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INVESTIGATION OF PROBLEMS AND BENEFITS OF UNDERGROUND MULTIPLE SEAM COAL MINING

FINAL TECHNICAL REPORT

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The views and conclusions contained in this document are those of the authors and should not be interpreted as necessarily representing the official policies or recommendations of the U. S. Department of Energy.

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FOREWORD

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ABSTRACT

It is estimated that over 156 billion tons of coal in the United States are amenable to multiple-seam mining. However, currently most operations mine only a single seam, and in the past indiscriminate practices have sterilized large amounts of coal in continguous seams. In the interests of conservation, it is imperative that procedures be followed that enhance resource recovery.

The total life-cycle costs of mining are site specific because of the wide variations in land acquisition costs, capital expenditures, resource recovery, labor productivity, and geological conditions. However, under similar circumstances the costs of single- and multiple-seam mining are within 5 percent, using the best available technology. Improvements in present methods could lower costs of multiple-seam mining further, making it more competitive.

Ground control (entailing roof support, bumps, and subsidence) is the most important technical problem encountered in multiple-seam mining, mainly caused by remnant pillars. However, the nature and thickness of partings and overburden, as well as the type of floor, roof, and coal play a significant role. Ventilation control to prevent air leakage and gas accumulation, haulage difficulties because of floor undulations and roof falls, and fear of water innundation from an abandoned upper seam are other problems to be considered. Spontaneous heating may be experienced in some western coals.

Changes in regulations that streamline permitting procedures and encourage multiple-seam mining need to be introduced. Union attitudes that permit better coordination between seams should be fostered.

A research program addressing some of these problems is presented which costs about $5 million over a 5-year period. It is anticipated that the results of this research could lower the costs of multiple-seam mined coal by about $1.35 per ton.

EXECUTIVE SUMMARY

Conservation of the nation's energy resources requires that as much as possible of the coal reserves in the United States be exploited. In many areas of the country, coal seams overlie one another. It is therefore, imperative that each minable seam be extracted in a manner that causes minimal damage to others in the area. It was the objective of this study to ascertain how much coal was affected by multiple-seam mining, determine the technical, regulatory, and institutional problems involved, outline a program of research that would minimize these problems, and indicate the cost/benefit ratios entailed.

It was estimated that there are 229 billion tons of minable coal (under 1,000 ft of cover), of which 156 billion tons (68 percent) was amenable to multiple-seam mining. Most of this coal occurs in 8 States--Colorado, Illinois, Kentucky, Ohio, Pennsylvania, Utah, West Virginia and Wyoming.

Mine life-cycle cost analyses of single-seam and multiple-seam mining operations indicated that mining costs were highly dependent on land acquisition expenses, capital investment requirements, labor productivity, geologic conditions, and total resource recovery. Hence the precise production costs are site specific and would not be very meaningful to generalize. But comparisons of costs computed for single- and multiple-seam mining under the same conditions showed that these varied less than 5 percent. This order of magnitude of cost differentials can occur with single-seam mining because of changed geological conditions or operational procedures. Hence, it is evident that some multiple-seam operations are already competitive with single-seam mining. A well planned research program could further reduce costs and , equally significantly, conserve resources and augment safety by permitting enhanced recovery with diminished health and ground control problems.

Multiple-seam mining may entail working below a previously worked-out area (undermining), working above it (overmining), or working two or more seams concurrently (simultaneous mining). In the latter case the working faces in the upper seam could be in advance of those in the lower seam (undermining mode), or behind them (overmining mode).

In all cases, the major factors governing ground control conditions are parting and overburden thickness, nature of the parting, and roof and floor strata. Generally, ground control problems, which include roof

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In all cases, the major factors governing ground control conditions are parting and overburden thickness, nature of the parting, and roof and floor strata. Generally, ground control problems, which include roof

support requirements and potential for bumps, decrease significantly when the parting thickness-to-seam height ratio exceeds 40 (for seam heights up to 8 ft). As may be expected the parting thickness needed for the same likelihood of experiencing potential problems when working over a mine area is somewhat greater than when mining below it. Subsidence problems depend on the seam thicknesses extracted, and are reduced with simultaneous mining because surface damage only occurs once. Pillars left in a seam while mining create considerable difficulties during the extraction of both sub- and superjacent seams, and should be avoided as much as possible. Unfortunately, current mining methods and regulations in the United States require leaving a certain number of pillars.

Besides ground control, there are a number of other operations that merit attention in multiple-seam mining. Ventilation and methane control need to monitored closely since air leakage into adjacent seams can occur and gas may accumulate, especially in non-working areas in an upper seam. Large roof falls may interrupt ventilation circuits and interfere with haulage. Mine transportation is also affected by floor heave or undulations that may occur, and by water creating slippery conditions. Generally water inflow into the mine tends to drain into the lower seam, thus permitting the installation of only one set of pumping stations. However, if water collects in an upper seam there is the potential danger of an innundation. Spontaneous heating is not experienced in the Appalachian and Interior coalfields, but does occur in some western coals. The precautions that need to be taken are similar to those for single-seam mining, although this entails leaving barrier pillars. Dust problems are not unique to multiple-seam operations.

Superpositioning and columnization of entries and pillars between adjacent seams is helpful, especially if the parting thickness is small. However, this technique requires careful planning and considerable surveying and engineering skill, and should not be embarked upon lightly.

Regulatory and institutional constraints that impact multiple-seam mining relate to resource recovery, leasing procedures, mine environment, worker health and safety, mine operations, and labor practices. The Bureau of Land Management requires that leasing of coal areas be based on an evaluation of individual seams. This practice does not encourage the combined evaluation of several seams which may be preferable in some instances, and permits the leasing of different seams to different lease holders. When this occurs, coordination of workings becomes difficult. The U. S. Geological Survey requires that

workings be superposed and that the upper seam be mined first. These could be restrictive under certain circumstances. Under the Office of Surface Mining regulations, sequential mining of multiple-seams entails repetitive subsidence control measures and some states (e.g. Pennsylvania) require recurrent repairs.

Most health and safety regulations do not impose special requirements on multiple-seam operations, although more inspections may result if each seam is considered a separate mine. Maps may be required for each seam, and precautions would be needed if portions of the upper seam are water-filled. Many agencies require that the pillars be left for escapeways, ventilation, ground control, barriers, protection of surface structures or prime farmland, oil/gas wells, and other reasons. These remnants cause bumps and ground control problems when mining other seams in the area.

Some mining companies operate separate seams in the same areas different mines, so that wildcat walkouts by organized labor do not close the entire operation. This practice tends in increase costs and diminish coordination between the operations.

Based on the assessment of technical economic, and regulatory problems encountered by multiple-seam operations a research program which covers leasing and regulatory reform, examination of union attitudes, ventilation control, parting behavior, ground control investigations, economic model development, and cost studies, needs to be undertaken. It is estimated that this program will cost nearly $5 million over a 5-year period, with about $2.5 million being spent during the first 1½ years. This could reduce the cost/ton of coal mined from multiple seams by over $1.35, besides permitting greater resource recovery and improving miner health and safety. The cost/benefit ratio for various elements of the program varies--from a low of over 100 for ground control to a high of nearly 150,000 for improvements in leasing and regulations. However, as in all research programs the various elements tend to be synergetic and the overall results may be expected to be greater than the sum of the individual parts!

TASK 1

ECONOMICS OF MULTIPLE-SEAM MINING

1.0 UNITED STATES COAL RESERVES AMENABLE TO MULTIPLE-SEAM MINING

1.1 Sources of Information

Individual state geological surveys were contacted and lists of publications were obtained. The reserves estimations were based on isopach maps and State and Federal Agency Reports and Bulletins.

1.2 Method of Computing Reserves

By overlaying maps of areal distribution of individual coal seams, the "Area of Interaction" of seams was determined. This "area" multipled by the average thicknesses of the seams and divided by 25 cubic feet per ton of coal gave the tons of "Coal Subject to Multiple-Seam Mining." Often this method resulted in an over estimate. In which case, upon overlaying the seam maps, the "Area of Interaction" as a percent of the total area of seam distribution was estimated and that number multipled by the most recent in-place reserves estimated gave "The Reserves Subject to Multiple-Seam Mining" (see Table 1). Table 2 gives the number of coal seams included in the reserves estimated by State.

Wherever possible an effort was made to subtract strippable reserves, seams less than 28" thick, and seams under more than 1,000 feet of overburden.

1.3 Results Obtained

A total of 28 states were included in the reserves study. The original reserves of bituminous coal for these states totaled 229 billion tons. Of these reserves up to 156 billion tons of bituminous coal may be subject to underground multiple-seam mining.

In the Eastern coal region the estimated reserves subject to underground multiple-seam mining are as follows, by state:

West Virginia (27.8 Billion Tons),
Pennsylvania (16.61 Billion Tons),
Ohio (12.6 Billion Tons),
Eastern Kentucky (8.19 Billion Tons),
Virginia (2.7 Billion Tons),
Alabama (0.61 Billion Tons),
Tennessee (0.53 Billion Tons),
Maryland (0.31 Billion Tons),
North Carolina (0.01 Billion Tons).

TABLE 1 - Estimates or Coal Reserves Subject to Multiple Seam Mining

STATE	ESTIMATED ORIGINAL RESERVES OF BITUMINOUS COAL (MILLION TONS)	SOURCE	TOTAL MEASURED AND INDICATED RESERVE BASE, JAN. 1. 1976, 0-1,000 FT. (MILLION TONS)	ESTIMATED RESERVES OF BITUMINOUS COAL SUBJECT TO UNDERGROUI MULTIPLE-SEAM MINING (MILLION TONS)
Alabama	13,800	Culbertson, 1963	2,009	611
Alaska	19,413	Schmidt, 1979	698	209
Arizona	21,234	Schmidt, 1979	326	98
Arkansas	1,638	Schmidt, 1979	270	81
Colorado	63,203	Landis, 1959	9,144	2,743
Georgia	24	Schmidt, 1979	1	0
Illinois	104,800	Smith, Stall, 1975	67,969	57,773
Indiana	37,300	Spencer, 1953	10,714	7,268
Iowa	7,200	Landis, 1965	2,202	771
Kansas	18,668	Averitt, 1975	998	299
Eastern Ky.	33,500	Huddle, et al., 1963	11,701	8,190
Western Ky.	41,000	Kentucky G. S., 1979	14,300	10,010
Maryland	1,152	Schmidt, 1979	1,048	314
Michigan	205	Schmidt, 1979	126	38
Missouri	31,184	Schmidt, 1979	5,014	700
Montana	2,299	Keystone Manual, 1978	1,385	416
New Mexico	10,748	Schmidt, 1979	1,859	558
North Carolina	110	Schmidt, 1979	31	9
Ohio	46,600	Keystone Manual, 1978	19,230	12,600
Oklahoma	7,117	Schmidt, 1979	1,618	485
Pennsylvania	75.100	Reese, Sisler, 1928	23,727	16,609
Tennessee	1,900	Luther, 1959	965	531
Texas	6,048	Schmidt, 1979	0	0
Utah	39,300	Keystone Manual, 1978	6,552	1,965
Virginia	11,700	Berryhill, et al., 1952	4,166	2,700
Washington	1,867	Schmidt, 1979	255	77
West Virginia	116,700	Tukker, 1940	38,606	27,797
Wyoming	33,500	Glass, 1978	4,003	1,201
TOTAL	746,310		228,917	155,853

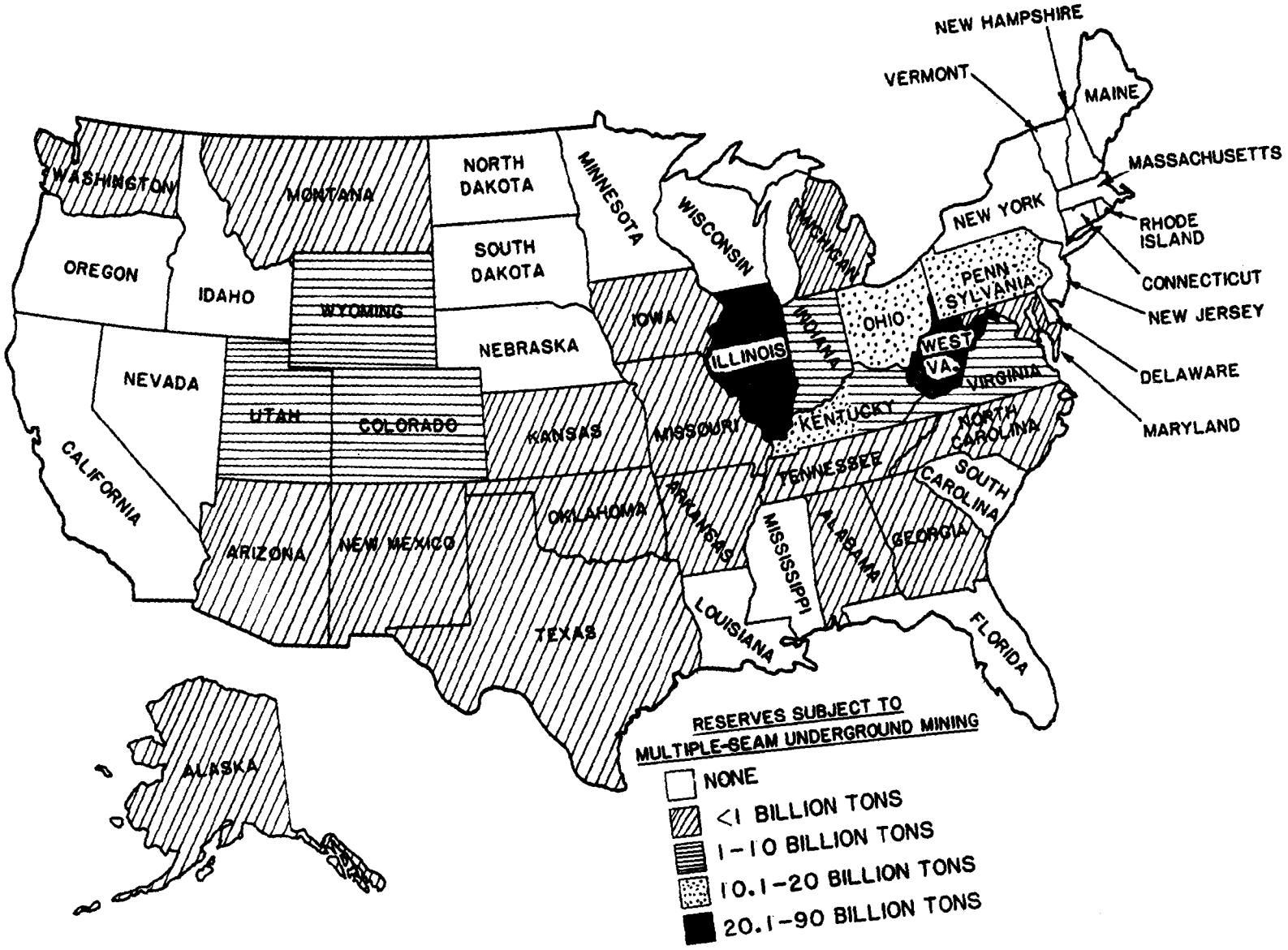


Figure 1 - U. S. Reserves Amenable to Multiple-Seam Underground Mining.

TABLE 2 - Number of Seams Included in Reserves Estimate by State

STATE	NO. OF MINABLE MULTIPLE-SEAMS
Alabama	23
Alaska	Not Available
Arizona	Not Available
Arkansas	4
Colorado	>100*
Georgia	2
Illinois	2
Indiana	12
Iowa	20
Kansas	21
Kentucky	20
Maryland	11
Michigan	2
Missouri	11
Montana	Not Available
New Mexico	Not Available
North Carolina	Not Available
Ohio	6
Oklahoma	4
Pennsylvania	9
Tennessee	27
Texas	8
Utah	>20
Virginia	17
Washington	54
West Virginia	55
Wyoming	Not Available

*Most of the minable coal seams of Colorado are lenticular and not well-correlated, thus the high figure.

The term "Not Available" implies that many of the coal seams have not been correlated and further information is needed in order to determine the number of seams. As one can see, Colorado has over 100 seams. This is probably typical of some of the coal-rich western states, such as Utah, Wyoming, and Montana, where information is scarce at this point. As these states continue to be explored, additional information will become available and better estimates of the number of seams and reserves will be possible.

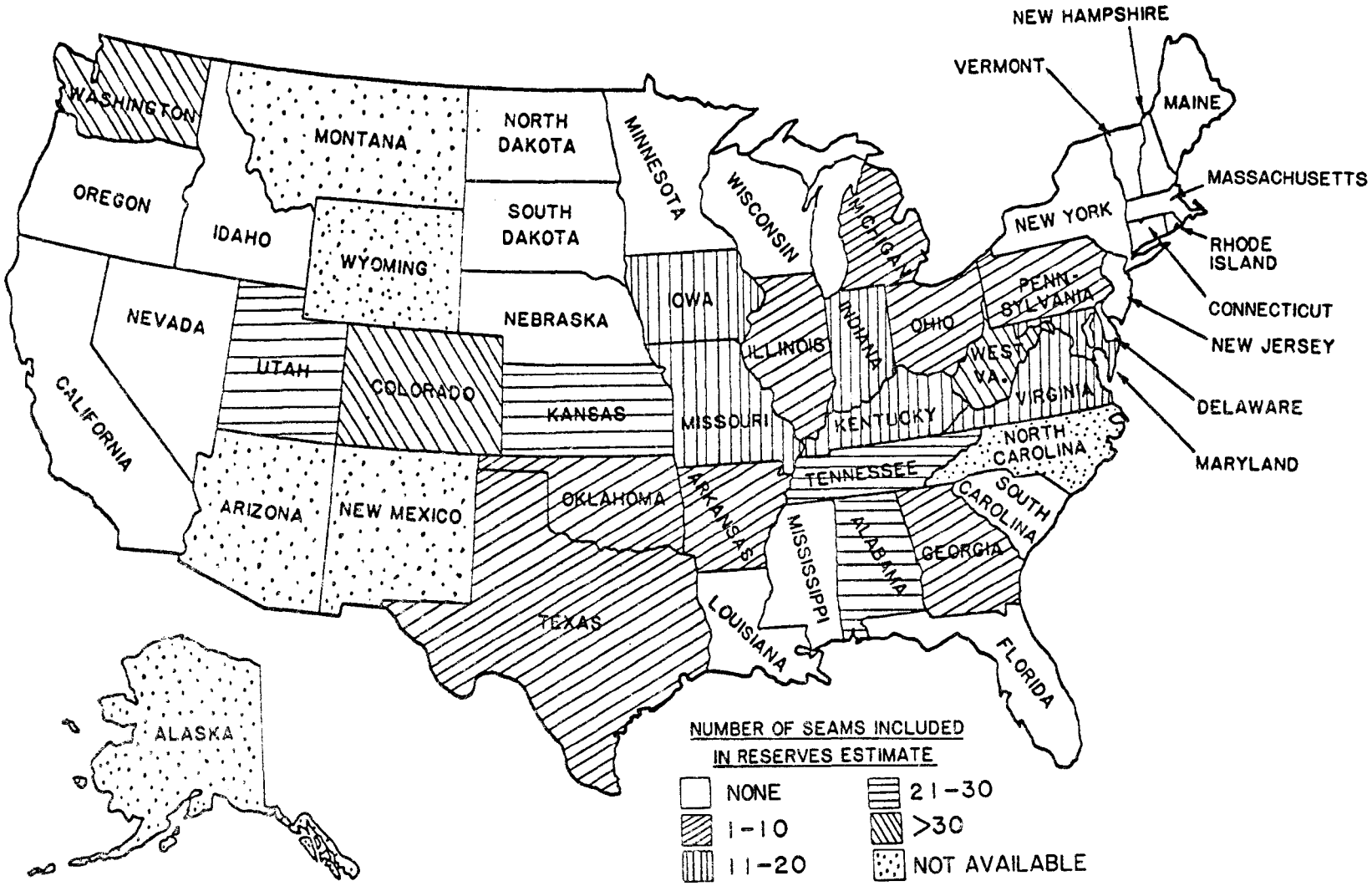


Figure 2 - Number of Seams Included in Multiple-Seam Reserve Estimates.

For the Midwest Coal Region the results are:

Illinois (57.78 Billion Tons).
Western Kentucky (10.01 Billion Tons),
Indiana (7.27 Billion Tons),
Iowa (0.77 Billion Tons),
Missouri (0.7 Billion Tons),
Oklahoma (0.49 Billion Tons),
Kansas (0.3 Billion Tons),
Arkansas (0.08 Billion Tons),
Michigan (0.04 Billion Tons).

The Western Coal Region Reserves subject to multiple-seam mining are:

Colorado (2.74 Billion Tons),
Utah (1.97 Billion Tons),
Wyoming (1.2 Billion Tons),
New Mexico (0.08 Billion Tons),
Montana (0.42 Billion Tons),
Alaska (0.21 Billion Tons),
Arizona (0.1 Billion Tons),
Washington (0.08 Billion Tons).

Texas and Georgia have no known reserves subject to multiple-seam mining.

All reserves estimates are accurate within 20 percent. As more reserves are delineated in future exploration, these reserves may increase.

2.0 REVIEW OF HRB-SINGER AND OTHER RELEVANT REPORTS

2.1 The Impact of Overmining and Undermining on the Eastern Underground Coal Reserve Base (Report prepared by HRB-Singer, Inc.)

2.1.1 Introduction

It is widely accepted that coal recovery from an underground seam, expressed as a percentage of total coal available, is reduced if prior mining has occurred in a vertically adjacent seam. Due to the magnitude of the potential losses and to the importance of coal, as a long-term source of energy a thorough understanding of seam-interaction effects is of great interest. The HRB-Singer Report reviewed here, was one of the first quantitative studies of seam interaction in the United States.

HRB-Singer, Inc., under Contract No. JO357129 from the Bureau of Mines, estimated the impact of coal seam interaction on the Eastern Coal Province. The primary objective of the study was to provide estimates of expected coal recovery, expressed as a percentage of the original in-situ reserves, when another seam had been previously overmined or undermined. Further, it was desired to understand the factors that affect the recovery and workability of the seam, so that overall recovery may be enhanced.

The report contains a considerable amount of quantitative information, but most of this is derived from maps of mines. The reliability of the data deduced from such sources is questionable, but these were used for statistical analyses and the results presented as conclusive. Because of the myriad of figures interspersed throughout the report, the relevant information can be extracted only with substantial effort. This may partly be the consequence of the fact, that it was not until the end of the study that it was recognized which variable should have been measured and which computed.

The Singer study conducted a review of the literature and a survey of opinions from experts on the subject of coal mining. In addition, studies were conducted in four (4) mines located in two states, West Virginia and Pennsylvania, in each of which a second seam was being mined. Data were gathered for both the previously- and currently-mined seam at each mine. The two types of multiple-seam mining were distinguished as follows:

> The currently-mined seam (CMS) lay above the previously-mined seam and was referred to as the undermined condition. The two mines were denoted by UM (1) and UM (2).

The currently-mined seam (CMS) lay below the previously-mined seam and was referred to as the overmined condition. The two mines were designated OM (1) and OM (2).

A major part of the discussion in the report dealt with the case of undermining and with the results from the first mine, UM (1). The data from the second undermined case do not appear to have been included in the statistical analysis.

For the two mines in the overmined condition, OM (1) and OM (2), the data were analyzed, but with little text and interpretation. This made a review difficult.

A list of twelve basic input variables were identified, and most of the computations were related thereto. These were:

1. Roof strength of currently-mined seam (CMS)
2. Floor strength of currently-mined seam (CMS)
3. Previously-mined seam (PMS) thickness
4. Percent extraction in the previously-mined seam (PMS)
5. Roof strength of the previously-mined seam (PMS)
6. Floor strength of the previously-mined seam (PMS)
7. Maximum pillar width in the previously-mined seam (PMS)
8. Maximum width of span in the previously-mined seam (PMS)
9. Distance between seams
10. Depth of the previously-mined seam (PMS)
11. Time between mining
12. Remnant pillar pattern.

Factors such as marketability and productivity have no direct impact on the technology of multiple-seam mining, but need to be considered in an economic evaluation. In fact, Lowrie (1968), has shown that higher priced coals were generally associated with higher recovery (up 10%), whereas productivity was inversely related to recovery.

The study area comprised of 9 states in the Central and Eastern United States. The four mines selected for detailed investigation, were from two eastern states and belonged to one geological formation, namely the Pottsville Group formation of the Pennsylvanian System.

In order to develop the Coal Loss Calculation Model (CLCM) planimetric measurements of the coal left underground were made from mine maps. However, to validate the CLCM, the recovery estimates used were provided by operators. It was not possible to determine how these estimated figures compared with the actual recovery achieved. It should also be borne in mind that often coal stubs left underground during pillar recovery operations are seldom depicted on mine maps.

2.1.2 Technological Considerations

2.1.2.1 Advances in Technology

The methods of extraction of underground coal seams, using room-and-pillar systems of mining, have changed enormously during the past 50 years, and especially during the last 20 years or so. Whereas the methods practiced during the 1920's and 1930's gave overall recoveries of 50-55%, current methods and equipment are quite capable of achieving a recovery of 90% assuming that the seam is flat and of relatively moderate thickness.

In the past, a seam was generally opened at portals and the entire coal area was developed into pillars up to the boundaries of the property. Then pillar extraction was started. In some cases, when difficulties were experienced a large block or chain of pillars was left intact and further mining was performed outby of the troublesome areas. This treatment of a mine as a single block resulted in significant losses of coal resources, whenever difficulties in mining are encountered.

Now the mines are invariably planned with panels which may be considered as separate, isolated blocks. With improved methods, early diagnosis of impending problems, and quick response to problems of strata control, gas drainage, ventilation, transportation and communications, even a small panel is abandoned only when safety and health considerations are involved. With current mining methods, coal recovery from a panel can vary from 60% to 90% of the in-situ reserves. The precise amount depends partly upon whether or not old gob areas are ventilated by a network of bleeder entries. For ventilation it is necessary to leave at least one line of chain pillars on one side of the panel. If there are no bleeders the panel is sealed off entirely.

In the HRB-Singer report, a review of Table VIII-1 indicates that for both the mines with undermining the average percentage extraction for a previously-mined seam was 54.57 and 48.16%, while the extraction in the currently-mined seam (CMS) was 65.17 and 64.18% respectively. This implies 10.60 and 16.02% greater extraction over the previously-mined seam. This higher recovery could be because of better technology and improved methods of mining available for the currently-mined seam. It should be noted that the time lapse between the prior and present mining activities for the two mines was 10.84 and 25.27 years respectively.

2.1.2.2 Effect of Seam Thickness

The vertical extent to which the overburden or superjacent strata is broken or disturbed depends on the thickness of the seam previously mined. A recent study conducted by Engineers International, Inc. (1979) indicates that the strata up to a distance equal to nearly 10-12 times the thickness of seam extracted is broken and fractured. The strata lying above this gradually settles on the broken rock mass. This results in surface subsidence, with tension cracks developing at the edge of the subsidence trough. The ease of working any nearby seam is affected by both the thickness of the seam and the nature and thickness of parting between the seams. Cognizance of the thickness of the parting has been taken into consideration in the HRB-Singer equations derived statistically, but the thickness of the seam mined has dropped out as not being significant. This does not appear reasonable from a physical viewpoint.

2.1.2.3 Size of Remnant Pillars

In the past, mine surveys and plans were made using instruments that were not as precise as those available now. Generally measurements of remnant pillars are seldom made at the time of abandonment. The remnant pillar is either shown on such plans as either fully extracted, or at best its approximate size is shown. This gives rise to inaccuracies with respect to maximum span width, minimum and maximum size of pillars, and the shape and configuration of the remnant pillars.

The occurrence of such practices is borne out by the experience of HRB-Singer in the computation of extractions from mine UM (1). In this case, in 19 blocks (each of 16 acres) 100% extraction was noted in the previously-mined seam using room-and-pillar mining. However, in such workings some pillars are invariably left for maintaining roadways for supply, haulage, and escape routes. Besides pillar stubs are also left behind for safety reasons. Thus full extraction is not possible from any block.

2.1.2.4 Percentage of Coal Extraction in the Two Seams

The percentage extraction from individual blocks in the previously-mined seam (PMS) was found to vary from as little as 15% in two blocks to 100% in 19 blocks, out of a total

sample population of 50 blocks. Coal losses were attributed to:

- surface support
- control of subsidence
- maintenance of entries for normal mining operations
- difficult mining conditions arising from geologic, tectonic, or technical considerations

A comparison with the percentage extraction in the corresponding blocks in the CMS indicates that generally this increases or decreases in the same manner as the PMS, with relatively few exceptions. This implies that probably the same factors govern recovery in both the seams, even though there was no superposition of entries and pillars in the two seams.

