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The mining of South African thick coal seams: rock mechanics and mining considerations

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surface methods. It should be noted that category IV reserves, those mineable by surface mining methods, do not include reserves contained in overlying seams which are less than 4 m thick but which would also be extracted in the course of extracting thick seam reserves.

2.4 The Significance of South African Thick Coal Seam Reserves

The Petrick Commission's (Petrick et al, 1975) estimates of mineable and extractable coal reserves have been widely disputed (ref. e.g. Anon 1976, Anon 1978, Friedland 1979, King 1979). In general it is considered that reserve estimates are conservative, primarily because the estimates are based on a consideration of economic and technologic conditions existing at the time (1970-1975). In the particular case of thick seams, for example, these considerations resulted in a limit of 6 m being placed on the maximum extractable seam thickness. Furthermore, significant mineable coal reserves contained in seams in close proximity to each other were excluded from extractable reserve estimates because it was considered that the then prevailing conditions prevented the extraction of all seams.

Nevertheless, until the current revision of reserves by the Department of Mineral and Energy Affairs is completed, the Petrick Commission's reserve estimates represent the most accurate and detailed assessment of both mineable and extractable coal reserves in South Africa. Consequently, these reserve estimates are utilized to highlight the significance of the magnitude and distribution of the mineable thick seam reserve estimates presented in Table 2.

On the basis of the Petrick Commission's estimate of coal reserves, thick seam reserves represent over 50 per cent of the country's mineable coal reserve. An additional 5 190 million tonnes of thick seam reserves have been generated by

removing the Petrick Commission's limit of 6 m on the maximum mining height and by taking into consideration certain multi-seam situations which approximated to thick seams. This additional reserve represents almost 12 per cent of the total thick seam reserve and, therefore, is significant.

In excess of 85 per cent of thick seam reserves can only be extracted by underground mining methods. Coal seams between 4 and 6 m thick contain just over 70 per cent of the thick seam reserve. However, the overall percentage extraction achieved from the underground mining of these seams is less than 23 per cent. Similarly, the overall percentage extraction achieved from the underground mining of seams more than 6 m thick is less than 16 per cent. Thus, the overall percentage extraction achieved from the underground mining of ams more than 4 m thick is only of the order of 20 per t.

assive dolerite sills overlie 7,6 per cent of thick seam reserves. Over 97 per cent of these affected reserves are located in the South Rand and Vereeniging-Sasolburg Coalfields. In the South Rand Coalfield almost 60 per cent of the thick seam reserves are overlain by massive dolerite sills, whilst in the Vereeniging-Sasolburg Coalfield this figure is 16 per cent.

A comparison of the mineable reserve estimate of this thick seam survey for the South Rand coalfield with the corresponding extractable reserve estimate of the Petrick Commission, reveals that, utilizing local conventional mining methods, particularly bord and pillar mining, only 12 per cent volumetric extraction will be achieved from the thick coal seams of the South Rand Coalfield. A review of thick seam mining operations in this coalfield over the last forty years reveals that economic and technologic restrictions have resulted in only about 9 per cent extraction having been achieved. This close agreement between actual and predicted

percentage extraction is an indication of the accuracy of thick seam reserve estimates derived from the data base.

2.5 Conclusions

Thick coal seams constitute in the order of 50 per cent of South Africa's mineable coal reserve. Over 85 per cent of the thick seam reserve can only be extracted utilizing underground mining methods. Persistence with present local underground mining methods will only result in the order of 20 per cent extraction of the thick seam reserve. Thus, at least 40 per cent, or more than 36 000 million tonnes, of the country's total mineable coal reserve will remain unextracted in thick seams. Such low percentage extraction represents poor utilization of capital resources, especially in those instances where less than 10 per cent extraction is achieved.

It is apparent that the low percentage extraction and poor utilization of capital resources currently associated with local thick seam mining operations occur because no adequate mining methods exist locally for the underground extraction of thick coal seams. However, because of the rapidly improving economic viability of the South African coal mining industry the potential may now exist to introduce efficient thick seam mining methods in this country. In view of the extreme importance of South Africa's coal reserve to the future economic development of the country, the significant contribution of thick coal seams to this reserve, and the low percentage extraction currently being achieved from thick seams, it is considered that research into the introduction into South Africa of suitable thick seam mining methods is not only justified but is required urgently.

CHAPTER 3

THE MINING OF SOUTH AFRICAN THICK COAL SEAMS - AN OUTLINE OF THE THESIS

3.1 Introduction

With the changing economic conditions and a greater awareness of the need to increase percentage extraction of coal reserves, the potential exists to introduce efficient thick seam mining methods in South Africa. The basic aim of this thesis is to establish a foundation on which to base decisions concerning the implementation of these methods. A broad range of factors have to be taken into account to achieve this aim. Because the potential and need for thick seam mining methods in the past has been limited, few of these factors have been investigated previously. Consequently, a broad field of research findings is presented in this thesis. This chapter outlines and justifies the approach adopted in conducting the research and in presenting research findings.

3.2 Overall Approach

The primary aim of this thesis is to establish a foundation on which to base decisions concerning the implementation of efficient thick seam mining methods in South Africa. It is proposed to achieve this aim primarily on the basis of mining and rock mechanics considerations which, in the final analysis, will be influenced significantly by economic considerations. The thesis is restricted to the introduction of methods which have become established in the field of thick seam mining.

The overall structure of the thesis is outlined in Fig. 3. The figure highlights that although only established thick seam mining methods have been considered a broad range of factors have to be researched. In instances, this research is only required in order to be able to quantify the influence of a factor on thick seam mining methods. As such, a reader utilizing this thesis as a basis for introducing thick seam mining methods in a specific region may not be interested in research details but only in the research findings.

Therefore, appendices have been utilized extensively to present details of research investigations which only form the basis for further research presented in the main text and/or which may not find application in all circumstances. In the main text of the thesis the need for these research investigations is motivated and res arch findings are applied.

As reference to Fig. 3 shows, the thesis is structured such that the local features of ashfilling and/or dolerite sills are presented as discrete entities. This is because these features are not relevant to all coalfields investigated and/or to all regions within these coalfields.

3.3 Specific Approach

Economic constraints, supported by the opinion that South Africa's coal reserves were almost inexhaustible have, until recently, restricted local mining operations in coal seams more than 1,5 m thick to bord and pillar mining. With top- and/or bottom-coaling this method typically extracts up to a 6 m thickness of coal. Bord and pillar mining has been refined to a high degree under local conditions and there is little to be gained by investigating overseas bord and pillar mining operations. Consequently, research into increasing percentage extraction from local thick coal seams utilizing

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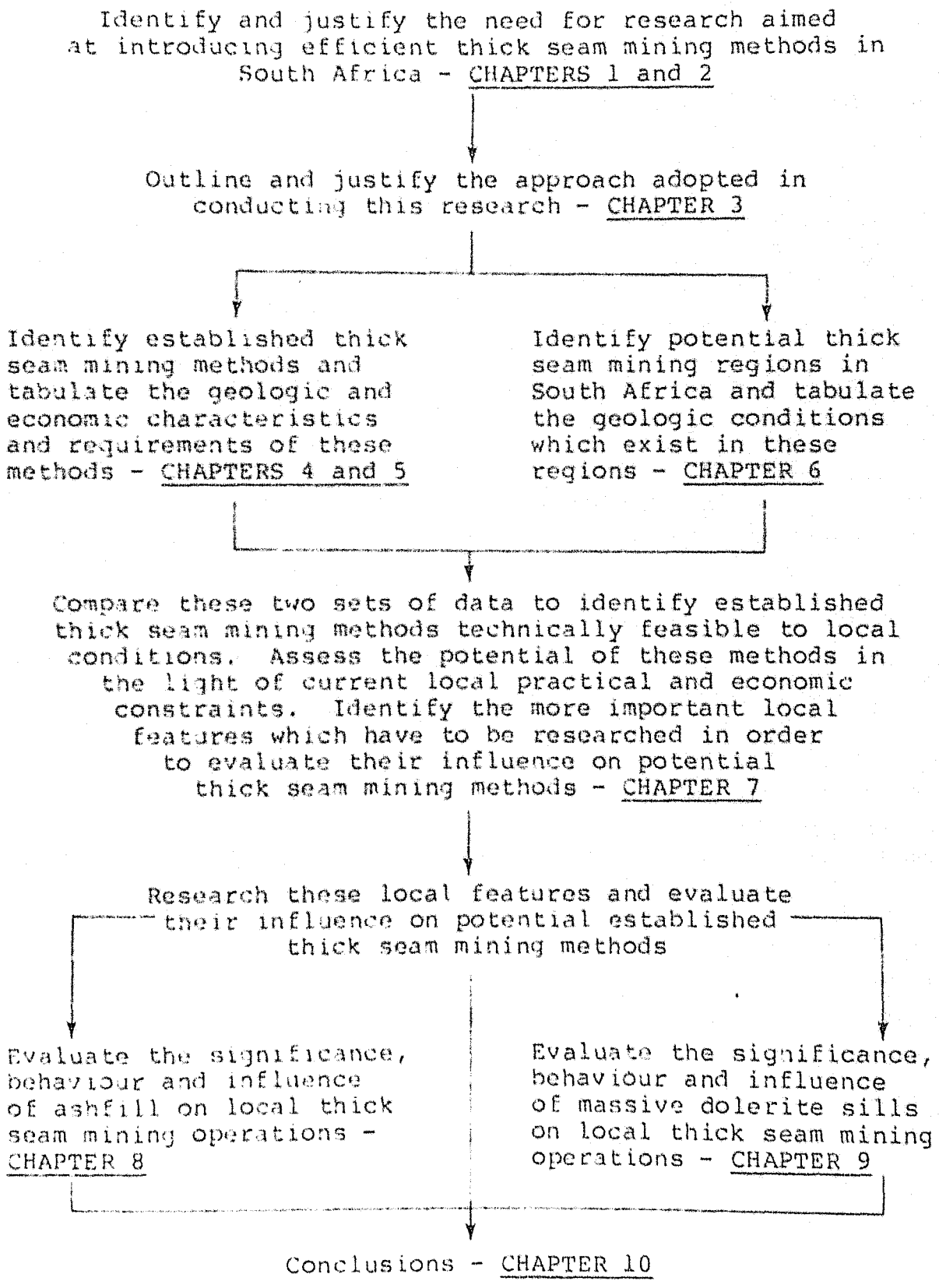

