a dolerite sill:

Model 7.1

Assume a coal seam 160 m below surface (to the roof of the seam) overlain by a 40 m thick dolerite sill. The base of the dolerite sill is 40 m above the upper contact of the coal seam. The mining height is 2,5 m, the bord width is 6 m and the pillars are 18 m square. The first subsidence on surface, and thus the first break of the dolerite sill, occurs 150 m after commencing pillar extraction, assuming that the panel is wide enough to cause the sill to break. The angle of fracture is 15 (measured from the vertical).

The linear elastic MINLAY computer program was used to simulate the mining parameters given in Model 7.1. The simulated stresses on the pillars adjacent to the goaf, before and after failure of the dolerite sill, are shown in Figure 7.2. It must be noted that the stress profile is dependent on the values of the input parameters (e.g. modulus of the coal and strata, bulking factor, size of elements, etc.) and that the failure of the pillar sides is not taken into account. The stress profile after sill failure is also affected by the mode of caving of the roof strata.

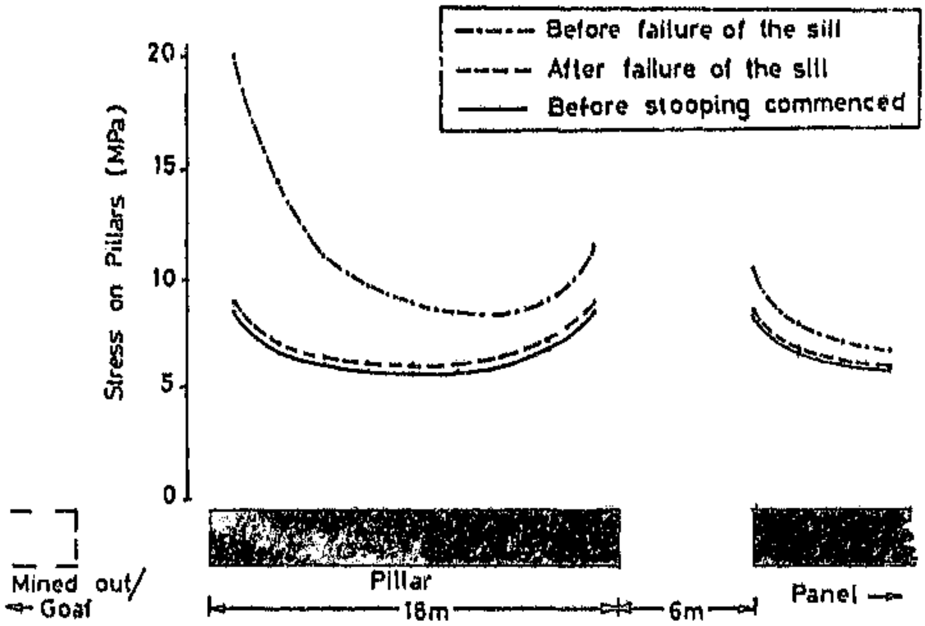


Figure 7.2 Stresses on the Pillars Before and After Failure of the Dolerite Sill

Van der Merwe, 1989, developed a concept named the Dynamic Safety Factor to determine the minimum safety factors of pillars during pillar extraction. In a paper published in November 1990 (van der Merwe, 1990), he changed the name of this concept to the Extraction Safety Factor (ESF). In order to calculate the ESF it is assumed that, in addition to the normal load, a certain percentage of the mass of the unbroken strata is borne by the pillars on the goaf edges. The geological composition of the overburden strata is used in computer simulation models to determine the total load on the pillars and the minimum ESF is determined by back analysis. If back analysis cannot be used due to the lack of suitable historical cases, an ESF limit of 1 can be assumed. Details of this concept are discussed by van der Merwe, 1989 and 1990.

Salamon and Oravecz (1976) pointed out that during pillar extraction the pillars are reduced until they reach a stage when they are "undersized" by ordinary pillar designed principles. However, the strength of rock depends, to some extent, on the duration of loading, and pillars can support loads exceeding their ultimate strength for short periods. The success of pillar extraction, and the actual value of the safety factor, therefore depends strongly on the rate of extraction. They made the following recommendations:

(i) When the rate of retreat is slow, as in handgot pillar extraction, safety factors exceeding 2,0 are recommended.

(ii) If pillar extraction is mechanized and a faster rate of retreat is achieved, a safety factor of between 1,8 and 2,0 is recommended.

(iii) When thin seams are stooped, a safety factor as low as 1,5 is permissible provided the width-height ratio of the pillars is more than ten.

Further research is necessary to determine if pillars with lower safety factors can be stooped safely and under what conditions.

7.2.1 Conventional pillar extraction

The main difference between pillar extraction with conventional equipment and that with continuous miners is that with continuous miners one pillar is extracted at a time, whereas with conventional equipment a number of pillars, often a complete row, are extracted simultaneously. This means that the size of a row, or number, of pillars is reduced according to a planned work cycle until they have been extracted completely.

Another difference between conventional and continuous miner extraction is the pillar extraction angle. The majority of the collieries employing continuous miners for pillar extraction, extract the pillars in a straight line, whereas in conventional pillar extraction the pillars are generally extracted at an angle of between 30° and 45°. The effect this has on the load borne by the pillars on the goaf edge will be discussed in the section on stooping angles (Section 7.3).

As was discussed above, the safety factor for the pillars is only the start of the design process. The other important factors such as the behaviour of the local strata, the mining method to be practised and the equipment to be used must be carefully considered during the design process.

The most common methods of conventional pillar extraction are splitting and quartering and the open end lift, but as discussed in Chapter 4, many different methods, depending on pillar size and strata conditions, are used. The pillars must be designed to accommodate the extraction method to be used.

The following factors need to be considered when determining the pillar sizes for conventional pillar extraction:

(a) The strength of the pillars must be sufficient to support the overburden in the worst possible situation (e.g. before failure of the dolerite sill). Unless the strength of the pillars and the load on the pillars can be accurately determined and the safety factor derived from this data, the recommendation of Salamon and Oravecz (1976) to use a safety factor of not less than 1,8, determined by the Salamon or squat pillar formula, is a good guideline. When the rate of retreat is slow, as in handgot pillar extraction, safety factors in excess of 2,0 are recommended.

(b) The size of the pillars should be designed to correspond with the extraction method. This is important as it will improve productivity and prevent the formation of large snooks. If the normal bord width on a colliery is 5,5 m, but the pillars in pillar extraction are designed such that it requires 4,5 m wide cuts, the productivity will be reduced as it results in less tons per blast.

(c) Unnecessarily large pillars should be avoided as it will increase the time spent in extracting the pillar thus exposing the diminishing pillar to increasing stress for too long which could lead to premature pillar failure. In addition to this it also leads to a slow retreat of the stooping line.

(d) Back-to-back lifts should be avoided as far as practically possible.

7.2.2 Pillar extraction with continuous miners

Although the safety factor of the pillars is important to ensure that the pillar strength is adequate to support the overlying strata, it is only the start of the design process. Other factors that play equally important roles are the mining method to be practised, the equipment to be used and the behaviour of the local strata.

The following example (Model 7.2) will be used to illustrate the influence of some of these factors on the pillar size:

Model 7.2

A coal seam is situated 125 m below surface and is overlain by a 40 m thick dolerite sill 25 m above the coal seam. The immediate roof consists of weak, laminated shale that goafs readily. The bord width is 6 m and the mining height is 3 m. A Joy 12HM9 continuous miner and 12 ton shuttle cars are to be used to extract the pillars. Seven road panels are to be developed and extracted. *If the safety factor is the only parameter used to design the pillars and the pillars are designed to a minimum safety factor of 1,8, it will result in 14 m square pillars.* What methods can be used to extract these pillars ?

The following factors will affect the pillar extraction method:

(i) The minimum panel width necessary to cause the dolerite sill to fail is 191 m (calculated with Galvin's formula). As the planned panels are only 126 m wide, the dolerite sill will only fail when the second (adjacent) panel is extracted, provided the barrier pillar is removed.

(ii) The size of the 12HM9 continuous miner and 12 ton shuttle cars is such that a split of at least 6 m wide is required for the split and fender method (see Figure 7.4).

(iii) As the immediate roof consists of a weak shale, the initial goaf is likely to occur as sections of the pillar are extracted rather than on completion of the whole pillar. The extraction method and placing of the breakerlines must take this into consideration.

There are numerous possible methods for extracting these pillars. For practical reasons only two of these will be used to illustrate this example. Figure 7.3 shows two possible methods of extracting these pillars.

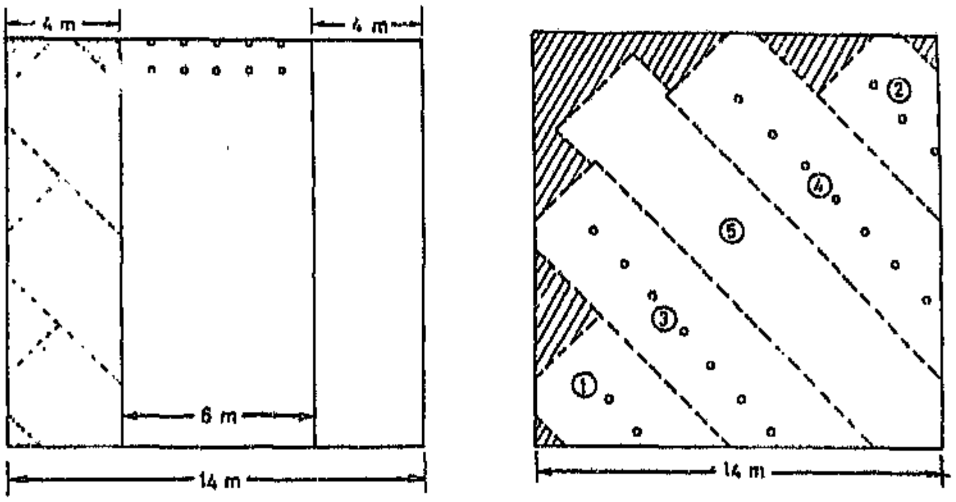
Method 1

Figure 7.3(a) depicts the situation if the pillar is split into two 4,0 m wide fenders by a 6 m wide development through the centre. The following problem will arise from this extraction method:

The 4,0 m wide fenders could be very unstable under these circumstances. These fenders are equivalent to a 6,2 m square pillar as indicated by:

$$W_{eff} = \frac{4(W \times L)}{2(W + L)} \qquad (8)$$

$$= 6,2m$$



(a) (b)

Figure 7.3 Extraction of 14 m Pillars (Example only)

This means that the strength of these fenders is equal to that of a 6,2 m square pillar which has a safety factor of only 0,67 and a width to height ratio of only 1,3 (based on the minimum pillar dimension). This situation is aggravated further by the additional stress on the pillars because of the dolerite sill spanning the goaf. It is therefore very likely that these fenders will fail prematurely.