2.1.3 Statistical Analysis

Two independent approaches for predicting the loss of coal due to seam interaction were attempted. The first was statistical, based on principal components analysis and multiple regression. The second was an engineering model, based on a set of empirical and assumed relationships.

In any statistical study one must be assured that a population is defined in advance, and that a sample is drawn from that population. Theory requires that the sample be drawn at random. Measurements are then made on the sample members. If the results are aggregated suitably, and if certain other things are true, one can then make an inference or induction as to the population at large. In the HRB-Singer study the target inference was an estimate of the percent of coal recovery in the currently-mined seam (CMS).

For each mine the population was defined geometrically. For mine UM (1) the entire mine was divided into square blocks of 16 acres each. The result was 287 such blocks, each block being about 834 feet on a side. An association was made here. The behavior in a 16-acre block in the CMS was to be predicted from the history in the vertically adjacent 16-acre block in the previously-mined seam (PMS).

For each of the 50 blocks some 43 observations were made. For each block an additional 20 variables were calculated resulting in 63 variables or observations for each block. Among the 63 are perhaps 4 or 5 variables that one wishes to predict. All others are candidates for prediction.

It does not seem useful to define all 63 variables here as most of them play little role. However, a few variables are central to the argument and it is useful to repeat their definitions here:

X_{15}	CMS % extraction
X_{37}	PMS % extraction
X_{52}	Vertical distance between the seams (feet)
X_{60}	PMS depth of overburden (feet)
X_{61}	Time elapsed between mining vertically adjacent blocks (years)

Each variable has a fixed value in each sample block.

In a prediction model the analyst has two competing objectives. First, one wants the model to be simple. This means that the predictors chosen should be few and should be easy to measure. It is especially useful if the predictors can all be measured in advance. Second, one wants to have an accurate prediction. This tends to increase the number of predictors as well as their expense and complexity. What normally happens is that the law of diminishing returns applies. Suppose there are 50 candidate predictors available. The best 4 predictors might describe, say, 50 percent of the total variation. If the next best 4 are included with the first 4 one might be able to describe, say, 60 percent of the total variation. With all 50 predictors one might still only describe 70 or so percent of the total variation. This occurs because relevant predictors may have been ignored entirely, because of non-randomness in the sample, or because of measurement errors.

If the prediction model is statistically based, the situation can be rather worse than that described above. What one wants are predictors that are statistically independent. Then, when a new predictor variable is included, new independent information is added to the prediction. One cannot assume that the candidate predictors will be independent. Here is a case from UM (1). Let X_{54} be a candidate predictor defined as

X_{54} Maximum subsidence.

A calculation shows that X_{54} is highly correlated with X_{37}, PMS percent extraction, at 0.979. Thus if X_{37} exists in the model as a predictor, and X_{54} is then included as another predictor, nearly no new information is added to the equation. One can say that X_{37} and X_{54} are near perfect proxies or surrogates for each other. Including both in the prediction model, however, tends to destabilize the calculation which produces the (regression) coefficients in the prediction equation.

The existence of relationships among variables can be explored most easily by applying principal components analysis. The result is to classify the variables into (approximately) independent sets, and to identify redundant variables. This was done. For the dependent variable (predicted variable) 4 candidates were identified but X_{15} (defined above) was chosen as representative. A group of five dependent variables (predictors) was identified and X_{37} was chosen as representative. Another group of 8 dependent variables was found and X_{60} was chosen. Finally, a separate argument, based on factor loadings, led to the inclusion of X_{52} and X_{61} as predictors.

Strictly speaking, the program described above was carried out twice for mine UM (1). In the first case 19 blocks were removed from the sample of 50 blocks. In each of these 19 blocks the previously mined seam had been completely mined (X_{37} = 100%). The rationale was that if pillars in the previously mined seam had an effect on coal recovery in the current seam, then one could not legitimately use variables describing these pillars if the pillars had all been removed. There were three such variables:

X_{55} PMS Pillar Strength

X_{56} PMS Pillar Load

X_{57} PMS Ratio of Pillar Strength to Load.

This is all to say that, with sample size n= 31 blocks, the principal components analysis was run including X_{55}, X_{56} and X_{57} as potential candidate predictors. They were later excluded, as outlined above. Subsequently a prediction equation was found based on the 31 blocks.

In the second case the complete sample of 50 blocks was used, but variables X_{55}, X_{56} and X_{57} were excluded as candidate predictors. The principal components analysis was run and a new, somewhat different, prediction equation was found.

The next step in the analysis is to produce the prediction equation. This is readily done using multiple linear regression. One assumes a functional form such as

$$X_{15} = \alpha + \beta_1 X_{37} + \beta_2 X_{52} + \beta_3 X_{60} + \beta_4 \log X_{61}$$

and determines the α and β coefficients based on the data. The logarithm of X_{61} was used instead of X_{61}, it is not clear to the reviewer why this was done. The two prediction equations obtained were, for m = 31:

$$X_{15} = 146.824 + 0.2718 X_{37} + 0.2563 X_{52} + 0.0307 X_{60} - 105.5506 \log X_{61},$$

with $R = 0.668$ and $R^2 = 0.446$.

and for m = 50:

$$X_{15} = 191.823 + 0.2266 X_{37} - 0.1583 X_{52} + 0.0158 X_{60} - 105.8583 \log X_{61},$$

with $R = 0.50$ and $R^2 = 0.25$

The quantity R is the coefficient of multiple correlation while R^2 is the coefficient of multiple determination. The latter quantity is interpreted by the ratio

$$R^2 = \frac{\text{Variation of } X_{15} \text{ explained by all predictors}}{\text{Total variation of } X_{15}}$$

The authors stated that while both values of R are significant at the 2.5 percent level, both equations have low predictive ability. They attribute this to the fact that all the predictor variables relate to the previously-mined seam (PMS), and not to the current seam (CMS). This is about as far as the report has carried the statistical calculations. The report does contain numerous additional regression equations for all three mines based on different choices of predictors. An elaboration of these alternatives would be tedious and would add little to the discussion which follows. Instead, at this point an attempt will be made to interpret the results and to suggest some variations on the analysis which might prove more productive. It should be kept in mind that the work described by the authors was finished in 1976. Statistical data of the type gathered and analyzed had apparently never been collected before. With this background the choice of principal components analysis followed by multiple regression is perfectly reasonable. In view of the number and variety of predictors actually included one would have been entitled to believe that excellent predictions could be achieved.

The HRB-Singer report states in several places that the results are mine specific. This is clearly true. Suppose a new mine is to be considered. One might be willing to assume that the functional form of the prediction equation is appropriate with X_{37}, X_{52}, X_{60} and X_{61} as predictors. However, new data would have to be gathered and new α and β coefficients would have to be computed. For one thing the lithology will be different; this will surely have an effect on the coefficients. Also, in UM (1) and the other mines studied only room-and-pillar extraction was used. If shortwall or longwall is used one would expect the prediction to change. Finally, it may be necessary to repeat the principal components analysis as well. For example variable X_{22} refers to roof problems in the currently-mined seam (CMS). For mine UM (1), X_{22} was equal to zero for all 50 problems. Thus X_{22} was never considered as a candidate predictor. However, in the new mine X_{22} could be highly relevant.

One result that might have been useful, would have been if the variable X_{15} had been computed for all the remaining blocks in the mine. This could then be compared with the observed percent extraction for each block. Of the 287 blocks available only 31 or 50 were used. The extention to all of the blocks would have required an additional 5 observations for the remaining blocks, and may have been beyond the scope of the study. This would have been a legitimate use of the prediction equation.

Another calculation that would have been of interest would be to provide interval estimates for the predicted quantities. The result might take the form: "We are 95% confident that X_{15} lies in the range

$$\text{Lower Limit} \leq X_{15} \leq \text{Upper Limit.}"$$

Here Lower Limit and Upper Limit will vary from block to block, but they can be computed as a byproduct of the regression analysis. The output listing already contains the the standard error of estimate. Also, it would have been possible to provide an interval estimate for the average percent extraction in the entire currently-mined seam. The width of the interval estimate gives an indication of the accuracy achieved.

Recall the objective of estimating the coal loss attributable solely to mining a second seam. The statistical portion of the current study, however, does not attempt to reconcile the multiple-seam case with the single-seam case. Here is an approach that might lead to the desired result. Select a number of multiple-seam mines. Divide each mine into square blocks and measure the percent extraction in each block.

For each mine construct a frequency distribution. Do the same for a number of single-seam mines. A comparison of the distributions could then be made. It would be necessary to pair multiple-seam mines and single-seam mines on the basis of other factors. These might include method of mining, seam thickness, depth of overburden, and so on. To gather the data would be tedious, but the analysis and interpretation are straight forward.

Now consider the coefficients found for the prediction equations of mine UM (1). The results were $\beta_1 = + 0.2718$ (for m = 31) and $\beta_1 = + 0.2266$ (for m = 50). The report tells us that both are statistically significant at the 5 percent level. For m = 31 this means that if X_{37}, the percent extraction in the previously mined seam, increases one percent then the extraction in the current seam should increase by about 0.2718 percent. At first glance this does not seem reasonable. To the extent that settling is a problem, recovery in the current upper seam should decrease when more complete recovery had occurred in the lower seam. That is, β_1 should be negative. There may be, however, other factors in some blocks, which permit higher recovery in the first seam, and are still present to permit higher recovery in the later vertically adjacent block. If those factors could be isolated they might make better predictions than X_{37}.

Next consider β_2. This coefficient is attached to X_{52} which is the vertical distance between seams, i.e., parting thickness. For m = 31 the result was $\beta_2 = 0.2562$, while, for m = 50, the result was $\beta_2 = - 0.1583$. The authors claim both results are significant at varying levels. This is disturbing. How can the quantity be significant when it is positive, and then still be significant when it is negative. A positive coefficient seems reasonable; it is not clear why the negative result occurred.

The last term in the prediction equation was $\beta_4 \log X_{61}$. Here X_{61} is the elapsed time between mining. β_4 was about -105 and is significant at the 2.5 percent level. The negative sign is troublesome again. One would think that an extended delay in mining would lead to a more stable floor and roof in the current seam and therefore greater recovery. In fact, in many multiple-seam mines it is standard practice to mine an adjacent seam 8-10 years after the first seam, so that the strata have settled. Also, with a greater time elaspe there might be better technology producing higher recovery. Finally, however, there may be more stringent safety requirements in effect for the later seam which would tend to reduce recovery percentages.

The last topic in the discussion of the statistical approach concerns the choice of predictors. It was noted that the regression equation does not have predictors

relating to the currently-mined seam (CMS). This is an advantage if mining has not yet begun in the new seam. A number of possible predictors based on the current seam were tested but, as described above, were not included in the prediction equation. In an extended investigation such as this, one often wonders whether there is a superior predictor that was gathered. For example, no economic factors were included. Finally, something should be said about the nature of the predictors that were incorporated in the prediction equation. All of them are of quantitative or interval type. This means that they vary continuously and that it is legitimate to compute means and standard deviations for them, and to compute correlations among them. To take one case consider variable X_{21}, which refers to roof problems in the CMS. This is a nominal or categorical variable and is coded zero if there are no problems and coded one otherwise. This variable appears not to have been included in the principal components analysis. Had it been selected for a predictor, however, multiple regression might be inappropriate. Analysis of covariance would probably be the choice.

2.1.4 Engineering Model

The second approach to computing the expected coal loss was the engineering model. This was based on theories of rock mechanics, subsidence, seam interaction, and working rules were adopted for the calculation and prediction of specific reactions, ratios, and limiting values. These were determined from a review of the literature and definitions of critical parameters, and were modified to meet specific conditions as required. The model considered two major effects of seam interaction:

1. Subsidence due to undermining

2. High stresses due to remnant pillars.

Engineering judgement was used in the absence of specific supporting data. A set of engineering relationships were established based on some assumptions, so as to estimate the coal loss. The process may be described simply:

1. Determine if subsidence will occur. If it does, calculate the maximum subsidence and percent subsidence. A percent coal loss is then assigned. This step is omitted if the currently-mined seam (CMS) is underlying

2. Determine if high stress-zone effects will occur. If they do, assign a coal loss percentage based on the geometry and on the strength of the roof and floor in the

current seam. The coal-loss percentage is then adjusted according to the pillar pattern, the pillar alignment and the depth of the previously mined seam (PMS).

3. The actual coal-loss percentage is then reported as the larger of the percentages found in steps one and two.

As in the case of the statistical model the seams are divided into 4-acre or 16-acre blocks. The 3 steps above are executed for each block in the sample and the results are averaged.

The engineering model requires 12 input quantities for each block, compared to 4 used in the statistical model. These quantities were listed earlier but may be repeated here:

1. Percent extraction in PMS
2. Distance between seams
3. Seam thickness or pillar height in PMS
4. Span in PMS
5. Depth of overburden for PMS
6. Strength of roof in PMS
7. Strength of roof in CMS
8. Strength of floor in PMS
9. Strength of floor in CMS
10. Minimum pillar width in PMS
11. Elapsed time since previous mining
12. Multiplier describing shape and distribution of remaining pillars.

Clearly a model based on more input data has the potential for better accuracy than a model based on less. It is not clear, however, if the desired accuracy has been achieved in the engineering model.

Consider the coal losses computed in step one. These are restricted to lie between zero percent and an arbitary upper limit of 30 percent. For moderate subsidence an assignment of coal loss is then made between these limits but this is also arbitrary. Similar remarks apply for step two. Finally, in step three, it is not certain that this is the most appropriate way to combine the coal losses.

Related to this model it should be noted that some of the coefficients seem to be rather elastic. That is, they may have to be adjusted for the mine, or at least for the region. This occurs, for instance, on page 102 of the HRB-Singer report in connection with the formula for maximum subsidence.

Similarily, the choice of the last input item, the multiplier describing pillar geometry, is necessarily subjective. The model does provide a percentage coal loss for each block. Suppose a 15-percent loss is computed for a given block. The model does not tell whether expected recovery is reduced from 80 percent to 65 percent or whether it is reduced from 50 percent to 35 percent. This is in contrast to the statistical model. There, one might learn that expected recovery is 60 percent, but the model does not provide an estimate of what the recovery would have been if there were no previously-mined seam.

It should not be concluded that the model is not appropriate. On the face of it the assumptions seem as reasonable as any that might have been made. However, analysis by itself is unable to provide a justification of the model. That requires a full scale validation based on field data.

The authors do offer some data attempting to validate the model. Apparently in each of the 4 mines there were a few blocks in the currently-mined seam which had not been previously undermined or overmined. However, the number of these blocks available were too small to provide an adequate validation. The numbers of single-seam blocks available were 2, 3, 20 and 7 for the mines UM (1), OM (1), OM (2) and UM (2) respectively. Also, for the first three mines, the double-seam blocks were chosen deliberately from those where coal loss was being experienced.

A field validation requires larger samples as well as a random selection of blocks. Ideally mines could be found where the currently mined seam has, say, 30 or more single-seam blocks, and another 30 or more double-seam blocks. A statistical test of a simple type would then confirm or reject the validity of the model. It may be that the needed data already exist. The engineering model has been available for distribution as a computer program. A survey of the program users might produce some sample mines for the validation effort. However, it appears to the reviewers that the program has never been used by any mines since it was developed.

2.1.5 Comments

The HRB-Singer report presents a generalized overview of the problems associated with undermining and overmining, with specific examples as to problems that are encountered.

The primary objective of the study was to estimate the effect of undermining or overmining on the expected coal recovery in the second seam. Two models were developed to accomplish this. In the statistical model for the undermining situation, a regression equation was developed with a predictive ability of only 25% (at the 95% confidence level) and restricted in use to specific mines.

The report states:

> "Results obtained from this analysis must be used with caution. The data used are mine specific, and hence, the results apply to mine specific situations."

It appears that the model derived from mine UM (1) data could not be applied to mine UM (2).

In case of overmining situations, the study does not provide any equation or model.

The report reads:

> "The statistical analysis was extremely useful in that it aided in the selection of the significant variables that should be used in the engineering assessment model and provided estimates of the total coal loss to be expected in current-mining practices in areas where multiple-seam mining has occurred."

The engineering model is based on empirical constants and coefficients, which need to be determined for each mine, and even within a mine. This limits the value of the model. Quoting the report on the utility of the coal loss model:

> "It is therefore specific in the prediction of coal loss in the reserve seam as a result of conditions caused by factors originating in a specified previously-mined seam. The CLCM may theroretically be extended to predict the general effects on the same reserve seam by the same previously-mined seam within the county supplying the original mine prediction data. It may be difficult to project, for a given county, exactly how much of each type of mining has or will occur and what the combined effect will be on the reserve seam. The CLCM, however, can be used to provide maximum or worst-case effects

of each type of mining on the coal reserve tonnages. The possibilities for handling the data are many.

Specific mine data should be used to characterize each natural subregion. Extending predicted coal losses from one subregion to another, even though the identical seams are represented, would be stretching the acceptability of the model beyond researched results. Theoretically, this can be done by applying a regional multiplier based on the expected reaction of the varying lithologic and tectonic parameters from one subregion to another, provided, again that the two identical coal seams being considered are present and that basic input parameters are relatively the same. Since this is highly unlikely between certain subregions and even within certain subregions, the uncertainties involved outweigh the probabilities for successful predictions.

HRB-Singer's position is that specific mine data should be used to characterize each of the twenty subregions in the eastern bituminous underground coal reserve base, and that, where possible, this should be done county by county."

The reviewers believe that the results obtained by the investigators were quite adequate, considering the scope of the study. It is difficult to isolate a few governing parameters in multiple-seam mining, which would be applicable over the wide range of geologic, economic, and technical conditions that exist throughout the country, or even within a single coal province - such as the Eastern region. Besides, the duration of mining extends over a period of 20 to 50 years or more. During such an extended period factors such as market conditions, technologic advances, management techniques, federal and state laws, workers' attitudes, and physical and environmental working conditions may have much greater effects on the percentage coal recovery from a seam than those due to seam interaction. Even with simultaneous mining, had such data been obtainable, this is a task of considerable complexity, not amenable to ready resolution.

2.2 A Study of Problems Encountered in Multiple-Seam Coal Mining in the Eastern United States.

(VPI Bulletin prepared by Mr. David T. Stemple).

2.2.1 Introduction

Even as far back as a quarter of a century ago there was concern over the rapid depletion of premimum coal seams in the Eastern Coal Province of the United States. This led to a study of the effects of mining a seam on the overlying and underlying beds which was intended to address the following parameters related to the disturbances that may be caused thereby:

- amount of damage
- manifestations of disturbance
- coal losses incurred
- areal extent
- method of minimizing.

The study was conducted by Mr. David T. Stemple as a part of his thesis for a master's degree and was published as Bulletin no. 107 by the Virginia Polytechnic Institute Engineering Experimentation Station. The results reported are partially based on a review of the existing literature and partially on the results of information collected from coal companies, primarily located in Pennsylvania and West Virginia.

2.2.2 Subsidence

Subsidence is of major concern to the mining of multiple seams, and this subject is discussed at some length in the bulletin. Various references that were current at the time are mentioned. However, considerable research has been done on subsidence in the past 25 years in both Europe and the United States, so some of the facts in the report are somewhat outdated.

The bulletin quotes British experience where the amplitude of subsidence decreases with depth, from 75 percent to 15 percent. Similar observations were noted in the U. S. (Eastern Province). In Belgium the amplitude of subsidence was noted to be 30 percent, irrespective of depth. Now, in Britain the maximum subsidence is generally taken to be 90% of seam height, although it could be a little lower (75%) for shallow beds (NCB, 1975). In the U. S. subsidence has

been quoted to extend from 6 months to as much as 50 years. The depth of overburden, nature of the strata, seam thickness, and mining method are governing factors. A wide range of this type is not very helpful to industry. It would be well to note that in the U. S. most of the subsidence occurs within weeks, and it essentially ceases within about 6 months with full mining. (Adamek, 1981, Abel, 1981).

The Stemple report finds that in the U. S. (Eastern coalfield) the angle of draw ranges from 0 to 20 degrees. In Limburg (Belgium) angles of up to 45 degrees have been noted. The NCB now suggests 35 degrees as the angle of draw and this figure has been commonly used in this country for design or legal purposes (e.g. Pennsylvania). In the Midwest angles of draw ranging between 14 degrees and 30 degrees have been noted (Wade & Conroy, 1977). In the Rocky Mountain area, and angle of draw of about 15.5 degrees has been observed (Gentry & Abel, 1977).

The method of mining, i.e. room-and-pillar or longwall affects both the nature and extent of subsidence. If pillars are left in place, they deteriorate over time and crush. This makes the time of subsidence uncertain. The report discusses the mechanism of subsidence and the theories in vogue at the time. However it fails to mention "piping" type of subsidence (i.e. gradual collapse of a pipe of strata until it manifests itself at the surface) which causes "potholes", a feature not uncommon in the Pennsylvania - West Virginia area, where the study was conducted.

The author appears to promote the concept that below a certain depth, the pressure arch will help support the overburden, and subsidence will not propagate to the surface. This is contradictory to the evidence of European mines, which are all considerably deeper than most U. S. mines. The width (W) of the pressure arch in feet was given by

$$W = 3\left(\frac{D}{20} + 20\right)$$

and D is the depth in feet. This relation is still used in making estimates of the pressure arch width (SME Mining Eng. Hdbk, 1973).

Geological structure affects subsidence, and this is recognized. From this is derived the conclusion that there is a "possibility of subsidence affecting a subjacent seam, provided that it was not too far below the one being mined." Consideration of the pressure arch, however, leads to the conclusion that subjacent seams are influenced by mining as much as 200 feet above. An aspect of the effect of geological

conditions that is not mentioned in the report is that European conclusions on multiple-seam mining cannot be embraced for U. S. conditions without careful study and, perhaps, modification.

2.2.3 Support

The bulletin states that leaving 50 to 60 percent of the coal seam does not allow any subsidence to take place either in the seams above or at the surface, provided the pillars are uniform and of regular size, the roadways between the pillars are not unduly wide, and the floor and roof strata are sufficiently competent. By leaving this coal behind, however, there is an economic loss in the value of the commodity being produced. The size of pillars that needs to be left in-place increases with depth; hence the percentage extraction decreases. An alternative method of providing the same support is by backfilling.

The amount of coal that needs to be left in place for support depends upon the depth of the coalbed, the strength of the coal in the pillars, and the nature of the overlying and underlying strata. The extent of overburden determines the ultimate weight which needs to be borne by the remaining pillars. The strength of coal has been determined in the laboratory, but its strength in pillars is still open to conjecture, although some investigations to this end have been made recently (Bieniawski 1969, Wilson and Ashwin, 1972, Panek 1979). Further, the report suggests that pillars left behind should be uniform both as to size and shape, but that the exact size remains to be determined. If the overlying strata is strong then it has a beam-type action, and it tends to fill the voids when it breaks. If the bottom is soft shale then it tends to flow under the weight above, because of its plasticity.

Of all the mines studied by Stemple, in no case where 50% or more coal was left in place was any surface subsidence observed. In two instances where 50% of the coal was mined, there was some subsidence under 200 ft to 350 ft of cover. It was reasoned that this may have been due to shifting of the overburden, and because the overburden was not thick enough to provide a strong beam. It is claimed that if the beam had been thicker or had stronger rock layers in it then such subsidence would not have occurred. In another case where only 40 to 45% of the coal had been left behind the surface was undisturbed, but stress concentrations were noted in the seam below. It was concluded that this would have caused problems had multiple-seam mining been undertaken. Even in cases where 40% of

the coal was left in place, there was no subsidence under overburdens upto 300 ft thick. In those cases where subsidence did occur this was because the floor strata were soft and heaved, not because of pillar failure.

In the anthracite region, it is suggested that if surface protection is desired about 40% of the coal needs to be left in the upper veins and about 60% in the lower veins. This has been proven inadequate, however, as evidenced by the number of subsidence incidents observed in the area during the last two decades.

Based on these observations a guideline is provided, which states that for bituminous coalbeds not exceeding 6 ft to 7 ft in thickness, the amount of coal left in pillars is dependent upon overburden thickness as follows:

Overburden	Coal in Pillars
upto 250 ft	40%
250 ft to 500 ft	50%
over 500 ft	60%

An additional caveat is that there should not be too many clay minerals, such as montmorillonite, in the floor. The amount of clays that can be tolerated is not specified. The long-term effects of water collecting in abandoned mines is evidently not considered.

If two seams are close to one another superpositioning of layouts should be practiced, i.e. pillars should be located above pillars and entries above entries. This is especially desirable if the intervening strata are weak shales. If the intervening strata are strong, they tend to bridge between the pillars and superpositioning is not as necessary. In the latter case, it may be preferable to have staggered pillars, since these may provide more rigid support for the surface. It should be pointed out, however, that in accord with the pressure arch theory, staggered pillars result in an increase in the effective width of the openings.

If the roof or floor of the seams being mined are soft and plastic there may be some sag or heave in these members, which accentuates the surface subsidence.

2.2.4 Multiple-Seam Mining

The problems encountered in multiple-seam mining are not as bad as are generally imagined. The damage done to an upper seam by previously working a lower seam depends on the thickness of the lower seam, the method of working, and the thickness of the parting between the beds. It may be pointed out that under favorable circumstances the upper seam may show very little disturbance because of the prior working of a lower seam. In fact, shearing of the upper seam occurs and this may facilitate the extraction of that seam.

If an upper seam has been developed before a lower seam is mined, then considerable amount of breakage can occur in the upper seam. However, if the lower seam is mined completely prior to mining the upper seam the damage may not be excessively deleterious, since no remnant pillars exist. This becomes more significant with lapse of time.

2.2.4.1 Lower Seam Mined First

The investigation showed that the most common phenomenon observed was that cracking or horizontal parting of the overlying strata occurred. This was most noticeable in the roof of the upper seam because the cracks in the floor of this seam became filled with silt and other material. This cracking did not cause any problems as far as the recovery of the upper seam was concerned, except in necessitating a small amount of additional support. If the cracks between the seams remained open, any water that collected in the upper seam drained to the lower bed facilitating pumping. Cracks of this sort disrupted ventilation in that, either unwanted air was drawn in or shortcircuiting of the ventilation network occurred.

Often the upper seam was displaced vertically, from a fraction of an inch to as much as a few feet depending upon the thickness of the lower seam that was mined. If displacement was a gradual bending of the strata, it was accompanied by a series of cracks similar to fracture cleavage associated with natural faulting. On the other hand, if the displacement was abrupt, poor roof conditions were found in its vicinity and could extend as far as a few hundred feet from the discontinuity. Occasionally, separation of the strata occurred. This implied that either the floor dropped away from the coal (if the cohesion of the coal to the roof was strong) or the coal separated from the roof. This type of disturbance did not necessarily present any difficulty in mining. In the early days of mining it was helpful if the coal remained with the roof, because undercutting was eliminated. But, it did introduce problems in ventilation.

Other disturbances noted were roof falls, floor heaves, and pillar crushing or squeezing. This is due to excess weight on pillars, and may even be observed with single-seam mining, but multiple-seam mining may aggravate the situation. Existence of a poor roof causes the most problems in mining an upper seam below which the lower seam has already been extracted. Support costs may be increased significantly and occasionally some of the coal cannot be recovered and may be abandoned. Maximum disturbance in the upper seam was generally observed when isolated pillars, groups of pillars, or solid coal (barrier pillars, chain pillars) were left in the lower seam. This caused the upper seam to shear along the coal line in the lower seam. The maximum damage area, however, often did not lie immediately over the edge of the coal but at a distance of between 100 and 300 ft from it, on the gob side. This may be explained by the cantilever action of the parting strata; the zone of maximum tension occurs some distance away from the supported end. In most cases, the angle of draw to the surface was noted to be either zero or very slightly positive.

The report states that if the lower seam has been mined previously, the operator has no control over the damage that may occur to the upper seam, and can only plan for bad conditions over pillars left in the lower seam. Whenever possible an attempt should be made to get complete extraction in the lower seam, and pillars that cannot be recovered should be destroyed as to their strength by blasting, so that uniform subsidence occurs. An example is quoted where breaks were encountered in an upper seam which corresponded to pillar falls in the lower seam. It is noted that there was no difficulty in mining, not even requiring additional timbering.

Less disturbance is caused when the lower seam is thin rather than thick. The nature of the strata between seams has an influence; if the roof of the lower seam is a shale followed by a sandstone the tendency is for the upper seam to bend rather than break, because the shale fills the voids and the sandstone lies on this debris. The longer the time lapse between the mining of the two seams, the more stable the strata; in general a period of 5 to 10 years is ample.