FIGURE 3 An outline of the overall structure of the thesis.

alternative established thick seam mining methods can only be justified when some of the severe local economic constraints are relaxed. Furthermore, a demand must exist for the increased production resulting from the introduction of such methods.

Therefore, in Chapter 1 the overall economics of coal mining in South Africa has been reviewed briefly. This review highlights the fact that economic constraints no longer present a complete barrier to the introduction of alternative thick seam mining methods. Furthermore, a need exists to increase local coal production.

In order to establish if the introduction of alternative thick seam mining methods can contribute to satisfying this need, it is necessary to determine the magnitude and distribution of South Africa's thick seam reserves. A prerequisite for conducting this research is to define a thick coal seam. This definition is presented in Chapter 2. On the basis of the definition, thick coal seams constitute over 50 per cent of South Africa's coal reserve. Furthermore, only about 20 per cent of this reserve can be extracted utilizing present underground mining methods, primarily bord and pillar mining.

Obviously, a need exists to introduce alternative thick seam mining methods. But, because of limited local experience with such methods in the past, no foundation exists on which to base the implementation of these methods. Thus, it can be concluded that research aimed at providing this foundation is not only justified but is required urgently. Because of the broad nature of the problem and of the limited research which has and is being conducted into the problem, it is necessary to research a broad range of factors if the aim is to be achieved.

An approach to conducting this research needs to be formulated (the approach adopted being that under

discussion). A logical starting point in the research program is to review literature relating to thick seam mining methods which are or have been used extensively throughout the world. The primary purpose of this review is to tabulate the characteristics and requirements of the various methods for later comparison with local conditions, thus enabling the identification of methods which may be potentially suitable for use in South Africa. But, in the course of conducting the review it has been found that a number of published proposals and conclusions could not be accepted as correct. Furthermore, some of these proposals and conclusions could have serious implications if they were to form the basis for selecting and implementing methods under local conditions. Therefore, Chapter 4 has been restricted to classifying the literature available on thick seam mining and critically assessing the proposals and conclusions contained therein.

In conducting the literature review a large number (20) of thick seam mining methods were identified. Therefore, a system has been devised for classifying these methods. This classification system is based on two parameters, namely the seam height extracted in each stage of the mining operation, and the effects of mining on the roof strata. These two criteria are combined into the form of a 3x3 matrix, thus resulting in the identification of nine categories of thick seam mining methods. This classification system, presented in Chapter 5, is utilized extensively throughout the thesis, especially to tabulate and compare features associated with the various thick seam mining methods.

In view of the large number of mining methods reviewed, it is considered inappropriate to describe each method in detail in the main text of the thesis. Therefore, only a general description of the methods in terms of the extracted seam height criterion is presented in the main text whilst each method is described in some detail in Appendix III. To facilitate obtaining further information when detailed consideration may be given to introducing a specific method,

a bibliography of the literature reviewed is presented in Appendix IV.

Having devised a system for classifying thick seam mining methods, this classification system is utilized in Chapter 5 to facilitate tabulation of the geologic and economic characteristics and requirements of each established thick seam mining method identified. The next logical step in the thesis is to research the geologic conditions which exist in those South African coalfields which contain thick seam reserves. But, since there are 12 such coalfields, some of which contain up to 5 thick seams, it is clearly impractical to assess geologic conditions pertaining to each thick seam in each coalfield.

Therefore, at the commencement of Chapter 6, the potential for introducing thick seam mining methods in these coalfields has been assessed. It is apparent from this assessment that research investigations should concentrate on specific potential thick seam mining regions in the Springs-Vischkuil-Witbank, Highveld, South Rand and Vereeniging-Sasolburg Coalfields. Before established thick seam mining methods which are potentially suitable for use in these regions can be identified, it is necessary to tabulate the geologic conditions which exist in each region. The need for such information in the past has been very limited and so much of the information required is not available. Therefore, an extensive field investigation had to be undertaken to assess these geologic conditions.

This assessment has been facilitated by tabulating geologic conditions encountered in bord and pillar workings which are distributed throughout potential thick seam mining regions. To further facilitate the assessment, a number of quantitative geologic classification systems have been devised and are presented in Appendix V. Whenever possible, geologic conditions have been tabulated in the same format as

that utilized in Chapter 5 to record the geologic characteristics and requirements of established thick seam mining methods. Since four tables of geologic information pertain to each thick seam assessed, and nine such seams are present within the four relevant coalfields, a large volume of geologic information has been collected. It is impractical to present this information in the main text and the information is contained in Appendix VI.

On the basis of a comparison between the geologic characteristics and requirements of established thick mining methods, presented in Chapter 5, and the geologic conditions which pertain to potential thick seam mining regions, Appendix VI, those established thick seam mining methods which are technically feasible under local conditions can be identified and are presented in Chapter 7. This identification process is facilitated significantly by having used a similar format to record geologic conditions in Chapter 5 and Appendix VI.

However, whilst technically feasible, a number of practical problems are associated with implementing these methods. These problems include factors such as the effect of a mining method on overlying mineable seams, market availability for the increased percentage extraction, the availability of an economic stowing material and panel design to minimise support costs when massive dolerite sills are present in the superincumbent strata. As such, these factors are mostly concerned with the economics of the environment in which technically feasible mining methods must operate, rather than the economics of the methods themselves. After eliminating those technically feasible mining methods which are not practically feasible the present economic feasibility of the remaining methods has been assessed. The economic characteristics of mining methods currently employed in South Africa have been used as a guide in assessing the economic feasibility of technically and practically feasible mining methods. These characteristics have been recorded in the same format in Chapter 7 as that used to record the economic

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characteristics of established thick seam mining methods in Chapter 5, so that methods presently economically feasible can be readily identified.

The underlying theme of the identification process adopted in Chapter 7 is that of applying factors to identify methods not feasible in the order in which these factors are least likely to vary in the foreseeable future. That is, factors which are likely to vary in the immediate future are applied last. Therefore, when these factors change it is only necessary to go a short way back into the identification process to re-establish the technical, practical and economic feasibility of methods.

Were it not for two local features recognised during the identification process as requiring research in order to quantify their influence on methods potentially feasible under present conditions the aim of the thesis would have been achieved at this stage. However, it is apparent that if bord and pillar methods incorporating stowing, which are potentially feasible in regions of all four relevent coalfields, are to be implemented in these regions, power station ash constitutes the only economic stowing material. Since this utilization of power station ash is unique it is necessary to quantify the effects of ashfill on pillar behaviour. A prerequisite to this research is the determination of the chemical, physical and mineralogical properties of local power station ashes. The findings of research into determining these properties is presented in Appendix VII. On the basis of these findings the effects of ashfill on pillar behaviour have been quantified and discussed in Chapter 8.