Method 2

Figure 7.3(b) depicts another possible method for extracting the pillars. Variations of this method are used by some collieries that have a competent sandstone roof and a mining height of approximately 1,5 m. However, taking into account the conditions in Model 7.2, the following problems will arise:

Due to the weak, laminated shale roof that goafs readily and the mining height of 3 m, it is unlikely that the fingerlines installed after cuts 1 and 2 will prevent the roof from goafing until after cut 5 has been completed. If goafing occurs after cut 3, the goaf could extend into the intersection and prevent the extraction of cuts 4 and 5.

The above examples illustrate the dangers of using only the safety factor to determine pillar size, ignoring the other critical factors such as the behaviour of the overlying strata, the type of mining equipment to be used and the method of extraction. Alternative approaches should thus be considered taking these factors into account.

One such alternative is to change the pillar dimensions by creating 18 m x 12 m rectangular pillars. The effective width of these pillars is 14,4, resulting in a safety factor of 1,9, and the minimum width to height ratio is 4. If these pillars are split by a 6 m wide development it will result in two 6 m wide fenders (see Figure 7.4).

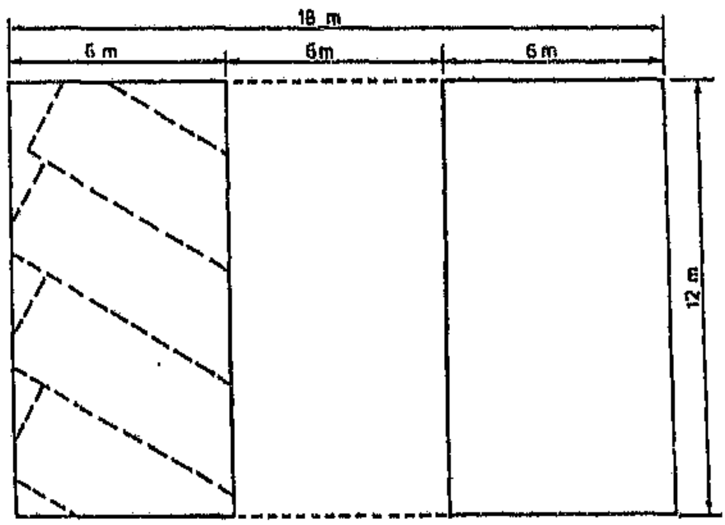


Figure 7.4 Possible Extraction Method for a 18 m x 12 m Pillar

The safety factor of these fenders is 0,95 and the width to height ratio is 2. It is evident that these fenders will be more stable than those depicted in Figure 7.3(a) and could be extracted effectively and safely. A disadvantage of increasing the pillar size is that the percentage in-panel extraction during the development phase will decrease. With this pillar size, however, the primary percentage extraction will be reduced by only one per cent. The panel width will be increased to 150 m which is still insufficient to induce sill failure.

The following factors should be carefully considered when designing pillars for pillar extraction with continuous miners:

(a) The strength of the pillars must be sufficient to support the overburden in the worst possible situation (e.g. before failure of the dolerite sill). Unless the strength of the pillars and the load on the pillars can be accurately determined and the safety factor derived from this data, the recommendation of Salamon and Oravecz to use a safety factor of not less than 1,8, determined by the Salamon or squat pillar formula, is a good guideline.

(b) The development adjacent to and through the pillar should be wide enough to accommodate the existing mining equipment. If the roads are too narrow much time is wasted in aligning and tramming the equipment during the extraction phase.

The number of road headers used in pillar extraction is on the increase and the width and length of these machines, as with some continuous miners, makes it difficult to turn off splits at right angles. In order to decrease the time spent on splitting pillars at right angles, consideration should be given to splitting the pillars at an angle. An example of splitting a 18 m square pillar at a 70° angle is illustrated in Figure 7.5.

When pillars are split on an angle, it is important to ensure that the remainder of the pillars being extracted is of adequate size to prevent them failing prematurely during the pillar extraction process. Strict control should also be exercised to ensure that the development is turned off at the correct angle and position.

(c) The extraction method should require the minimum continuous miner tramming as tramming reduces the actual production time.

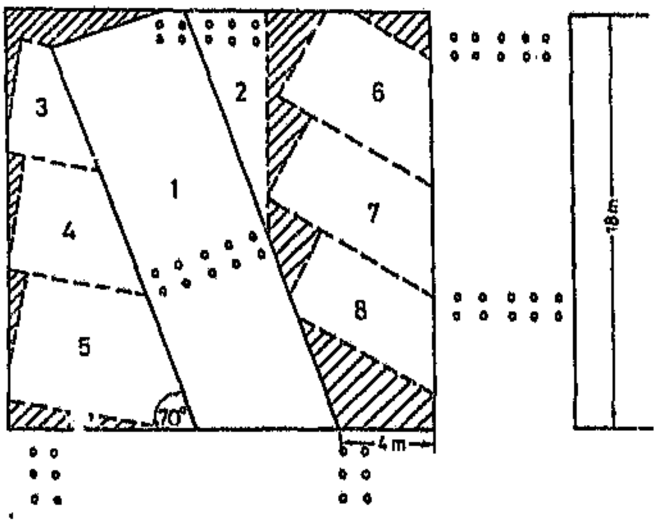


Figure 7.5 Splitting a Pillar on a 70° Angle

(d) The extraction method should require the minimum of breaker and fingerlines as these are not only costly, but the installation thereof is time consuming which could result in production time being lost.

(e) If a pillar is split into fenders, these fenders should be wide enough to withstand the load for the duration of the extraction, but narrow enough to avoid the formation of excessive snooks. It must be noted that, when a pillar is split into fenders, the bulk of the strength of the pillar is removed as the strongest portion of a pillar is seated in the centre.

(f) The pillars should not be designed unnecessarily large so that individual pillars can be extracted in the shortest possible time, thus exposing the diminishing pillar to high loads for the shortest possible period, and allowing for a fast retreat of the stooping line.

(g) The extraction method should be such that the minimum amount of coal is left behind in the form of snooks (pillar remnants). Snooks not only lead to a loss in reserves, but they may prevent the overlying strata from failing properly thus causing unnecessary stress on the pillars to be extracted.

(h) Back-to-back lifts should be avoided as far as practically possible.

7.2.3 Rib pillar extraction

The safety factor formulae are not suitable for determining pillar sizes in the primary and secondary rib pillar development consisting of only two to four roadways. This is due to the fact that the width of the section is so small that the full cover load is not supported by the pillars. The pillar load is therefore distorted and the safety factor is invalid. A panel width at least equal to the mining depth is necessary to cause equal distribution of the cover load on the pillars. It is thus important that local experience of the strata behaviour be carefully considered when designing the pillars. It is recommended that the pillars be designed such that, wherever possible, the extraction method used for extracting the fenders could also be used for extracting these pillars. This could prove to be more productive and it requires less training. Figure 7.6 depicts an example of such a design.

The geology and behaviour of the overburden strata plays a major role in the design of the length and width of the fenders in rib pillar extraction.

A number of factors must be taken into consideration during the rib pillar extraction design:

(a) The fenders should be wide enough to prevent premature failure, but narrow enough to enable the continuous miner to cut through it without exposing the continuous miner driver to unsupported roof. Depending on the equipment being used, the width normally varies between 6 m and 7 m, the most common being 6 m. In Australia fenders of up to 8 m wide are extracted, and one mine in the USA increased the width of the fenders to 10 m to reduce the amount of fender development required. However, the effectiveness of this method could not be verified. At Hlobane Colliery 10 m wide fenders are extracted in the Wilcox sections using a form of rib pillar extraction.

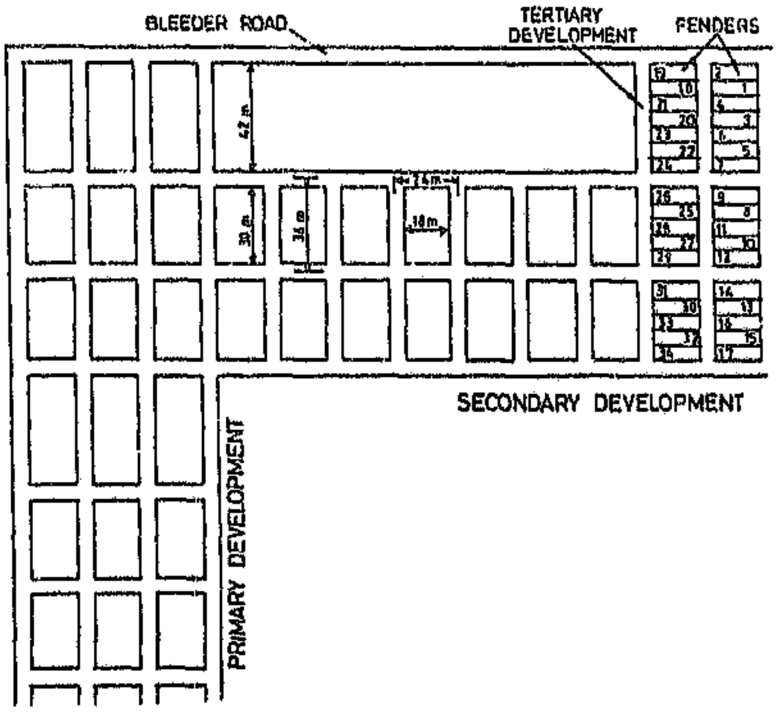


Figure 7.6 Example of a Rib Pillar Extraction Layout

(b) The length of the fenders can vary considerably from one colliery to another and depends largely on the behaviour of the overburden strata, the mining height and the strength of the coal. The length of the fenders should be such that they can be extracted before premature failure can occur. Fenders must be completely extracted during the last shift before a weekend or any other break in production.