2.2.4.2 Upper Seam Mined First

If an upper seam is mined first, it is evident that the lower seam will be affected to a lesser extent. Generally lower seams are influenced when the intervening

strata are relatively weak. The disturbance to the lower seam is dependent upon the thickness of the parting and the overburden above the upper seam, since the damage is a function of the total stresses that are induced.

The damage caused to the lower seam when the upper seam has been mined earlier, is of two types. If water has collected in the upper seam the cracks in the parting could precipitate an inrush. The weight of the overburden manifests itself by crushing or sloughing of coal, fracture of the roof, or bottom heave, and these may occur either singly or in combination. The nature of the immediate roof has considerable influence upon the nature of the damage. With a strong roof member, heaving of the bottom occurs. If the floor is strong and hard, this results in roof falls and crushing of the coal.

As in the case of the lower seam being mined first, stress concentrations are caused by the leaving of isolated, or groups of, pillars or solid coal. The weight of the overburden is borne by these pillars and is transmitted to the lower seam. If the intervening strata are thin or weak, the effects of this weight are much more than if the parting were stronger. It was observed that the maximum disturbance did not occur immediately below the pillars in the upper seam, but 100 or 200 ft on either side. This was explained by the pressure arch theory, since the maximum stress occurs at the legs of the arch rather than at the pillars. If the intervening strata are competent then the effect of pillars in the upper seam may be negligible.

The effect of time when the upper seam is mined first is not as evident as when the lower seam is mined earlier. If the upper seam has not been mined completely, even a lapse of 30 years does not completely eliminate the effects of mining that seam. The factors that influence the mining of a lower seam when the upper seam has been mined, are the parting thickness, the amount of overburden, the nature of the strata, and the method of mining. Difficulties are minimized if the upper seam is completely recovered. Alternatively, if partial mining is conducted then sufficient coal should be left in the upper seam to support the overburden and diffuse the pressure exerted on the lower seam. Instances are quoted where areas of coal could not be recovered in the lower seam, because of the mining of the upper seam. With partial mining of the upper seam there was very little effect if the lower seam was also partially mined. The benefits of columnization could not be clearly established.

2.2.4.3 Simultaneous Mining

In simultaneous mining the problems that occurred were similar to those found with either the upper seam being mined first or the lower seam being mined first. The nature of the problems depended on which seam was mined ahead. If mining of the second coalbed was difficult, it was suggested that the strata would have stabilized if more time had elapsed between the two minings thereby ameliorating the problems. Generally disturbances will be more marked in cases where there is a relatively short interval between the two seams.

Problems due to transmission of overburden weight show up when some coal is left unmined because of poor roof conditions or want areas. These manifest themselves as broken roof strata, crushed coal, and/or heaving floor. The weight problem may be observed directly adjacent to these pillar areas or as much as 300 ft on either side.

One instance in which severe problems were noted was when the lower seam was partially mined and the upper seam, which was 55 ft to 75 ft above, was mined later. The upper seam was overlain by 2 ft or 3 ft of draw slate which, in turn, was overlain by 35 ft to 50 ft of strong, hard sandstone. The nature of the sandstone necessitated that a large area of coal be extracted before a fall occurred. When these falls occurred they caused a noticeable caving of the entries in the lower seam and exerted considerable pressure on the pillar lines in that coalbed. To minimize the effects, the distance between the face lines in the two seams had to be kept sufficiently apart.

If the parting between the two seams is relatively thin, i.e. less than 100 ft, and consists primarily of weak shales, disturbances may occur in either one or both seams. Pillar recovery of the lower seam may cause settlement of the upper coalbed floor and loosen timbers, which induces roof problems. Heavy falls in the upper bed may cause caving of rooms and entries in the lower seam. If pillars in the upper seam are extracted while the lower seam is just being developed, the floor in the lower bed may heave sufficiently to cause serious problems, and even abandonment of the work. Alternatively, if the lower seam pillars are extracted, the upper seam may encounter serious problems, or be abandoned, because heavy roof falls cannot be supported.

There were instances of simultaneous mining where little disturbance took place in either seam. In these cases it was difficult to clearly attribute any disturbance to the multiple-seam mining situation.

The method of mining is of greater importance in the case of simultaneous mining of two contiguous seams than in the mining of these seams sequentially. In most cases the upper bed was mined ahead of the lower seam but either seam could be developed first. Generally the upper seam was kept about 100 ft to 150 ft in advance of the lower pillar line during pillar extraction. If the upper pillar line lagged behind, this was endangered because of subsidence induced by the lower seam. If the upper bed progressed too far in advance, there was a possibility of closure of the lower haulageways due to the impact of the falls in the upper bed. Correlation of these seams was achieved by superpositioning of the main and cross entries. However, not all mines practice superpositioning or correlation. Differences in the thickness of the parting, in the conditions of the seams, types of equipment used, and systems of mining, may make this difficult. Superpositioning of entries and columnization of pillars could be carried to the extreme where every individual pillar and entry is superposed. Wider entries in the upper bed could cause squeezing in the lower seam, so columnization could help in the mining of the lower seam. It should be remembered, however, that columnization involves a high degree of engineering and supervisory control, and even then its success cannot be guaranteed.

Whenever complete extraction of either of the two seams is attempted, but a few pillars are left behind, stress concentrations will occur in the second seam causing difficulties in mining. In many cases partial mining of both seams has been resorted to and found to be successful.

2.2.4.4 Mining of More than Two Contiguous Seams

When more than two seams are involved the problems encountered are similar to those experienced for mining of two seams. Complications may arise, however, depending on the order in which the various seams are mined. In most cases, disturbances and problems arise because of either the subsidence that occurs, or the transmission of weight from the overburden.

Economic conditions dictate the sequence of mining of the various seams. Hence, in the study it was difficult to predict what disturbances would occur and where these might

appear. It was also difficult to isolate their causes when they arose. Subsidence fractures were readily recognized as being due to a lower seam, but it was difficult to say which of the lower seams was liable. In most such situations best results were obtained when the upper seams were mined first. If the intervals between seams were thin, it was suggested that these be mined simultaneously, preferably with partial recovery and with pillar columnization.

2.2.4.5 Conclusions of the Study

The factors that influence the amount of disturbance in multiple-seam operations include:

- Proximity of the seams
- Method of mining
- Amount of overburden above the upper bed
- Nature of the strata between the beds
- Thickness of the coalbeds
- Lapse of time between mining the various seams
- Dip of the beds
- Percentage of coal extraction
- Uniformity of coal extraction
- Strength of the coal
- Strength of the floor
- Strength of the roof

If a lower seam is mined first, then its effects can extend to almost any distance above it. If the thickness of the parting between the two seams is over 300 ft, the lower seam is not more than 8 ft high, and it has been mined carefully and completely, mining in the upper bed may not be affected. If the lower bed has not been mined properly then the upper seam will be affected, no matter how great the parting thickness. Factors that govern the successful mining of an upper seam over a previously-mined lower bed include:

- the thickness and marketability of upper seam
- the economic situation of the coal industry during the time that the upper seam is being mined
- the mined thickness of the lower seam
- geologic and structural characteristics of the parting between the seams
- time lapse since the mining of the lower seam
- the method and care used in mining the lower seam
- the mining method used for the upper seam

For successful mining of an upper seam, after the lower seam has been mined, the following conditions should prevail:

- the interval between the two beds should be approximately 30 ft or more
- the lower bed should be completely and systematically extracted
- the elapsed time following the mining of the lower bed should not be less than 5 to 10 years
- the lower bed should not be more than 5 or 6 ft

The cost of mining the upper bed with this minimum parting interval is considerably greater than if the lower seam had not been mined. As the interval between the beds increases the costs drop; when the interval reaches about 300 ft the cost differential becomes negligible. If the mining in the lower bed has been done poorly, this will reflect in an increased cost in the upper seam. If the mined thickness of the lower bed exceeds 5 ft to 6 ft, the thickness of the parting between the seams should also increase, otherwise the costs of mining the upper seam will rise.

Difficulties in mining multiple seams simultaneously occur when the interval between seams is less than 100 ft. It is recommended that, if possible, consecutive mining be practiced. Should the interval between seams be less than 30 ft, simultaneous mining with the extraction of the upper seam slightly in advance of the lower bed offers the best chances for maximum recovery. Columnization is imperative under such circumstances. To be successful, complete recovery should be attempted in these cases.

If the parting thickness between the seams is less than 100 ft, it is best to mine with partial recovery. The quality of the two seams may determine the best procedure. Stemple suggests that if the interval between the beds is between 30 ft and 100 ft, it is best to partially mine the bed of lower quality first and then try to recover as much as possible of the better quality seam. Another factor that governs the mining sequence and extent is the condition of the seams. If the interval between two seams is less than 30 ft then the highest percentage of recovery may be obtained by partial mining of both seams, utilizing simultaneous mining methods and columnization of pillars.

No matter what method of recovery is chosen when mining contiguous seams the importance of careful planning cannot be overly emphasized. All of the factors that cause disturbance in multiple-seam mining need to be considered. A scheme that is best suited to the situation can then be developed so as to minimize the disturbance of the strata. Careful advance planning of the mining system tends to reduce difficulties in multiple-seam mining and to allow the most economic and maximum recovery of coal.

2.3 Comments

It is evident from the above discussion that most of the results of the Stemple investigation are rational and logical. These are based on both theory and practice. The author is to be commended for the thoroughness and systematic approach of his study. Evidently, during the quarter century between the compilation of that report and the present considerable progress has been made in rock mechanics and strata control. These advances need to be incorporated in the present and future investigations of the subject. But the essential conclusions drawn in the VPI study will continue to hold valid.

3.0 COAL MINE COST MODELS

The following three sections address the requirement in the contract that:

> "For representative type locales (i.e., locales where the economic performance could be used to extrapolate an estimate for the total reserve base) the Contractor shall perform a life cycle economic analysis of a single-seam and multiple-seam mining situation. These analyses shall reflect accepted accounting and economic evaluation procedures and shall produce a realistic measure of the economic benefits or disbenefits of multiple-seam mining. The term 'economic evaluation' shall be used in its broadest sense and shall include not only the direct economic benefits but also the estimated relative measures of health and safety, resource recovery; and environmental protection consequences of both forms of mining."

It was not within the scope of this contract to develop a new life cycle economic analysis model which would make a direct comparison. Hence, existing models were reviewed and evaluated, and may be briefly discussed here.

3.1 The Penn State Model

This was developed under Grant No. GO111808 and is entitled "A Master Environmental Control and Mine Systems Design Simulator for Underground Coal Mining." This is a fairly comprehensive computer simulation model which can be used for planning, designing, and controlling either existing or new operations. The model is quite broad-based and considers the following parameters

- geological conditions
- support functions
- materials handling operations
- mining methods
- environmental impact
- market economics

The model can accommodate simulation of an entire mine, using the time-increment method, and can be employed to study the effects of mine health and safety.

3.2 Bureau of Mines Circulars

The U.S. Bureau of Mines has issued a number of Information Circulars (including nos. 8682, 8689, 8715, 8716, 8720, and 8757) which outline capital and operating costs for coal mines. These are primarily listings of typical costs for:

- construction
- equipment and working capital
- manpower requirements
- operating costs
- federal and state taxes (including depletion and depreciation)
- expendable supplies

and other similar items.

The capital charges are discounted by the present worth factor and then totaled to give the present worth of the total mine investment. If it is assumed that the mine production is constant over the life of the mine, and the sales are steady, the cost of run-of-mine coal may be computed. Since these documents follow simple procedures, often used by small operators in industry, they are quite useful.

3.3 Twin Cities Research Center Model

This computer simulation model is general enough to be used for the mining of minerals other than coal, and is based on elements common to all types of mining i.e., activities or events, equipment, and inventories. Within certain geological constraints, it has been used to ascertain the feasibility of both longwall and room-and-pillar methods of coal mining.

3.4 VPI Model

This model was initiated in 1962, under the sponsorship of the Office of Coal Research, with the objective of improving mine efficiency. The study resulted in two programs, each simulating a production section. One could accommodate as many as 12 mining machines and 6 shuttle cars. The second was designed for use with one continuous miner and up to 3 shuttle cars. The programs are based on events in the mining cycle.

3.5 NUS Model

The NUS cost model was developed for EPRI (the Electric Power Research Institute), so that the costs of mining could be analyzed and minimum selling prices determined. Essentially, this model performs the calculations done by the

Bureau of Mines by means of a computer. However, it is capable of relating section production to

- seam thickness
- seam pitch
- overburden
- roof and floor conditions
- methane generation

Labor, equipment, construction, and supply costs are stored in the computer for 1975 but may be updated by means of inflation factors through 2000. Section production is given by tables which compose empirical and simulation data, and consider geological conditions. The model can accommodate a wide range of variables and hence is applicable to all types of mining situations in the United States.

3.6 STRAAM Estimating Procedures

Under a contract from the Bureau of Mines, (JO255926), STRAAM Engineers, Inc. prepared a manual for estimating costs for feasibility investigations, based on the use of equations, factors, and curves. Both capital and operating costs for mining and primary benefication in the United States and Canada may be obtained using the procedures outlined. This is applicable, however, to all types of minerals except fossil fuels. Hence it is not directly applicable to coal. The estimation system is essentially intended to make preliminary estimates with little hard data, in order to ascertain if further, more detailed estimates are justified. The method was developed mainly to provide means for evaluating deposits in the Bureau of Mines' Mineral Availability System (MAS).

3.7 Wierco Cost Procedures

The Paul Wier Company has developed a method of evaluating coal mining properties using a compound discounted cash flow procedure. The method is applicable to even or uneven streams of income from the mining operation. The cash flow which is discounted is the annual net cash flow remaining from sales after deduction of all operating costs, payment of income taxes, provision for necessary future capital investments, replacements of short-life equipment and expenditures for extension of mine facilities. The procedure is based on selecting an expected rate of return which is related to the risk inherent in the mining venture. For this given rate of return, there is a relationship between the investment per annual ton of capacity for a given mine life and the unit amount of net cash flow per ton required on an annuity basis. This relationship is established and used to compute the desired cash flow per ton of coal after

necessary expenditures for replacements of short-life equipment. The final actual rate of return is established by trial and error discounting at various rates and interpolation.

3.8 JPL Model

This model relates the major technologic economic variables which influence underground coal mining systems. An algebraic expression for the selling price of clean coal is presented, which is a function of labor and capital productivities, required return on investment, average wage rate, equipment availability, initial development cost, recovery factor, tonnage losses due to debris and washing, and other such gross technology descriptors. The model not only accounts for the costs of physically extracting the coal, but also the intangible costs resulting from health and safety regulations, resource conservation measures, and environmental improvements at both the working face and the surface. Although the model initially requires a fixed amount of equipment and personnel throughout the production period of the mine, an extension thereof permits the accommodation of varying annual production levels. The model is very sensitive to required return on investment, productivity of capital and labor, tonnage lost in beneficiation, wages and salaries, and operating supplies.

4.0 MINE LIFE-CYCLE COSTS

4.1 Components of Life-Cycle Model

An algebraic model describing the life-cycle cost of an underground coal mine has been developed by the Jet Propulsion Laboratory (JPL) of the California Institute of Technology. In this model the annualized selling price of coal is based on the revenue required to cover all operating costs, amortized capital outlays, and yield a specified return on aggregate investment.

Simply, the annual operating cost of the mine is given by the expression

$$C_p = \frac{1}{(1-\tau)} \left\{ \left(p_C \cdot V_R (1-\alpha_R)(1-\alpha_P) \right) \quad [1-\tau(1-\gamma)] - \gamma E_K + D \right\} \ldots \text{eq 1}$$

where C_p = annual operating cost

p_C = selling price of coal

V_R = annual production capacity of raw coal

α_R = fraction of raw coal that is rock, dirt, and other debris

α_P = fraction of coal lost in the cleaning process

τ = federal income tax rate

γ = capital recovery factor, f(r,T)

r = discount rate

T = projected mine life

E_K = present value of capital investment

D = annual depreciation charge

Generally in the Bureau of Mines studies,

$$\alpha_R = \alpha_P = 0$$

$$\tau = 0.50$$

and $$\gamma = 0.10$$

It should be noted that the model given above does not provide for inflation in capital costs or operating costs. This is a severe limitation considering that generally labor, equipment, and operating supplies escalate at somewhat different rates, or when the market conditions dictate a changing rate of return over the life of a mine. These must be regarded as important variables when planning a new mining venture. However, these are of secondary concern in the present analysis where only a comparison between single-and multiple-seam mining are being made. The introduction of the effects of inflation would merely complicate the analysis but not significantly alter the major conclusions drawn from this study.

Another simplification in the model is the underlying assumption that annual sales and operating costs are constant and equal to their capacity values during the period which begins with all sections producing at full capacity and ends with mine deactivation. This, of course, is not realistic since the production varies considerably throughout the life of a mine. However, if the mine production and cost are considered to be annualized (i.e. level values which are equivalent in present value impact to a time series that fluctuates over the years), this restriction does not appear to be so severe.

The model is based on the time origin (t_o) being when the mine attains full production. In other words, cash flows which are entailed with resource evaluation, acquisition of mineral rights, obtaining permits, construction of the mine and its infrastructure, purchase of equipment, mine development, and so forth must be discounted forward to t_o.

The present value of the capital investment, E_K, in the model (eq 1 above) is given by

$$\hat{E}_K = \hat{K}_{EO} + \hat{K}_{EF} + \hat{K}_A + \hat{K}_D \quad \text{. . . . . eq 2}$$

where $\hat{K}_{EO}$ = initial investment in plant and equipment

$\hat{K}_{EF}$ = deferred investment in equipment

$\hat{K}_{A}$ = cost of acquiring rights to the land

$\hat{K}_{D}$ = net expenditures to obtain initial access to the seam and bring all sections up to full production.

The circumflex is used to denote present value as of the beginning of the year t_o.

Productivity of capital, ρ_E (i.e. present value of all capital investment less land and development costs) is defined by

$$\rho_E = \frac{V_R}{\hat{K}_{EO} + \hat{K}_{EF}} \quad \ldots\ldots\ldots\ldots\ldots \text{eq 3}$$

and is dependent upon a number of factors, such as equipment capability under ideal conditions, need for spares, scheduled downtime for maintenance, travel time to and from the face, lunch break, construction delays, unplanned work stoppages due to bad mining conditions, equipment failures, time losses due to labor disputes, interest charges during construction and initial development, need to replace equipment periodically, and others.

The annual depreciation charge, D, depends upon a number of factors, including first costs, economic versus tax lifetimes, salvage values, capitalized repairs, and the depreciation procedure adopted. It should be remembered that in actual practice the treatment of depreciation for a new mining venture is very complex, and certainly cannot be depicted by a list such as presented. Current tax laws treat exploration, development, and production differently, with expensing of initial outlays permitted in some cases (Mikelonis, 1976). However, simply, D is given by

$$D = \beta_D \left(\frac{K_{EO}(1-w_c)}{(1-\alpha_A)(1-\alpha_U)} + K_D \right) \quad \ldots\ldots\ldots \text{eq 4}$$

where β_D = ratio between the computed annual charge and total first cost

$\frac{K_{EO}}{(1-\alpha_A)(1-\alpha_U)}$ = effective first cost of plant and equipment considering all work stoppages

K_{EO} = amount which must be invested under ideal conditions (i.e. no spares, predicted costs, no system downtime). This is historical cost, exclusive of interest charges

α_A, α_U = fraction of capital productivity lost due to anticipated and unanticipated system downtime, respectively

w_c = fraction of initial capital investment expended on working capital

K_D = aggregate historical expenditures on initial mine development, net of any coal sold.

The total annual operating cost C_p, is given by

$$C_p = a_L C_L + a_S C_S + C_U + C_W + C_{INS} + C_T + C_R + D \quad \text{eq. 5}$$

a_L = constant multiplier which adjusts total labor cost to reflect $C_{O/H}$ and C_I.

$C_{O/H}$ = payroll overhead (i.e. social security, unemployment compensation, and various fringe benefits)

C_I = indirect cost, assumed to be directly proportional to the sum of total labor cost and cost of operating supplies

C_L = total labor costs, both hourly and salaried

a_S = constant multiplier which increments the outlay on operating supplies to account for indirect cost (C_I)

C_S = outlays on operating supplies (e.g. roof bolts, rock dust, replacement parts, etc.), assumed to vary directly with raw coal tonnage for a seam of constant thickness

C_U = cost of power and water, assumed to be proportional to raw coal tonnage

C_W = union welfare payments, which are a function of both raw coal tonnage and the hours worked by those under the union contract

C_{INS} = cost of insurance, computed as a percentage of initial capital investment, excluding all interest charges

C_T = local taxes, expressed as a percentage of sales, in accord with typical local tax laws

C_R = royalty payments, expressed as a percentage of annual sales

D = annual depreciation charge.

In the Bureau of Mines models, generally

a_L = 1.55

a_S = 1.15

$C_{O/H}$ = 40 percent of total labor cost

C_I = 15 percent of total labor cost and cost of operating supplies.

4.2 Price Sensitivity

The sensitivity of a variable to changes in price may be obtained by obtaining the partial derivative of price with respect to that variable. A listing of these variables is provided by Lavin et al (1978), and is reproduced in Table 3.

It should be noted that two important sensitivities are not included in Table 3. These are price sensitivity to mine life and rate of return. These are difficult to compute because their relationships to price are very complex, and often involve considerations other than economic.

Sometimes it is difficult to compare rates of change of variables when they differ in scale by orders of magnitude by using partial derivatives. In such cases it may be convenient to measure sensitivity in terms of partial elasticity, which calculates the percentage change in price due to a one percent change in a particular variable. To obtain a partial price elasticity for a variable, its partial derivative is divided by the ratio of the nominal value of the variable to the nominal price, i.e.,

$$E_{p_C, x} = \left(\frac{\delta p_C}{p_C}\right) \Big/ \left(\frac{\delta x}{x}\right)$$

$$= \left(\frac{\delta p_C}{\delta x}\right) \left(\frac{x}{p_C}\right) \quad \text{. . . . . eq 6}$$

Identify all variables

Table 3

The Sensitivity of Price to Changes in Individual Variables
(after Lavin, et al, 1978)

Variable Name	Symbol	Price Sensitivity
Labor productivity	ρ_L	$-A_L/\rho_L^2 B$
Capital productivity	ρ_E	$-A_E/\rho_E^2 B$
Debris Fraction in Raw Coal	α_R	$\frac{1}{(1-\alpha_R)^2(1-\alpha_p)}\left[\frac{A_L}{\rho_L}+\frac{A_E}{\rho_E}+A_O\right]-\left(\frac{Fc_{WT}}{(1-\alpha_R)}\right)$
Preparation Losses	α_p	$\frac{1}{(1-\alpha_R)(1-\alpha_p)^2}\left[\frac{A_L}{\rho_L}+\frac{A_E}{\rho_E}+A_O\right]-\left(\frac{Fc_{WT}}{(1-\alpha_p)}\right)$
Average Daily Wage	$\bar{w}_T$	$Fa_L/B\rho_L$
Welfare Payment (per man-hour)	c_{WH}	$F h_S (M_H/M_T)/B\rho_L$
Hours worked per shift	h_S	$F c_{WH} (M_H/M_T)/B\rho_L$
Hourly Employee Fraction	(M_H/M_T)	$Fc_{WH}h_S/B\rho_L$
Royalty Fraction of Sales	μ	$\frac{1}{B}\left(\frac{A_L}{\rho_L}+\frac{A_E}{\rho_E}+A_O\right)$
Local Tax Fraction of Sales	σ	$\frac{1}{B}\left(\frac{A_L}{\rho_L}+\frac{A_E}{\rho_E}+A_O\right)$
Cost of Operating Supplies (per ton)	c_S	Fa_S/B
Water and Power Cost (per ton)	c_U	F/B
Insurance Fraction of Capital Cost	c_{INS}	$\frac{F}{B}\left(\frac{1}{\rho_E(1+\lambda_{EO}+\beta_E)}\right)$
Depreciation Factor	β_D	$-\frac{F}{B}\left(\frac{\tau}{1-\tau}\right)\left(\frac{1-w_c}{\rho_E(1+\lambda_{EO}+\beta_E)}+k_D\right)$

Variable Name	Symbol	Price Sensitivity
Deferred Investment as a Fraction of Total Capital Investment	β_E	$\frac{F\gamma}{1-\tau}\left(\frac{K_{EO}}{(1-\alpha_A)(1-\alpha_U)}\right)\Big/ BV_R$
Interest During Construction Factor	λ_{EO}	$\frac{F\gamma}{1-\tau}\left(\frac{K_{EO}}{(1-\alpha_A)(1-\alpha_U)}\right)\Big/ BV_R$
Anticipated Work Stoppages	α_A	$\frac{F}{(1-\alpha_A)^2(1-\alpha_U)}\left(c_{INS}K_{EO} - \frac{\beta_D\tau}{1-\tau}K_{EO}(1-w_c) + \frac{\gamma}{1-\tau}(1+\lambda_{EO}+\beta_E)K_{EO}\right)\Big/ BV_R$
Unanticipated Work Stoppages	α_U	$\frac{F}{(1-\alpha_A)(1-\alpha_U)^2}\left(c_{INS}K_{EO} - \frac{\beta_D\tau}{1-\tau}K_{EO}(1-w_c) + \frac{\gamma}{1-\tau}(1+\lambda_{EO}+\beta_E)K_{EO}\right)\Big/ BV_R$
Capital Recovery Factor	γ	$\frac{F}{B}\left(\frac{1}{1-\tau}\right)\left(\frac{1}{\rho_E} + \frac{p_A T}{v_S \eta}(1+r)^n + \hat{k}_D\right)$
Acreage Cost	p_A	$\frac{F}{B}\left(\frac{\gamma}{1-\tau}\right)\left(\frac{T}{v_S\eta}(1+r)^n\right)$
Seam Density	v_S	$\frac{-F}{B}\left(\frac{\gamma}{1-\tau}\right)\left(\frac{p_A T}{(v_S)^2\eta}(1+r)^n\right)$
Recovery Ratio	η	$\frac{-F}{B}\left(\frac{\gamma}{1-\tau}\right)\left(\frac{p_A T}{v_S \eta^2}(1+r)^n\right)$
Development Cost Per Ton	k_D	$\frac{F}{B}\left(-\frac{\beta_D\tau}{1-\tau} + \frac{\gamma}{1-\tau}(d_{INT})\right)$

Those symbols not defined on pages 46 to 49 are listed below:

E_{p_c} = partial elasticity of selling price, p_c

x = variable

S_{p_c} = partial derivative of selling price, p_c

$A_1 = F\left[a_L \bar{w}_T + c_{WH}\, h_S\, (M_H/M_T)\right]$

$B = (1-\alpha_R)\ (1-\alpha_P)$

$A_E = F\left[\left(\frac{1}{1 + \lambda_{EO} + \beta_E}\right)\left(c_{INS} - \frac{\tau\beta_D\ (1 - w_c)}{1 - \tau}\right) + \frac{\gamma}{1 - \tau}\right]$

$A_\Theta = F\left[a_S c_S + c_U - c_{WT}\, B - \frac{\tau\beta_D}{1 - \tau} k_D + \frac{\gamma}{1 - \tau}\left(\frac{p_A T}{v_S}\ (1 + n) + k_D\right)\right]$

$F = \frac{1 - \tau}{1 - \tau\ (1 - \delta) - (1 - \tau)(\sigma + \mu)}$

n = initial development period

d_{INT} = differential of interest rate

A closer look at the price sensitivities of the variables involved in the cost model (Table 3) shows that labor productivity, capital productivity, unanticipated work stoppages, acreage cost, seam density, recovery ratio, and development cost per ton are affected by multiple-seam mining. But, although these variables are affected, from eq. 1 it is evident the price per ton of coal is not changed dramatically. Variables that remain unchanged include debris fraction in raw coal, preparation losses, average daily wage, welfare payments, hours worked per shift, hourly employee fraction, royalty fraction of sales, local tax fraction of sales, cost of operating supplies, water and power cost, insurance fraction of capital cost, depreciation factor, deferred investment as a fraction of total capital investment, interest during construction, anticipated work stoppages, and capital recovery factor.

4.3 Major Factors Affecting Mine Life-Cycle Costs

This discussion is based on the model presented above, but is not intended to be a complete or elaborate description of all the variables that must be considered in planning a mine. The thrust of this study is primarily to highlight the effects of multiple-seam mining on the mine-mouth costs of producing clean, saleable coal. Hence only those factors that are significant or pertinent to multiple-seam mining are presented here.