It is also apparent from the identification process that an understanding of the theory of dolerite behaviour is a necessary prerequisite for successfully implementing, in potential thick seam mining regions of the South Rand and Vereeniging-Sasolburg Coalfields, methods which result in

caving of the roof strata. However, recent mining experiences have highlighted that previous research conducted into dolerite behaviour and its influence on mine design is inadequate. Consequently, further research has been conducted into this topic. The various approaches adopted and the outcomes of each of these approaches are presented in Appendix VIII. The more important research findings are presented in Chapter 9 and applied to conditions existing in potential thick seam mining regions in the South Rand and Vereeniging-Sasolburg Coalfields.

Whilst a number of secondary areas requiring research remain outstanding, the primary aim of the thesis, that of establishing a foundation on which to base the implementation of efficient thick seam mining methods in South Africa, is considered to have been achieved at this stage of the thesis. This accomplishment has been based primarily on research conducted into mining and rock mechanics aspects associated with both established thick seam mining methods and local potential thick seam mining regions. The more important findings and conclusions of this research are presented in Chapter 10.

3.4 Conclusions

Research conducted previously into introducing efficient thick seam mining methods in South Africa has been very limited. Consequently, it has been necessary to undertake a broad field of research in attempting to achieve the aim of the thesis; that of providing a foundation on which to base decisions concerning the implementation of efficient thick seam mining methods in this country. Presentation of research findings has been facilitated by the extensive use of appendices, and by the recording of aspects researched under one or more of the four potential thick mining coalfields to which they pertain.

Mining and rock mechanics considerations form the basis for achieving the aim of the thesis. But, as in any free enterprise economy, these considerations must ultimately be influenced by economic considerations. Consequently, mining and rock mechanics considerations primarily determine the technical feasibility of established thick seam mining methods under local conditions. A combination of mining and rock mechanics considerations and economic considerations determine the so-called 'practical' feasibility of introducing these technically feasible mining methods whilst, obviously, economic considerations determine the ultimate feasibility of introducing methods. However, it must be appreciated that under South African conditions rock mechanics considerations, in particular, can be utilized to great advantage in improving the economic viability of a mining method or operation.

Finally, although the thesis has been restricted to considering the introduction of only established thick seam mining methods, it also forms the basis for devising novel thick seam mining methods for use in the relevant regions of the four coalfields investigated. This is because conditions, both geologic and economic, under which a method must operate in these regions have been identified and tabulated and, in instances, the influence of rather unique local features which pertain to some of these regions has been quantified. Thus, methods may be designed to meet these conditions and requirements. Obviously, the potential also exists to utilize the thesis in the future to evaluate, under local conditions, other thick seam mining methods not currently established.

CHAPTER 4

A CRITICAL EVALUATION OF LITERATURE RELATING TO ESTABLISHED THICK SEAM MINING METHODS

4.1 Introduction

A logical starting point for conducting research into introducing underground thick seam mining methods in South Africa is to review the use of such methods elsewhere throughout the world. A comparison between the characteristics and requirements of these methods with conditions pertaining to South African thick coal seams enables the identification of methods which may be potentially suitable under local conditions.

Practical considerations limit the review almost entirely to literature. In the course of conducting this literature review some proposals and conclusions contained therein could not be accepted as correct. In particular, publications often highlighted a general lack of understanding of the manner in which stresses are distributed around mine workings. Such an understanding is essential to the selection and success of methods under South African conditions, primarily because economic considerations restrict the range and density of underground support which can be employed. Therefore, publications must be evaluated critically.

For clarity and easy reference, this Chapter is restricted to presenting this evaluation, and data relating to the characteristics and requirements of each specific thick seam mining method reviewed is presented in the next Chapter, Chapter 5. However, because some appreciation of the various methods in use is required in order to evaluate literature relating to these methods, a generalized classification and description of methods is presented in this Chapter.

4.2 General Classification and Description of Methods

An appreciation of the mining methods discussed in literature is conveniently and simply obtained by classifying methods under one of the following three types of mining system: full face, slicing, and caving and drawing. These mining systems, recognised by Cochrane (1972) as the basic major classifications of underground thick seam mining methods, are based on a consideration of the manner in which the total mining height is extracted and can be described briefly as follows:

i) Full face systems

The total mining height is extracted in each stage of the mining operation. Methods such as longwall mining are single stage operations, whilst methods such as bord and pillar mining with pillar extraction are multiple stage operations.

The equipment used is normally an extension of the commonly used equipment, and because rapid face advance is usually required to minimise strata control problems these systems are generally confined to those countries possessing a high level of mining technology.

The trend in full face mining in Europe is towards the use of mechanised longwall equipment, Plates 1 and 2, whilst in North America it is towards bord and pillar applications utilizing continuous miners. Conventional bord and pillar mining is employed in India.

ii) Slicing

The total mining height is extracted by mining the seam in a number of slices, either in an ascending or a descending order. These slices may be mined concurrently, in which case the term 'simultaneous' is used to describe the operation, or there may be a

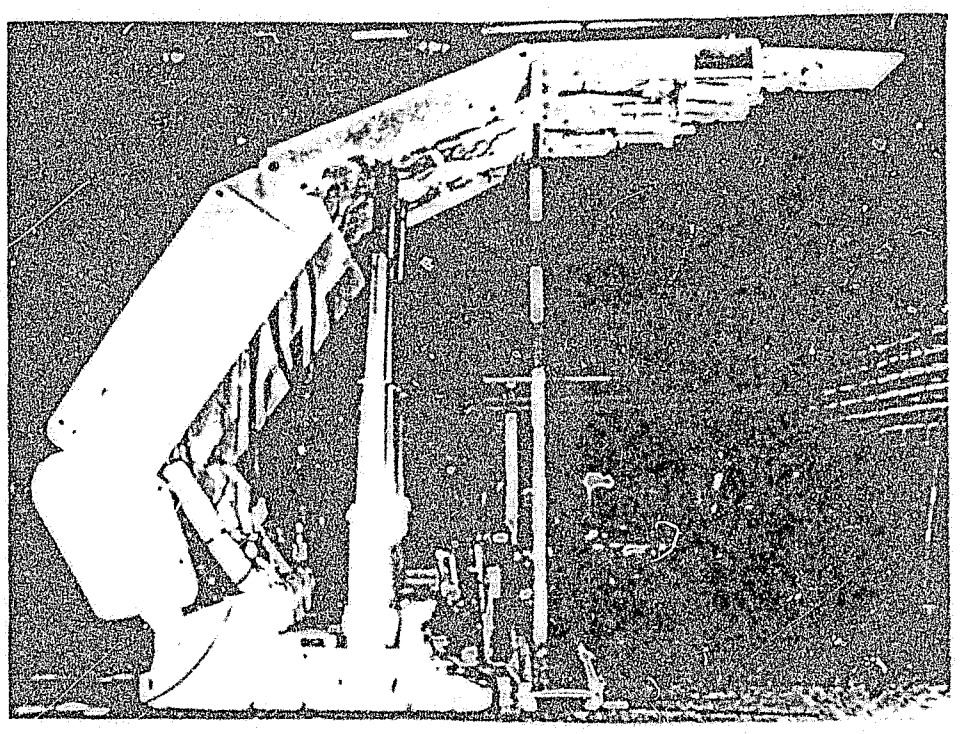


PLATE 1 Full face mechanised longwall support unit fully extended to 6 m.