(c) Long fenders require long fender developments. This normally results in a fluctuation in production output as the production during fender development is significantly lower than during fender extraction. This is not only due to the installation of roofbolt support, but also to the easier cutting conditions during fender extraction as the fenders are subjected to higher stresses which pre-fractures the coal.

(d) Fenders should be developed at right angles to the secondary or tertiary development as it is easier for direction control. If the fenders are developed at an angle to the development, it is more difficult to implement direction control and the width of the longer fenders could fluctuate.

7.3 Designing Panels for Pillar and Rib Pillar Extraction

7.3.1 Designing panels for pillar extraction

When a reserve area is overlain by a dolerite sill or a competent massive sandstone, it is important to determine beforehand if the panels are to be designed wide enough to allow the overburden rock mass to fracture through to surface or narrow enough to prevent it from failing. Under normal circumstances a panel would be designed wide enough to induce failure, but under certain conditions, such as a need for surface protection, it may be necessary to prevent the overlying strata from failing thus minimising surface subsidence.

In some coal reserves however, the panel width required to facilitate failure of the overburden strata can be of such dimensions that it could decrease productivity if mined as a single panel or it would result in too many pillars per row to be extracted effectively. In such cases it may be necessary to mine the area with two adjacent panels and extract the interpanel pillar. The following example (Model 7.3) should illustrate this:

Model 7.3

A coal seam 180 m below surface (to the base of the seam) is overlain by a 60 m thick dolerite sill which occurs 30 m below surface. Continuous miners are to be used for both the development and pillar extraction phases and the mining height is 2,5 m, the bord width is 6 m and the pillar size is 18 m.

Safety Factor = 1,86 (using the normal formula).

Safety Factor = 2,03 (using the squat pillar formula).

The panel width necessary to induce sill failure = 228 m.

According to this information the pillar sizes conform to the requirements of the safety factors. However, to create a 228 m wide panel would require 11 roads. This could be an unproductive section during the development phase due to the long tramming distances, unless it is developed as a double header section. In addition to this, extracting 10 pillars per line would slow down the rate of extraction considerably and could result in large pressure increases on the last row of pillars.

If this area is extracted by using two panels, either two 6 road panels or a 6 road and a 5 road panel, as well as the barrier pillar, the rate of extraction will increase considerably.

The COMSIM computer simulation program was used to simulate the potential production, for the parameters in Model 7.3, in a 11 road panel versus the production in a 5 and 6 road panel during the initial development and during pillar extraction using one 12HM9 continuous miner and two 10 ton shuttle cars. The simulations are based on three eight hour shifts per 24 hours, a machine availability of 80% and a continuous miner cutting rate of 5 tons per minute.

The potential production during the development of a 5, 6 and 11 road section is shown in Table 7.1, and Table 7.2 shows the production potential of a 6 and 11 road section during pillar extraction.

Table 7.1 Productivity During Development

Number of headings	11	6	5
Tons per shift	1271	1321	1370
Tons per face minute	3,31	3,44	3,57
Cont. miner utilization:			
Cutting %	66,2	68,8	71,4
Shuttle car utilization:			
Load & discharge %	49,9	51,9	[illegible]
Travelling %	19,3	15,3	14,8
Shuttle cars:			
Total route dist.(km) (for two rows of pillars)	308	[illegible]	104
Tons/km travelled	64,3	[illegible]	82,9

Table 7.2 Productivity During Pillar Extraction

Number of headings	11	6
Tons per shift	1257	1375
Tons per face minute	3,27	3,58
Cont. miner utilization:		
Cutting %	65,5	71,6
Shuttle car utilization:		
Load & discharge %	49,1	53,7
Travelling %	39,1	32,4
Shuttle cars:		
Total route dist.(km)	531	212
(for two rows of pillars)		
Tons/km travelled	38,4	48,2

At the above production rates it will require 4,4 shifts to extract a row of pillars in a 6 road panel and 9,7 shifts (more than three days) to extract a row of pillars in a 11 road panel.

If a third shuttle car is added to the 11 road section during development, the potential production improves only marginally to 1285 tons/shift or 3,34 tons/face minute.

If this area is extracted with two narrow panels (i.e. 5 or 6 roads) instead of one wide panel, it is very important to note that when the pillars in the second panel and the interpanel pillar are extracted, the first sill failure will occur when extraction has progressed for a distance approximately equal to the depth below surface. This failure to the surface will include the overburden strata spanning both panels and could result in an air blast due to the sudden displacement of the large volume of air. In addition to this, the goaf may overrun breakerlines or even partially extracted pillars. This was actually experienced on two collieries, using continuous miners, in the Highveld Coalfield. It is thus of great importance that, when the critical span is reached, breakerlines are properly installed (in some cases a breakerline with three rows of props instead of the normal two may be necessary), pillars are not pre-split or left partially extracted between shifts and the operating crews are kept aware of the situation. It will be appreciated that the above comment is even more critical when conventional pillar extraction is practised as a number of pillars are being extracted simultaneously.

If it is practically possible, extraction of the second panel could start when the extraction in the first panel has progressed for approximately 50 m. Extracting the two panels in this manner will reduce the stress increases on the interpanel pillar and the pillars in the second panel.

The following factors should be considered when designing panels for pillar extraction with continuous miners:

(a) The critical panel width, based on the superincumbent strata, necessary to induce caving to the surface must be determined.

(b) In the case of competent overburden strata, it must be decided if the panel should be wide enough to induce failure of the overburden strata or if the surface subsidence should be kept to the practical minimum for the protection of surface structures.

It must be pointed out that if the superincumbent strata consists of weak, incompetent strata, the panel width necessary to prevent surface subsidence is so small that it makes total extraction both unrealistic and uneconomical. Under such conditions partial extraction can be considered (Salamon, 1990). This can be achieved by either extracting a narrow rib pillar panel adjacent to bord and pillar development (Figure 7.7), or by extracting alternate rows of pillars (Figure 7.8), as practised by Gretley, Munmorah and Newvale No.2 Collieries in Australia, provided the remaining pillars are strong enough to support the spanning overburden.

(c) If adjacent panels are necessary to induce overburden strata failure, the barrier or interpanel pillars between such panels must be designed of sufficient strength to support the overburden strata and to prevent a goaf overrun during the extraction of the second panel. The interpanel pillar should then be extracted with the second panel.

It must be noted that the extraction of several adjacent, subcritical panels will result in additional load on the interpanel or barrier pillars as well as the pillars in the adjacent panels. It is important to determine the stress situation in such a mining layout prior to mining to prevent unsafe working conditions and loss of reserves due to high stresses.

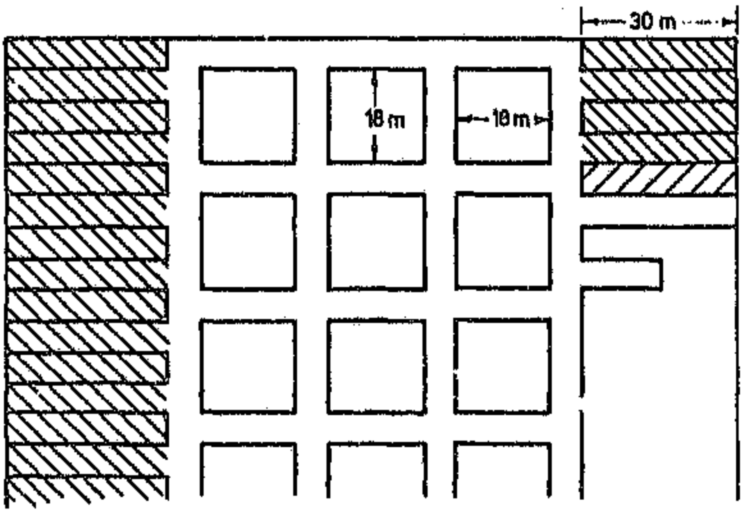


Figure 7.7 Partial Extraction Using Rib Pillar Extraction

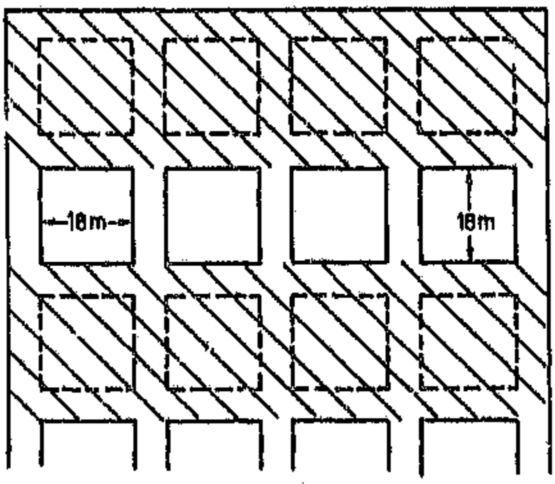


Figure 7.8 Extracting Every Alternate Row of Pillars

(d) The number of roads per panel, and thus the number of pillars per row, should be small enough to allow a fast retreat during pillar extraction taking the productivity during the development phase into account.

(e) In the case of a 45° stooping line, the panel width and number of pillars per row has a major effect on the tramming distances and production. The tramming routes and distances must be determined in detail before the panel layout is finalised. The COMSIM simulation program can be used to assist with the layouts and to compare the productivity of alternative layouts.

The details in Model 7.3 were simulated using COMSIM to determine the potential production for an 11 road and 6 road pillar extraction panel on a 45° stooping line. The results of the simulations, based on one 12HM9 continuous miner and two 10 ton shuttle cars, are shown in Table 7.3.

Table 7.3 Productivity of a 45 ° Stooping Line Panel

Number of headings	11	6
Tons per shift	998	1349
Tons per face minute	2,60	3,51
Cont. miner utilization:		
Cutting %	52,0	70,3
Shuttle car utilization:		
Load & discharge %	39,0	52,7
Travelling %	51,2	29,1
Shuttle cars:		
Total route dist.(km) (for two rows of pillars)	422	98
Tons/km travelled	24,2	51,9

As can be seen from these figures the distance travelled by the shuttle cars in an 11 road panel is more than four times longer than in a 6 road panel and the production potential is approximately 26% less.