4.3.1 Labor Productivity

This is the total of raw coal produced divided by all of the mine personnel i.e., underground and surface. This helps to provide the labor component of the total cost of the coal, and is given by the tons of raw coal/person-shift.

The labor productivity of a multiple-seam mining operation would vary significantly from that of a single-seam operation, only if either the total tonnage of raw coal produced in a mine is changed or the labor requirements are altered. Obviously, in making the comparison, the total coal that may be recovered from multiple-seam operations must be taken to be the sum of the coal that may be recovered from each of the seams, if they were to be mined individually. There are no definitive data to indicate that the overall labor productivity is always lower, although it may be expected to be so. In the United States there are few historical data available on multiple-seam mining. Besides, methods of mining have changed so radically during the past 20 to 30 years that even if reliable data were available, their applicability would be seriously questioned.

EI visited 37 mines located in Alabama, Illinois, Kentucky, Ohio, Pennsylvania, Tennessee, Utah, Virginia, West Virginia, and Wyoming during this study, and found that the maximum productivity loss was of the order of 10 percent. It was, however, not possible to attribute this entire change to multiple-seam mining. Local changes in geology and environmental conditions could not be differentiated. Many operations reported no change in productivity.

None of the literature reviewed, which included over 300 domestic and foreign papers and articles, provided information on how much more labor was required for multiple-seam mining.

Overhead costs may be considered to be proportional to the combined costs of labor and operating supplies, but since the labor component is generally larger these could be combined with labor costs.

4.3.2 Productivity of Capital

This provides a measure of the capital intensiveness of a mining system. Capital may be defined as the present value of initial and deferred investments in construction and equipment. Capital productivity is given by tons of coal produced/year/dollars invested.

It would appear that for a given mine capacity relatively little extra capital is required for multiple-seam mining than for single-seam mining. Very seldom is the quality of coal of the various seams sufficiently different to necessitate the construction of a new preparation plant. Even if minor modifications are required, the overall coal production over which it can be depreciated is increased considerably. This may actually lower the production cost of clean coal.

Similar reasoning may be presented for the other surface facilities -- offices, workshops, coal loading and unloading facilities, refuse disposal or treatment plants, hoisting equipment, and so forth. In some areas, each seam is worked through a separate access - shaft or slope - so that this is considered another mine. This permits one seam to remain in operation, should the other be closed by a wildcat strike. Even in such a case, however, many of the other facilities are common to the mines.

Only in a few instances, where two or more superposed seams are being worked by different operators, is there a complete duplication of facilities. This type of arrangement is not only inefficient because it uses more capital, albeit belonging to different companies, but also because there is generally poor coordination between the mine operators, which results in considerable coal losses.

The only capital investment which may be dictated by multiple-seam operations is perhaps the purchase of extra roof bolting machines or other roof support equipment. However, the cost of a typical roof bolter is about $100,000 whereas that of the overall mine capital investment, including a preparation plant, may be of the order of $70,000,000.

A complexity is introduced by the fact that the tax life of a piece of equipment is often different from its economic life. Besides, each company depreciates its equipment in a somewhat different manner. It may be, of course, assumed that the same procedure will be used for mining single or multiple coalbeds.

Insurance costs can vary but may be taken as a fixed percentage of the total capital investment, for the sake of simplicity.

The consumption of supplies, water, and power depend largely upon the annual volume of raw coal produced, although these are greatly influenced by seam geometry and mining conditions. The costs for these are not dependent on whether multiple or single seams are mined.

4.3.3 Number of Mine Personnel

Evidently the number of personnel employed by the mine and preparation plant is dependent upon the overall production expected, but not on whether the coal is being produced from a single seam or more than one seam. It is recognized that the number of personnel required at the surface is somewhat more inelastic.

If it is decided to operate the various seams as separate mines (to minimize the effects of walkouts), there may be a few persons that might duplicate the work done by others. However, if these operations are profitable as individual mines, probably a few extra personnel would be required anyway, to efficiently handle the production.

Multiple-seam operations may have some problems associated with roof support, water influx, gas emissions, or haulage. It is not anticipated that either the water or ventilation aspects of multiple bed mining will require extra manpower. Strata control and haulage may necessitate using more personnel, thereby decreasing productivity.

4.3.4 Average Wage Rate

The average wage rate is primarily determined by the union contract and by the market conditions. There is no difference in these whether there is a single-or multiple-seam operation.

The fringe benefits may be taken to be proportional to the average rate. These obviously vary with geographic location and past history, but are generally fairly constant for a given mine. These benefits include the union welfare payments, which in many areas are dictated by the Bituminous Wage Agreement. Strictly, these charges are partly proportional to tonnage and partly to the number of hours worked. However, assuming them to be a proportion of the average wages is sufficiently accurate for most planning purposes, or for the comparisons made during this study.

4.3.5 Acquisition Price for Mineral Rights

This is the price paid either for the purchase of the land, including the mineral rights, or for the option to mine. The overall effect of this cost component is significant.

If the land is purchased with all mineral rights associated therewith, the cost advantages may be considerable. Often the purchase price is depreciated over coal produced from the first seam that is mined, and it may well be over only a fraction of the coal mined from that bed. Also, if the property was purchased a decade or more back, as is the case with many of the older coal companies, the price that may have been paid would be quite low compared to current values.

If the operator only holds an option to mine, then a certain amount of money may be paid per acre of land, in addition to a royalty per ton of coal produced. If more than one seam is mined the cost per acre is distributed over the total coal production, and hence this component becomes smaller. However, the royalty (i.e. cost/ton) is dependent upon whether the royalty is a fixed amount per ton of coal (as was common until a few years ago, e.g., $0.10/ton), or a percentage of the price of coal (as is becoming more popular with the steep rise in the price of coal in the past 5 years, e.g., 5 percent of the sale price). In either of these two cases, there is no effect on whether the coal is mined from a single or from multiple beds.

4.3.6 Resource Recovery Factor

This is the fraction of raw coal extracted as a proportion of the in-place coal in the seam.

For single-seam mining, the recovery factor depends upon the method of mining. With room-and-pillar mining, without pillar extraction, this figure may be about 50 percent. With pulling pillars on retreat this figure would rise to about 85 to 90 percent. With longwall mining the recovery factor may run about 90 to 95 percent.

With multiple-seam mining the coal recovery may vary considerably. If the coal is mined indiscriminately, the overall resource recovery may be expected to be considerably lower than for single beds since large tracts of coal may need to be abandoned. With planned mining, however, the overall extraction ratio may well be expected to be the same as for single seams. Certainly the differences are under 10 percent, and several instances are identified where the overall coal recovery in the second seam was higher than in the first seam (e.g. Peabody's Camp No. 11, Republic Steel Mine No. 4, Island Creek's Fies Nos. 9 and 11).

It is fallacious to attribute the entire change in recovery factor to multiple-seam mining. Geological conditions, e.g., nature of roof and floor, water influx, gas emissions, play an important role. Since the local geology often varies markedly it is difficult to extrapolate results, even if the recovery ratio for a given coal bed is known in a nearby area where there is a single-seam operation.

The overall coal recovery from a seam has significant impact upon the cost/ton. However, both the literature and mine data collected by EI visits indicated that there is no general pattern by locale, i.e., either by geographical area (Appalachia, Interior, or Rocky Mountain), or mode of mining (over, under, or simultaneous), by which recovery varies. Rather this is site specific and depends strongly on the planning and coordination between the mining operations of the two seams.

It would, therefore, be inappropriate to assign certain extra costs to coal recovery with multiple seams as compared with the mining of single coalbeds.

4.3.7 Mineable Coal Density

This term refers to the tons of coal/acre that are amenable to being mined. It combines the effects of coal-bed thicknesses, pitch, nature and thickness of partings, occurrence of faults, rolls, washouts, and other geological features.

This term is not affectd by whether coal is mined by single-seam operations or multiple-bed mining. In fact, if this term considers more than one seam at all, it assumes multiple-seam mining is to be conducted.

If the partings are thin, there may be considerable interaction between the seams. This may affect overall coal recovery. However, if the parting is about 40 times the seam thickness, there is no noticeable impact.

4.3.8 Coal Benefication Losses

Losses occur during the preparation or washing of the coal. This is a measure of the quality of the coal. If the term also includes the dirt or debris mined with the coal, as it does here, it also reflects the effect of local geology and the skill of the mining crew. These losses may be expressed as the fraction of raw coal which is lost in washing or other beneficiation processes.

The quality of the coal does not, of course, change whether it is mined by single-or multiple-seam methods. The amount of dirt mined along with the coal may be expected to increase with multiple-seam mining. However, none of the data collected by EI indicate that this is the case. Again geological conditions, the mining equipment used, operator skill, and other factors tend to make it difficult to isolate the effect of multiple-seam mining. Should the amount of dirt mined be increased signficantly, however, its affect on mining costs can be signficant.

4.3.9 Downtime

(1) Anticipated: Mining equipment cannot be operational all of the time. There are obviously scheduled times during which maintenance occurs, or when workers are non-productive e.g., during off-shifts, lunch-time, transportation to and from the portal. This may be readily expressed as a fractional reduction in capital productivity.

Multiple-seam mining does not affect anticipated downtime in anyway. Hence no changes in cost may be attributed to this cause.

(2) Unanticipated: Often slowdowns in coal production occur because of unscheduled maintenance, difficult geological conditions, work stoppages, and so forth. These constitute unanticipated downtime, and this also tends to reduce capital productivity.

Some unanticipated downtime may be expected with multiple-seam mining. This may occur because of delays caused by poor roof or floor conditions or because of excessive haulage maintenance. Although the incremental costs in each of these items may be significant, their effect on overall capital productivity is small.

4.3.10 Rate of Return

The rate of return is determined by the mining company, and is governed by the market conditions and the cost of money. Mathematically, it is the discount rate which yields an aggregate net present worth of zero when applied to all cash flows resulting from both investment and operations.

Although the rate of return has a considerable impact upon the cost/ton of the coal mined, it is not affected in any way by whether the product is obtained by single-or multiple-coalbed mining.

4.3.11 Annualized Price of Coal

This is the price of coal in constant dollars at the mine mouth which covers all costs incurred in its production plus the desired rate of return. This is expressed in dollars/ton and is not directly affected by whether the coal is mined from a single seam or from multiple beds. However it reflects all costs, including those influenced by other parameters as discussed above.

This price should include all mine closing costs, but these are generally small and occur far in the future. Hence their effect is negligible. Closing costs are not changed appreciably because of multiple-seam operations.

The costs of surface subsidence and other consequences of mining are included in the annualized price. These costs could be significant, depending on the surface conditions, e.g., if structural damage occurs to important buildings or prime farmland is destroyed. If there are major structures on the surface, e.g., dams, railroads, reservoirs, then coal barriers may need to be left in place which affects recovery. However, under most circumstances the influence of multiple-seam mining is not much different from that of single-bed operations. The extent of subsidence may be greater with multiple-seam operation, but the surface is damaged even with the extraction of a single coalbed.

4.3.12 Market Conditions

The effect of the market probably governs the annualized price of coal more significantly than any of the other factors discussed above. However, these changes are most difficult to predict or account for and most of the cost models that are currently used do not take this into consideration. They are essentially static models that do not reflect changes in the market price of coal or the impact of altered labor or capital productivity. Hence it is infeasible to ascertain the effect of market conditions on multiple-seam mining. This is why it is not very meaningful to make direct cost comparisons for periods of time with considerable time lapses, even if the costs are computed in constant dollars and adjusted for inflation. It is also intractable to account for the technological changes that occur over long time periods.

5.0 RELATIVE COSTS OF MULTIPLE SEAM MINING

5.1 Basis for Analysis

In the previous section, costs have been compared for single and multiple seams in a generalized manner. It is worth while to be more specific so that these costs may be placed in perspective. It is abundantly clear that these costs are highly site specific. Hence no set of figures that may be compiled will be adequate for even an adjoining mine, let alone a region or the nation. Unfortunately, from the mines that EI visited, it was not possible to get a complete set of cost figures for a single mine. This may be expected, since such data are considered proprietary and confidential by most mines. These not only have impact on taxes and earnings, but also on labor negotiations and operating policies. Besides, most mines do not have cost data in a form that may be useable for an analysis of this type. Further, comparing costs of mining multiple seams to the costs if each of these seams is mined singly is an inexact exercise. However, sufficient information was collected to form a composite which would be realistic. Most of these cost data were obtained from mines in Appalachia. Hence this region was chosen for analysis in this task. The discounted cash flow technique was used to estimate the selling price per ton of coal at a 20 percent discount rate. The analysis was conducted assuming the mines are operating at their full target capacity. Capital and operating costs were determined for mines using the room-and -pillar system of mining and producing about 1.0, 1.5, and 2.0 million tons per year raw coal. In addition, longwalling costs are also provided for mines producing 0.9 and 1.7 million tons of coal per year.

The single-seam mining costs, which are the basis for generating cost benefits for multiple-seam mining, are described in the following, (for room-and-pillar mining):

1. Underground labor costs are calculated on the basis of $90.00 per person-shift with an average of 25 persons per continuous miner (divided nearly equally between the working section and outby). Total labor cost is divided by the productivity to obtain the labor cost per ton.

2. Supplies include all mine repair and provisioning items. Supply costs are estimated on the basis of $3.25 per ton variable plus $285.00 per shift fixed.

3. Power costs are calculated at $0.20 per ton variable plus $90.00 per shift fixed.

4. Health and union welfare costs are calculated on the basis of $12.77 per man per shift. Total health and welfare costs are divided by the tons per shift to obtain per ton value.

5. Compensation and black lung are calculated on the basis of $18.00 per man per shift.

6. Administrative costs are $255.00 per shift and are assumed to be constant and independent of tons produced and not affected by any changes in manpower.

7. Insurance and taxes are also assumed to be fixed at $120.00 per shift.

8. Depreciation costs are calculated from the total investment costs and dividing this by the total tons extracted during the 15-year production period. Table 4 provides the approximate capital cost summary based on capital expenditure required at the various portions of the mine. Table 5 provides the specific items and costs as summarized in the individual categories in Table 4. Total capital costs for mines of varying capacities are estimated from the total number of operating sections needed to achieve the annual production and the outby section capital costs. The capital expenditures for spare continuous miner units are determined on the basis of 80% equipment availability.

5.2 Single-Seam Room-and-Pillar Mining

Table 6 provides a summary of operating data for single seam room-and-pillar mining planned to produce 1.0, 1.5 and 2.0 million tons per year and longwall mining producing 0.86 and 1.7 million tons per year. Assuming each continous miner section produces 300 tons per shift and operates 2 shifts a day for 220 operating days per year, a total of 8 continous-miner units are required to achieve a million tons of coal per year. The corresponding total labor force, union and supervisory, required per day is shown on the lower portion of the table. Productivity (tons per man-day) can be

TABLE 4 - Capital Cost Summary
(Thousands of Dollars)

Section Related Capital Costs (Per Section)		
Face	1,349	
Haulage	797	
Other	35	
Electrical	93	
		~2,274
General Inside		
Equipment	926	
Other	316	
		1,242
Bottom Area, Shafts, Slope	4,766	
Shop and Mobile Equipment	595	
Top Area	15,602	
Initial Capital	8,492	

TABLE 5 - Capital Cost Detail
(Thousands of Dollars)

Section Equipment (Face)		
Continuous Miner	700	
Shuttle Cars (2)	220	
Roof Bolters (2)	180	
Feeder Breaker	90	
Scoop with Battery	64	
Rock Duster	4	
Spare Parts @ 10%	91	
		1,349
Section Haulage		
Belt (3000 x 36")	220	
Rail (60lbs. x 3000')	180	
Parts Car	15	
Trolley and Feeder Wire	5	
Supply Cars (3)	22	
Portal Bus	29	
Supply Loco	70	
Spare Parts	42	
		583
Section - Other		
Face Pumps	5	
3000' Pipe	15	
Auxiliary Fan	10	
Welder and Tools	5	
		35

Capital Cost Detail (Cont'd)

Top Area	
Temporary Power	183
Main Power Line	732
Surface Substation	146
Site Preparation	293
Coal Silos	1,098
Preparation Plant	10,248
Fresh Water Supply	146
Rail Extensions	366
Refuse Ponds	146
Refuse Bins	146
Refuse Truck	146
Refuse Site	110
Refuse Dozer	146
Supply Loco	70
Storage Yard	73
Powder Magazine	15
Office & Bathhouse	440
Warehouse & Shop	440
Training Site	220
Roads	146
Fan & Housing	204
Office Equipment & Furniture	44
Temporary Office & Bathhouse	44
	15,602

Capital Cost Detail (Cont'd)

Section - Electrical		
Power Center	37	
High Voltage Cable (3000')	26	
Belt Transformer	15	
Trailing Cables	15	
		93
Section Haulage (1500')		
60 lb Rail (1500')	90	
Sectionalizing Switch	10	
Rectifier	37	
Belt Conveyor (1500' x 48")	49	
Gathering Pump	9	
Steel Pipe (6" x 1500')	12	
PVC Pipe (6" x 1500')	7	
		214
General Inside - Mobile Equipment		
Cutting Machine	176	
Loading Machine	132	
Drill	110	
Track - Roof Bolter	81	
Compressor	41	
Rock Dust Loco	37	
Bulk Rock Duster & Tank Car	59	
Supply Cars (10)	73	
Stoper	3	
Service Loco & Oil & Grease Cars	51	
Personnel Jeeps	117	

Capital Cost Detail (Cont'd)

General Inside - Mobile Equipment (cont'd)		
Ballast Car	16	
Flat Car	12	
Main Pump	12	
Powder Car	6	
		926
General Inside - Other		
Shop Tools	59	
Belt Splicing Kit	44	
Fire Cars	29	
Gas, Dust, Noise Detectors	37	
First Aid & Mine Rescue	37	
Miscellaneous & Training	37	
Mine & Trolley Phones & Wire	73	
		316
Bottom Area & Shaft, Slope		
Site Preparation for Shafts	146	
Slope Bottom Preparation	73	
Shaft Bottom Preparation	146	
Slope ($3000/vertical ft)		
Shaft ($2500/vertical ft)		
Ventilation Shaft ($1500/vertical ft)		
Emergency Hoist	22	
Slope Belt Terminal	59	
		446 + 7.2 x vert. ft

Capital Cost Detail (Cont'd)

Shop & Mobile Equipment		
Shop Tools	146	
Front End Loader	113	
Crane	106	
Trucks (2)	113	
Auto & Jeep	22	
Pick-up Trucks	22	
Fencing, Shrubs	73	
		595
Initial		
Drilling	732	
Mapping	293	
Study	146	
Development Losses	7,321	
		8,492

TABLE 6 - Summary of Operating Data

	ROOM - & - PILLAR			LONGWALL	
	1.0 MTPY	1.5 MTPY	2.0 MTPY	0.86 MTPY	1.72 MTPY
Operating Data					
Number of Face Units	8 (2 spares)	12 (3 spares)	16 (4 spares)	1	2
Tons per Unit Shift	300	300	300	1,300	1,300
Unit Shifts Per Day	16	24	32	3	6
Operating Days Per Year	220	220	220	220	220
Annual Production	1,056,000	1,584,000	2,112,000	858,000	1,720,000
Labor					
Union - Face & Outby	400	600	800	126	252
Union - Preparation	7	7	7	7	7
Union - Miscellaneous	18	21	24	15	25
Supervision	48	72	96	12	24
Total	473	700	927	160	308
Productivity	10.15	10.28	10.39	24.38	25.33
Average Daily Wage	$ 90.00	90.00	90.00	90.00	90.00

estimated by dividing the total tons produced per day by the total number of men employed per day, e.g. for the 1 million-ton-per-year mine productivity is estimated as:

$$\frac{300 \times 16}{473} = 10.15 \text{ tons per man-day}$$

Yearly capital expenditures for coal lands and surface are shown on Table 7. The sum total of these expenditures divided by the total tons extracted provides the depletion cost per ton which is computed to be 4 cents per ton. Since the surface area affected will be proportional to the tons extracted for a fixed seam height, this depletion cost will remain fairly constant throughout this analysis.

Table 8 provides the total capital expenditures for the mines producing about 1.0, 1.5 and 2.0 million tons per year. This capital expenditure forms the basis for determining the depreciation cost per ton, which, as shown in Table 8, is $4.22 per ton for the 1 million-ton-per year mine.

The computations leading to the total cost of production per ton is shown in Table 9. The labor, supply, power and the other costs leading to the total cash cost of production per ton is estimated using the cost basis outlined in the beginning of this section. The total cost of production is $22.66, $22.25 and $21.76 for the 1.0, 1.5 and 2.0 million-tons-per-year production levels, respectively.

The cash flow analysis is conducted on the basis of a 15-year peak production period. If the selling price at a 20-percent discount rate is assumed to be $X per ton, the net income per ton before Federal income tax is X - 22.66 for the 1 million ton per year mine. The federal income tax can be estimated by considering the cost of production before cost depletion, which for the 1 million ton per year mine is $22.62. The net income for depletion would therefore be $(X - 22.62). Using 50% of net income as the percentage depletion allowance the taxable income after considering depletion would be $0.5 (X - 22.62). Estimating income tax at the rate of 48 percent would provide us the income tax value per ton which in this case is 0.24 (X - 22.62). These computations for income tax determination are shown in Table 10. The projection of net cash flow for each of the 15 years is shown in Table 11. The capital requirements are uniformly spread over the 15-year period. The assumed cost of working capital is determined on the basis of 1.5 percent of the gross sales. The net cash flow for each of the 15 years can therefore be estimated. Using the present value

TABLE 7 - Capital Expenditure for Lands & Surface

Coal Lands	$ 30,000
Surface	75,000
Contingencies	20,000
Book Value - Coal Lands	500,000
	$625,000

Depletion Cost for 1.056 MTPY Mine = $\frac{625,000}{1,056,000}$ = ~ $0.40/ton

TABLE 8 - Capital Expenditures for Equipment and Depreciation

Mine Capacity	Capital Cost	Depreciation, $/ton
1.056 MTPY	53,437,000	4.22
1.584 MTPY	64,807,000	3.41
2.112 MTPY	76,177,000	3.01

TABLE 9 - Cost of Production for Single-Seam Mining
(Room-and-Pillar and Longwalls)

	Room-and-Pillar			Longwall	
Annual Production	1,056,000	1,584,000	2,112,000	858,000	1,720,000
Productivity	10.15	10.28	10.39	24.38	25.33
Labor Cost	8.87	8.75	8.66	3.69	3.55
Supplies and Power	4.60	4.70	4.70	9.64	9.64
UMWA Welfare	1.80	1.70	1.70	0.52	0.52
Black Lung Compensation	1.78	2.40	2.40	0.73	0.73
Administration	0.50	0.40	0.40	0.20	0.20
Insurance	0.85	0.85	0.85	0.09	0.09
*Depreciation	4.22	3.41	3.01	3.71	2.21
Depletion	0.04	0.04	0.04	0.04	0.04
Total Cost of Production	22.66	22.25	21.76	17.77	16.98

TABLE 10 - Computation for Federal Income Tax

	Room – and – Pillar		
	1.0 MTPY	1.5 MTPY	2.0 MTPY
Net Selling Price	X	X	X
Total Cost of Production before Cost Depletion	22.6	22.21	21.72
Taxable Income before Depletion	(x-22.62)	(x-22.21)	(x-21.72)
Percentage Depletion Allowable (50% of Net Income)	0.5 (x-22.62)	0.5(x-22.21)	0.5(x-21.72)
Taxable Income	0.5 (x-22.62)	0.5(x-22.21)	0.5(x-21.72)
Income Tax at 48 Percent	0.24(x-22.62)	0.24(x-22.21)	0.24(x-21.72)

TABLE 11 - Projection of Cash Flow For Each of 15 Years For 1 MTPY MINE

Years	1 - 15
Annual Production	1,056,000
Selling Price	X
Total Cost of Production	22.66
Net Income before Taxes	(x-22.66)
Federal Income Tax	0.24(x-22.62)
Gross Cash Flow Per Ton	(x-22.66 - 0.24 (x-22.62)
Gross Cash Flow	$\left\{(x-22.66) - 0.24\ (x-22.62)\right\}$ 1,056,000
Capital Requirements	2,177,000
Cost of Working Capital	0.015x(1,056,000)
Net Cash Flow	$\left\{(x-22.66) - 0.24\ (x-22.62)\right\}$ 1,056,000 - 2,177,000 - 0.015x(1,056,000)

factors at 20-percent discount rate over the 15-year period, the sum of the cash flows over the 15-year period can be determined. Equating this to zero and solving for X would provide the selling price necessary for a 20-percent discount rate.

The above procedure was used to compute the selling price per ton of coal at the 20-percent discount rate. The calculated selling prices were 27.13, 25.87 and 24.96 dollars for the 1.0, 1.5 and 2.0 million tons per year mine, respectively. The corresponding production costs were 22.66, 22.25 and 21.76.

5.3 Multiple-Seam Room-and-Pillar Mining

The economic analysis for the multiple-seam mining situation followed the same procedure as described in the preceeding section. However, in this case, productivity was decreased by 10 percent to reflect the maximum adverse mining conditions, mainly due to roof and roadway deterioration. This was considered to be equal for either overmining or undermining. In addition supply costs were increased by 2%. The economic analysis was conducted for two cases. In the first case, it was assumed that separate surface structures such as shafts, slopes, hoisting system, etc.were required to mine the adjacent seam. The second case considered only the deepening of the existing shafts, slopes, etc. and utilized the same surface infrastructure as previously used for mining the first seam. The capital and operating cost details for these two situations are shown in Tables 12 and 13. The computed selling prices at 20-percent discount rate are 27.17, 25.92 and 25.02 dollars per ton for the 1.0, 1.5 and 2.0 MTPY mines respectively when new facilities were required. In the case where the existing facilities were used, the selling prices were 26.98, 25.79 and 24.92 dollars per ton respectively.

Table 14 provides a summary of the production cost and selling prices for the single-seam and multiple-seam situations. Figures 3 and 4 were constructed utilizing the data in Table 14, which show the cost of production and selling prices for the single-seam and multiple-seam situations.

It is evident that the production costs are somewhat higher for multiple-seam mining but not significant enough to make the mining of the coal uncompetitive. Specific instances of single-seam mining may sometimes show larger variations in costs. It should also be borne in mind that these costs were computed assuming the maximum adverse mining conditions. In most instances these cost differentials may be less marked.