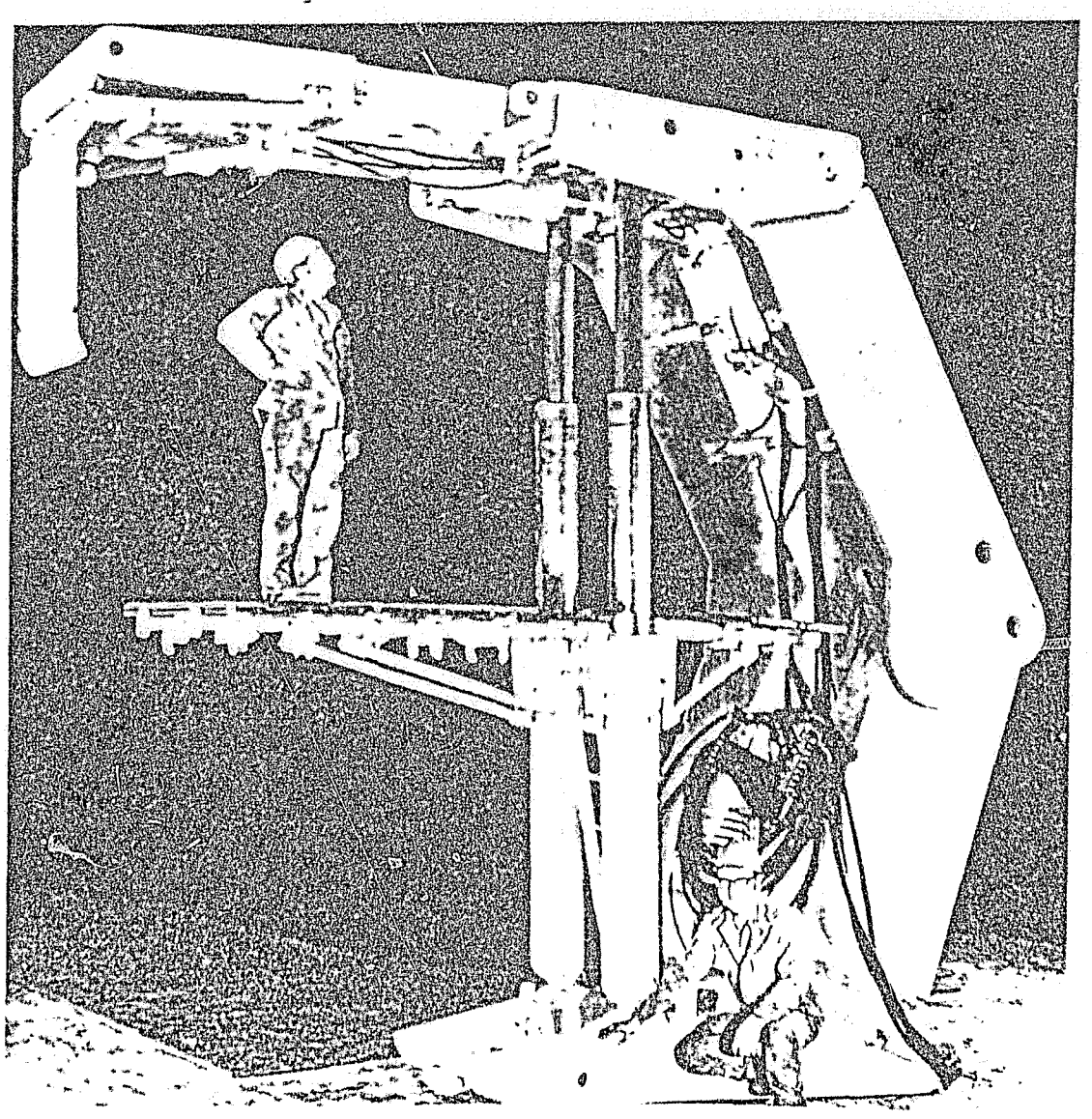


PLATE 2 Full face mechanised longwall support unit with elevated travelling way and face sprag.

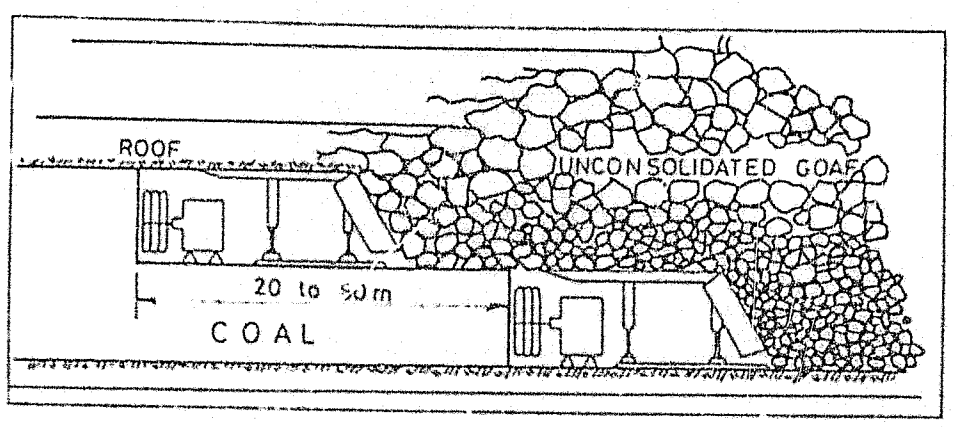
considerable time lapse between the mining of each slice, in which case the operation is referred to as 'non-simultaneous'.

In Britain, Japan and Europe, extraction is usually achieved by mechanised longwall mining, referred to as multi-slice longwall mining, Fig. 4. In North America a bottom-coaling and pillar extraction operation utilizing continuous miners is practiced.

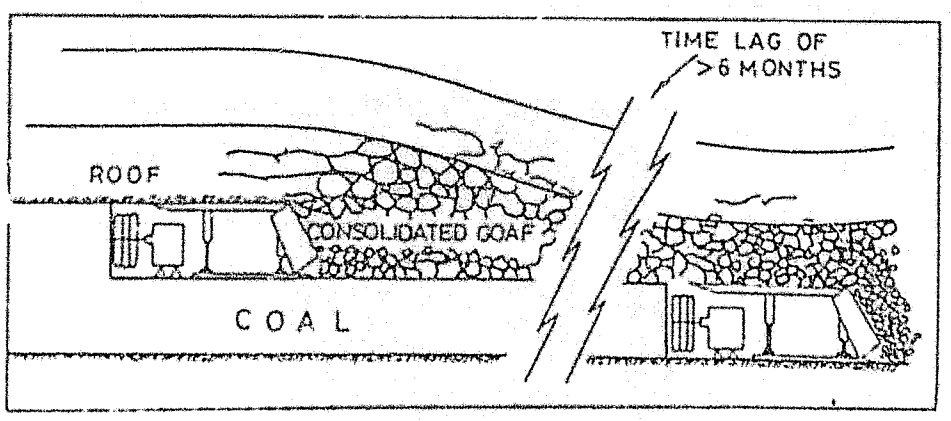
iii) Caving and drawing

The total mining height is extracted by developing the lower horizon of the seam and then caving the overlying coal into this development, from where it is drawn off. This system finds widespread application throughout the world. In France and Eastern European countries an integrated mechanised longwall mining and sublevel caving system is used, Fig. 5(a). Metalliferous based, open stoping and/or sublevel caving and drawing systems are also employed in these countries, Fig. 5(b). Hydraulic mining is used in Canada, Japan, West Germany and the U.S.S.R. to cave and draw the coal remaining in the seam after the primary development has been completed, Fig. 5(c).

Gasification techniques have been excluded from the review since these techniques are largely in the development stage and are not likely to be commercially feasible in South Africa for a number of years. In addition, mining methods which have been designed specifically to operate in seams dipping at more than 10 degrees have not been reviewed because South African thick coal seams tend to be flat dipping, with seam dips of more than 10 degrees being very localized.

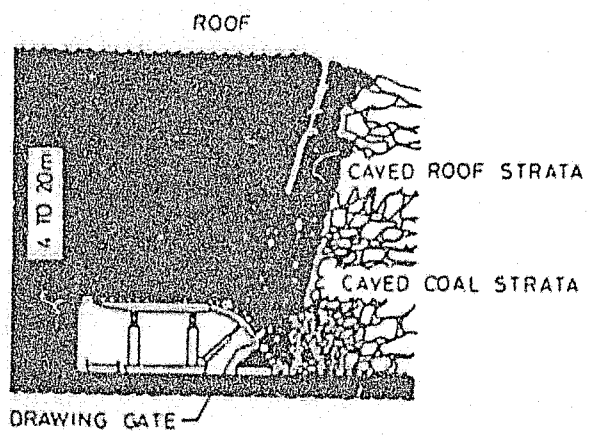


(a) Simultaneous - the lower slice lags 20 to 60 m behind the upper slice.

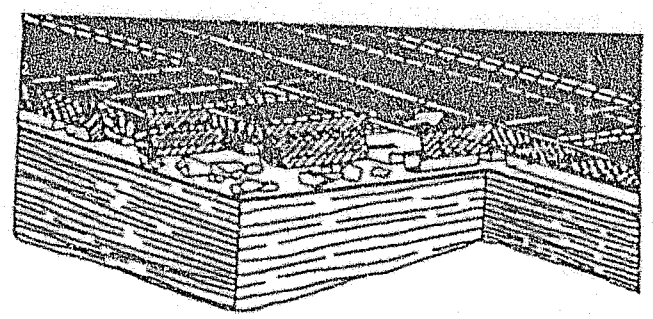


(b) Non-simultaneous - the lower slice lags a minimum of 6 months behind the upper slice.