(f) If a panel is not planned to be stooped immediately after the development has been completed, the primary support must be adequate to prevent bord failure until pillar extraction commences. In certain cases additional support may be necessary once pillar extraction commences. If excessive scaling of the pillars is experienced under normal circumstances, allowance should be made for this in the primary support, bord width, pillar dimensions and cleaning time required before pillar extraction can commence. The spalled coal should only be cleaned where it restricts operations as it assists in preventing further deterioration of the pillars.

(g) If pillar extraction panels are planned on both sides of a main development that needs to be protected, care should be taken that the strength of the barrier pillar as well as the pillars in the main development is sufficient to support the spanning overburden strata.

(h) The ventilation layout also plays an important role in the design of pillar extraction panels and the environmental personnel should design the ventilation layout and requirements for each panel during the planning process. Good control over ventilation standards is required due to the effects of goafing and possible damage of ventilation walls by roof pressure or floor heave.

7.3.2 Designing panels for rib pillar extraction

The critical panel width, based on the superincumbent strata, necessary to induce caving to the surface must be determined for the rib pillar panels.

The second, and even more critical, factor to determine, is the width of panel that can be extracted without restricting the positive ventilation flow across the goaf.

If a panel is too narrow to induce caving to the surface, it is very important to note that when the second panel is extracted, the first sill failure will occur when extraction has progressed for a distance approximately equal to the depth below surface. This failure to the surface will include the overburden strata spanning both panels and could result in an air blast due to the sudden displacement of the large volume of air. In addition to this, the goaf may overrun breakerlines or even partially extracted fenders. This was actually experienced with rib pillar extraction on two collieries in the Highveld Coalfield.

7.4 Stooping Angle

7.4.1 Pillar extraction with continuous miners

The angle at which pillar extraction with continuous miners is practised will depend largely on the behaviour of the local strata and may differ from mine to mine. Although the majority of the collieries extract pillars in a straight line, some collieries find it necessary to do so at an angle of 45°.

The first pillar extraction panel at Sigma Colliery was started at a 45° angle, but the pressures on the lagging pillars became so high that premature fender and bord failure occurred and this method had to be abandoned. The pillars were then stooped in a straight line which proved to be successful (Beukes, 1989). This is also the method followed by nine of the twelve collieries using continuous miners in pillar extraction.

The reason why pillars can also be extracted in a straight line when using continuous miners is that only one pillar is extracted at a time. The pillar being extracted is thus partially protected by the adjacent pillars (Figure 7.9). As can be seen from Figure 7.9, the pillar being extracted is partially protected by pillars 1 and 2.

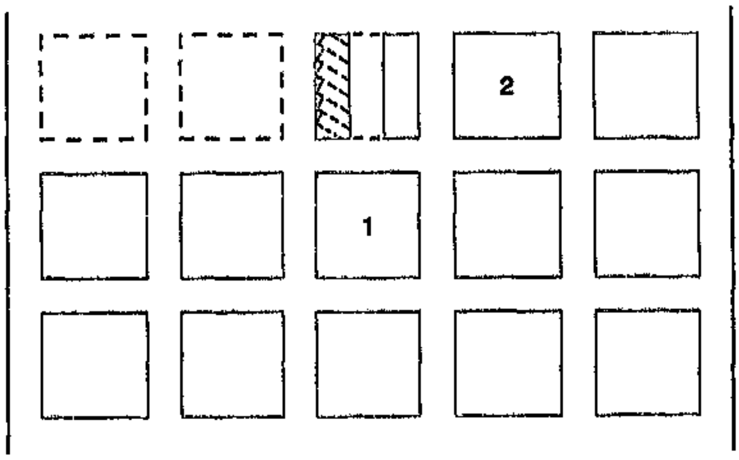


Figure 7.9 Extracting Pillars in a Straight Line Using Continuous Miners

At Greenside Colliery, Usutu Colliery and Ermelo Mines straight line pillar extraction resulted in high stresses on the pillars adjacent to the goaf. This resulted in severe scaling in the roadways and difficulties were experienced when removing the last pillars in the line. It was thus decided to change to a 45° extraction line to overcome these problems. The main difference between these three collieries and the other collieries extracting pillars in a straight line with continuous miners, is the number of roads per panel. The number of roads on these three collieries varied between 11 and 13 in comparison with the 5 to 7 roads on the other collieries. The larger the number of roads, the slower the retreat during pillar extraction. The slower retreat can result in the pillars adjacent to the goaf being exposed to the higher stress for prolonged periods, causing pillar and bord deterioration. Greenside Colliery and Usutu Colliery are still using this sequence.

At Ermelo Mines, however, the 45° line across the 11 to 13 road panels resulted in such long tramming distances that the stooping angle was changed to a short 45° line consisting of two to four rows of pillars (Chapter 5, Figure 5.2) and in adverse geological conditions to a 30° stooping line (Chapter 5, Figure 5.3). These proved to be successful and are still being used. These methods are discussed in detail in Chapter 5.

At Zululand Anthracite Colliery the pillars are normally extracted in a straight line, but a 45° stooping line is sometimes followed in adverse geological conditions or when the panel geometries are distorted due to faulting.

These examples should indicate that when using continuous miners there is no right or wrong angle. The angle of extraction depends mainly on the behaviour of the local strata, while factors such as panel width and speed of extraction also play an important role.

7.4.2 Conventional pillar extraction

As mentioned previously, whereas one pillar at a time is extracted with continuous miners, a number or row of pillars is extracted simultaneously in conventional pillar extraction. If these pillars are extracted in a straight line, the full load of the overburden strata would rest on these diminishing pillars as they are adjacent to the goaf. The other pillars would thus not be able to offer any protection (Figure 7.10).

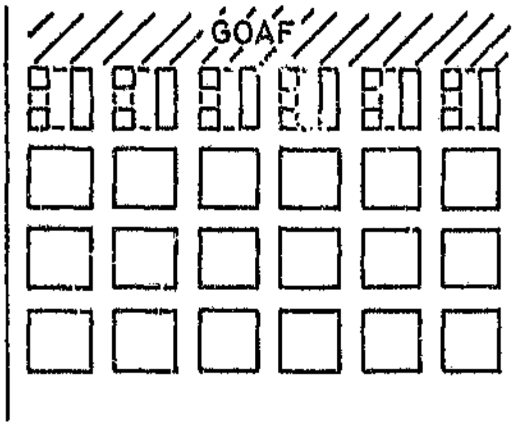


Figure 7.10 Conventional Pillar Extraction - Straight Line

It is for this reason that conventional pillar extraction is generally done at an angle. The majority of the collieries use a 45° stooping line. The reason why an angled stooping line is used in conventional pillar extraction is that every pillar being stooped is partially protected by at least two other solid pillars (Figure 7.11).

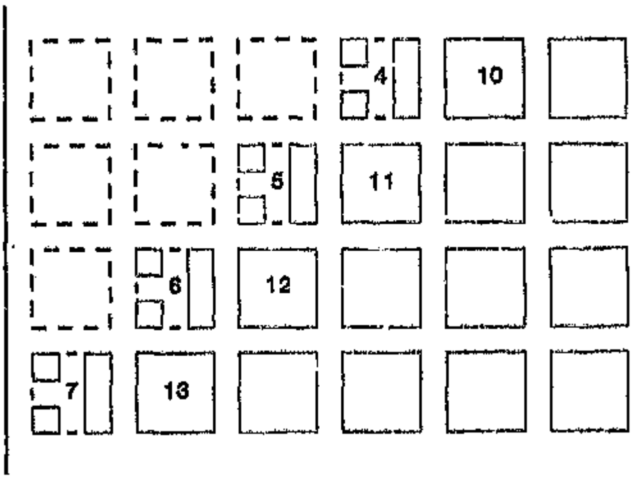


Figure 7.11 Protection of Pillars on a 45° Stooping Line

As can be seen from Figure 11, Pillar 7 is protected by the barrier pillar and pillar 13, pillar 6 is partially protected by pillars 12 and 13, pillar 5 is partially protected by pillars 11 and 12, etc. This configuration offers much more protection than the configuration shown in Figure 7.10.

In addition to this, the goaf formation is such that the stre:ses are distributed to the other pillars instead of resting entirely on the pillars being extracted due to the ability of strata to bridge between intact pillars.

At Vryheid Coronation Colliery and Welgedacht Exploration, the use of the 45° stooping line was not successful, and the stooping line was changed to 30°. In the western area of the Vrede Section at Vryheid Coronation Colliery, the weak roof strata resulted in unstable working conditions with the 45° stooping line. These problems were significantly reduced by extracting every second pilla . This gave rise to the 30° stooping line at Vryheid Coronation Colliery (Chapter 4, Figure 4.11) At the Utrecht Section of Welgedacht Exploration floor heave was experienced with the 45° stooping line and the angle was also changed to 30° by extracting two adjacent pillars, similar to the handgot method depicted in Chapter 4, Figure 4.2.

Savmore Colliery constitutes one of the exceptions in conventional pillar extraction as a complete row of pillars is extracted in a straight line across the panel (Chapter 4, Figure 4.13). This is possibly as a result of the very competent sandstone roof coupled with the extraction method of pillar splitting with fender destruction. In all the methods mentioned above, a complete row of pillars is extracted at a time.

Another exception to the 45° stooping line occurs at Vryheid Coronation Colliery and Hlobane Colliery. At these two collieries the occurrence of floor heave necessitates that the pillars are extracted in a straight line (Chapter 4, Section 4.2.4 (i))

At Hlobane Colliery and Alpha Anthracite Colliery an arrowhead configuration is used (Chapter 4, Figure 4.12). This pillar extraction configuration, however, is not recommended due to the high stresses on the lagging pillars and should be avoided as far as practically possible.

A number of two and three dimensional computer simulation programs are available to simulate the stresses on the pillars for various mining layouts. When designing pillar extraction panels, it is recommended that strata control engineers use one of the available computer programs to simulate the alternative layouts in order to determine the most suitable pillar extraction layout. An example of one such simulation is shown in Figure 7.2.

7.5 Complete Extraction of Pillars

It is very important that pillars be extracted as completely as possible. The lower the mining height, the more critical this becomes. The support resistance of small snooks is often much higher than anticipated and is responsible for load transfer onto adjacent fenders and pillars as it can prevent large areas from goafing in the short term.