It is recognized that the above analysis does not account for decreased coal recovery. This is because with

TABLE 12 - Capital and Operating Costs for Multiple Seam Mining Considering New Surface & Portal Facilities for Mining the Second Seam

	1.0 MTPY		1.5 MTPY		2.0 MTPY	
Operating Data	Years 1-15	Years 16-30	1-15	16-30		
Number of Face Units	8	9	12	13	16	17
Tons Per Unit Shift	300	270	300	270	300	270
Unit Shifts Per Day	16	18	24	26	32	34
Operating Days Per Year	220	220	220	220	220	220
Annual Production	1,056,000	1,069,200	1,584,000	1,544,400	2,112,000	2,019,000
Capital Cost for Depreciation	53,437,000	47,057,000	64,807,000	58,427,000	76,177,000	69,797,000
Labor Force						
Union - Face & Outbye	400	450	600	650	800	850
Union - Preparation	7	7	7	7	7	7
Union - Miscellaneous	18	20	21	23	24	27
Supervision	48	54	72	78	96	102
Total Manpower	473	531	700	758	927	986
Productivity	10.15	9.15	10.28	9.26	10.39	9.31
Operating Cost						
Labor	8.87	9.84	8.75	9.72	8.66	9.67
Supplies & Power	4.60	4.90	4.70	4.90	4.70	4.90
UMWA Welfare	1.80	1.87	1.70	1.87	1.70	1.87
Black Lung Compensation	1.78	2.67	2.40	2.67	2.40	2.67
Administration	0.5	0.44	0.40	0.44	0.40	0.44
Insurance & Taxes	0.85	0.94	0.85	0.94	0.85	0.94
Depreciation	4.22	3.67	3.41	3.15	3.01	2.88
Depletion	0.02	0.02	0.02	0.02	0.02	0.02
Total Cost of Production	22.64	24.35	22.23	23.71	21.74	23.39

TABLE 13 - Capital and Operating Costs for Multiple Seam Mining Considering Old Surface & Portal Facilities for Mining the Second Seam

	1.0 MTPY		1.5 MTPY		2.0 MTPY	
Operating Data	Years 1-15	Years 16-30	1-15	16-30		
Number of Face Units	8	9	12	13	16	17
Tons Per Unit Shift	300	270	300	270	300	270
Unit Shifts Per Day	16	18	24	26	32	34
Operating Days Per Year	220	220	220	220	220	220
Annual Production	1,056,000	1,069,200	1,584,000	1,544,400	2,112,000	2,019,000
Capital Cost for Depreciation	53,437,000	27,135,000	64,807,000	38,505,000	76,177,000	49,875,000
Labor Force						
Union - Face & Outbye	400	450	600	650	800	850
Union - Preparation	7	7	7	7	7	7
Union - Miscellaneous	18	20	21	23	24	27
Supervision	48	54	72	78	96	102
Total Manpower	473	531	700	758	927	986
Productivity	10.15	9.15	10.28	9.26	10.39	9.31
Operating Cost						
Labor	8.87	9.84	8.75	9.72	8.66	9.67
Supplies & Power	4.6	4.90	4.70	4.90	4.70	4.90
UMWA Welfare	1.8	1.87	1.70	1.87	1.70	1.87
Black Lung Compensation	1.78	2.67	2.40	2.67	2.40	2.67
Administration	0.5	0.44	0.40	0.44	0.40	0.44
Insurance & Taxes	0.85	0.94	0.85	0.94	0.85	0.94
Depreciation	4.22	2.12	3.41	2.08	3.01	2.06
Depletion	0.02	0.02	0.02	0.02	0.02	0.02
Total Cost of Production	22.64	22.80	22.23	22.64	21.74	22.57

TABLE 14 - Summary of Production Costs and Selling Prices

	1 MTPY		1.5 MTPY		2.0 MTPY	
	Production Cost	Selling Price	Production Cost	Selling Price	Production Cost	Selling Price
Single-Seam (Room & Pillar)	22.66	27.13	22.25	25.87	21.76	24.96
Multiple - Seam (Room & Pillar) (first seam mining)	24.35	28.82	23.71	27.06	23.39	26.45
Single & Multiple-Seam Longwall	17.77	21.71	16.98	19.34	-	-
Multiple-Seam (New Facilities (second seam mining)	24.25	27.17	23.71	25.92	23.39	25.02
Multiple-Seam (Existing Facilities) (second seam mining)	22.80	26.98	22.64	25.79	22.57	24.92

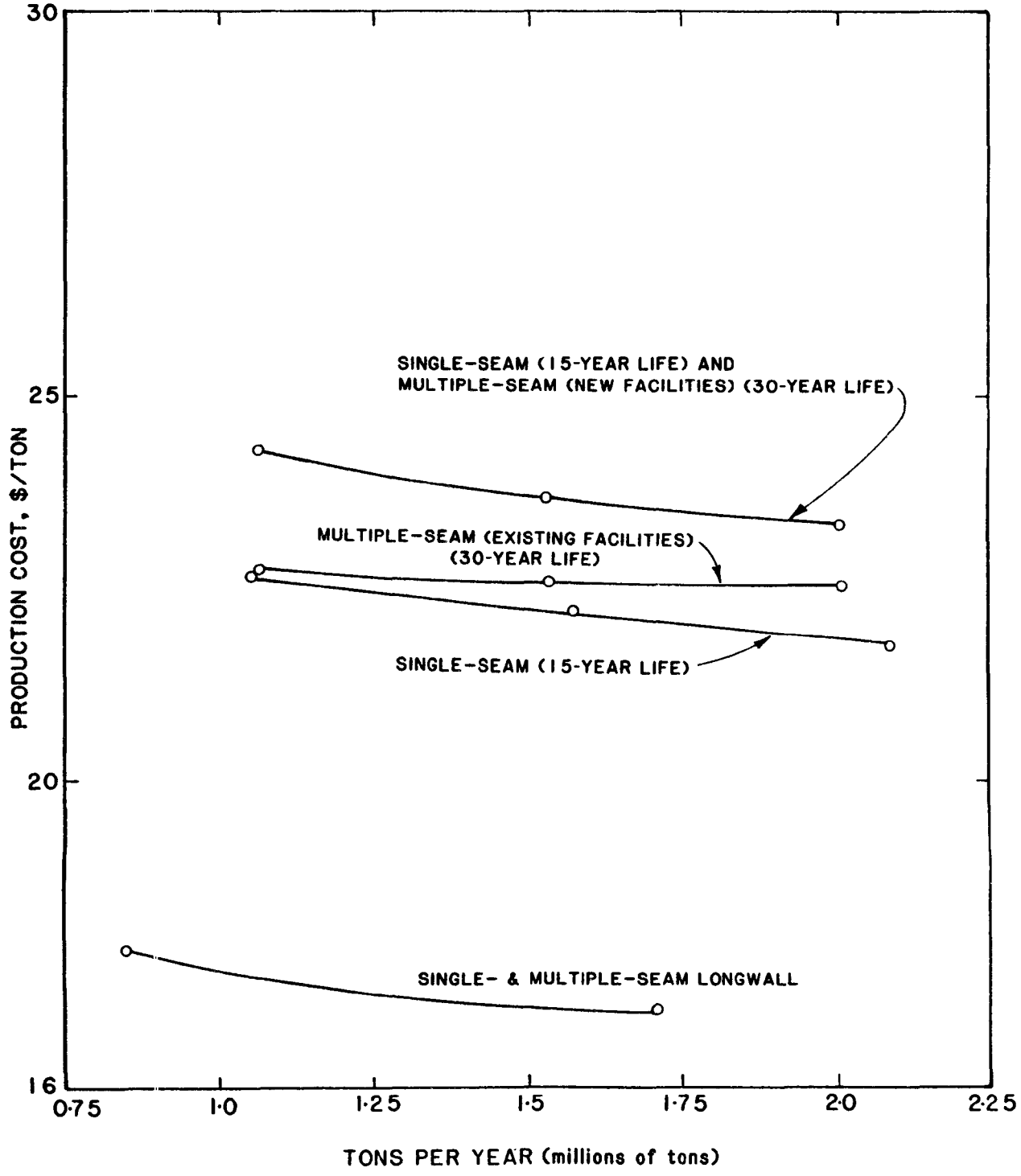


Figure 3 - Comparison of Production Cost for Different Mining Methods

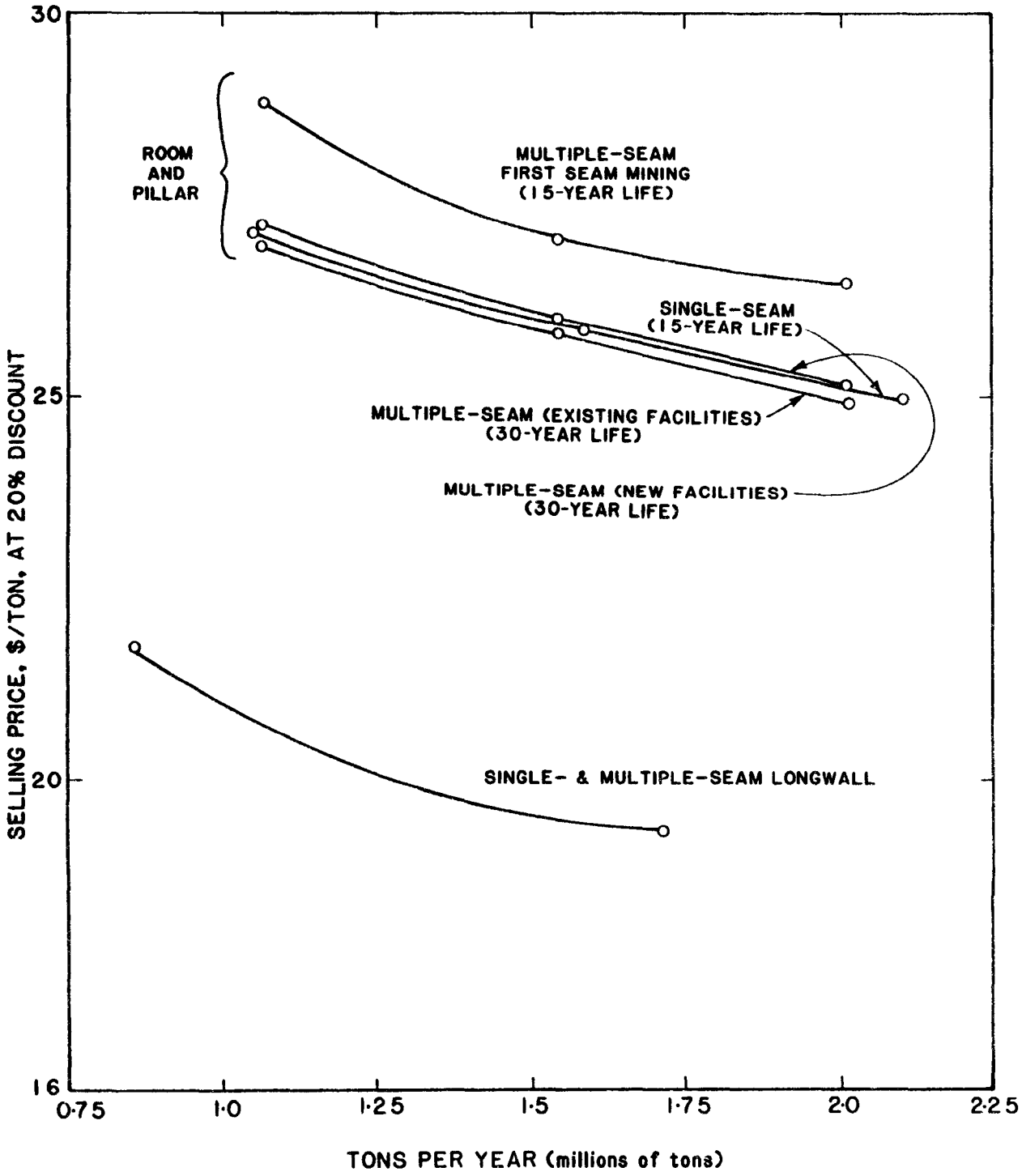


Figure 4 - Comparison of Selling Price for Different Mining Methods

good planning and modern mining techniques, the recovery of multiple seams is not affected. In specific instances, when working over or under old mine workings some coal may have to be left behind. This can only be analyzed on a site specific basis.

5.4 Longwall Mining

Evaluation of the longwall system shows that single-seam production costs are $17.77/ton and $16.98/ton for a 0.9 and 1.7 million ton per year mine, respectively. The corresponding selling prices were $21.71/ton and $19.34/ton. With multiple-seam mining the roof and floor conditions do not play a major role, except in the gate roads. Hence productivity is not affected to any significant extent. Besides, the costs of maintaining gate roads is generally considerably higher than those for room-and-pillar operations. Thus any increases in these costs due to multiple-seam operations has relatively less impact. Hence production and selling costs remain essentially unchanged.

5.5 Mine Startup and Deactivation Costs

The analysis presented above covers the mine-life cycle during its full capacity production period. The costs incurred for starting up a new coal mine or closing it down vary considerably depending upon the specific situation. Reliable figures for these could not be obtained during the EI visits to the mines However, should these be available, these can be readily "annualized" and incorporated into the analysis, as discussed in the last chapter (Section 4.1) of this task. The overall results will be increased only slightly. The startup and deactivation costs for multiple-seam mining are not materially different from those for single-seam operations.

5.6 Comments

As may be expected, the mining conditions do introduce cost differentials between single-and multiple-seam mining. However, the precise amount of differences can vary markedly from mine to mine. Hence it is difficult to generalize cost comparisons.

Although the cost examples presented above are for Appalachian mines, similar analyses may be presented for the other geographic regions of the country. These would naturally change the base costs and the precise figures entailed. However, the overall results may be expected to be very similar in nature.

6.0 CLOSURE

Based on this investigation, there are nearly 156 billion tons of coal which may be subjected to underground multiple-seam mining. This is over 68% of the total estimated reserve base (estimated at 229 billion tons). It is, therefore, in the nation's interest that considerable attention be devoted to multiple-seam mining problems. Prior studies (e.g. Stemple, 1956) have clearly indicated that in the past indiscriminate mining practices have sterilized many areas of valuable coal lands. Under current conditions, with energy shortages and consequent enhanced coal prices, this is wasteful and costly. Coal that could be mined by underground methods from multiple seams lies primarily in 8 states--3 in the East (Ohio, Pennsylvania, and West Virginia), 2 in the Midwest (Illinois and Kentucky). and 3 in the West (Colorado, Utah, and Wyoming). Hence any further studies should preferably be conducted in these regions.

Only two major studies related to this subject have been performed. Stemple's (1956) work presents an excellent grasp of the problems involved, but is somewhat outdated. The HRB-Singer Study (1976) was quite restrictive in scope and attempted to attack the problem statistically with a very limited data base. It is evident that more intensive investigations, perhaps under somewhat more controlled, but commercial, conditions are required.

Mine life-cycle costs for multiple-seam operations have not been developed to date. It would be worth while to develop economic models for this situation, especially in light of the vast amounts of coal to be mined under these conditions in the Unites States.

In general, the accounting practice of most mine operators do not provide sufficiently detailed cost data so as to permit a direct comparison between various unit operations (e.g. roof supports, ventilation, haulage, pumping) for single- and multiple-seam operations. Study of costs at several mines did, however, provide ranges in which these costs may vary. Unfortunately, site-specific conditions (such as local geology) make it difficult to generalize costs. For a given set of conditions, however, comparisons can be made.

Based on the cost data obtained from the various mines a composite of typical mine costs was established. Since most of the input data were from Appalachia, cost analysis was conducted for this region. It was found that the overall mine life-cycle costs for single- and multiple-seam mining were very close to each other. For the case studied, these varied by well-below 5 percent of the costs per ton of coal for room-and-

pillar mining and were equivalent with longwall mining. Since geological and operating conditions may cause cost changes of that order, it cannot be categorically stated that single-seam mining is necessarily less expensive than multiple-seam operations or vice versa. It should be borne in mind that these costs are developed using the best available technology. If poor mining practices are adopted, however, considerable coal reserves may be lost with multiple-seam mining and the overall costs may be significantly higher.

Although the example presented in this task was for a mine in the Appalachian region, the same methodology may be used for other parts of the country. The specific land acquisition expenses, capital and labor costs, and mine productivity, will vary with the location; hence the total costs computed will differ. However, it does not appear likely that the overall conclusions will be markedly different.

The study highlights the significance of resource aquisition costs and labor productivity, which may vary considerably between mines --even if the geological conditions are similar. This emphasizes the need to make site-specific analyses based on the experience of each company's management, when making decisions as to the relative costs of single- or multiple-seam mining.

7.0 SUMMARY OF DATA FROM MULTIPLE-SEAM MINES

TABLE 15 Northern Appalachia; Southwestern Pennsylvania, Northeastern West Virginia, and O...

LOCATION	COLUMNAR STRATIGRAPHICAL DESCRIPTION		TYPE AND METHOD OF MINING	NATURE OF IMMEDIATE ROOF	NATURE OF IMMEDIATE FLOOR	RECOVERY WITH RESPECT TO MINERO SYSTEM EMPLOYED	MINING PROBLEMS AND ITS EFFECTS ON ANY FUTURE / SUBSEQUENT OPER / UNDER / SIMULTANEOUS MINING.	EFFECTS ON COSTS	NATURE OF FUTURE / SUBSEQUENT MINING	DISCUSSIONS / CRITICISM / REMARKS
	THICKNESS	DESCRIPTION								
1	2	3	4	5	6	7	8	9	10	11
Cambria County PA	Average 450' 54" - 80" 115' to 125' 42' to 48'	Overburden: Predominantly shales, with several sandstone beds 15' to 40' thick. Lying mostly 200' to 300' above the upper seam Coal seam: Upper Kittanning Parting: Mostly shales; The unmined dirty middle Kittanning seam 5A about 80' below upper seam, underlain by fireclay and overlain by a 20' to 60' thick sandstone bed directly above it. Coal seam - Lower Kittanning	Room and Pillar. Complete recovery. Some pillars lost as in upper seam. Room and Pillar. Complete recovery. Entries on 90' centers. Some pillars lost as in upper seam.	Sandy shale, generally good top. 1' to 8' bone (drawn down with coal), overlain, usually by black low lustred slate which falls often up to Middle Kittanning, seam 70'-75' above.	Smooth medium hard fireclay Fireclay, clayite flint	85% 85%	None: Where upper seam extraction preceded that of lower seam. Normal conditions in lower seam no poor, as to make it difficult to determine whether any disturbance was caused by upper seam mining. Caving chambers parallel to main entries have been used to obtain relief from roof pressure on the mains. Colmonization attempted but not continued due to local mine conditions.	Increase roof support and ventilation costs	Undermining	Simultaneous mining in the two seams gave much difficulty. Minor falls in the lower seam caused caving of development work in the upper seam. In one case 100 feet, but heavy and heading had to be continually re-timbered due to the disturbance. In some areas, the lower seam was mined 5 to 20 years before the upper, only disturbance to the upper was along "Shear Zones" areas, about 50' on either side of the line between lower seam pillars, and solid coal. This disturbance consisted of broken top, and caused one of perhaps twice as much timbering as normal. One other difficulty was of the lower seam ventilation forcing gas from the increasing strata on into the upper seam at one of the shear zones and resulting in a minor explosion. (After Stemple, 1956)
Indiana County PA	200' Maximum 100' Average 68" to 76" including 8"-10" of bone. 200' Average 62"	Overburden: Predominantly shales with a sandstone bed 15' to 50' thick directly over the upper seam. Coal seam: Upper Freeport Parting: Nearly all shales; some are persistent sandstones and limestones not over 15' thick; 2 or 3 coal seams, 8" to 10" thick, and fireclays. Coal seam: Lower Kittanning	Room and Pillar mostly robbed, but in some places just split; all on 50' centers. Room and Pillar. Entries on 45° to 60° centers. Rooms overlie by on 42' centers, 25' wide, cross cuts on 20' centers. Pillars left in place.	Dark shale 1 to 10' thick, more or less fossiliferous in areas. Generally good 6" bone coal with coal overlie by thin shale. Fair top.	Bone and bottom coal vesicular by fairly firm fireclay Fireclay, Soft.	80% Approximately 60% Approximately	Essentially none. Pens of coal known not driven due to bad top.		Undermining	Some mining in the lower seam done, where upper seam pillaring is done simultaneously, an additional trouble reported in the lower seam. (After Stemple, 1956)
Monongalia County WV	600' Average in area investigated. 54" to 66" 80' to 110' Average 90' Average 96" with non-persistent parting	Overburden - shales, fireclays, thin coal seams with several strong limestones 10' to 25' thick, and some sandstones up to 50' thick, nearer to the surface Coal seam - Sewickley Parting: Predominantly shales with an 18" thick limestone bed about 6' below the upper seam; also the unlain 12" Redstone coal, about 35' above the lower seam. Coal seam - Pittsburgh	Room and Pillar. In older sections with complete recovery attempted; some chain and barrier pillars left, also some inclosed pillars and stumps. Block system in newer sections.	Sandstone in shaley areas; slate. 6" to 12" drawslate overlain by shales and fiber coal seams up to 9' thick. Then the black rock "shale".	Shale or fireclay, fairly soft in some instances. Shale, fairly firm, with some decomposition on exposure to air.	Approximately 85% in older sections. 65% Average	Weight is evidenced under blocks left in the upper seam. First by coal slugging off the ribs, then by ribs buckling and finally by fracture of the roof close up into the black rock. Most weight appears under the edges of the blocks, predominantly under large blocks and most evident where these blocks are isolated in the center of the goaf.		Undermining Overmining	Appearance of weight requires much additional timber and some roof can't or held for any length of time. It appears certain a place must remain for mining may be unsafe to enter 20 minutes later. A section of roadway where much remaining pillars was observed where top had been taken up to the black rock, which in general remained quite sound, and still much heavy timbering and relining was required into it. (After Stemple, 1956)
Cambria County PA	32" 25' 5' 3"	Overburden - Coal seam "D" Seam Parting: Shale and sandstone Coal seam: Base -	Room and Pillar				Coal too badly crushed and misplaced with roof and bottom too badly broken to permit mining of seam			(After Stemple, 1956)
Cambria County PA	30" to 36" 120' 5' 3"	Overburden Coal seam "E" Seam Parting: Shale, sieve and sandstone Coal seam:	Room and Pillar				E seam broken, cracks 3" to 6" wide. Successfully mined with increased timber cost and slatework increased production of fine coal.	Increased timber cost. Increased slatework.	Overmining	(After Stemple, 1956)
Cambria County PA	80' 4'	Overburden: Coal seam: Parting: Sandstone, shale and coal Coal seams	Room and Pillar				No trace of damage in upper seam. In one mine a heading double track width over robbed area without cracks and roof good. In one case a settlement of 8" noted coal in good condition. Rooms driven 21 to 26 ft wide with 3 rows of posts. Necessary to drill holes to lower seam to drain upper seam.		Overmining	(After Eavenson, 1923)
Somerset County PA	25' 8'	Overburden: Coal seam: Redstone Parting: 5 ft of hard sandstone, Pittsburgh remainder soft slate and shales Coal seam: Pittsburgh					Rimstone seam subsided from 1' to 4'		Undermining	Subsidence on account of lower seam mining: 66% of area subsided (After Stemple, 1956)
Central PA	3' 6" 20'	Overburden: Coal seam: Parting: Coal seam:					In places coal had separated from roof and several large cracks extended through coal and floors; at other places floor had separated from coal. Effects did not appear to form serious obstacles to recovery of coal.			
Connellsville PA	5' 72' to 147' 8"	Overburden: Coal seam: Sewickley Parting: Shales, sandstone, limestone slate Coal seam: Pittsburgh					Surface cracks developed over robbed area in which percolating water and air had disintegrated top rock, causing falls up to 4' thick. This condition not noticed where robbing had not been done. Can frequently noticed entering upper seam from seam below. Where sufficient time had elapsed after robbing lower seam, nothing was found in the upper seam that indicated material increase of roof, danger, or decreased recovery. The surface had been broken but numerous pools of water gathered in upper bed which had to be drained by pumping. In two cases where upper seam had been developed, first coming in lower seam caused subsidence of 3 1/2' to 4' with heavy falls in upper seam.			Subsidence on account of lower seam mining - 45 to 50% (After Eavenson, 1923)

TABLE 15 (Continued)

LOCATION	OVERBURDEN STRATIGRAPHIC DESCRIPTION: THICKNESS	OVERBURDEN STRATIGRAPHIC DESCRIPTION: DESCRIPTION	TYPE AND METHOD OF WORKING	NATURE OF IMMEDIATE ROOF	NATURE OF IMMEDIATE FLOOR	RECOVERY WITH RESPECT TO MINING SYSTEM EMPLOYED	MINING PROBLEMS AND EFFECTS ON FUTURE/SUBSEQUENT OVER/UNDER/SIMULTANEOUS MINING:	EFFECTS ON COST	NATURE OF FUTURE/SUBSEQUENT MINING	DISCUSSIONS/CRITIQUE/REMARKS
1	2	3	4	5	6	7	8	9	10	11
Cambria County PA	0' to 600'	Overburden: Shales, sandstones, limestones, fireclays, and thin coal seams. Some sandstones 10' to 40' thick, lying 200' to 300' above the upper seam. Coal Seam: Upper Kittanning	Room and pillar, entries on 90° centers, 17' and 14' wide. Rooms on 60' centers, 24' to 30' wide. Pillars recovered.	12" bone coal, falls with coal, overlain by firm shale.	Hard, firm calcareous shale.	88% 88% in pillared area and 50% in surface support area	Occasional separation of coal from roof. Bending of coal seam, accompanied by broken roof and floor for about 100' on either side of lower seam line between goaves and main entry barrier pillars.	Increased cost of timber and floor lifting in lower seam below pillared areas of upper seam.	Overmining Overmining	Greatest difficulty was in lower seam along one of the remaining main entries. Impact of upper seam pillar falls caused much weight and bottom heave, immediately after pillaring above and worsening gradually over a period of days. This closed up all but two entries, which were kept open only by much additional timber and taking of bottom. Simultaneous mining caused greatest difficulty: Pillaring in lower seam caused loss of all equipment, track, etc. in an upper seam section. Minimum time for complete settlement not known. 8-10 years appears to be ample. (After Stemple, 1956)
	30' to 110' Average 95'	Parting: Shales and sandy shales with very little sand stone and Middle Kittanning coal seam, thin in the area.	Room and pillar, complete recovery. Active mining at present of main, chain, and barrier pillars.	6" bone coal which falls with coal, overlain with good shale.	Very soft fireclay. 2' thick underlain by sandy fireclay.					
	36" to 39"	Coal Seam: Lower Kittanning								
Cambria County PA	300'	Overburden: Predominantly shales with several sandstone beds, 15' to 40' thick, lying mostly at 150' to 250' above the upper seam.	Room and pillar, complete recovery. All gnats = 60' centers, entries 21' to 24', rooms 24' to 28' wide.	Sandy shale generally very firm.	Fairly soft shaley fireclay.	85%	Only disturbance noted was some bending and broken roof for about 100' on either side of lower seam edge goaf. Some additional timber required.	Some additional costs on timbering.	Overmining Overmining? Overmining	(After Stemple, 1956)
	52"	Coal Seam: Lower Freeport								
	40'	Parting: Mostly gray sandy shales. Coal Seam: Upper Kittanning	Room and pillar, complete recovery. Entries on 90' to 100' centers, rooms on 60' centers.	Sandy shale generally good.	Firm fireclay.	85%				
Cambria County PA	620'	Overburden: Predominantly shales with several sandstone beds 15' to 40' thick, lying mostly at 150' to 250' above the upper bed.	Room and pillar, complete recovery all places on 60' centers, entries 21' to 24' wide, rooms 24' to 28' wide.	Sandy shale generally very firm.	Fairly soft shaley fireclay.	85%	Some bending and disruption of strata where entries crossed over line between lower seam goaves and solid barrier pillars.			No colonization attempted over lower seam barrier pillars. Only a few cases of disturbance encountered. (After Stemple, 1956)
	52"	Coal Seam: Lower Freeport				90%				
	130' to 150'	Parting: Shales with a 20' to 40' thick bed of sandstone lying 5' to 90' above the lower seam.	Room and pillar, complete recovery only coal left in the barrier pillar.	Partly firm shale.	Fireclay.					
	18"	Coal Seam: Lower Kittanning								
Cambria County PA	100' to 150'	Overburden: Almost entirely shales, with a sandstone bed 5' to 15' thick immediately over the upper seam.	Room and pillar, limited development work only. 3 place entries on 60' centers, 12' to 16' wide. A few rooms on 50' centers.	12" to 18" bony coal and slate overlain by sandstone.	Fireclay about 5' thick.	35% to 40% in the immediate areas of mining. About 50% in area robbed.	None. Some poor roof which may or may not be due to lower seam mining.			Insufficient mining to constitute any results. (After Stemple, 1956)
	Average 36"	Coal Seam: Lower Freeport								
	145' to 160'	Parting: Shales, fireclays, thin coals and some sandy shales to sandstones 10' to 20' thick directly above the lower seam.	Room and pillar, 4 place main entry on 60' centers with 12' to 16' wide, with a 200' barrier pillars. Some robbing done.	Black slate, bony coal and rash, overlain by dark sandy shale.	Sandy fireclay.					
	44"	Coal Seam: Lower Kittanning								
Monongalia County WV	400'	Overburden: Shales, fireclays, thin coals, several limestones 10' to 25' thick and a sandstone up to 50' thick near the surface.	Block system 20' square centers, 20' wide, pillars pulled, split or left depending on coals of particular section.	Sandstone to strong sandy shale, good.	Fireclay to shale, fairly soft.	Approximately 25% overall.	No disturbance where lower seam pillars left above robbed areas, upper seam strata, floor, coal and roof fractured. Mining difficult.			Experience has shown that upper seam mining conditions are fair when 3 or 4 years have elapsed since lower seam mining. Simultaneous mining causes greatest difficulties. Good roof conditions in one section over lower seam first mining were attributed to mining with a continuous miner, therefore, with no blasting, which might have jarred the partially supported strata. (After Stemple, 1956)
	66"	Coal Seam: Sewickley								
	Average 90'	Parting: Predominantly shales, unmined redstone seam 12" thick 35' from lower Pittsburgh seam and a limestone bed 18" thick, 6' below upper Sewickley Seam.	Block system on 90° centers, 20' wide pillars. Pillars pulled in some areas, left in others.	8" to 12" draw slate overlain by about 5' of shales and slate coal.	Fairly hard shale.					
	Average 96"	Coal Seam: Pittsburgh								

TABLE 15 (Continued)