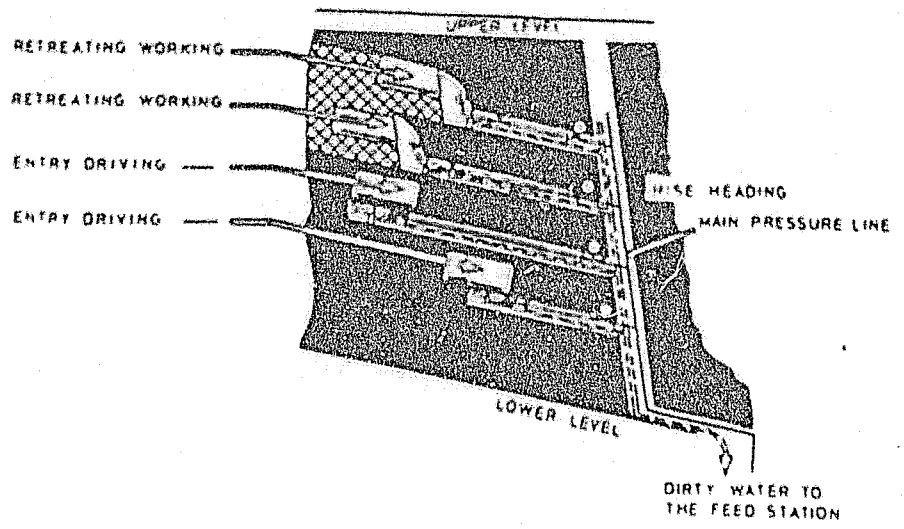
FIGURE 4 Multi-slice longwall mining (adapted from Dunham, 1978).



(a) Integrated mechanised longwall mining with sublevel caving (Barron, 1974)



(b) Sublevel caving and drawing (Stoces, 1966)



(c) Hydraulic mining (Milstein, 1979)

FIGURE 5 Caving and drawing mining methods.

4.3 Critical Evaluation of Literature Reviewed

In general, the literature reviewed has been published during the last decade in the English language. On the basis of subject matter, literature can be classified and discussed under the following categories:

i) Descriptive ; Publications which describe thick seam mining methods.

ii) Innovative ; Publications which propose modified thick seam mining methods.

iii) Evaluative ; Publications which are concerned with evaluating the potential of thick seam mining methods under a specific set of conditions.

Since the major criticism concerning the literature is that many of the publications exhibit a lack of understanding of the manner in which stresses are distributed around mine workings, a number of basic stress distribution profiles are presented and discussed in Appendix II. Reference to these facilitates the evaluation of literature in the main text.

4.3.1 Descriptive literature

This category contains the largest number of publications on thick seam mining methods. Whilst generally explaining and illustrating the mining methods well, these publications often fail to discuss the design and development of the methods, and the conditions under which they operate successfully. In particular, rock mechanics and strata control aspects, on which the success of thick seam mining methods can largely depend, are often completely ignored. The content matter of many of the papers presented at the Symposium on Thick Seam Mining by Underground Methods held in Queensland, Australia, in 1976 and the International Symposium on

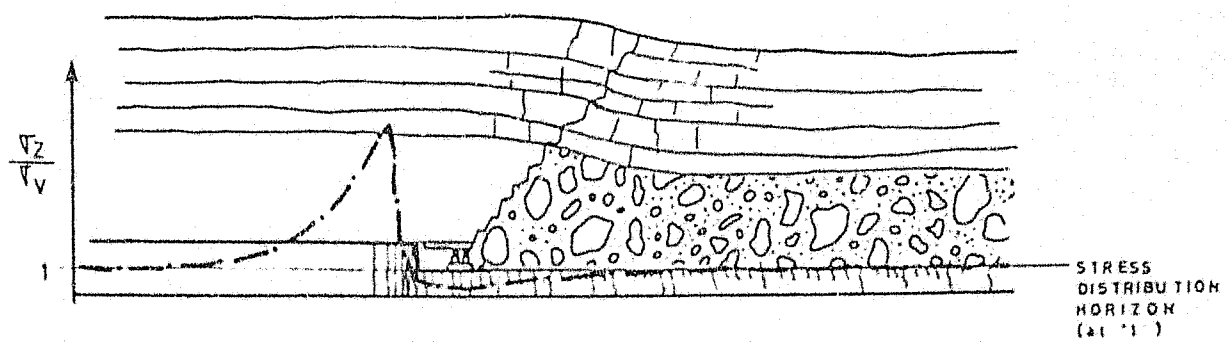
Thick Seam Mining, held in Dhanbad, India, in 1977, illustrate this point.

The fact that English speaking countries are, in general, not thick seam mining countries and that many of the publications are concerned with mining operations in the Eastern European countries, West Germany, Japan and India may account somewhat for the lack of detailed information contained within the papers. However, a lack of appreciation of fundamental rock mechanics principles by many authors is also thought to account largely for this lack of information.

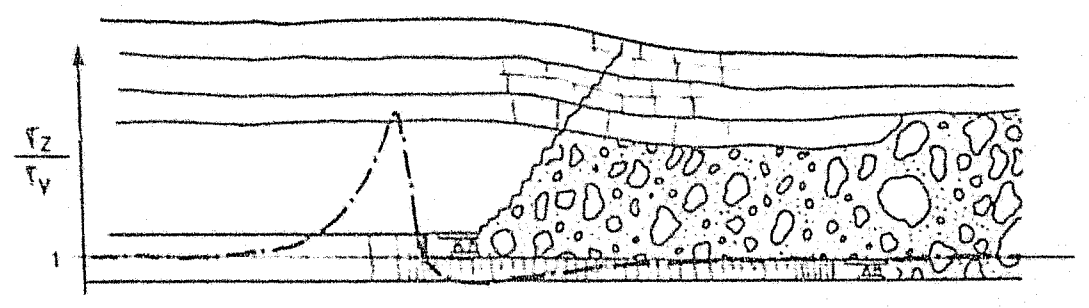
Dunham (1978), in discussing simultaneous multi-slice longwall mining, states that 'As a general rule, when the longwall faces approach one another, the face in the lower slice experiences less pressure while the face in the upper slice is subject to greater pressure'.

It is correct that the lower longwall face would experience less pressure as it approached the upper longwall face, since the overburden load acting on the lower longwall face is reduced (refer to Fig. II.2, Appendix II). But it cannot be accepted that the pressure on the upper face would increase significantly, as the location of the lower face has a negligible influence on the overburden load acting on the upper face, Fig. 6.

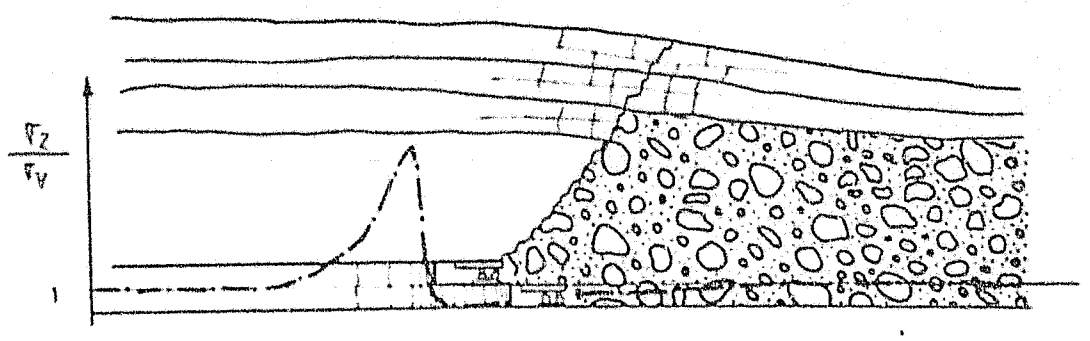
However, as the lower face approaches the upper face it does result in an effective reduction in the lateral confinement provided to the upper face by the floor strata, Figs. 6(b) and 6(c). This, in turn, results in decrease in the strength of the upper face coal and so slabbing, spalling and convergence on this face may increase significantly. As a consequence additional load will be transferred onto the face support system. Nakajima (1976) reports that at Kushero Colliery, in



a) Single slice longwall mining - stress distribution profile at the floor horizon.



b) Simultaneous multi-slice longwall mining - faces far apart. The stress distribution profile at the upper floor strata horizon and the lateral confinement of the upper slice longwall face are almost identical to that associated with a single slice longwall operation.



c) Simultaneous multi-slice longwall mining - faces in close proximity. The stress distribution profile at the upper floor strata horizon is almost identical to that associated with a single slice longwall operation. However, the lateral confinement offered to the floor strata of the upper longwall face is reduced significantly.

$$\frac{\sigma_z}{\sigma_v} = \frac{\text{VERTICAL STRESS}}{\text{VIRGIN STRESS}} = \text{STRESS CONCENTRATION FACTOR}$$

FIGURE 6 Stress distribution and lateral confinement to face associated with simultaneous multi-slice longwalling.