In the case of a strong overburden stratum, such as a massive sandstone, snooks could prevent the stratum from failing thus causing additional load to be transferred to the remaining pillars. This can result in premature pillar or fender failure, or in the failure of a large area of roof strata which could result in the goaf overrunning the breakerlines and fenders.

In the case of relatively weak roof strata, such as shales and mudstones, the temporary support provided by the snooks could prevent the roof from failing at the breakerlines. In such cases failure often occurs adjacent to the next solid abutment which are the fenders or pillars being extracted.

In addition to the safety aspects, the more snooks that are left behind in the goaf, the lower the percentage extraction. Small alterations in the design and mining method often lead to considerable increases in the quantity of coal that can be extracted.

A number of factors relating to snooks must be taken into account when designing the extraction method:

(a) The size of the pillars and the development method practised should be such that the minimum amount of snooks of the smallest possible size are created.

(b) When the creation of snooks is unavoidable, and they cannot be extracted safely, they should be destroyed if at all possible. The lower the mining height, the more important this is. This does not apply to small snooks that crush readily and do not affect goafing.

Even if snooks are small enough to fail after a period of time, they can offer sufficient support resistance in the short term to cause stress transfer onto the pillars being extracted. Failed snooks can be compressed and can offer effective support resistance even in the long term.

7.6 Pre-splitting of Pillars and Pre-development of Fenders

As a number of pillars are extracted simultaneously during conventional pillar extraction, this applies mainly to rib pillar extraction and pillar extraction with continuous miners.

7.6.1 Rib Pillar Extraction

The number of fenders that can be pre-developed safely will depend mainly on the geological conditions and behaviour of the strata, but should be restricted to the practical minimum. Except when the geological conditions are unfavourable, a certain amount of pre-development is necessary to improve productivity.

Due to the lack of suitable roofbolt equipment to install roofbolts without removing the continuous miners from the working face, the continuous miner can only develop a given distance, specified by the systematic support rules or dictated by roof conditions and behaviour, before roofbolts have to be installed. During the development of two or more roads this is not a problem as the continuous miner can be trammed to another roadway whilst the roofbolting is carried out. During fender development, however, this does not apply. In order to prevent the continuous miner from waiting until the roofbolting in the first fender development has been completed, the development of the second fender is started during this period. This results in the second fender being partially, or fully, developed before the first fender is extracted.

As the rate of production during fender extraction is much higher than during fender development, a number of fenders are often developed in advance. This gives rise to very high production rates during the extraction of these fenders. However, it leads to large fluctuations in the production output between the fender development and extraction phases. It must be stressed again that the pre-development of fenders should be restricted to the practical minimum to prevent premature failure of the fenders and possible goaf overruns.

7.6.2 Pillar Extraction with Continuous Miners

When systematic support has to be installed during pillar splitting, it is often necessary to start splitting a second pillar during roofbolt installation in the first pillar.

This pre-splitting of pillars should be restricted to the practical minimum necessary for improving or maintaining the production. This will depend to a large extent on the composition and behaviour of the local roof strata. If a number of pillars are pre-split in advance, the partial protection by the adjoining pillars, discussed in 7.4 above, is reduced considerably as the narrow fenders do not offer the same support resistance as the large pillars. This could result in a situation similar to that of straight line conventional pillar extraction.

7.7 Speed of Extraction

The rate of retreat during pillar extraction should be as fast as is practically possible. Salamon and Oravecz, 1976, confirmed this and recommended that the safety factor of pillars in the slower retreating handgot pillar extraction should be larger than for mechanized pillar extraction.

When the roof goafs adjacent to a pillar, the stresses on the pillar are reduced considerably. During the pillar extraction of this pillar, as the pillar size diminishes, these stresses increase gradually until they reach a maximum prior to goafing. The longer it takes to extract the pillar, the longer the diminishing pillar has to support the load. This could lead to hazardous mining conditions and premature failure of the remaining pillar.

The panel and pillar sizes should thus be designed to allow for the fastest practical rate of retreat. The parameters will vary considerably between various coalfields and collieries as it depends on the condition and behaviour of the local strata, the mining method and the type of mining equipment used.

A number of factors affecting the speed of extraction must be taken into account when planning pillar extraction operations:

(a) The number of roads per panel, and thus the number of pillars per row, should be small enough to allow a fast retreat during pillar extraction. Table 2, discussed in 5 above, indicated that the rate of retreat, using the data in Model 7.2, for a 11 road panel could be less than half that of a [illegible] road panel.

(b) The pillars should not be designed unnecessarily large as this will result in a slow rate of retreat.

(c) The size and capacities of the production equipment should be taken into consideration when designing pillar sizes and extraction methods.

(d) The condition and behaviour of the local strata must be assessed before deciding on the panel width, pillar size and extraction methods as this will, in addition to safety and productivity, affect the rate of retreat.

7.8 Support

7.8.1 Systematic support during development

The systematic support on the various collieries differs vastly as it depends mainly on the composition, competence and behaviour of the overlying roof strata.

When panels are planned and mined with the aim of secondary extraction, the systematic support should be designed and installed to accommodate pillar extraction as far as practically possible. If pillar extraction commences and the systematic support is found to be ineffective, it is more costly and unproductive to install additional support at this stage than it would have been to install adequate support during development.

The condition and behaviour of the roof strata, including local experience, must be carefully considered when systematic support for pillar extraction panels is designed.

7.8.2 Support of geological discontinuities

It is of critical importance that faults, slips and other geological discontinuities be effectively supported during the development phase. If such discontinuities are not supported during the initial development and problems are experienced with these during pillar extraction, bed separation has already occurred and the installation of roofbolts at that stage is no longer an effective means of support.

This can lead to hazardous mining conditions and loss of reserves if pillars or portions of pillars cannot be extracted. This in turn can result in high stresses on the remaining pillars to be extracted.

7.3.3 Sidewall support

Mining at depths in excess of 200 - 300 metres can produce considerable sidewall spalling as the stress on the edges of the pillars is greater than the strength of coal. When mining at these or greater depths, some form of sidewall support will be necessary to prevent spalling and to maintain the designed dimensions of the bords and pillars without restricting the extraction of the pillars. Abutment stress created during pillar extraction, especially in thick seams, can also cause spalling and may in severe cases also require some form of sidewall support. Spot bolting of the sidewall may be necessary in some coal seams where the coal tends to form blocks which slide out.

Sidewall support should be installed as close to the working face as is practically possible to prevent or control spalling. Practice has shown support to be most effective if installed immediately after the coal sidewall is exposed. Supporting the sidewalls after spalling has taken place is usually difficult and not as effective.

The type of sidewall support required will vary from one site to the next, but it is important that the support should not interfere with the pillar extraction process.

At Springfield Colliery the wooden dowels installed in the pillar extraction sections as part of the systematic support to contain and prevent spalling proved to be very effective.

Field trials were conducted on Majuba Colliery, mining at a depth of 320 m, and Piet Retief Colliery where the depth of cover ranges from outcrop to 580 m. During the trials various types of support, ranging from rockbolts to wooden dowels were installed. The trials on both collieries have shown that wooden dowels are only suitable where minimal spalling has occurred. Their use on pillar corners is not recommended due to their inability to control large amounts of fracturing and spalling. Where the support was installed timeously, degradation of the pillar sides was minimised and rarely required further support (Hill, 1988 and Lear and Hill, 1989).

Sidewall support is expensive and it will be advantageous for mines to conduct field trials to determine the most suitable sidewall support for pillar extraction in their specific conditions.

7.8.4 Breakerline support

The different types of breakerlines and their advantages and disadvantages were discussed in detail in Chapters 4 and 6.

Due to the factors discussed in these chapters, it is not possible to recommend specific or general methods or patterns for pillar and rib pillar extraction, but the important factors relating to breakerlines and fingerlines are the following:

(a) Breakerlines should be installed as stiffly as possible. When installed properly, they provide a line of high support resistance which prevents the goaf from extending into the working area.

(b) Wherever possible, the breakerlines should be extracted once a fender or pillar has been completely extracted, and the next breakerlines have been installed in order to prevent load transfer. The support resistance that can be afforded by a breakerline should not be underestimated as it can prevent large spans of roof strata from caving if left in the goaf. The narrower the seam, the more important this becomes.

(c) When the type and pattern of breakerlines are designed, strata control engineers should take into account the composition and behaviour of the local strata. The importance of using local experience when assessing new designs or support methods cannot be over-emphasised.

7.9 Training

Pillar extraction can be more hazardous than normal bord and pillar mining and therefore it requires strict operational control and proper training of the operating personnel.

The miners, team leaders, machine operators and persons installing and withdrawing support should be properly trained before they start working in a pillar extraction section. They should not only be taught the mining method and extraction sequence, but also the importance of adhering to prescribed standards. The dangers of leaving snooks and deviating from the extraction sequence should be emphasised.

If pillar extraction has not been practised on a mine previously, it is recommended that, apart from their normal training, the key personnel of the intended pillar extraction section spend a number of shifts in a pillar extraction section on a mine with similar conditions or a similar pillar extraction layout.

7.10 Conclusions

The design guidelines are based on the experience of the various collieries, their problems and successes, and the research conducted by COMRO, individual mines and mining houses. These facts are itemised in these guidelines so that improved performance and safety can result from pillar extraction operations.

Although strata control theories and principles were used to evaluate the validity of these guidelines, the cost implications of the various mining layouts and pillar sizes were not considered.

In the following chapter, the guidelines are applied to different mining scenarios to illustrate the cost implications of different panel layouts, pillar sizes and extraction sequences. This not only serve to examine the cost implications, but it also verifi·· to some extent the validity of the guidelines.

CHAPTER 8

ECONOMIC OPTIMISATION OF PILLAR EXTRACTION

8.1 Introduction

In the previous chapter on the guidelines for pillar and rib pillar extraction it is pointed out that the behaviour of the overburden strata possibly is the most critical factor as it also affects the mining method, the type of mining equipment that can be used, and the support required during development and pillar extraction. These factors therefore also play a critical role in determining whether pillar or rib pillar extraction should be used as a means of secondary extraction.

In addition to these strata related factors, the economics of the mining method is important to determine if it is beneficial to do secondary extraction, and also to assist in optimising the secondary extraction.