LOCATION	COLUMNAR STRATIGRAPHIC DESCRIPTION		TYPE AND METHOD OF WORKING	NATURE OF IMMEDIATE ROOF	NATURE OF IMMEDIATE FLOOR	RECOVERY WITH RESPECT TO THE MINING SYSTEM EMPLOYED	MINING PROBLEMS AND ITS EFFECTS ON FUTURE / SUBSEQUENT OVER / UNDER / SIMULTANEOUS MINING	EFFECTS ON COSTS	NATURE OF FUTURE / SUBSEQUENT MINING	DISCUSSIONS / CRITIQUE / REMARKS
	THICKNESS	DESCRIPTION								
1	2	3	4	5	6	7	8	9	10	11
Green County PA	0' to 350' Average 92"	Overburden: Medium cover shows sandstone out surface in beds up to 30' thick with cover of less than 250' most of it is shales and 6 or 7 limestone beds running 5' to 15' thick. Coal seam: Sewickley	Block system 100' centers in old works, 50' to 60' centers in new works, 16' or more wide, 4 to 6 place mains, 100' to 300' barrier pillars, 4 to 5 place butts. Much of old work is room and pillar.	Normally 3' to 5' shale, found top. Some sandstone, poor top.	Firm shale	90% in robbed area, old first mined areas to be robbed eventually.	Only two conditions creating disturbance have been encountered. 1. In an area where the lower seam has been pillared 20 years previously, the upper seam strata was found highly disturbed at points about 300' on the goaf side of the lower seam robbings. This was evidenced by a relative displacement of the seam, together with roof and floor strata of about 3 or 4 ft necessitating heavy timbering for 100'. The cover over the upper seam at this point was about 110'. Further out over the gob, strata were settled, but additional timber was required due to broken top. There was no evidence of separation between floor and coal, or between coal and roof. 2. In an area where another company pillared lower seam at the same time that the upper seam was being developed, such top-caving was caused in the upper seam that equipment was nearly lost and coal had to be abandoned. It is thought actually this area may be recovered, but time required for stabilization of conditions is not known. Less than two years is thought to be insufficient.	1. Increased cost of roof control. 2. Possible reduction in rate of advance	Simultaneous mining	The upper seam is pillared before the lower, but by no uniform distance or time interval. The development work in the seams has not been uniform because of piece meal acquisition of the property much of it after some development had been done. (After Stemple, 1956)
	110' to 130' Average 96" with 12" top coal left; 2 or 3 partings 1/2" thick, about midway in the seam.	Parting: Predominantly shales and limestones. Also the extremely non-uniform Redstone coal, about 45' above the lower seam. Coal seams: Pittsburgh	Block system on 80' and 100' centers, places 14' wide; 5 and 10 place mains, 5 place butts. Several sections first mined (by other companies) all to be pillared. One area of snap-top has been heavy caved.	Coal top left normally is haulageway, all coal is taken, leaving a 6" to 12" thick shale top overlain by 3" to 18" coal, the lowest of the 3 or 4 booster seams.	Normally fireclay which deteriorates badly.	90% in pillared area 50% in honeycomb area				
Indiana County PA	220 ft. Coal - 42" Bone - 3" Coal - 3"	Overburden: Almost entirely shales, fireclay. Coal seam: Upper Freeport	Room and pillar; Old: 1-8 entry mains; 40' to 50' centers, 12' wide, 100' barriers, left in; 2 entry butts 50' centers, 20' wide; rooms on 40' to 45' center, pillars pulled. New: 3 and 4 entry breaks, on 50' centers, 18' to 20' wide; rooms on 50' centers, 25' wide, pillars left in place.	Dark shale, several feet thick, not too good, generally.	Fireclay 3' to 5' thick; firm but deteriorates when wet.	70% Approximately overall	In one section, the lower seam was first mined and some pillars split. In the period there to eight years later. The upper seam was first mined and the top was found broken, the floor heaved so that mining had to be stopped. The main difficulty was encountered where, the top seam was first mined and then the lower seam pillared.		Simultaneous mining	The most successful mining was regarded as that where the upper seam was mined completely. Prior to any mining of the lower seams, regardless of the difficulties due to any water lying in the mined out upper seam. (After Stemple, 1956)
	55' to 70' Average 65	Parting: Nearly all thin bedded shales (each less than 15' thick) some of it sandy; one limestone bed 3' - 5' thick.	Room and pillar, 4 entry mains, 40' centers, 12' wide; 100' barrier pillars, 2 and 3 entry butts; 50' centers, 15' to 20' wide, breaks on 50' centers; rooms on 50' centers; some pillars pulled but not uniformly.	Dark shale	Fireclay 2' to 4' thick underlain by sandy shale to sandstone	60% Approximately overall	Some mains more or less superimposed, but pillars are not columniged.			
Monongalia County WV	500' to 900'	Overburden: Predominantly shales and sandy shales, with several limestone beds from 5' to 25' thick, lying from 30' to 130' above the upper seam also one sandstone bed, about 50' thick, lying at about 300' above the upper seam.	Block system room on 60' square centers, 7 place mains on 90' centers. Pillars left in place	Normally 5' to 50' of shale, with some sandstone top.	Hard fireclay with some deterioration when wet.	70% overall; some older sections were pillared	Upper seam pillaring over lower seam development caused much disturbance to the lower seam.		Upper seam mining proceeds that in lower. Partial recovery methods used in both seams.	New main entries are superimposed but not columniged. No pillaring at present in either seam. Present system of partial recovery in both seams has caused no trouble in either.
	48" to 66" 90' Average Average 96"	Coal seam: Sewickly Parting: Predominantly shales with two fairly thick limestone beds, and a thin coal seam Coal seam: Pittsburgh	Room and pillar, block split.	Shales and rider coals	Firm, fireclay	65% to 75%	It was found out that upper seam pillaring had to be done before lower seam, to be successful.		Simultaneous mining	(After Stemple, 1956)
Portage PA	3 1/2' to 8' 80' to 100' 3 1/2' to 6'	Overburden: Coal seam: Upper Kittanning Parting: Relatively thick sandstone Coal seam: Lower Kittanning	Room and Pillar				No serious trouble.		Overmining	Even where pillars were drawn in Lower Kittanning seam, in the later mining in the Upper Kittanning seam no serious trouble was experienced, and each seam was mined without any apparent effect upon the other.
Portage PA	3 1/2' to 4 1/2' 50' to 60' 3 1/2' to 8'	Overburden: Quite heavy sandstone Coal seam: Lower Freeport Parting: Coal seam: Upper Kittanning	Room and Pillar				Usually no trouble experienced if lower seam (Upper Kittanning) is mined before upper seam (Lower Freeport). Considerable roof trouble results if the two are mined simultaneously.		Overmining	
Portage PA	3 1/2' to 4' 3 1/2' to 4 1/2'	Overburden: Coal seam: Upper Freeport Parting: Sandy shale Coal seam: Lower Freeport	Room and Pillar				Mining of Lower Freeport almost invariably causes trouble in Upper Freeport overlying because of vertical breaks. Trouble attributed to lack of strength of strata.		Overmining	
Southern Somerset County (4-mines) PA	4' to 4'10" 19' to 35' Average 26' 8'	Overburden: Coal seam: Redstone Parting: Mostly slate which readily breaks into small pieces. Coal seam:	Room and Pillar			90%	Any two seams can be mined with this thickness between them if low-lower seam has been removed entirely before upper one is mined. Cost of mining upper one is not perceptibly increased, nor percentage recovery lowered or danger increased by mining the lower seam first. Upper seam to be mined 3 months after removal of lower one. Lessee's engineers at one mine state that a recovery of 90% obtained of Redstone bed. Cost increased by 4 to 6%. Data for this district only.	Increase in cost of production 4 to 6%.	Overmining	(After Eavenson, 1923)

TABLE 15 (Continued)

LOCATION	COUNDER STRATIGRAPHIC DESCRIPTION: THICKNESS	COUNDER STRATIGRAPHIC DESCRIPTION: DESCRIPTION	TYPE AND METHOD OF WORKING	NATURE OF IMMEDIATE ROOF	NATURE OF IMMEDIATE FLOOR	RECOVERY WITH RESPECT TO THE MINING SYSTEM EMPLOYED	MINING PROBLEMS AND ITS EFFECTS ON FUTURE/SUBSEQUENT/OVER/UNDER/ADJACENT MINING	EFFECTS ON COSTS	NATURE OF FUTURE / SUBSEQUENT MINING	DISCUSSIONS / CRITIQUE / REMARKS
1	2	3	4	5	6	7	8	9	10	11
Tioga County PA	3'6" to 5'4" 50' 1'6" to 2'8"	Overburden: Coal seam: Morgan Parting: Coal seam:		Strong sandstone		85%	Morgan bed successfully mined. Broken roof, separation of coal and roof found. Recovery about 85%, loss not primarily due to mining lower seam. Relative movement of top and floor occurred occasionally. Extraction in lower seam probably not complete. Strong sandstone roof in Morgan bed contributed much to success of operation.		Overmining	
Monongalia County WV	4' to 6' Avg. 5' 90' to 100' 2' to 9' Avg. 8'	Overburden Coal seam: Sewickley Parting: sandstone, limestone and shale Coal seam: Pittsburgh	Room and Pillar with long extraction lines			95%	When undermined subsidence in Sewickley bed occurred, usually the floor dropped away from the coal. Cracks developed in pavement and water drained to Pittsburgh bed. Mining in the Sewickley bed was not feasible while pillars were being extracted beneath it. Sewickley coal was successfully mined 4 to 5 years after the Pittsburgh was removed, and recovery approached 95% in Sewickley. If properly planned both can be removed if Pittsburgh pillar line lies Sewickley by approximately 100 ft, weathers less. Reopening and maintenance costs in this area were slightly more than average, but average recovery for seam was obtained.	Higher reopening and maintenance costs in overmined seam.	Undermining and Overmining	(After Rice, 1930)
Scranton PA		Overburden: Coal seam: Parting: Coal seam:					Caving of a seam below lowered an entire city block by 5' to 6'. Mining in the upper bed continued with increased difficulties in haulage and at higher cost.	Higher costs and increased difficulties in haulage.		(After Rice, 1930)
Monongalia County WV	190' to 200' 4' to 6' 90' to 140' 8' to 9'	Overburden: Mostly sandstone and limestone Coal seam: Sewickley Parting: Mostly sandstone and limestone Coal seam: Pittsburgh					Cracks in the pavement, subsidence of pavement causing the coal and roof to hang. Followed by caving of roof.		Overmining Undermining Simultaneous Mining	If lower bed has been completely removed, the upper bed can be worked with additional cost of timber. If the upper bed is completely and properly removed, no harm to the lower bed will occur. Beds can be simultaneously mined, if the workings in two seams are colinearized and pillar line in upper seam is kept about 100 ft ahead of lower seam. (After Brady, 1931)

TABLE 16 Central Appalachian; Southwestern West Virginia, Southwestern Virginia, and Eastern Kentucky.

LOCATION	COLUMN OF STRATIGRAPHIC DESCRIPTION: THICKNESS	COLUMN OF STRATIGRAPHIC DESCRIPTION: DESCRIPTION	TYPE AND METHOD OF WORKING	NATURE OF IMMEDIATE ROOF	NATURE OF IMMEDIATE FLOOR	RECOVERY WITH RESPECT TO MINING SYSTEM EMPLOYED	MINING PROBLEMS AND EFFECTS ON FUTURE/SUBSEQUENT OVER/UNDER/SIMULTANEOUS MINING	EFFECTS ON COST	NATURE OF FUTURE/SUBSEQUENT MINING	DISCUSSIONS/CRITIQUE/REMARKS
1	2	3	4	5	6	7	8	9	10	11
McDowell County WV	300' to 1600'	Overburden: Predominantly sandy shales or sandstones, some thin coals, fireclays, etc. Several sandstone beds about 50' thick.	Room and pillar, development work only; 6 entry mains, 90' centers, 12' and 18' wide.	Sandy shale, in layers of variable thickness, or massive sandstone 10' to 50' thick.	Hard sandy fireclay about 3' thick underlain by sandstone.	85% to 90% planned	Some previous robbing of the lower seam caused cracks in the upper seam floor, 2" to 3" wide and with some relative vertical movement. The chief difficulty here was in the loss of ventilation.		Lower seam being honeycombed; upper seam to be extracted completely at any time following the lower. Overmining.	No columnization of pillars. Success of this system has not yet been determined, as none of the upper seam mining has progressed over the lower seam honeycombing.
	76" to 80" Average 42"	Coal Seam: Pocahontas No. 4								(After Stemple, 1956)
	50' to 55'	Parting: Mostly shales with a hard sandstone bed about 10' to 15' thick midway between the seams.	Room and pillar, honeycomb; rooms on 40' centers, 22' wide, breaks on 60' centers; 3 entry cross-entries on 65' centers, 16'wide.	6" to 24" of slate overlain by 2" to 4" of rooster coal, then by highly stratified shale.	12" to 18" sandy shaley fireclay, underlain by sandy shale.	70%				
	Average 52"	Coal Seam: Pocahontas No. 3								
Mingo County WV	0' to 1050'	Overburden: Predominantly sandstones, with shales, etc. First heavy sandstone above upper seam is about 60' above it.	Room and pillar, 6 and 7 entries, 22' wide rooms on 40' centers, 20' wide; all breaks on 80' centers. Pillars left in place.	Fire shale, some sandstone.	Firm fireclay.	68% to 72%	Trouble encountered both mining top seam first and mining lower seam first. In one case, the lower seam places, driven up about 6 months. After the upper seam places, (where parting was 65' and cover over top seam, 500'). A month later, floor heave, caused abandonment of the lower seam section.		Originally, mining in upperseam proceeded, now trying lower seam mining in advance. Undermining, in parts Overmining, in parts	Originally, entry and room projections were superimposed, but not cross cuts; now all pillars are columniated. The two examples are believed to be typical of the difficulties encountered under the two situations.
	42" to 48" Average 46"	Coal Seam: Upper Thacker				65%				
	30' to 80'	Parting: A persistent sandstone bed 15' to 25' below the upper seam, which varies in thickness from 10' to 50' depending upon the thickness of parting strata. Rest shales and fireclay.	Room and pillar, same plan as for upper seam except rooms 4' to 6' narrower and entries 2' narrower.	8" to 10' of rotten shale overlain by sandy shale or sandstone.	Slate, streaked with coal 15" to 20" thick, underlain by 2" to 4" coal. This underlain by shale or sandy shale.		In another case, the lower seam places, driven up 6 rooms completed & to 6 months prior to development of the upper seam (parting 75' and cover over top seam, 150'). The upper seam, with first rooms only, completed off entry, fell in as the entry advanced, due to heavy roof falls which could not be held.			(After Stemple, 1956)
	62" to 86" Average 68"	Coal Seam: Lower Thacker								
Mingo County WV	0' to 800' Average 500'	Overburden: Sandstones, shales and thin coal seams, several sandstone beds are 40' to 50' thick.	Room and pillar, place entries on 65' centers, 28' wide; 41 crosscuts on 72' centers, 20' wide, pillars left in place.	Dark sandy shale, which scales very easily.	Hard shale.	74% on room entries and 70% on main entries	No difficulties due to two seam mining, with the exception, that when upper seam places pass through a 'wheat' zone, over the line between lower seam mined out areas and solid coal, where top conditions are poorer than normal).		Upper seam mining leads in some areas; lower seam mining in others, some sections nearly simultaneously mined.	Pillars columnized throughout the mine with the exception of few old workings. Total recovery of both seams could not be accomplished economically or without loss of considerable coal; due to falls, breaking of surface, high pumping and drainage costs, etc. The present system affords nearly as high a recovery at lower cost, as possible, but requires high competence of engineering and supervision.
	34" to 48" Average 40"	Coal Seam: Upper Thacker (Upper Cedargrove)								
	Extremes: 65' to 120' Normally: 65' to 80' Average 70'	Parting: One prominent sandstone bed, varying in thickness up to 50'. Usually closer to upper seam; rest in shales and a non-persistent thin coal seam, 3' to 25' over the lower seam.	Room and pillar, same centers as for upper seam but rooms 6' narrower.	Soft shale, usually laminated. Fall up to rider coal 3' to 25' above.	Very soft shale, normally wet.	60% to 70%	The greatest difficulty experienced arose in attempting to mine the upper seam over robbed lower seam. Lower seam places passing under top seam mined out areas and solid coal, have not been observed to cause any disturbance.			(After Stemple, 1956)
	Average 58'	Coal Seam: Upper Thacker (Lower Cedargrove)								
Mingo County WV	0' to 900'	Overburden: Shales, thin coal beds etc; with several sandstone beds, some up to 30' thick; one thick sandstone bed at about 30' above the upper seam.	Room and pillar, honeycomb mining; rooms on 65' centers, 28' wide; breaks on 73' centers, 20' wide.	Dark, sandy shale, some sandstone top.	Hard shale.	70%	In one section of the mine, total extraction in the upper seam had to be stopped because of heavyweight riding over as the rooms cut into an old robbed section; this was thought due to mining practices with in the seam only.		Mining in the upper seam precedes that in the lower seam by 600'. Undermining.	Effectiveness of this system not yet known. The system just being started. Completely columnized except that rooms in the lower seam are driven only under every other room in the upper seam system.
	30" to 42" Average 34"	Coal Seam: Upper Thacker (Upper Cedargrove)								
	Average 90'	Parting: Shales, with a sandstone bed, 20' to 30' thick, midway in the interval, perhaps nearer the upper seam. Rider coal does not always show over the lower seam.	Room and pillar, complete recovery; rooms on 90' centers.	Soft shale, usually laminated; will fall up to rider coal seam, 3' to 25' above.	Very soft shale, normally wet.	80% to 85%				(After Stemple, 1956)
	60" to 66"	Coal Seam: Lower Thacker (Lower Cedargrove)								
Wyoming County WV	0' to 1500' Average 500' to 800'	Overburden: About two thirds sandstone, the rest shales, etc; several heavy sandstone beds, two of which are 800' to 150' thick.	Room and pillar, entries on 80' centers, 16'wide; rooms on 28' centers, 20' wide, pillars left in.	Coal or shale soft; overlying seams vary in proximity to the Campbell Creek; from 40' to 100' of coals and shales, to the overlying heavy sandstones.	18" to 24" soft shale, underlain by sandstone.	75%	Some indications of weight and roof disturbance have occured in the upper seam over the lines between lower seam barrier pillars and mined areas; also in upper seam, over the intersection of main entries in the lower seam, where the barrier pillars are surrounded by mined areas (Cover over top seam in one of these mined areas is 1200').		Lower seam mined first, upper seam follows, by about 6 years. Overmining.	Main entries columnized. Pillars not columnized. Height of extraction in the upper seam varies, according to proximity of the overlying lowless and Alma seams. If the partings between the 3 seams are minimum, part or all the coal may be removed from all 3 seams, making a total height up to 12' or 35'. The roof thickness [illegible] making a total height up to 12' to 35'. The roof thickness also varies, being coal, either workers or Alma, in some cases, and soft grey shale in others. Some areas of top seam expected to be bad, have held well and then failed suddenly, indicating possibly support from lower seam pillars for a period followed by their failure and subsequent subsidence.
	220' to 240'	Parting: Predominantly sandstone with some shales and sandstone beds up to 50' thick, one closely underlying the Campbell seam and about 35' in the later	Room and pillar, entries on 65' centers 14' wide rooms on 65' centers 67' wide, breaks on 80' centers 14' wide. Pillars left in place.	Shale, fairly hard, laminated.	Shale to sandy shale	65%				(After Stemple, 1956)
	Average 62"	Coal Seam: Eagle								

Location	Columnar Stratigraphic Description		Type and Method of Working	Nature of Immediate Roof	Nature of Immediate Floor	Recovery with Respect to Mining System Employed	Mining Problems and Effects on Future/Subsequent Over/Under/Simultaneous Mining	Effects on Cost	Nature of Future/Subsequent Mining	Discussions/Critique/Remarks
	Thickness	Description								
1	2	3	4	5	6	7	8	9	10	11
Floyd County, Kentucky	100' to 300' Av 38" 22' to 24' Av 36"	Overburden: Predominately slate. Coal seam: Elkhorn No.2 Parting: Mostly shale or slate. Coal seam: Elkhorn No.1	Room and pillar entry work development only. 4 entry mains, 60' centers, 20' to 22' wide. Room and pillar as above.	Slate, 6' to 8' thick overlain by sandstone. Good top. Mostly slate, some sandstone. Good top.	Hard shale Fireclay, soft, trouble-some at times.	65 -70%, planned 65-70%, planned	The first work was in the upper seam with wide places shot off the solid. These places eventually squeezed. Subsequent mining in the lower seam, below this area, showed similar disturbance; a gradual settling of the roof, squeezing of pillars, bottom heave, rather than abrupt roof falls. No difficulties encountered when columnization of pillars was tried.		Upper seam mining preceded the lower seam thus creating simultaneous undermining.	Mining of upper seam was stopped for economic reasons (cleaning problems). All entries were superimposed and pillars were columnized. (After Stemple, 1956)
Harlan County, Kentucky	Av 250' Av 48" 1000' 225' 38" to 60"	Overburden: Sandstones and shales. Maximum bed 15' thick. Coal seam: Splint Parting: Sandstone, shale, and fireclay. Several thick sandstone beds, 25' to 50' thick. Coal seam: Darby Parting: Mainly sandstone, 70' thick. Coal seam: Harlan	Room and Pillar. Entries on 60' centers, 16' wide; rooms on 40' centers, 20' wide. Pillars slab 8' to 10'. Very little robbing. Room and Pillar Room and Pillar Entries on 60' centers, 16' wide, rooms on 70' and 80' centers, 18' wide. Pillars pulled in most cases.	Weak slate Slate	Firm slate Firm shale	75% 60% 90% on pillared sections, 35% where pillars are left.	Cracks in coal and floor of Splint seam have been reported.May be related to a violent hump in the lower Harlan seam. Machine cuttings were lost in these cracks, but the cracks apparently did not reach the surface as there was little water at these locations. There is no evidence that these cracks were caused by pillaring in the Harlan, due to the presence of the reportedly undisturbed intervening Darby seam.		Overmining. The lowest seam workings are kept ahead of other seams, but by no definite time or distance.	The Darby seam, 225' above the Harlan, was being mined by another company over mined areas of the Harlan seam. Conditions in the Darby were fair, and were not related to lower seam extraction. (After Stemple, 1956)
Tazewell County, Virginia	0' to 700' Av 51" 70' to 110' 60" to 80"	Overburden: Sandstone, shale, fireclay. 700' of sandstone directly above coal. Coal seam: Pocahontas No.5 Parting: Slate, shale, 15' thick sandstone above No.4 and below No.5. Coal seam: Pocahontas No.3	Room and Pillar. Rooms on 70' centers. Room and Pillar. Entries on 90' centers, rooms on 75' centers.	2" to 8" rash overlain by drawslate, 2' to 3' of slate. Slate and bad shale	Rash coal underlain by sandy fireclay. Slate or fireclay underlain by sandstone.	90% 80% planned	Power hole support pillars left 200' to 300' on all sides of the power hole in upper seam, when approached by pillaring operations, produced intence weight on the main entry chain pillars in the lower seam. This weight was evidenced directly below the support pillars, and to about 300' outbye of them until sufficient pillars had been extracted in the upper seam to induce a fall around the support pillars. The weight then appeared only directly below the support pillars, squeezing the entries in the lower seam.		Undermining, upper seam retreating as lower seam is being developed.	Main entry system is superimposed but pillars are not columnized. (After Stemple, 1956)
Kanawha County, WV	0' to 700' 54" 400' to 500' 42" to 66" 8' to 30' 36"	Overburden: Sandstone and shale. Coal seam: Parting: Predominately sandstone and shale. Coal seam: No.2 gas Parting: Slate and sandstone. Coal seam: Powellton	Room and Pillar. Rooms on 50' and 60' centers, 30' and 40' wide. 30'x60' pillars left in place. Room and Pillar. Rooms on 40' centers, 25' wide. Pillars left in place.	Shale underlain by sandstone. Usually slate, sometimes sandstone.	Usually slate and sandstone. Soft fireclay underlain by sandstone.	70% when conditions are good. 70%	Where the top seam was mined first, conditions became unbearable in the lower seam. Bad top occurred if upper seam was pillared clean, and worsened when pillars were left. Best conditions resulted from mining lower seam for 70% extraction, allowing settlement for at least 2 years, and then mine the upper seam for not over 70% extraction.		Mostly overmining	Mined out in the past. Columnization not attempted due to different equipment for each seam. Wherever the parting was less then 8' only the better quality seam was mined. (After Stemple, 1956)
Logan County, WV	0' to 700' 40' 36" to 42" Av 125' 30" to 60"	Overburden: Sandstone and shale. Coal seam: Island Creek Parting: Sandstone and shale. Coal seam: Alma Parting: Sandstone Coal seam: Eagle	Room and Pillar. 80' centers, split pillars. Room and Pillar. Rooms on 70' centers, hand-work on 40' centers.	Laminated shale 6" rash underlain by drawslate, overlain by sandstone.	Firm fireclay Fireclay	75% 65% to 70%	Mined out in the past, irregular stumps and pillars left. Trouble was evidenced in the upper seam due to 20% of coal left in irregular stumps and pillars in the Island Creek seam.		Varies	Columnization not attempted or tried. Surface cracks seen through maximum cover. (After Stemple, 1956)
McDowell County, WV	0' to 870' 61" to 95" Av 76" Av 85' 72" to 116" Av 78"	Overburden: Sandstone up to 200' thick. Coal seam: Pocahontas No.4 Parting: Sandstone up to 69' thick, and shale. Coal seam: Pocahontas No.3	Room and Pillar. Entries 18' wide, 90' centers. Rooms on 35' centers, 20' wide. Room and pillar on 75' centers, pillaring fairly complete.	Slate, hard to hold. Shale with drawslate.	Firm shale Shale	60% to 65% 80%	Pillaring in the upper seam ahead of the lower seam led to poor top conditions in the upper seam causing abandonment of considerable coal. Lower seam workings below these abandon areas lost coal due to remnant pillars transfering weight.		Undermining, upper seam leads pillar line 750' to 1000', or one year's work in advance of the lower seam.	Original plan of mining the two seams called for pillar lines of both seams to be nearly superimposed, or not over 100' apart; and to recover only 50% of the upper seam. Good conditions in the upper seam led to complete pillaring. It was then deemed advisable to advance the upper seam working. Poor top conditions developed in the upper seam causing abandonment of considerable coal. When lower seam mining advanced under the remnant pillars,considerable weight caused loss of coal. Leaving 50% of the upper seam, by entry driving only, was considered as a possible solution. (After Stemple, 1956)

TABLE 16 (Continued)