Japan, hydraulic props on the upper slice longwall face yielded excessively when the the lower slice face came within 7 m of the upper slice face. Thus, additional strata movement could be misinterpreted as an indication of increased face pressure rather than a reduction in the strength of the upper coal face. The content matter of the remainder of Dunham's publication is similar to that contained in previous publications by Cochrane (1972) and Callier (1972).

Nevertheless, some authors whose publications fall into the 'descriptive' category have noted design and strata control considerations. Coates et al. (1972) noted briefly that geology, mine geometry, and exploitation systems all influence the profitability of thick seam mining operations. Cochrane (1972) defined a thick seam on the basis of productivity and considered the influence of seam thickness, seam dip, the nature of hanging and footwall strata, and the nature of coal on the selection of thick seam mining systems. Development systems were also briefly discussed and the technical-economic indices for full face, slicing and caving and drawing systems employed throughout the world were tabulated. Wilson et al. (1977) expanded on Cochrane's design considerations governing the selection of thick seam mining methods. In addition, these authors recognised that thick seam mining methods could be utilized to mine seams that were in close proximity to one another, but no attempt was made to define quantitatively such situations.

A number of publications which fall into the descriptive category have originated from India, and these describe the many different thick seam mining methods employed in that country. However, the subject matter of these publications tends to be of limited value since most of the systems described are either highly labour intensive full face mining methods which are uneconomic in most other thick seam mining countries, or else they are

non-mechanised versions of other established thick seam mining methods. The lack of mechanisation results in low production, low productivity, labour intensive mining methods, at a time when the general trend in mining is in the opposite direction; that is, towards methods that achieve high production and high productivity and require a small labour complement.

Publications which have not been written in English are also included in the category under discussion. These publications often contain many illustrations which serve to describe and explain the mining methods under consideration, even though the text may not be understood. The Hungarian book 'Bányamívellés' by Zambo (1957) is an example of such a publication. This book contains many useful illustrations of basic thick seam and multiple seam mining methods.

Finally, a large number of mining methods employed in the mining of thick brown coal seams in Czechoslovakia, West Germany and Britain are illustrated and described by Stoces (1963, 1966) in the Atlas of Mining Methods, Vols. I and II. These are very useful publications since they contain a considerable amount of information, otherwise difficult to obtain, on Czechoslovakian thick seam mining methods which are employed in seams which have very similar characteristics to South African thick coal seams.

4.3.2 Innovative literature

Literature falling into this category is concerned primarily with proposing modified thick seam mining methods. Because these methods are not designed around a specific set of geologic and economic conditions they are proposed usually in only broad outline.

Bise and Ramani (1975) and Bise et al. (1976, 1977) propose four underground extraction techniques for mining thick coal seams in the western United States. These methods are based on the philosophy of Bise and Ramani (1975) that 'although the development of new technology and equipment (for thick seam mining) may be in order for the long run, attention must be directed for short term gains to the adoption of current technology'. In the latter paper the authors have concluded that foreign thick seam mining technology could not be imported into the United States for the foreseeable future because of the dependence of this technology upon stowing procedures and because of its labour intensive nature. However, stowing procedures are only employed on a large scale in Poland and India, and are generally not integral parts of thick seam mining methods. In addition, the claim that the methods are labour intensive is open to debate, as is the claim (Bise et al, 1977) that their four proposed thick seam mining methods have been adapted from existing United States mining methods. All four methods, in fact, are similar to methods employed elsewhere in the world.

In particular, the authors propose the extraction of a 9 m thick seam utilizing mechanised non-simultaneous multi-slice longwall mining, a method employed, for example, in Britain (Whitworth, 1975), Japan (Wilson et al, 1976) and Austria (Galvin, 1978). However, in contrast to these and all other known similar operations, the authors propose to locate the lower slice panel entries beneath the upper slice interpanel pillars, Fig. 7, rather than outside these pillars and, therefore, under destressed ground as is the conventional practice, Fig. 8. The authors acknowledge that rock mechanics considerations indicate that the lower slice panel entries should be placed outside upper slice interpanel pillars but, nevertheless, they 'feel' (Bise and Ramani, 1975) that this could result in potentially dangerous roof conditions, because when the roof was serving as the

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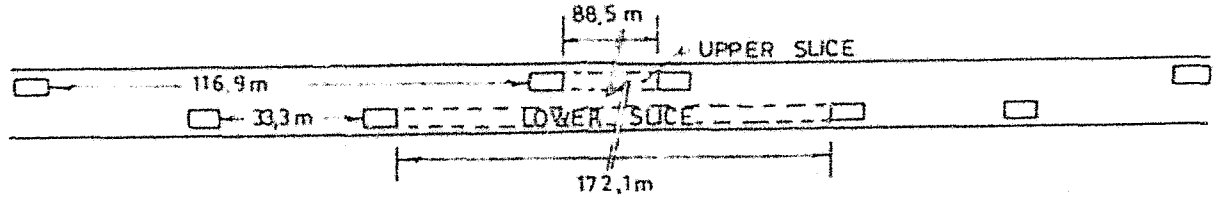
(a) Cross-section.



(b) Plan.

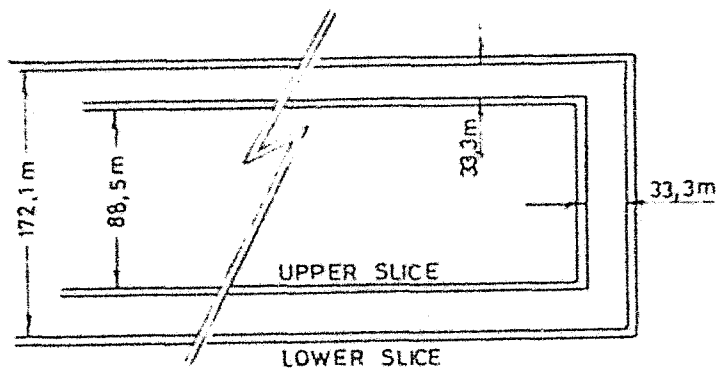
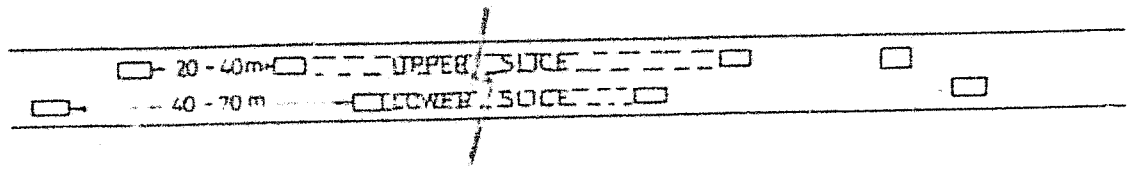


FIGURE 7 Panel entry layout for non-simultaneous multi-slice longwall mining as proposed by Bise et al. (1976).

(a) Cross-section.



(b) Plan.

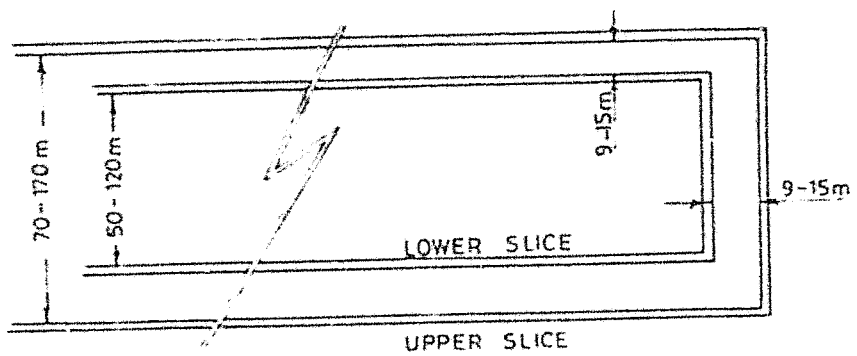
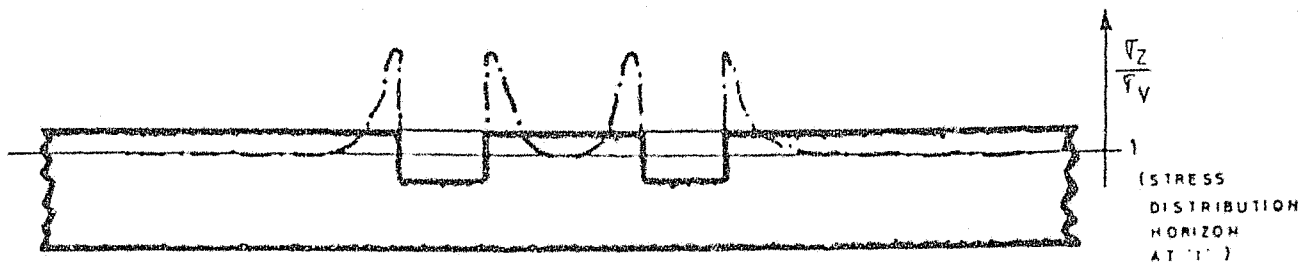


FIGURE 8 Conventional panel entry layout for non-simultaneous multi-slice longwall mining. Dimensions based on Japanese experience as reported by Wilson et al. (1976).