In order to do the cost comparisons and cost simulations, it was necessary to obtain actual costs from the mines who practised both pillar and rib pillar extraction. The costs used in this report are based on actual production costs during the period January 1991 to December 1991. Due to the sensitivity of some of the costs, it is not reported individually, but the average figures are used in this report. When the COMSIM computer simulation model is used to determine the effect of certain changes on the production costs, the actual average costs are applied to the base case.

In this chapter some of the design principles are applied to different panel layouts, pillar sizes and extraction sequences to determine the effect on the production costs.

8.2 Pillar Extraction versus Rib Pillar Extraction

In addition to the strata related factors, it is also necessary to examine whether there are economic benefits in practising either pillar or rib pillar extraction.

Two major difficulties are experienced when the economics of these two mining methods are examined:

(a) A very limited number of collieries have employed pillar and rib pillar extraction during the same time period. It is thus very difficult to obtain reliable and objective cost comparisons.

As the support requirements and the mining heights of the various mines practising these two mining methods may vary considerably, the mining costs of one of the methods on one mine cannot be compared directly to the mining costs of the other method on a different mine.

(b) In rib pillar extraction the development and extraction of the pillars is one operation and is reflected as such in both the production output and the production costs. With pillar extraction, the development of a panel is done prior to the commencement of the pillar extraction, and both the production output and the costs are reflected as bord and pillar mining. When pillar extraction commences, it does not include any development, apart from the splitting of the pillars, which normally result in higher production and lower support costs.

In order to compare the costs of the two methods, it is therefore necessary to determine the mean cost of both the development and pillar extraction before comparing it with rib pillar extraction.

The average estimated present value of the total mining cost in Rand/ton for the various continuous miner mining methods is given in Table 8.1. These are average costs of collieries which have practised both pillar and rib pillar extraction, and are not necessary representative of the total mining industry.

Table 8.1 Mining costs of different mining methods

Mining Method	Estimated cost in Rand/ton
Bord and Pillar Development	24.83
Pillar Extraction	23,66
Ave. Pillar Extraction/Development	24,25 *
Rib Pillar Extraction	24,38

* *Derived by averaging the cost for both development and pillar extraction. (It must be noted that the development is normally done by a different crew to that doing the pillar extraction. This can have an effect on productivity and thus on production costs.)*

The following conclusions can be drawn from these figures:

(i) The production cost of pillar extraction (extraction/development) is only 13 cent per ton less than the cost for rib pillar extraction. There is thus no significant cost advantage in practising either of the two methods.

(ii) The production cost for development is approximately R 1,20 higher than that of pillar extraction. This is mainly due to the higher cost of the systematic roofbolt support necessary during development and the softer cutting conditions during pillar extraction.

The most important selection criteria thus still remain the condition and behaviour of the coal bearing strata and the mining equipment and method to be used.

8.3 The Economic Optimisation of Panel Width

In the previous chapters it has been stressed that the most important factors effecting pillar size, and also panel width, is the condition and behaviour of the overburden strata, and the mining equipment and method employed.

Quite often, however, pillars and panels are designed without considering the economic impact of such designs. The following example will be used to illustrate the economic impact of different panel widths and extraction sequences:

Model 8.1

A coal seam is situated 180 m below surface (to the base of the seam) is overlain by a 50 m thick dolerite sill which occurs only 5 m below surface. Continuous miners are to be used for both the development and pillar extraction phases and the mining height is 2,5 m and the bord width is 6 m. The panels are to be designed for pillar extraction and therefore the pillars must have a minimum safety factor of 1,8.

If the conventional (Salamon) formula is used, it will require pillars of 17,34 m square. Using the squat pillar formula, the pillars would have to be 16,56 m square. It is decided to mine 18 m square pillars as they meet the requirements of the safety factor and can be extracted effectively with the available mining equipment.

The panel width necessary to induce sill failure (using Galvin's formula) is 192,5 m which will require 9 road sections if the pillars are mined at 24 m centres.

The economic impact of the following alternatives are to be determined:

(a) What is the effect of mining a single 9 road panel or two 5 road panels ?

(b) What is the effect of extracting the pillars in a 9 road and in a 5 road panel in a straight line and on a 45° stooping angle ?

8.3.1 Productivity

The COMSIM computer simulation program was used to simulate the potential production in a 5 and 9 road panel during the initial development and during pillar extraction, in a straight line and on a 45° angle, using one 12HM9 continuous miner and two 10 ton shuttle cars. The simulations are based on three eight hour shifts per 24 hours, a machine availability of 80% and a continuous miner cutting rate of 5 tons per minute during development and 7 tons per minute during pillar extraction. In order to determine the trend in the production output when the number of roads are increased, 5, 7 and 9 roads were simulated. The results are presented in Tables 8.2 and 8.3.

Table 8.2 Productivity During Development (18 m Pillars)

Number of headings	5	7	9
Tons per shift	1253	1192	1179
Tons per face minute	3,73	3,55	3,51
Cont. miner utilization:			
Cutting %	74,6	71,0	70,2
Shuttle car utilization:			
Load & discharge %	49,3	46,9	46,4
Travelling %	23,5	29,6	31,8
Shuttle cars:			
Total route dist.(km)	128	212	304
(for two rows of pillars)			
Tons/km travelled	67,3	58,5	53,2

Table 8.3 Productivity During Pillar Extraction (18 m Pillars)

	Straight Line			45° Angle		
Number of headings	5	7	9	5	7	9
Tons per shift	1426	1372	1315	1412	1225	1122
Tons per face minute	4,25	4,08	3,91	4,20	3,65	3,34
Cont. miner utilization:						
Cutting %	60,6	58,3	55,9	60,0	52,2	47,7
Shuttle car utilization:						
Load & discharge %	43,0	41,3	39,6	42,5	36,9	33,8
Travelling %	29,2	34,2	37,5	31,3	43,1	48,8
Shuttle cars:						
Total route dist.(km) (for two rows of pillars)	56	97	145	60	133	214
Tons/km travelled	59,9	52,4	46,6	56,3	38,5	31,9

The following conclusions can be drawn from the results presented in the two Tables above:

(a) During the development phase, the production output of a 9 road section is 74 tons per shift (5,9%) less than that of a 5 road section. The travelling distance for the shuttle cars, however, more than doubles which results in a 21% reduction of the tons/km travelled by the shuttle cars. This will have an impact on the maintenance cost of the shuttle cars.

(b) During pillar extraction, the difference in productivity when extracting the pillars in a straight line and on a 45° stooping line in a 5 road panel, is very small.

(c) When the pillars are extracted in a straight line, the production output of a 9 road section is 111 tons per shift (7,8%) less than that of a 5 road section. The distance travelled by the shuttle cars, however, is nearly three times longer which results in a 22,5% reduction of the tons/km travelled.

(d) The major impact is experienced when the pillars are extracted on a 45° stooping angle, when the production output of a 9 road section is 290 tons per shift (20,5%) less than that of a 5 road section. The distance travelled by the shuttle cars, however, is nearly four times longer which results in a 43,4% reduction of the tons/km travelled.

8.3.2 Cost comparison

In order to do cost analyses for the various mining methods, it is necessary to break down the production costs into fixed costs and variable costs.

The variable costs consist of items such as roofbolts, picks, and production bonuses. These costs fluctuate directly with the production output. The fixed costs consist of items such as salaries, depreciation and other overheads and is not influenced by the rate of production. The variable costs therefore form a significant part of the in-section costs, but a much smaller part of the total cost per ton mined, which include all overheads.

In continuous miner development (bord and pillar), the variable costs constitute approximately 39,5% of the in-section costs, but only 16,6% of the total cost per ton mined. In pillar extraction , the variable costs constitute approximately 31,6% of the in-section costs, but only 12,8% of the total cost per ton mined. The total cost per ton will be used for the purpose of analysing the cost implications of the mining methods shown in Table 8.2 and Table 8.3.

The following assumptions have been made for the purpose of these cost analyses:

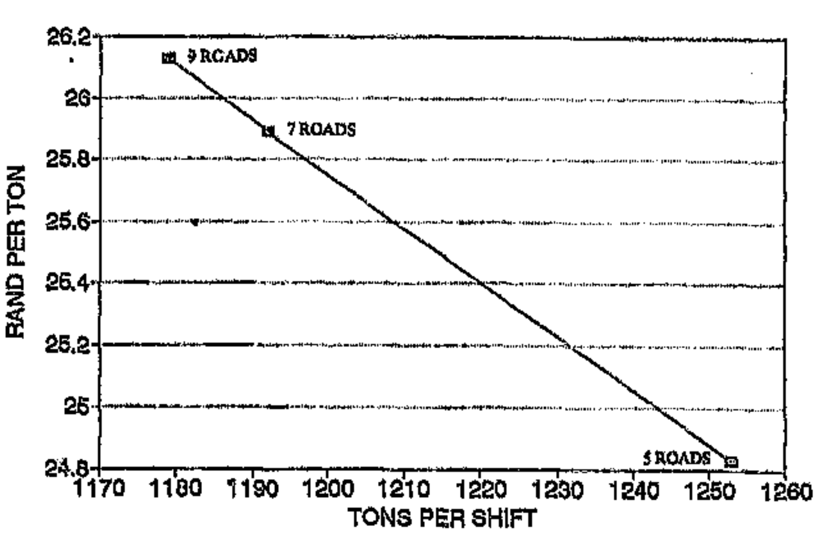
* the optimum production during development is 1 253 tons/shift (as for the 5 road development in Table 8.2)
* the variable cost for development is 16,6% of the total cost per ton for continuous miner development
* the optimum production during pillar extraction is 1 426tons/shift (as for the 5 road pillar extraction on a straight line in Table 8.3)
* the variable cost for pillar extraction with continuous miners is 12,8% of the total cost per ton.

The comparative costs for the development of the 18 m pillars are summarised in Table 8.4, and graphically presented in Table 8.5.