LOCATION	COLUMNAR STRATIGRAPHIC DESCRIPTION		TYPE AND METHOD OF WORKING	NATURE OF IMMEDIATE ROOF	NATURE OF IMMEDIATE FLOOR	RECOVERY WITH RESPECT TO MINING SYSTEM EMPLOYED	MINING PROBLEMS AND EFFECTS ON FUTURE/SUBSEQUENT OVER/UNDER/SIMULTANEOUS MINING	EFFECTS ON COST	NATURE OF FUTURE/SUBSEQUENT MINING	DISCUSSIONS/CRITIQUE/REMARKS
	THICKNESS	DESCRIPTION								
1	2	3	4	5	6	7	8	9	10	11
McDowell County, WV	800' 38" Av 50' Av 60"	Overburden:Sandstone and shale. Coal seam: Pocahontas No.4 Parting: Mostly shales. Coal seam: Pocahontas No.3	Room and Pillar. Rooms on 80' centers, pillars are split, stumps left in place.	Sandstone Drawslate and shale	Sandy shale Shale, bone coal	90% in areas not faulted 70% to 75%	Weight observed on lower seam workings over an area about 300' on either side of robbed areas. Roof and floor conditions are bad.		Overmining over honeycombed lower seam workings.	Upper seam has extensive faults and wash areas.Honeycombing the lower seam before robbing the upper seam worked successfully; columnization was not used. (After Stemple, 1956)
McDowell County,WV	800' 48" to 102" Av 78" Av 60' 85" to 94" Av 88"	Overburden: Sandstone and shale. Coal seam: Pocahontas No.4 Parting: 20' to 30' of sandstone between shale beds. Coal seam: Pocahontas No.3	Room and Pillar. Rooms on 60' to 90' centers, 20' wide. Room and Pillar. 60' centers, 35' to 20' wide.	Laminated shale and strong sandstone Shale	Hard shale Hard fireclay, deteriorates when wet.	60% planned 90%	Where large pillars or rows of chain pillars are left, intense weight was felt in the lower seam directly underneath. The roof breaks, coal sloughs off ribs, bottom heaves, and coal must be abandoned.		Undermining, honeycombing of upper seam precedes lower seam pillaring but not by a set distance.	No columnization. Honeycombing caused bad conditions in upper seam. When pillars in the upper seam were split, no trouble was encountered. Pillars are split once parallel to rooms, and twice when perpendicular to rooms. (After Stemple, 1956)
McDowell County, WV	1130' to 1080' Av 48" Av 67' Av 60"	Overburden: Sandstone and shale Coal seam: Pocahontas NO.4 Parting: Sandstone, shale, and fireclay. Coal seam: Pocahontas No.3	Room and Pillar. 60' centers, 35' to 20' wide. Room and Pillar. Areas allowed to stand idle for yrs.by shale before pillaring.	Hard sandstone Drawslate overlain by shale	Hard fireclay Firm fireclay	85% to 90% 80% to 85%	Whenever the upper seam pillar line got 100' to 400' ahead of the lower seam development, old first mined sections tended to fail in due to the impact of upper seam pillar falls. When the lower seam pillar got ahead of the upper seam pillar line, the upper floor settled and loosened timbers.		Simultaneous mining	Large surface cracks up to 20' wide occurred directly over pillar lines of both seams. Best results were obtained when the upper seam pillar line was directly over that of the lower seam; 150' ahead was considered the maximum distance for best conditions. (After Stemple, 1956)
McDowell County, WV	250' to 1400' Av 72' 50' to 55' Av 55"	Overburden: Sandstone 200' thick, shales. Coal seam: Pocahontas No.4 Parting: Mostly shale with hard sandstone 10' to 15' thick. Coal seam: Pocahontas No.3	Room and Pillar. Entries on 60' centers, rooms on 75' centers. Room and pillar as above.	Sandstone, shale, or drawslate. Slate and shale.	Hard fireclay or hard shale. Hard fireclay or sandy shale.	90% where not faulted. 80% to 85%	Some water from the upper seam workings. Some areas of excessive weight for about 100' of either side of upper seam lines between fault and pillared out areas.		Undermining. Upper seam is pillared before lower seam is mined.	Only 25% of the property had a minable upper seam. The original plan was to mine seams concurrently with the upper seam advancing 150' ahead of the lower seam. Good conditions in the upper seam led to extraction without regard to the lower seam. Generally conditions were good in both seams. (After Stemple, 1956)
Kanawha County W VA	0' to 1,500' 56" 300-350' 30" to 54"	Overburden: Shales, coal seams, sandstones, including some thick beds. Coal seam: Winifrede. Parting: Several strong sandstone beds 20' to 40' thick, balance mostly shales. Thin Cedar Grove seam (unmined), underlain by 100' to 150' of sandy shales. Coal seam: No. 2 gas-a parting 0' to 13' at 30" from roof. Only top 30" mined	Room and pillar. Entries 16 ft wide, rooms 30' wide. Both on 50' centers robbing only of some barrier pillars. Room and pillar. Entries 12' and 16' wide, 30' and 60' centers. Room 30' wide at 50 ft centers pillars left.	0" to 15" Hard shale overlain by 40' to 75' thick sandstone shale could not be held. Sand shale, up to 20' thick, brittle, shears, and arches very poor.	Firm shale. Sandy shale, fairly firm.	70% 55 - 60%	None. No columnization of pillars. No pillar falls made in the upper seam.		Undermining	Poor top in lower No. 2 gas seam. Apparently characteristic of seam and not due to upper seam mining. Rooms must be driven up test; roof as seen as mined, to rool shearing at the ribs of the room, with some coal slougning off the ribs. (After Stemple, 1956)
Kanawha county W VA	0' to 900' 56' to 72" Av 66" 260' to 300' 30" to 54"	Overburden: Shales, sandstones etc. Coal seam: Coalburg- includes 12" to 20" of parting. Parting: Shales, some thick sandstones, coal beds, including unmined Winifrede coal seam 90' below Coalburg seam. Coal seam: Cedar Grove.	Room and Pillar. Double entry on 50' centers. Room 35 ft wide on 50' centers. Pillars left in place. Room and pillar. rooms on 60' centers, 40' wide. Pillars left but sometimes split.	Shale-0' to 8' thick, overlain by sandstone poor top. Slate 3' to 5' thick overlain by sandstone good top.	Shale, medium hard. Shale, fairly soft.	75% approx. 80%	None. No columnization attempted.		Undermining	The Belmont seam, 45' to 75' above the Coalburg, was mined simultaneously with and also after, the mining of the Coalburg. This mining caused disturbance in both seams. The bottom dropped away from the Belmont in some cases. (Possibly as a result of pillaring in Coalburg, ahead of pillaring in upper Belmont seam.) Weight appeared irregularly now unexpectedly on the Coalburg, under Belmont pillared areas. No specific information available. (After Stemple, 1956)

TABLE 16 (continued)

LOCATION	COLUMNAR STRATIGRAPHIC DESCRIPTION		TYPE AND METHOD OF WORKING	NATURE OF IMMEDIATE ROOF	NATURE OF IMMEDIATE FLOOR	RECOVERY WITH RESPECT TO MINING SYSTEM EMPLOYED	MINING PROBLEMS AND EFFECTS ON FUTURE/SUBSEQUENT OVER/UNDER/SIDE/ADJACENT MINING	EFFECTS ON COST	NATURE OF FUTURE/SUBSEQUENT MINING	DISCUSSIONS/EDITOR'S REMARKS
	THICKNESS	DESCRIPTION								
1	2	3	4	5	6	7	8	9	10	11
Fayette County W VA	0' to 600'	Overburden: Predominantly shales, with sandstones, coal seams, etc. about 40' to 60' above the upper seam there is usually a massive-bedded sandstone or sandy shale, from 60' to 120' thick.	Room and pillar complete recovery.	Firm sandy shale, 20' or more thick.	Firm shale.	Not known.				In one area, the lowest Eagle seam is being mined below mined out No. 2 gas, which was mined 25 or more years previously. No difficulties have arisen, where the interwall is about 140'. In another area, the Eagle was mined 8 to 10 years before present operations in the overlying No. 2 gas seam. Extraction in the Eagle is not definitely known (perhaps 25%). But 30' to 40' falls are known to be present in the Eagle. However, there has been no evidence of subsidence in the No. 2 gas seam nor have any difficulties been encountered which might be attributed to mining of the lower seam. In another area, the Eagle was also 8 to 10 years before present mining in the overlying Powellton seam, mining in both seams. In this case, has been only entry development, and no disturbance has been noted in either seam. (After Stemple, 1956)
	Avg. 48"	Coal seam: No. 2 gas.							Overmining and Undermining	
	Avg. 40'	Parting: Mostly shale or sandy shale, with a thin coal seam shortly below the No. 2 gas, and a sandstone bed up to 10' thick, directly above the Powellton.	Room and pillar. Mostly entry development at present. Honeycombing.	Shale or draw slate overlain by sandstone.	Firm shale.	60% where mined.	None.			
	Avg. 42"	Coal seam: Powellton								
	Avg. 100'	Parting: Almost entirely sandy shales interbedded with thin coal seams	Room and pillar extensively mined, pillars spotty. Newer sections are mined on a block system, 45' and 90' centers for total recovery.	Usually shale, up to 8' thick, sometimes sandstone.	Sandy shale, sometimes fireclay.	75% approx. in older works.				
	30" to 108"	Coal seam: Eagle. Thicker sections contain many partings.				90% approx. in newer works.				
Kanawha County W VA	0' to 800'	Overburden: Predominantly sandstones, with shales, the No. 5 block seam, etc. (no logs available).	Room and pillar. A three entry system, entries on 60' centers, 24' to 30' wide; rooms turned off both sides at 90° and then a set of entries on 90° centers, 55' to 60' wide. Pillars left in place.	About 2' of dirty coal, overlain by 8' to 10' black shale and then a 3' to 8' flint ledge and sandstone.	Light gray shale, fairly firm except when wet.	75%	Simultaneous mining of Stockton Lewiston and Dorothy. Caused cracking of Stockton-Lewiston coal, roof and floor, and in at least one case caused a 300' length of conveyor to be dropped down about 8". Overmining of Stockton-Lewiston, presented no great difficulty, although there were points of bad top where the strata was cracked particularly when passing over pillars that were left in place in lower Dorothy seam.		Simultaneous mining	Mining in the Stockton Lewiston, in one area, was done simultaneously with mining in the underlying Dorothy seam.
	Avg. 72"	Coal seam: Stockton Lewiston - a 10" to 12" slate parting at the midpoint.							Overmining	Present mining in the Stockton-Lewiston seam is over areas where lower Dorothy seam was mined 3-4 years ago.
	Avg. 150'	Parting: Sandstone, shale, and the unnamed Coalburg seam.	This seam exhausted. Room and pillar. Several pillars left unmined and properly faulted.			80% approx.				
	42" to 54"	Coal seam: Dorothy								
	400' to 440'	Parting: Mostly sandy shale, with a massive bed, or several fairly thick beds of sandstone in the upper half of the interval. Also the unnamed Peerless and Cedar Grove seams. As well as several other thin coal beds.	Room and pillar. Rooms turned off both sides of 5 place butt entries. Pillars either pulled or split. Some pillars left due to heavy mid-dip-man.	Hard sandy shale.	Slate, fairly firm, but prone to heaving.	85% approx. (of workable seam)	Overmining in No. 2 gas seam, over the mined out areas of lowest Eagle seam. Evidenced, disturbance in the form of bad top conditions, when No. 2 gas mining passes over remaining Eagle seam barrier pillars; or when it passes over the line, between Eagle seam robbed areas and solid coal.		Overmining	Mining in the No. 2 gas seam is being done over areas of the Eagle seam which were mined several years ago.
	42" to 60" Avg. 44"	Coal seam: No. 2 (varies from clean to containing a 20" parting midway in seam).								
	10' to 20'	Parting: Mostly shale.	Room and pillar. Very little mining done. Centers, etc. not known. Pillars left in place.	Dark shale.	Fire clay.	Unknown	In mining of both Powellton and No. 2 gas, the bottom of undermined No. 2 gas workings, felt away, and in one case a cutting machine dropped down about 3'. Mining in the Powellton was stopped and mining of No. 2 gas continued.		Simultaneous mining	In one small area, the Powellton and No. 2 gas seams were both mined. The lower Powellton mining being done first. Here the interval between seams was only 11', and the pillars in the two seams were columnized. It is thought that certain portions of the Powellton seam may be recovered in the future, after completion of mining in No. 2 gas, where the parting between the two seams is the maximum 20'. (After Stemple, 1956)
	36" to 48"	Coal seam: Powellton.								
	180' to 200'	Parting: Sandstone and shales. The Eagle rider appears about 15' above the Eagle and is overlain by a fairly thick sandstone bed.	Room and pillar. Head work. Not mined too clean, but considered exhausted. Several large barrier pillars left.	Shale	Sandy shale to Fire clay.	75% approx.				
	Avg. 82"	Coal seam: Eagle.								
Mingo County W VA	0' to 75'	Overburden: Sandstone and shale, about half and half.	Room and pillar. Entries and rooms on 50' and 60' centers; entries 18' wide, rooms 24' to 26' wide. Pillars pulled or split, leaving narrow fenders. Fenders and stumps left in all three seams are supposedly of insufficient size to support any weight. Same for all three seams.	Brownslate 0" to 36" overlain by sandstone.	Hard sandy shale.	85% approx.				The Pond Creek seam was mined 20 to 30 years. Before the present mining in the Upper 3 seams, which are now being mined simultaneously. Development work in these is done without regard to the stage of mining in any of the others. However, pillar robbing is always done first in the upper of any two of the seams that is in a given area. The Alma is never pillared before the Lower Cedar Grove, nor the Lower Cedar Grove pillared before the Upper Cedar Grove. Pillar lines in the three seams are fairly well correlated, with an upper pillar line preceding the lower by 2 or 3 months, or about 300 ft. Entries are more or less superimposed in the three seams. Due to the way the property lies on a mountain-top, main entries following the ridges. However, whether entries are superimposed or not, no disturbance has been evidenced in any of the seams. Either from present mining in one or the other of the upper three seams, or from previous mining in the Pond Creek seam, or on the surface from pillar extraction in the Pond Creek seam, indicating either that extraction was not too complete, or that time and nature of intervening strata have been sufficient to completely re-stabilize any disturbed strata. Surface breaks have appeared since pillaring of upper three seams. It is thought by the mining personnel at this operation that best results could have been obtained by complete extraction of each seam in turn, starting with the upper most seam; providing that no pillars would be left in the upper seams. (After Stemple, 1956)
	40'	Parting: Nearly all sandstone.								
	84'	Coal seam: Lower Cedar Grove (includes 3 parting of 6", 1", and 3")							Overmining three seams simultaneously.	
	70'	Parting: Sandstone and shale.		6' to 8' weak shale overlain by sandstone.	Very soft fire clay.					
	Avg. 72"	Coal seam: Alma				85% approx.				
	100'	Parting: Sandstone and shales.	Room and pillar. 3 and 4 place mains, 2 place cross entries, on 50' centers, 20' to 25' wide. Most rooms on 50' centers, 25' wide (or more), 100' to 200' wide barrier pillars left along mains. Completely pillared over three-fourths of the property, other than mains. Room pillars left in place elsewhere.	0" to 5" Brownslate overlain by sandstone.	Firm shale.	70% approx.				
	Avg. 60"	Coal seam: Pond Creek.								

TABLE 16 (continued)

LOCATION	OVERBURDEN STRATIGRAPHIC DESCRIPTION		TYPE AND METHOD OF MINING	NATURE OF IMMEDIATE ROOF	NATURE OF IMMEDIATE FLOOR	RECOVERY WITH RESPECT TO MINING SYSTEM EMPLOYED	MINING PROBLEMS AND EFFECTS ON FUTURE/SUBSEQUENT OVER/UNDER/SIMULTANEOUS MINING	EFFECTS ON COST	NATURE OF FUTURE/SUBSEQUENT MINING	DISCUSSIONS/CRITIQUE/REMARKS
	THICKNESS	DESCRIPTION								
1	2	3	4	5	6	7	8	9	10	11
Harlan County KY	0' to 1,200' Avg. 39'	Overburden: Two thirds shale or sandy shale, with the balance sandstone, thin coal seams, and fireclay. The sandstone beds occur throughout the column, varying in thickness from a few inches to 50 or more feet. Coal seam: 'D' seam - varies up to 72" thick with partings dividing the seam into two or more benches.	Room and pillar. 4 place main entries, 3 place cross entries, on 50' centers, 18' to 20' wide. Cross-cuts on 70' centers. Rooms turned off, both sides of cross entries on 10' centers, 50' wide, 330' long, crosscuts on 110' centers. Pillars left in place.	Gray sandy shale.	Gray sandy shale grading into fireclay at places.	75% where mined.	At a point, where both the 'C' and 'B' seams had been pillared, a relative displacement of 'D' seam strata, in the form of a more or less gradual down-bending of the floor, coal and roof strata, or a vertical distance of about 8' occurred. It was accompanied by slight cracking of the top but caused no great difficulty in the subsequent mining. This bending occured at a point about 600' out over the goaf from solid barrier pillar in 'C' seam, and about 270' out over the goaf from the solid barrier pillar over the 'B' seam goaf. In other sections, where only the 'C' seam had been robbed, no subsidence of the 'D' seam was observed. In one area, where the interval between seams was only 9' to 10', water lying in the 'C' seam seeped through to the 'B' seam. Cutting out the 'B' seam top and thus [illegible] ing up from the 'B' seam and draining off the water lying in the 'C' seam. No weight on the 'B' seam workings has been noted except underneath pillars, remaining in the 'C'. Weight on 'B' seam workings was also evidenced under 'C' seam pillars, where the cover over the 'C' seam was 600' to 700'. Weight also evidenced on 'B' seam cross-cuttes as they drove under the line between 'C' seam barrier pillars and robbed areas. At one point, where the interval was about 50' between the seams and the cover over the 'C' seam was about 1,000' to 1,200'. A violent bump occurred at the face of a 'B' seam entry, which was just starting to be driven under a large 'C' seam pillar surrounded by a robbed area. In other such places, more or less continuous non-violent bumping occurred.		Overmining [seam mining last]	Very little mining has been done in the 'D' seam, and this has been done about 20 years after mining of the 'C' seam, directly underneath, and about 5 to 6 years after the mining in the 'B' seam.
	45' to 70' Avg. 59' Avg. 60"	Parting: Predominantly sandy shale and sandstone, with a bed of sandstone up to 45' thick lying directly below the immediate floor of the 'D' seam. Coal seam: 'C' seam - fairly clean	Room and pillar. Complete recovery. 4 place main entries, 12' to 18' wide barrier pillars are left for first recovery. Room entries are also 18' wide, on 50' and 60' centers, 2 or 3 place entries. Rooms are on 60' centers 20' to 24' wide; or 72' centers, 36' wide. Some large pillars have been abandoned.	Dark shale. 0' to 5' thick (Avg. 2'), overlain by, sandstone.	Shale. Generally very soft.	88%			Mostly first mined seam.	With regards to 'C' seam and 'B' seam mining, the 'C' seam is nearly exhausted, and the mining in it has been done as much as 21 years before mining in the 'B'. Present mining in the 'C' seam is completed at least 6 months prior to any mining directly below in the 'B'. In some cases as much as 2 years is allowed. Some main entries in the two seams are superimposed, but at least in one case they are not, with conditions in the later case just as good, if not better, than elsewhere. In this case, a main entry in the 'B' seam was driven underneath a recently robbed area of the 'C' seam.
	8' to 50' Avg. 38' Avg. 42"	Parting: Varies from almost entirely sandstone to almost entirely shale. Where most of the mining is being done, the interval is predominantly sandstone. Coal seam: 'B' seam.	Room and pillar, complete recovery, 4 and 6 place ...ains, 3 place butts, on 50' centers, 16' wide 130' to 200' wide main barrier pil- Lrs. Rooms are on 72' centers, 36' wide, 220' to 260' long turned off both sides of butt entries.	Sandy shale to sandstone.	Fairly firm dark shale	98% (on pillared butt entries)			Undermining	Pillar falls in the 'B' seam, undermined by 'C' seam, are generally clean and complete, closely following the extraction. (After Stemple, 1956)
Dickenson County VA	0' - 700' 66" av	Overburden: Predominently sandstone and sandy shales, strong strata. Coal seam: Upper Banner.	Room and pillar. Pillars split in most cases, some complete mining.	Sandstone, some places up to 12" slate between coal and sandstone.	Mostly sandstone, some fireclay and sandy shale.	50% overall 75% in area mined.	No columniation attempted. Non attributable to mining of upper seam.			Nearly simultaneous robbing in upper seam and development in lower seam caused no disturbance in either seam. (After Stemple, 1956)
	75' - 150' Av 42"	Parting: Mostly sandy shales and slate with one sandstone 20' to 40' thick, about 20 ft below the upper bed. Coal seam: Lower Banner.	Room and pillar. Pillaring in some places pillars split in others.	Sandy shale and sandstone.	0" to 12" rash underlain by gray shale.	80% proposed.			Undermining.	
Wise County VA	0' - 1,800' 54" to 60"	Overburden: 53 ft thick massive sandstone directly above upper seam, shale and sandstone. Coal seam: Taggart	Room and pillar. Complete recovery attempted but many pillars left in place, not uniformly.	2" to 3" bone, then 2'	2" bone, underlain by 2" of soft shale or ... clay. Deteriates when wet.	75% to 80%	Where ever there were pillars left in upper seam, the lower seam showed effects of extreme weight, making mining impossible and causing abandonment of coal.			At an air shaft, pillars were left in the upper seam with nearest robbing at least 200' away, shaft pillars in the lower seam are approximately columnized and show no evidence of weight or other disturbance. (After Stemple, 1956)
	54" av 38" - 40"	Parting: 38' thick massive sandstone directly over lower bed and overlain by sandy shale, shale, and fireclay or shale. Coal seam: Marker	Room and pillar. Pillars left in place. Room driven off 3-plate crosscuts, 500 ft long, 65' wide on 100 ft center breaks on 90° centers.	Usually sandy shale, or sandstone, sometimes laminated shale with coal spars, generally good.	Dark grey shale, firm.	70%			Undermining.	
Harlan County KY	0' to 2,900' 45" to 60"	Overburden: Around 90% of the cover is sandstone spaced throughout with individual beds up to 100' thick; balance is mostly sandy shale and shales. 'C' Taggart	Room and pillar, complete recovery but many chain pillars, etc. left. Honey combing of main barrier and chain pillars is now being done.	0" to 12" of rotten shale overlain by good sandstone up to 60' thick.	Soft shale or fireclay. Deteriates with water.	80%	Weight on areas under upper seam pillars left in place, and under area of line between upper seam goafes and solid coal. No concentration of weight through upper seams pillars and other workings.			Columniation of pillars is attempted in some areas, and thought to be helpful. Difficult to accomplish under upper seam Honeycomb areas. (After Stemple, 1956)
	0' to 50' 36" - 42"	Parting: Predominently sandstone or sandy shale Coal seam: 'B' Marker	Room and pillar. Rooms on 40' centers, 20' to 25' wide. Pillars left to place.	Sandstone, good in most cases.	Shale fairly firm	65% approx.			Undermining.	

LOCATION	COLUMNAR STRATIGRAPHIC DESCRIPTION		TYPE AND METHOD OF WORKING	NATURE OF IMMEDIATE ROOF	NATURE OF IMMEDIATE FLOOR	RECOVERY WITH RESPECT TO MINING SYSTEM EMPLOYED	MINING PROBLEMS AND EFFECTS ON FUTURE/SUBSEQUENT OVER/UNDER/SIMULTANEOUS MINING	EFFECTS ON COST	NATURE OF FUTURE/SUBSEQUENT MINING	DISCUSSIONS/CRITIQUE/REMARKS
	THICKNESS	DESCRIPTION								
1	2	3	4	5	6	7	8	9	10	11
Mercer County, West Virginia	0 to 420' 16"	Overburden: Unknown Coal Seam: Pocahontas No. 11	Room and pillar. Rooms 90' wide on 40' centers. Pillars left in place.	Shale	Shale	74%	Cracks appeared where pillar falls occurred in lower bed. No increased difficulty of mining.	No additional cost.	Overmining over robbed workings of No. 3 seam lying 510' below.	Sizeable pillars of coal were left in lower bed, but no disturbance was observed in the upper bed. (After Stemple, 1956)
	350'	Parting: Shale and sandstones. Coal Seam: Pocahontas No. 4	Room and pillar. Development work only.			Development only.	Cracks, but no displacements. No increased difficulty of mining.	No additional cost.	Overmining over robbed workings of No. 3 seam and undermining below worked out workings of No. 11 seam 350' above.	
	160' 51"	Parting: Shale and sandstones. Coal Seam: Pocahontas No. 3	Room and pillar. Places on 60' centers mostly robbed.	Hard shale overlain by sandstone	Shale	80%	Seam mined first.		Seam mined first.	
McDowell County, West Virginia	0 to 750' 54"	Overburden: Shale, coal seams and 5 or 6 beds of sandstone 25 to 35' thick where cover is average of 450'. Coal seam: Pocahontas No. 4	Room and pillar. 5 and 7 entry mains on 60' centers. Rooms on 90' centers.	Slow shale about 3' nonclastic by 7' thick rider coal and then shale. Rock at places.	Firm slate to hard fireclay. Deteriorates when wet.	25 to 80% planned.			Overmining	Greater difficulty in mining upper bed occurs when time interval between mining is short. Simultaneous mining causes most difficulty even when upper bed pillar line is in advance of lower bed. Settlements of strata after mining of lower bed appears to be complete in 5 to 10 years. Reason for not robbing some pillars in upper bed appears to be squeeze due to remnant pillars in lower bed. (After Stemple, 1956)
	60 to 70' 68"	Parting: Shales and sandstones. Coal seam: Pocahontas No. 3.	Room and pillar. Some pillars robbed, some left.	10 to 12' dragshale overlain by blue shale.	Soft shale or fireclay.	75%	In areas above remaining lower bed pillars, the bottom heaved, top breaks, coal crushes. Strata disturbance for 50' on either side of lower bed goaf lines. No offset in elevation of upper bed is noted.			
McDowell County, West Virginia	0 to 409' Av. 150'	Overburden: 70' to 150' sandstone in 3 to 4 beds, rest shale, and coal seams.	Room and pillar. 3 place entries 20' wide on 60' centers. Rooms on 60' centers 40'wide and pillars left. Pillars sometimes split.	Partly coal, sandstone up to 100' thick partly drawslate 12" thick overlain by 12' to 15' firm shale.	Very soft fireclay.	75%			Overmining only one seam either No. 9 or No. 11 have been worked at any place.	Very wide cracks seen on the surface. Some settlement presumed. Wide cracks on the surface indicate to unusual settlement, differential movement and shear stresses in the overburden strata causing broken bad top. (After Stemple, 1956)
	16"	Coal seam: Pocahontas No. 11.								
	150'	Parting:	Room and pillar.							
	120'	Coal seam: Pocahontas No. 9.								
	42" to 96"	Parting: Shales, coal seams, fireclay and several sandstone beds from 1 ' to 50' thick.	Room and pillar places on 60' centers. Pillar robbed.	Laminated shale fairly good up to 25' thick.	Firm shale.	90% estimated	Roof and coal broken. Water enters from surface into workings. Percolates to lower bed through cracks. No pillaring done in either No. 9 or No. 11 seam due to bad top conditions.			
	Av. 90"	Coal seam: Pocahontas No. 3.								
Raleigh County, West Virginia	150' to 800' Av. 400'	Overburden: Shales and sandstone with a heavy sandstone about 80' thick, 150' above top most seam.	Room and pillar. Oldwork - 60' centers with 12' wide places, only some sections robbed. New - block system, 95' centers, 72' wide, robbed.	Hard shale about 10' thick. Good top.	Firm fireclay usually good, slightly muddy when wet.	Old work - 68% New work - 92%	Pillaring in lower bed under virgin upper bed caused offsets and broken top in upper bed. Pillaring in lower bed under developed upper bed causes intense damage to upper bed. Simultaneous mining caused most troubles. Mining of upper bed first, gave no trouble, except for water in upper bed.		Overmining.	Where lower bed was thin, settlement of upper bed appeared complete after 5 years. Where lower bed was over 6' thick, settlement was not complete after 12 years. (After Stemple, 1956)
	48"	Coal seam: Sewell								
	260' to 330'	Parting: Mostly shales and sandstones. Outstanding sandstone about 80' thick .lies 20' to 30' above lower bed.	Room and pillar. Oldwork - Places on 80' centers 16' wide pillars robbed or places on 60' centers 25' wide, with pillars left due to squeeze. New work - variable centers, most pillars robbed.	Bentered sandstone 5' to 10' thick usually good top.	Fairly firm fireclay heavvd in squeeze areas.	Overall - 65% Pillar sections - 92% Bottom bench mined only in haulageways.				
	33" to 165"	Coal seam: Beckley. Includes up to 72" of bone coal parting in between two benches.								
Fayette County, West Virginia	0 to 100'	Overburden: Predominantly sandstone with a 70' bed immediately overlying coal bed.	Room and pillar. Entries on 50' centers. Robbed clean except in soil areas.	Sandstone often broken and cracked.	Hard firm shale.	90% estimated.	Roof badly cracked, allowing much water to enter the working. No drainage to lower seam, possibly due to sealing of cracks in the parting between seams.		Overmining.	Roof conditions in the upper seam over previous lower seam mining were somewhat better. This is possibly due to the longer settlement period for strata. Water percolation into upper seam may be due to shallow cover. (After Stemple, 1956)
	30' to 60'	Coal seam: Sewell								
	275'	Parting: Shales and sandstones.	Room and pillar. Same centers as upper seam.	Slate-fairly good.	Firm shale.	90% estimated.				
	40"	Coal seam: Fire Creek								
Fayette County, West Virginia	0 to 300'	Overburden: Shales and sandstones.	Room and pillar. Part on 60' centers, robbed. Part on 35' and 40' centers - 25' to 35' wide, pillars left.	Black shale, bouey in some cases, blocky and broken - generally poor.	Firm shale.	Pillared section - 85% Other - 70%	None	None	Only one small area had been pillared in lower seam below upper seam workings.	Roof of upper bed generally poor but not due to limited lower seam extraction. Roof no worse in areas over worked out lower seams than over lower seam virgin areas. (After Stemple, 1956)
	38"	Coal seam: Sewell								
	420'	Parting: Sandstone, shale and thin coal beds. About 60' shales directly above lower coal seam.	Mostly development work; 6 entry mains 2 entry connected on soft centers - 14' and 18' wide.	Shale with many slicken side planes. Brecciate at places 8" thick, fair to poor.	Black slate 12" to 18" thick.	50% less under upper seam workings				
	44"	Coal seam: Fire Creek								
Fayette County, West Virginia	0 to 800' Where mined, 38"	Overburden: Shales and sandstones up to 35' thick. A 3' thick coal seam 7" to 35' above upper seam. Coal seam: Carbon-Powellton	Room and pillar. 6 entry mains, 2 and 3 entry butts on soft and 60' centers 18' wide. Rooms on 35' centers. 24' wide. Pillars left.	Slate 7" to 30" overlain by 3' coal. Sandstone up to 35' in some areas.	4" very soft fireclay underlain by shale.	70% in area mined.	Cracks in coal are evident, but cause no problems. Ventilation disrupted due to cracks from lower Powellton coal bed. Water drains to lower Powellton coal bed without need for pumping.	No increase in timber costs due to undermined lower seam ventilation costs. Pumping cost reduced.	Not possible to mine entire area.	Some prior mining of Powellton caused no adverse effects on Lower Eagle seam. No simultaneous mining in any area.
	65'	Parting: 2 sandstone beds 10' to 30' thick. Balance, shale, fireclay and thin coal.	Room and pillar. All places at 60' centers, 18' to 20' wide pillared in some places.	Dark shale av. 3' thick overlain by 3' rider coal	Fireclay, very soft 3" to 12"	80% in areas mined.	Cracks in coal are evident but cause no problems. Subsidence cracks out lining robbed Eagle seam are present.	The workings in these two seams are columnized.	Overmining.	Main entries, chain and barrier pillars columnized in Eagle and Powellton seams only and left in place in both seams. (After Stemple, 1956)
	48"	Coal seam: Powellton								
	110'	Parting:	Room and pillar. Same as Powellton, columnized.							
	45' to ?'	Coal seam: Eagle								