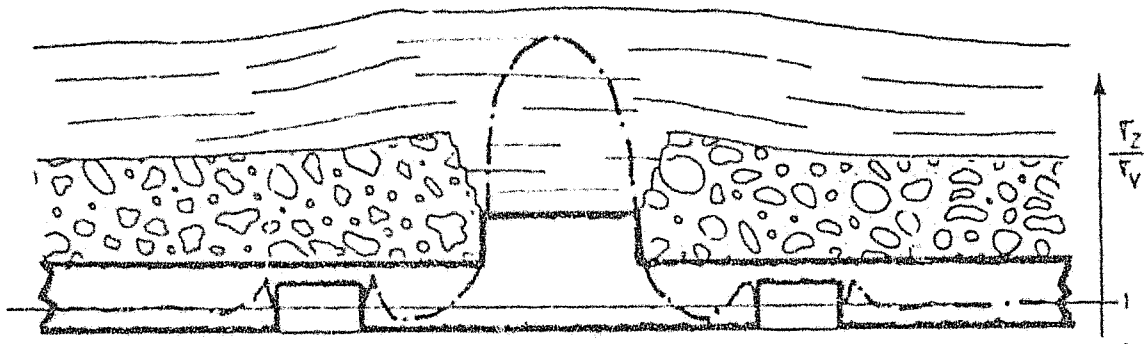
floor of the upper seam it may have been 'cracked' (Bise et al, 1976) during caving of the hanging strata.

This conclusion is unacceptable. Whilst it is reasonable to assume that the lower slice roof may be damaged while it serves as the floor of the upper slice, the damage caused by caving material is superficial and negligible when compared to that caused by the high face abutment stresses and the base pressure of the longwall support units associated with upper slice mining operations. Whilst the magnitude of abutment stresses ahead of a longwall face is a function of depth, measurements by Conroy (1977) at depth of 180 m and numerical calculations by Hebblewhite et al. (1979) for a depth of 480 m have yielded abutment stresses in the range of 2 to 2,5 times the virgin stress. Thus, at a relatively shallow depth of 300 m abutment stresses may be assumed to be in the order of 15 to 20 MPa. Since the uniaxial compressive strength of many coals is only of the same order, abutment stresses may cause considerable fracturing of the floor strata. Further secondary fracturing will be induced by stresses in the order of 1 to 5 MPa which act through the base of the support units. In comparison to the damage done to the floor strata by these two sources of stress, damage induced by controlled and friction impeded caving of the roof strata over small areas as each support unit is advanced is of no consequence.

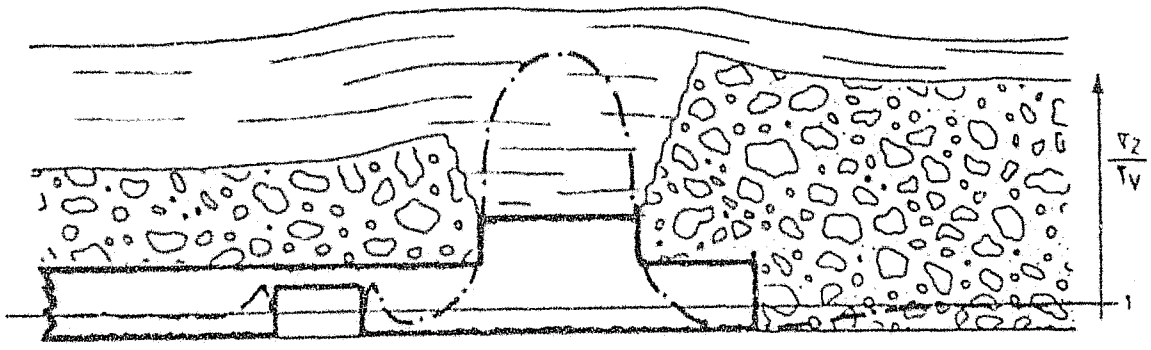
A simple and brief consideration of rock mechanics and mining principles indicates a number of disadvantages associated with the unconventional panel entry layout proposed by the authors. Some of these are highlighted in Figs. 9 and 10, which show generalized stress distribution profiles associated with interpanel pillars resulting from both a conventional panel entry and the proposed unconventional entry layout. The basic form of these profiles has been discussed in Appendix II. In



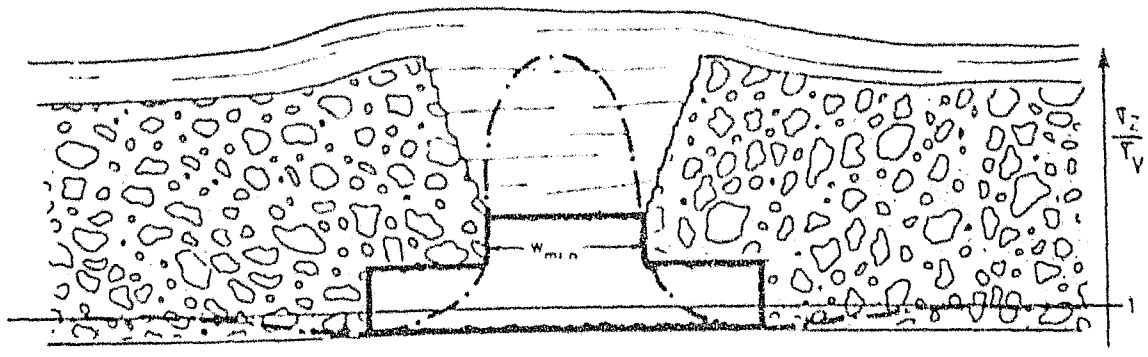
(a) Panel entry development for adjacent upper slices



(b) Adjacent upper panels extracted. Panel entry development for adjacent lower slices. Upper slice interpanel pillar formed.

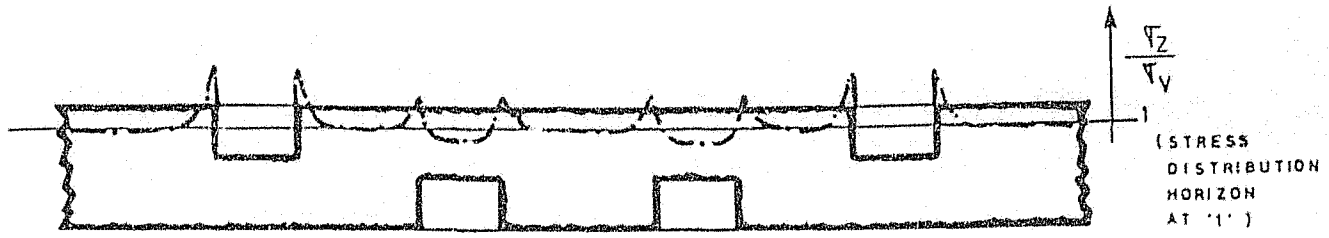


(c) Two upper slices and one lower slice extracted.

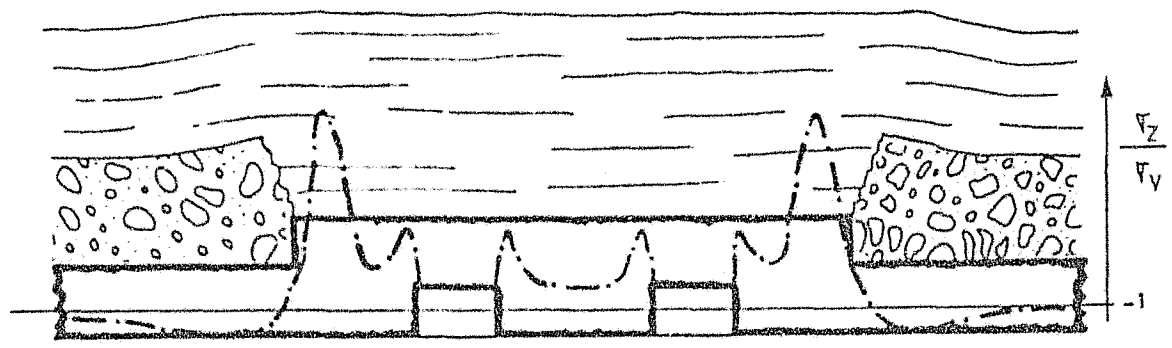


(d) All four slices extracted. Final interpanel pillar formed.