Table 8.4 Development Costs for the 18 m Pillars

No. of Roads	Tons/ Shift	Fixed Cost (R)	Vary. Cost (R)	Total Cost (R)	Cost/ Ton (R)
5	1253	25947	5162	31109	24,83
7	1192	25947	4911	30858	25,89
9	1179	25947	4857	30804	26,13

Table 8.5 Graphic Presentation of the Development Costs for the 18 m Pillars



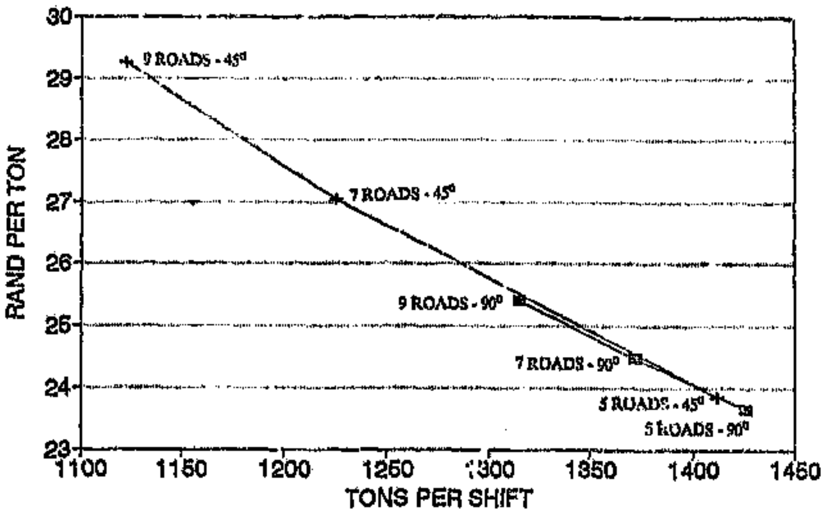
These costs illustrate that even during the development phase of larger pillars, the number of roads in a panel can make a noticeable difference to the production costs.

The comparative costs for the pillar extraction of the 18 m pillars, in a straight line and on a 45° angle, are summarised in Table 8.6, and graphically presented in Table 8.7.

Table 8.6 Pillar Extraction Costs for the 18 m Pillars

No. of Roads	Angle	Tons/ Shift	Fixed Cost (R)	Vary. Cost (R)	Total Cost (R)	Cost/ Ton (R)
5	90°	1426	29421	4321	33742	23,66
7	90°	1372	29421	4157	33578	24,47
9	90°	1315	29421	3984	33405	25,40
5	45°	1412	29421	4278	33699	23,87
7	45°	1225	29421	3712	33132	27,05
9	45°	1122	29421	3400	32821	29,25

Table 8.7 Graphic Presentation of the Pillar Extraction Costs for the 18 m Pillars



It should be noted that the costs for extracting the pillars in a 5 road panel in a straight line and on a 45° are very similar. When extracting the pillars in a straight line, the mining cost for a 5 road panel is R 1,74 less than the cost for a 9 road panel. If the pillars are extracted on a 45° stooping angle, however, the mining cost for a 9 road panel is R 5,38 higher that the cost for a 5 road panel.

If the strata conditions and behaviour are such that a narrow or wide panel may be worked, these production cost could assist in making a final decision on the mining parameters.

8.4 The Economic Optimisation of Pillar Size

In the design guidelines a number of factors to be considered when designing pillar dimensions were discussed. Two of these factors were:

(a) The pillars should not be designed unnecessarily large so that individual pillars can be extracted in the shortest possible time.

The size of pillars also has a significant effect on productivity as can be seen in Table 8.8 to Table 8.11.

(b) The number of roads per panel, and thus the number of pillars per row, should be small enough to allow a fast retreat during pillar extraction taking the productivity during the development phase into account.

The following mining scenario will be used to demonstrate the effect of pillar size on productivity and costs:

The bottom seam on a certain colliery has been mined extensively with bord and pillar mining, and with pillar extraction in the areas where the upper seam is considered to be too thin to be extracted economically. The bottom seam is situated 120 m below surface; the mining height is 2,5 m and the bord width is 6 m. The pillars in the bottom seam are mined at 18 m centres, forming 12 m square pillars with a safety factor of 1,83. The upper seam is situated 85 m below surface and the average mining height is also 2,5 m. Due to the success of developing and extracting the 12 m pillars on the bottom seam, the mine decides to retain these pillar dimensions for the upper seam. Due to the shallow depth of the upper seam, the 12 m pillars result in a safety factor of 2,58. At a safety factor of 1,8, however, the pillars could be reduced to 9 m square pillars. What is the effect of mining unnecessary large pillars on the upper seam ?

8.4.1 Percentage extraction

(a) The 12 m square pillars

Percentage extraction during development = 55,6%

The average percentage extraction of the pillars during pillar extraction in South African collieries is 70%. This extraction percentage will therefore be used to calculate the tonnages for pillar extraction.

Percentage extraction of the pillars = 31,08%

Total percentage extraction = 86.68%.

(b) The 9 m square pillars

Percentage extraction during development = 64,0%

Percentage extraction of the pillars = 25,2%

Total percentage extraction = 89,2%

8.4.2 Productivity

The COMSIM computer simulation program was used to simulate the potential production for both the 9 m and 12 m pillars. The simulations were done for a 7, 9 and 11 road panel during the initial development and during pillar extraction, in a straight line and on a 45° angle. The simulations are based on the following assumptions:

- three eight hour shifts per 24 hours,
- one 12HM9 continuous miner,
- two 10 ton shuttle cars,
- a machine availability of 80%, and
- a continuous miner cutting rate of 5 tons per minute during development and 7 tons per minute during pillar extraction.

The results for the development are presented in Tables 8.8 and 8.9 and for the pillar extraction, in Tables 8.10 and 8.11.

Table 8.8 Productivity During Development (9 m Pillars)

Number of headings	7	9	11
Tons per shift	1362	1362	1362
Tons per face minute	4,05	4,05	4,05
Cont. miner utilization:			
Cutting %	81,1	81,1	81,1
Shuttle car utilization:			
Load & discharge %	52,9	52,9	52,9
Travelling %	20,8	22,8	24,8
Shuttle cars:			
Total route dist.(km)	66	96	132
(for two rows of pillars)			
Tons/km travelled	109,0	96,7	86,7

Table 8.9 Productivity During Development (12 m Pillars)

Number of headings	7	9	11
Tons per shift	1321	1320	1312
Tons per face minute	3,93	3,93	3,90
Cont. miner utilization:			
Cutting %	78,7	78,6	78,1
Shuttle car utilization:			
Load & discharge %	51,2	51,2	50,9
Travelling %	22,9	25,5	27,9
Shuttle cars:			
Total route dist.(km)	106	156	214
(for two rows of pillars)			
Tons/km travelled	83,8	74,5	67,0

The following conclusions can be drawn from the figures presented in the two Tables above:

(a) The rate of production with the 9 m pillars is not affected when increasing the number of roadways from 7 to 11. This is mainly due to the small size which limits travelling distances. Despite the small size, however, the total distance travelled by the shuttle cars more that doubles when the number of roads are increased from 7 to 11 which reduces the tons/km travelled by approximately 20%. This has an impact on the maintenance and running cost of the shuttle cars.

(b) When the size of the pillars is increased from 9 m to 12 m, the production rate drops by 41 tons per shift for a 7 road section and 50 tons per shift for a 11 road section.

(c) The rate of production with the 12 m pillars drops by only 9 tons per shift when the number of roadways is increased from 7 to 11. The total distance travelled by the shuttle cars, however, also more that doubles when the number of roads are increased from 7 to 11 which reduces the tons/km travelled by approximately 20%.

Table 8.10 Productivity During Pillar Extraction (9 m Pillars)

	Straight Line			45° Angle		
Number of headings	7	9	11	7	9	11
Tons per shift	1632	1583	1530	1421	1229	1128
Tons per face minute	4,86	4,71	4,55	4,23	3,66	3,36
Cont. miner utilization:						
Cutting %	69,4	67,3	65,1	60,4	52,3	47,9
Shuttle car utilization:						
Load & discharge %	4[illegible],1	47,6	46,0	42,8	37,0	33,9
Travelling %	26,4	29,4	32,1	31,2	40,3	44,7
Shuttle cars:						
Total route dist.(km) (for two rows of pillars)	30	45	63	40	77	116
Tons/km travelled	84,2	74,9	67,1	63,6	43,9	36,6

Table 8.11 Productivity During Pillar Extraction (12 m Pillars)

	Straight Line			45° Angle		
Number of headings	7	9	11	7	9	11
Tons per shift	1382	1341	1298	1240	1079	994
Tons per face minute	4,11	3.99	3,86	3,69	3,21	2,96
Cont. miner utilization:						
Cutting %	58,8	57,0	55,2	52,7	45,9	42,2
Shuttle car utilization:						
Load & discharge %	41,1	39,9	38,6	36,9	32,1	29,6
Travelling %	26,7	29,7	32,3	32,2	41,5	46,1
Shuttle cars:						
Total route dist.(km) (for two rows of pillars)	65	98	136	85	163	244
Tons/km travelled	69,3	62,0	55,8	53,1	37,0	31,0

Contrary to the small differences in the production output between the different pillar sizes and the number of roadways during the development phase, the differences during pillar extraction are vast.

The following conclusions can be drawn from the figures presented in the two Tables above:

(a) When the pillars are extracted in a straight line, the production output for the 12 m pillars is 232 to 250 tons per shift (15,5%) less that that of the 9 m pillars. The distance travelled by the shuttle cars is double, which reduces the tons/km travelled by 17,3%.

(b) When the pillars are extracted at a 45° angle, the production output for the 12 m pillars is 134 to 181 tons per shift (12,7%) less than that of the 9 m pillars. The distance travelled by the shuttle cars is double, which reduces the tons/km travelled by 17,3%.

8.4.3 Cost comparison

The total cost per ton will be used for the purpose of analysing the cost implications of the mining methods shown in Table 8.8 to Table 8.11.

The following assumptions have been made for the purpose of these cost analyses:

* the optimum production during development is 1 362 tons/shift (as for the 7 road development in Table 8.8)
* The variable cost for development is 16,6% of the total cost per ton for continuous miner development
* the optimum production during pillar extraction is 1 632tons/shift (as for the 7 road pillar extraction on a straight line in Table 8.10)
* the variable cost for pillar extraction with continuous miners is 12,8% of the total cost per ton.

Table 8.12 Development Costs for the 9 m and 12 m Pillars

No. of Roads	Pill. Size	Tons/ Shift	Fixed Cost (R)	Vary. Cost (R)	Total Cost (R)	Cost/ Ton (R)
7	9 m	1362	28207	5611	33818	24,83
9	9 m	1362	28207	5611	33818	24,83
11	9 m	1362	28207	5611	33818	24,83
7	12 m	1321	28207	5443	33649	25,47
9	12 m	1320	28207	5438	33645	25,49
11	12 m	1312	28207	5405	33612	25,62

The production rate differs by a maximum of only 50 tons per shift, and the production cost for the 12 m pillars is only R 0,64 and R 0,79 per ton more that for the 9 m pillars. This, however, amounts to a loss of between R 25 600 and R 31 600 a month for a section producing 40 000 tons per month.

The cost implication during pillar extraction is much more significant and is shown in Tables 8.13 to 8.16.

Table 8.13 Pillar Extraction Costs for the 9 m Pillars

No. of Roads	Angle	Tons/ Shift	Fixed Cost (R)	Vary. Cost (R)	Total Cost (R)	Cost/ Ton (R)
7	90°	1632	33668	4945	38613	23,66
9	90°	1583	33668	4796	38464	24,30
11	90°	1530	33668	4636	38304	25,03
7	45°	1421	33668	4306	37974	26,72
9	45°	1229	33668	3724	37392	30,42
11	45°	1128	33668	3418	37086	32,88

Table 8.14 Pillar Extraction Costs for the 12 m Pillars

No. of Roads	Angle	Tons/ Shift	Fixed Cost (R)	Vary. Cost (R)	Total Cost (R)	Cost/ Ton (R)
7	90°	1382	33668	4187	37885	27,39
9	90°	1341	33668	4063	37731	28,14
11	90°	1298	33668	3933	37601	28,97
7	45°	1240	33668	3757	37425	30,18
9	45°	1079	33668	3269	36937	34,23
11	45°	994	33668	3012	36[illegible]	36,90

These pillar extraction costs for the 9 m and 12 m pillars are graphically presented in Table 8.15 and Table 8.16.

Table 8.15 Graphic Presentation of the Pillar Extraction Costs for the 9 m Pillars

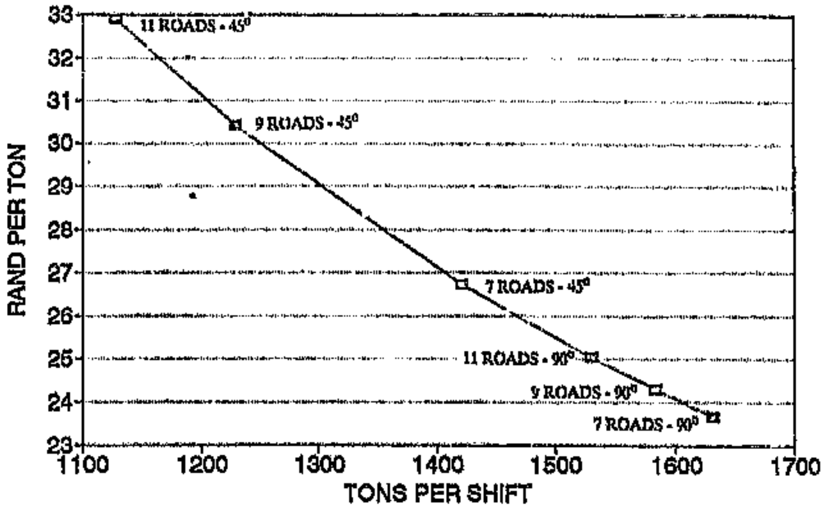
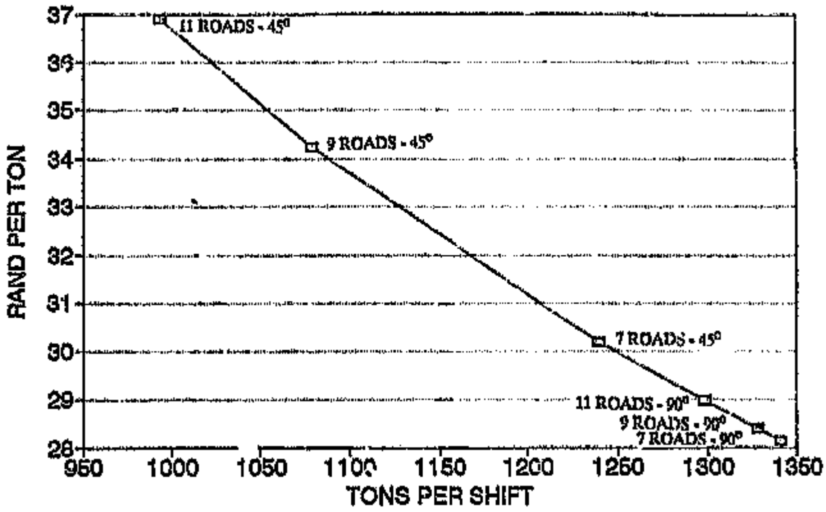


Table 8.16 Graphic Presentation of the Pillar Extraction Costs for the 12 m Pillars



When the pillars are extracted in a straight line, the mining cost for the 12 m pillars is R 3,73 to R 3,94 per ton higher than the mining cost for the 9 m pillars, and if the pillars are extracted on a 45° stooping line, the mining cost is R 3,46 to R 4,02 per ton higher. These are significant cost differences which will have a large impact on mining profits.

8.5 Conclusions

The production costs for pillar and rib pillar extraction on the collieries who practised both of these methods are very similar. It is therefore not possible to select one of these two methods on an economic basis. The main selection criteria are thus still the behaviour of the overburden strata and the type of mining equipment available.

When larger pillars are mined (e.g. 18 m pillars), the number of roads per panel can have a significant effect on the productivity and therefore on the production costs. The number of roads should thus be restricted to the practical minimum which will conform to the requirements for increased productivity and strata control. If the pillars are smaller (e.g. 9 m pillars), the number of roads has a very limited effect on the production costs during the development phase. During the pillar extraction phase, however, the production cost increases substantially as the number of roads is increased, especially if the pillars are extracted on a 45° stooping line.

Pillar size has a direct effect on the production costs as well as the percentage extraction. Because the production cost for development is higher than that of pillar extraction, it could be assumed that increasing the pillar size, which reduces the percentage extraction with development and increases that of pillar extraction, would be the most economic option. This could in some cases be indeed so, but increased pillar size can also decrease the productivity during development and, depending on the number of roads and the stooping angle, also during pillar extraction. It is therefore important to assess the production potential of a mining method and to determine its sensitivity to changes such as pillar size and panel width.

CHAPTER 9

CONCLUSIONS AND RECOMMENDATIONS

9.1 Summary and Conclusions

As a result of the vast differences in the geology, behaviour of the overburden strata, depth of the seam below surface and mining equipment used, it is not possible to recommend standardised extraction methods.

The behaviour of the overburden strata and local experience in the coalfield are the most critical factors to consider when designing pillars and panels for pillar and rib pillar extraction.

Stooping methods used effectively on some collieries, proved to be unsuitable, and even hazardous, on others. Careful consideration of all the relevant factors is therefore essential when designing pillars and panels for pillar and rib pillar extraction. It is for this purpose that the design guidelines have been formulated.

The number of roads in a panel, the pillar size and the sequence of extracting the pillar all have a significant effect on the productivity and production costs. The economic impact of the extraction method should therefore also considered during the design process.

9.2 Recommendations

Before designing panels for pillar and rib pillar extraction, all the relevant factors should be considered carefully.

If stooping has not been practised on the mine previously, the experiences of other mines in the coalfield or in similar geological conditions should be studied and if possible, the stooping sections on such mines should be visited to obtain all relevant information.

The pillar shape and size should be designed to augment the extraction method, bearing in mind the safety factor and the behaviour of the overburden strata during the stooping process. Rectangular pillars are often more suitable than square pillars for certain extraction methods.

The panel width should be restricted to the practical minimum. If a wide panel is necessary to cause a competent layer in the overburden to fail, two adjacent narrower panels should be considered. This will result in less pillars per panel and increase the rate of retreat during the stooping process.

The stooping angle should be designed to suit the specific geological conditions on each mine. Although the majority of mines using continuous miners extract pillars in a straight line, the behaviour of the local overburden strata may require a 45° or 30° stooping line (e.g. Ermelo Mines and Usutu Colliery). For conventional stooping a 45° stooping line is recommended, but local experience may indicate that a 30° stooping line is safer in some areas (Vryheid Coronation Colliery and Welgedacht Exploration). In some areas on mines where floor heave is a problem (Vryheid Coronation Colliery), a limited number of pillars are extracted in a straight line.

It is essential that all pillars are extracted as completely as possible to prevent load transfer onto the remaining pillars to be extracted as well as a loss of extractable reserves. Even small snooks can offer sufficient support resistance in the short term to cause stress transfer onto the pillars being extracted. Failed snooks can be compressed and can offer effective support resistance even in the long term.

The number of pillars or fenders that are pre-split should be restricted to the practical minimum necessary to augment the extraction process. Apart from the danger of premature failure of the narrow fenders, the narrow fenders do not offer the same support resistance, and thus not the same protection for the pillar being extracted, as the large pillars.

The rate of retreat during stooping should be as fast as is practically possible. The number of roads per panel and pillar sizes should thus be designed to allow for the fastest practical rate of retreat.

Unless it is not practically possible, stooping should commence as soon as the development in a panel has been completed. This prevents the deterioration of the bords and pillars prior to stooping.

Systematic roof support should be designed and installed to augment stooping as far as practically possible. If stooping commences and the systematic support is found to be ineffective, it is more costly and unproductive to install additional support at this stage than it would have been to install adequate support during development. It is critical that faults, slips and other geological discontinuities be effectively supported during the development phase. If sidewall support is necessary due to depth or abutment stress during stooping, the support should be designed such that it does not interfere with the extraction process.

Where stooping is conducted under overlaying, worked out seams, the possibilities of dangerous quantities of water and gas being present in the overlaying seams should be carefully considered and taken into consideration when the stooping panels on the lower seam are designed.

In addition to the strata and mining related factors discussed above, the economic impact of the extraction method should be carefully considered. The panel width, i.e. the number of roads per panel, the pillar size and the sequence of extracting the pillars can have a significant economic impact; not only during pillar extraction, but also during the development phase.

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