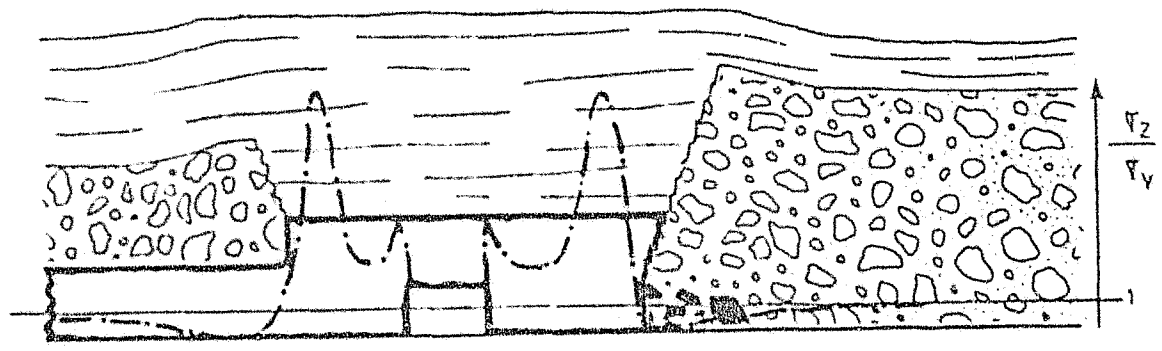
FIGURE 9 Generalized stress distribution in an interpanel pillar associated with a conventional multi-slice longwall panel entry layout.



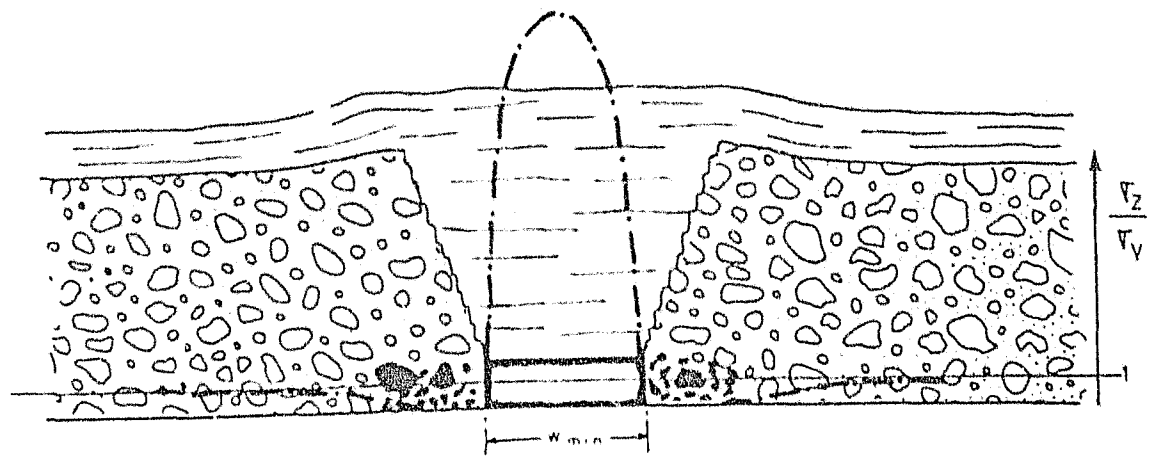
(a) Panel entry development for adjacent upper and lower slices.



(b) Adjacent upper panels extracted. Upper slice interpanel pillar formed.



(c) Top upper slices and one lower slice extracted, resulting in caving of upper slice interpanel pillar.



(d) All four slices extracted. Upper interpanel pillar reduced considerably in size due to caving when extracting lower slices. Final interpanel pillar formed.

FIGURE 10 Generalized stress distribution in an interpanel pillar associated with longwall panel entry layout proposed by Bise et al. (1976, 1977).

Figs. 9 and 10 the adjacent upper slice panels are both shown to be extracted before mining of the lower slice panels commences. This is usual in non-simultaneous multi-slice longwall mining in order to allow sufficient time for consolidation of the goaf of the first upper slice extracted before proceeding to mine immediately beneath this goaf. The disadvantages associated with the proposed unconventional panel layout include the following:

i) The upper slice interpanel pillar has to be very wide in order to avoid locating the lower slice panel entries within the high abutment stress zones, Fig. 10(b). This is especially important since the authors also propose to develop the lower slice panel entries before mining the upper slice panels. Therefore, these entries will be exposed to the travelling stress front associated with the mining of the upper slices, and consequently will be severely damaged unless they are located a considerable distance away from the upper slice panel abutments.

ii) The stress distribution through the interpanel pillar is constantly changing during the mining of the lower slice panels, Figs. 10(b), 10(c) and 10(d). In particular, due to caving of the edges of the interpanel pillar formed during mining of the upper slices, the high abutment stress moves further into the centre of the pillar, Fig. 10(c). Therefore, the lower slice entries for adjacent panels must be sufficiently far apart that the entry for the second of the two lower slice panels is not damaged by this redistribution of stresses during mining of the first panel.

iii) Locating the lower slice panel entries outside those of the upper slice results in varying face and roof

conditions along the length of the lower slice longwall faces. The extremeties of the lower longwall will be located under fractured uncaved coal, whilst the central portion of the longwall will be located under goaf. In the extreme case this could necessitate the use of two different support systems along the face.

iv) Percentage extraction may be considerably less than that achieved from conventional panel layouts. The authors (Bise et al, 1977) state,

'to minimize any side abutment pressure on the (lower slice) entries from the extraction of the upper slice, a barrier of approximately 33 m (110 ft), sufficiently large to withstand the pressures encountered, is maintained between the upper and lower gateroads, as well as between the lower lift gateroads in adjacent panels'.

Thus the maximum dimension of the interpanel pillar is in the order of 117 m. In practice, the size of this pillar is a function of depth, but for conventional multi-slice panel layouts, pillar width rarely exceeds 70 m.

v) For the same final minimum interpanel pillar width, W_{min}, (Figs. 9(d) and 10(d)) the effective width:height ratio of the interpanel pillar resulting from the unconventional panel entry layout is less than that resulting from the conventional panel entry layout because of partial caving of the upper slice interpanel pillar, Figs. 10(b) and 10(c). Since the strength of a coal pillar is directly proportional to the width:height ratio, this results in a lower strength interpanel pillar, which may be critical if the support properties of the interpanel pillar are required to support competent roof strata bridging over longwall panels.

vi) If the coal is prone to spontaneous combustion, the risk of such occurring is increased considerably. This is because a large proportion of the coal interpanel pillar between the upper slice longwall panels caves during mining of the lower slice panels and is not recovered.

The authors also propose to develop the lower face under unmined ground where good roof conditions exist, and thence to mine towards and under the upper slice goaf, leaving about 1,2 m of roof coal between the two slices. However, this method results in the formation of a small remnant pillar, as shown in Fig. 11, and the very high stresses associated with this pillar can give rise to severe strata control problems on the lower longwall face during undermining of the pillar.

No justification is provided by Bise et al. (1976) for the panel and interpanel pillar dimensions which they specify. In particular, interpanel pillar dimensions, on which the success of their proposed unconventional panel layout depends, appear to be convenient estimates. Overall, it is apparent that the authors have given little consideration to the implications of their proposals, which, under local conditions, should be disregarded.

Another paper falling in the innovative category is that by Thomas (1976), which proposes thick seam underground coal mining by a slice and fill method utilizing washery waste. The author acknowledges that he only proposes the system in broad outline and that the system has an extremely restricted application if washery waste, the characteristics of which he has yet to determine, does not prove to be a suitable fill material. The author has not decided on an actual mining sequence and mine layout nor given any consideration to the support potential and behaviour of the fill. Thus, many of the proposals are only speculative.

Author Galvin J M
Name of thesis The mining of South African thick coal seams - rock mechanics and mining considerations 1981

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