TABLE 16 (Continued)

LOCATION	COLUMNAR STRATIGRAPHIC DESCRIPTION: THICKNESS	COLUMNAR STRATIGRAPHIC DESCRIPTION: DESCRIPTION	TYPE AND METHOD OF MINING	NATURE OF IMMEDIATE ROOF	NATURE OF IMMEDIATE FLOOR	RECOVERY WITH RESPECT TO MINING SYSTEM EMPLOYED	MINING PROBLEMS AND EFFECTS ON FUTURE/SUBSEQUENT OVER/UNDER/SIMULTANEOUS MINING	EFFECTS ON COST	NATURE OF FUTURE/SUBSEQUENT MINING	DISCUSSIONS/CRITIQUE/REMARKS
1	2	3	4	5	6	7	8	9	10	11
Pike County, Kentucky	0 to 100' Av. 60"	Overburden: Sandstones and shales. Coal seam: Coalburg	Room and pillar.	Rolly sandstone.	Hard shale.	Unknown: Very little mining done. Coal not persistently good, large fault areas.	At no place in the Thacker seam has any difficulty been encountered which might be attributed to mining in the Alma seam. At one or two points in the seam, bad top conditions have developed which might be attributed to weight concentrations from remaining pillars in the Thacker seam, but conditions are so uniformly poor in the Alma that this is not at all certain.		Overmining.	The Coalburg and Winifrede seams were both mined 20 to 30 years ago. Where one seam was workable, the other very often was not, so that little if any vertically adjacent mining was done. The three lower seams were opened at about the same time (1916-20), but as far as is known, had no effect on the mining in the two upper seams. Mining in the Pond Creek area was carried on continuously from 1916 to 1920. As effects of mining in the upper seams were ever noticed in the Pond Creek, and as far as is known, the Pond Creek mining had no effect on the conditions in the upper seams. This last is quite possibly due to the relatively low coal of the Pond Creek, the excavation of which was apparently taken up by bending of the strata rather than breaking. (More reference to Pond Creek over.) The Upper Thacker and Alma seams are presently being mined, with the Upper Thacker seam about depleted. Due to extensive fault areas, there has been little if any conversion in the mining of the two seams where one seam has been mined, the underlying (or overlying) other seam often has not had minemable coal. Where both seams have had minemable coal, sometimes the Alma has been mined first, and sometimes the Thacker. (After Stemple, 1956)
	40' to 50' Av. 60"	Parting: Sandstones and shales, no drill log available. Coal seam: Winifrede	Seams exhausted, room and pillar, hand loading, complete recovery. Coal usually poor where overlying Coalburg was good, and vice versa.	Rolly sandstone and shale.	Firm hard shale.	80% estimated where coal was good.				
	300' to 350' 30" to 60" Av. 36"	Parting: Mostly shales but includes 1 or 4 beds of sandstone, 20' to 40' thick. Coal seam: Upper Thacker	Room and pillar, 2 and 4 place main entries, 2 place cross entries on 60' centers, 30' to 45' wide. Pillars left in place. Save large unmineable fault areas.	Firm blue slate, good top.	Hard to soft fireclay.	75% except in faulted areas.				
	Av. 200' 60" to 108"	Parting: Mostly shales. Includes the Lower Thacker coal, thin and dirty, about 100' below the Upper Thacker, with a heavy sandstone up to 50' thick, between these two coals. Also includes several other thin coals. Coal seam: Alma, varies from 60" thick, including about 30" slate in two partings, to 108" thick, including up to 54" slate in 3 partings.	Room and pillar, 5 place main and butt entries, on 60' centers 26' wide. Main entries are often paralleled by 5 place caving or auxiliary entries. Rooms are also on 60' centers 26' wide. Loaded cars contain 50 to 60% reject material. Pillars left in place.	Drawslate, 4" to 30" thick, which falls with coal, overlain by about 10" of blue slate which stands for a while but then falls in 30" layers. All overlain by sandstone.	Soft to medium hard slate.	60% approximate.				
	Av. 100' 64"	Parting: Sandstones and shales, including a sandstone bed up to 35' thick directly below the Alma, and a 25' thick bed 15' to 20' above the Pond Creek. Coal seam: Pond Creek. 6" top coal, 8" slate, 90" bottom coal.	Older sections mined by a semi-longwall system, between 7 place cross entries, turned off 5 place entries, both on 50' centers, about 25' wide. About 400' to 450' between cross-entries, all chain pillars left in place, newer sections mined by room and pillar, rooms on 60' centers 25' to 30' wide. In some sections pillars left in place; in others, pillars pulled or split. In both rooms and longwall sections, only the 30" bottom coal was mined.	Firm slate, sagged, but did not fall.	Firm shale	90% in longwall sections, 65% elsewhere.				
Lee County, Virginia	0 to 700' Av. 46"	Overburden: Predominantly sandstones and sandy shales. Coal seam: No. 12 Seam.	Room and pillar.	Varying thickness of shale overlain by sandstone; also some sandstone roof.	Fireclay	70% approximate.	In the No. 12 and No. 11 seams there has been no attempt at correlation of mining either between the two seams or with the lower No. 9 and No. 10 seams. The only disturbance to the upper two seams has been a slight cracking of the floor of the No. 12 seam, which has aided drainage and has not hindered the mining at all. In sections where the parting between No. 10 and No. 9 seams had been less than 12' coal has had to be abandoned in the No. 9 seam, underneath No. 10 mining, due to excessively poor top conditions. Some attempt with little success, has been made to mine the No. 10 over previously mined No. 9 seam. Some pillars have been pulled in both seams, but seldom in areas where both seams have been mined.			In the No. 10 and No. 9 seams, mining has generally been conducted first in the No. 10 seam, although not necessarily in an attempt for maximum recovery of both seams. Mining in the No. 9 seam has, in many cases, been in areas where the interval between seams was such as to prevent mining of both seams (less than 12'), and where better coal appeared them in the No. 10 seam where the interval between seams has been greater. Some success in the recovery of both seams has been by driving the No. 9 entries parallel to the No. 10 entries, but underneath the No. 10 entry barrier pillars, the No. 10 entries having been advanced first. It was thought by the superintendent of this operation that best results might have been achieved by simultaneous mining of the two seams, with the upper seam slightly in advance. (After Stemple, 1956)
	70' Av. 38"	Parting: Mostly sandstone. Coal seam: No. 11 Seam.	Same as for No. 12 seam.	About same	Firm fireclay	70% approximate.				
	280' to 300' Av. 55"	Parting: Shales and some fairly heavy sandstones. Coal seam: No. 10 seam.	Room and pillar, room centers vary. In some sections 30' centers 21' wide, pillars left. In others wider room centers, pillars split or pulled.	5" drawslate overlain by about 10" top coal, then by sandstone; in some areas, heavy slate overlain by sandstone.	Soft fireclay.	75% approximate (where mined).				
	3' to 25'	Parting: Entirely fireclay and shales. Coal seam: No. 9.	Room and pillar, amount of mining limited. Rooms on 30' centers, 21' wide. All pillars left in place with a few exceptions.	Fireclay or soft shale.	Fireclay fairly firm until wet.	Unknown.				

TABLE 16 (Continued)

LOCATION	COLUMNAR STRATIGRAPHIC DESCRIPTION		TYPE AND METHOD OF WORKING	NATURE OF IMMEDIATE ROOF	NATURE OF IMMEDIATE FLOOR	RECOVERY WITH RESPECT TO MINING SYSTEM EMPLOYED	MINING PROBLEMS AND EFFECTS OF FUTURE/SUBSEQUENT OVER/UNDER/SIMULTANEOUS MINING	EFFECTS ON COST	NATURE OF FUTURE/SUBSEQUENT MINING	DISCUSSIONS/CRITICISM/REMARKS
	THICKNESS	DESCRIPTION								
1	2	3	4	5	6	7	8	9	10	11
Kentucky	900' 7' 40' 3' 9"	Overburden: Very firm shale Coal seam: Parting: Firm shale. Coal seam: Harlan	Room and pillar, complete extraction, but some pillar remnants were left.				Bed above had been mined by complete extraction but room stump and pillar remnants had been left. When lower seam was developed, stump in bed above it caused roof to be pushed in. Cover above 900' strata between very firm shale.		Undermining.	(After Holland, 1947)
Kentucky	30' to 35' 36"	Overburden: Coal seam: Parting: Coal seam: '8' seam	Room and pillar, called complete extraction, but probably only 75%			75%	Where upper bed was not mined, lower bed could be successfully mined by complete extraction methods, although some remnants were left, lower bed could not be mined because of flow or creep of bottom rock. This creep attributed to remnants left in upper bed.		Undermining.	(After Holland, 1947)
Near Inez, Kentucky	120' to 160' 54" to 60" 105' Up to 12' to 14' Av. 90"	Overburden: Coal seam: Stockton Parting: Coal seam: Coalburg	Room and pillar, 6 mains at 70' centers and breaks at 50', each 20' wide. Room and pillar, 6 mains at 70' centers and 50' crosscuts. Panels 50' x 60' centers and 20' wide.					Pillar recovery in Lower Coalburg uneconomic due to the necessity of timber prop supports, as no self contained mechanical supports for this height is available now.	Simultaneous first working.	Pillar pulling is planned in Stockton seam for maximum recovery. In Lower Coalburg seam only first working are planned. 10' to 12' height makes timber installation difficult and time consuming. Requires 13' to 14' long, 12" to 16" diameter props at 4' interval for pillar removal or splitting of pillars. (After Mason, 1980)
Grundy, Virginia	34" 50" 19"	Coal seam: Blair seam Parting: Coal seam: Glamorgan seam	Room and pillar, 5 entry panels. Room and pillar, 5 entry panels.				Currently first working only 900' from portal. 1300' from portal.		Simultaneous.	Strict columnization of each pillar. (After Harrold, 1979)
Virginia City, Virginia	42" to 44" Av. 5½' to 6'	Coal seam: Imboden Parting: Coal seam: Jawbone	Room and pillar, 6 entry mains. 1st and 2nd entry - intake; 3rd and 4th entry - neutral; 5th and 6th entry - return. Same as above							(After Mason, 1977)
Bell County, Kentucky	Av. 80" 30" to 50"	Coal seam: Hazard No. 5 Parting: Coal seam: Hazard No. 4	Room and pillar, 5 to 7 entry system.				Method of working in same for both seams.			5 entry system - 1st and 2nd intake, 3rd neutral, and 4th and 5th return. 7 entry system - 1st, 2nd and 3rd return, 4th neutral, and 5th, 6th, and 7th intake. (After Mason, 1977)
Bell County, Kentucky	6' to 9'	Coal seam: Hazard Parting: Coal seam: Straight Creek Parting: Coal seam: Rim	Room and pillar, 5 to 7 entry system. Virgin seam - no workings yet.							Same as above. (After Mason, 1977)
Kanawha County	50' to 150' 48" 130' to 180' 41" 30' to 50' 48" to 74"	Overburden: Shales and sandstones. A very hard sandstone about 8' lying immediately above the immediate roof. Coal seam: No. 5 Block. Parting: Shales and sandstones. A very hard sandstone 3' to 8' lies 50' above the Lewiston coal bed. Coal seam: Lewiston Parting: Nearly all strong sandstone. Thickness variable but is rarely less than 10'. Coal Seam: Coalburg	Room and pillar partially worked. Room and pillar, 3 place entries on safe centers, 16' wide; crosscuts on 90' centers. Rooms on 40' to 50' centers 20' wide. Pillars left in place. Room and pillar. Entries on 90' centers, 16' wide; rooms on safe centers 20' wide. Very little pillaring.	Graywlate, soft 3" to 6". Overlain by 1" to 2' hard shale overlain by sandstone and sometimes pinched. Graywlate, 12" to 30" thick, overlain by sandstone.	Laminated coal and shale, 25" to 30" thick. Soft shale or fireclay.	65 to 70% 75%	Partial mining of No. 5 Block, 130' to 180' above the Lewiston caused no disturbance to the Lewiston. Known prior mining of some lower seams in the area also caused no disturbance either to Lewiston or Coalburg. Squeezes, broken floor, floor fallen away from coal in places, as much as 6' to 1', roof very bad in such cases. Relative displacement of all strata of about 6". Mining over a want area of lower seam (unmined) showed no such disturbance.		Seam mined first. Undermining No. 5 Block and overmining Coalburg. Seam mined after mining of No. 5 Block seam.	Superimposition of Lewiston projections over Coalburg exerted squeezes in most cases. Pillaring of Coalburg was tried, but unsuccessfully, due to shearing of roof strata along edges of Coalburg pillars. (After Stemple, 1956)

TABLE 16 (Continued)

LOCATION	COLUMNAR STRATIGRAPHIC DESCRIPTION		TYPE AND METHOD OF WORKING	NATURE OF IMMEDIATE ROOF	NATURE OF IMMEDIATE FLOOR	RECOVERY WITH RESPECT TO MINING SYSTEM EMPLOYED	MINING PROBLEMS AND EFFECTS ON FUTURE/SUBSEQUENT OVER/UNDER/SIMULTANEOUS MINING	EFFECTS ON COST	NATURE OF FUTURE/SUBSEQUENT MINING	DISCUSSIONS/CRITIQUE/REMARKS
	THICKNESS	DESCRIPTION								
1	2	3	4	5	6	7	8	9	10	11
Mingo County W VA	0-400 ft	Overburden: Predominantly shales and thin coal seams with one heavy sandstone 0' to 15' above Coalburg (Upper) seam.	Room and Pillar. Entries on 50 ft centers, rooms, 36 ft centers, 18 ft wide.	Shale 0' 15' thick, overlain by sandstone.	Soft gray shale - very muddy when wet.	68%	Large cracks, coal broken, roof and floor disrupted, ventilation disturbed, much water from surface.	Excessive timbering required.	Overmining	Distortion of strata 900 to 1,200 ft above the lower seam indicate incomplete recovery, with some large blocks left in place. (After Stemple, 1956)
	54" - 66" Avg. 60"	Coal seam: Coalburg								
	900 ft	Parting: shales, coal seams, and some sandstone up to 35 ft thick.	Room and pillar mined by contract miners. No maps available. Supposedly complete recovery.	Laminated dark sandy shale.	Hard shale	90%				
	48" (Estimated)	Coal seam: Upper Cedar Grove								
Floyd County KY	0' to 805' Average 580'	Overburden: Mostly sandstone, some from 30' to 130' thick; shales 20' to 60' thick, thin coal seams and fireclays.	Room and pillar, entries 16' to 20' wide on 50' centers, rooms 25' to 30' wide on 80' centers. Pillaring spotty.	Hard sandy shale or sandstone. Good top.	Hard slate.	75% approximately	Conditions vary from trouble due only to water in the upper seam to weight and bad top conditions in the low er seam. Columniation has been attempted in some areas and found helpful. Recovery in both seams is only partial.		Undermining.	Mining has been attempted with top seam first, lower seam first, and simultaneously, with difficulties encountered in all cases. Most method thought to be nearly simultaneous mining of both seams with pillars strictly re-timbered and left in place. Leaving at least 30% of the coal of both seams. (After Stemple, 1956)
	16" to 18" plus 4" to 6" of bone	Coal Seam: Elkhorn No. 2								
	20' to 35'	Parting: Mostly slate where interval is maximum sandstone appears.	Room and pillar, entries on soft centers 20' to 26' wide; rooms on 50' centers 30' wide. Pillars left in place.	6" to 12" dravlite overlain by 5' to 6' bloc shale; sometimes overlain by sandstone. Poor top.	Slate (shale) firm.	60% approximately				
	42" to 48"	Coal Seam: Elkhorn No. 1								
High Splint Harlan County KY	36" to 48"	Coal Seam: Darby	Room and pillar. 5/7 entry system.							5 Entry system: First and second entries intake; third neutral, fourth and fifth - return. 7 Entry system: First, second and third - return; fourth - neutral; fifth, sixth and seventh - intake (After Mason, 1977)
	18" to 60"	Coal Seam: Harlan	Same as above							
Brookside KY	36" to 48"	Coal Seam: Creech	Room and Pillar							Same as above. (After Mason, 1977)
		Parting:	Same as above							
	44" to 66"	Coal Seam: Harlan								
Pocahontas Field, West Virginia	3' 8"	Overburden:					Only evidence in top seam is in two places where subsidence and roof falls occurred, the robbing in the lower seam having been done after upper seam workings were driven. In all other areas conditions appear normal and water frequently collect over robbed area.		Overmining.	
	150'	Coal seam: Pocahontas No. 6.								
	3' 9"	Parting: Almost entirely sandstone except a few feet of shale over lower seam.								
		Coal seam:								
Pocahontas Field, West Virginia		Overburden:					Only trouble has been due to surface cracks, which allow water to enter mine, from which it does not drain well to lower seam.		Overmining.	
	340'	Coal seam: Name given, presumably the Sewell.								
		Parting:								
		Coal seam:								
Southwest, Virginia		Overburden:					Surface cracked for 1000'. Explorators headings revealed that, except for some cracks through which air came from lower working, absolutely nothing was found in upper seam either in levels or in character of coal to indicate that lower seam had been removed.		Overmining.	
		Coal seam:								
	445'	Parting:								
	5' 10"	Coal seam:								

TABLE 16 (Continued)

LOCATION	COLUMNAR STRATIGRAPHIC DESCRIPTION		TYPE AND METHOD OF WORKING	NATURE OF IMMEDIATE ROOF	NATURE OF IMMEDIATE FLOOR	RECOVERY WITH RESPECT TO MINING SYSTEM EMPLOYED	MINING PROBLEMS AND EFFECTS ON FUTURE/SUBSEQUENT OVER/UNDER/SIMULTANEOUS MINING	EFFECTS ON COST	NATURE OF FUTURE/SUBSEQUENT MINING	DISCUSSIONS/CRITIQUE/REMARKS
	THICKNESS	DESCRIPTION								
1	2	3	4	5	6	7	8	9	10	11
McDowell County W VA	0-500 ft Faulty Av 72" Where good. 60" to 70' 36" to 60" Av 44"	Overburden: shale with 5 to 8 sandstone beds 25' - 60' thick at varying intervals Coal seam: Pocahontas #4 Parting: Shales and some fairly thick sandstones Coal seam: Pocahontas #3	Room and pillar. Some sections pillared, some just first mined. Rooms 20 ft wide at 30 ft centers. Pillars pulled if conditions good.	Soft slate and rash, about 24" thick. 20" to 60" clod slate overlain by a fairly firm shale. Sandstone about 40 ft above the coal seam.	6" to 8" soft slate underlain by hard slate. Fairly firm shale.	75% approx.	Some bad roof conditions in lower bed, where lower seam places drove under a line between upper seam goaf and pillar line.		Undermining	Very little lower seam mining has been done under upper seam works. Upper seam mining incomplete and very spotty. (After Stemple, 1956)
Raleigh County W VA	0-650 ft Av 450' Av 50" 30" in low Av 44" Av 285' Av 44"	Overburden: Shales and sandstones with a 25 ft thick sandstone appearing persistently about 40 ft above the upper bed. Coal seam: Pocahontas #4 Parting: Mostly shales, with one heavy sandstone bed 80 ft thick lying about 50 ft above the lower seam. Coal seam: Pocahontas #4	Room and pillar. Complete recovery, except some chain pillars on soft centers 270' wide in low coal areas. Panel longwall. Empty chain pillars left between panels.	Shale. Shale, varying up to 50' thick. Some sandy shale 3' or more thick.	Shale. Firm shale.	85% approx. 80%	Evidence of weight at varying points in the longwall panels, evidenced by poor roof conditions and bearing bottom. Thought to be due to pressure from mining augmented by pressure concentrations from pillars, etc., left in upper seam. This weight caused failure of non-yielding type jacks and required in heavy rock falls.		Underseaing	Much of the weight evidenced in the longwall panels appears to be the result of the mining method employed. Evidence indicate that there is a transference of weight through coal left in place in the upper seam, possibly by an additive effects of abutment areas on eligible isolated pillars and group of pillars. The same weight was evidenced along a main entry under a low coal area of the upper seam where there was no mining; the weight was of such magnitude as to distort and shear 10", I-beam arches. (After Stemple, 1956)
Raleigh County W VA	0-650 ft Splits 270 ft to 900 ft Av 36" plus small partings	Overburden: Predominantly shale with a sandstone bed up to 50 ft thick about 100 ft over the upper seam. Coal seam: Beckley, one bench-20" to 36". Two benches- Top bench-30" to 72", Partings-10" to 42", Bottom bench-6" to 42". Parting: Several sandstone beds up to 25 ft thick. Balance shales and sandy shale. Fairly strong strata. Coal seam: Pocahontas #6 seam	Room and pillar. Complete recovery. All places on 60' centers. Room and pillar. Complete recovery. Entries on 50 ft centers, rooms on 56 ft and 70-80 ft centers.	Shale - 0" to several feet; at places sandstone. Top-excellent to very poor. Hard gray shale 3' or more thick, overlain in places by a rider coal, then sandstone.	Slate to sandy shale, generally firm. Soft slate tears up easily.	87 - 90% 90%	Some drainage of water from the surface and the upper seam into lower seam. After pillaring has broken the strata.		Undermining	Some pillars lost due to bad top or water top bench only worked where parting was thick. (After Stemple, 1956)
Kanawha County W VA	0'-450' 60" 90-130 ft 34" to 50"	Overburden: Shales and sandstone with a sandstone bed up to 20 ft thick immediately over lying upper coal seam. Coal seam: No. 2 gas, mid-parting of 6" - 24" thick. Parting: Sandstone up to 50 ft thick close over lower seam, then a 30" thick coal seam overlain by 8"-12' of sandstone. Balance up to upper seam-shales. Coal seam: Eagle	Room and pillar places at 60' centers 24 ft wide. Pillar recovery spotty with no large pillared areas. Old: Entries on 60' centers, 20' wide, rooms 50' and 70' centers, 25 ft wide, pillars left. New: Entries on 50 ft centers, 20' wide; rooms on 60' centers, 50 ft wide. Pillars left in place, 6 entry mains. 200-300 ft barriers.	Generally sandstone to sandy shale, thin bedded to 15 ft above coal. At places 6" of draw slate. Carbonaceous shale, up to 25' thick Has never broken up to sandstone.	Gray shale fairly soft Slate, fairly firm.	50% approx. Old - 60% New - 75%	None.	None.	Undermining.	Possibility of danger form flooded areas of upper seam, but interval has not been broken yet. Old mining-method areas of lower seam underlie the flooded area of the upper seam. 40% coal left in lower seam has proven successful to prevent breaking of parting between seam. No columnization of pillars. Winifrede seam, 800 ft above No. 2 gas was mined shortly after No. 2 gas; no information available, but thought no disturbance occurred from earlier mining of No. 2 gas. (After Stemple, 1956)
Kanawha County W VA	430'-500' 56" 200' 30" to 36"	Overburden: Shales, sandstones with a heavy bed of sandstone up to 75 ft thick. Close over the Winifrede seam and two worked out coal seams. Coal seam: Winifrede. Parting: Several strong sandstone beds, 20 ft to 40 ft thick, balance mostly shales. Coal seam: Cedar Grove.	Room and pillar. Entries 16 ft wide, rooms 90' wide, both on 50' centers. Robbing only of some barrier pillars. Room and pillar, entries 16' wide on 50' centers, rooms 50' wide on 70' centers, and 35' wide on 50' centers. Pillars left in place.	0" to 35" hard shale overlain by 40' to 75' thick sandstone. Shale could not be held. 12" to 18" heavy dark shale, overlain by light sandy shale about 20' thick.	Firm shale. 18" fireclay, soft	70% 80%	None. None, even under robbed Winifrede barrier pillars. No columnization of pillars.		Undermining. Undermining.	Two seams above the Winifrede seam were mined earlier, little information on mining or effects of mining in these seams, but no disturbance thought to have occured. Surface cracks as evidenced by drainage down Coalburg seam (one of the two seams mined earlier to mining of Winifrede seam). (After Stemple, 1956)

TABLE 16 (Continued)

LOCATION	COLUMNAR STRATIGRAPHIC DESCRIPTION		TYPE AND METHOD OF WORKING	NATURE OF IMMEDIATE ROOF	NATURE OF IMMEDIATE FLOOR	RECOVERY WITH RESPECT TO MINING SYSTEM EMPLOYED	MINING PROBLEMS AND EFFECTS ON FUTURE/SUBSEQUENT OVER/UNDER/SIMULTANEOUS MINING	EFFECTS OF COST	NATURE OF FUTURE/SUBSEQUENT MINING	DISCUSSIONS/CRITIQUE/REMARKS
	THICKNESS	DESCRIPTION								
1	2	3	4	5	6	7	8	9	10	11
West Virginia	Over 300'	Overburden: Shales and sandstone	Room and Pillar.							
	48"	Coal seam: Pocahontas No. 6					Top conditions generally good. Top hazards bad when No. 4 No. 3 seams are worked too close together.	No. 4 seam not workable due to variable thickness.	Undermining.	Strong, competent parting of more than 150 ft. and 15 to 30 years between mining No. 6 and No. seams results in good recovery and good working conditions with little interaction effects.
	170 to 200'	Parting: Slate and shale 18 ft. sandstone, 5 ft. below No. 6 seam.								
	84"	Coal seam: Pocahontas No. 3	Room and Pillar	18' drawslate.	Sandy, firm fireclay	80%				
Kentucky	300 ft.	Overburden: Alluvium, shale, sandstones, limestones	Room and Pillar 75' x 75' pillars with 24' wide rooms	Jointed limestone	Fireclay	45% overall.	Heavy occurrence of gas and water in both seams.	Larger pillar size, presence of gas and water, extensive of old workings and long haulage in No. 11 seam reduces [illegible] tivity.	Undermining.	Larger pillars are necessary in No. 11 seam to prevent pillar sloughing, scaling and crushing. Output per section shift in 100 tons (No. 11), 250 tons (No. 9) columnization in mains only.
	70'	Coal seam: No. 11					Subsidence caused potholes of 35 ft. deep due to failure of No. 11 seam roof aided by pillar sinking in [illegible]			
	78'	Parting: Sandstone and shale								
	62"	Coal seam: No. 9	Room and Pillar 50' x 50' panel pillars with 24' wide entries.	Laminated shale	Fire fireclay	90% overall.				
Kentucky	1000 ft.	Overburden: Sandstone 30-40 ft. thick massive and stratified with shale.								Competent parting accounts for no interaction effect Management feels that the coal seams can probably be worked in any order with no effects on resource recovery or mining costs.
	40 - 60"	Coal seam: Elkhorn No. 1	Room and Pillar, bone coal taken to raise working height. Mains 60'x60', 20' wide with 200' coal barriers. Panels are 60' x 60', 20' wide.	Bone coal 6" thick.	Hard slate stands well with water.	85-90% in panels, 80% overall.	Floor heaving on exposure to water.		Undermining.	
	230 ft.	Parting: Stratified sandstone with shale.								
	Ave. 43'	Coal seam: Climwood	Room and Pillar, same working dimensions.	Component sandstone and shale.	Fireclay worked with mean to control heaving.	75-80% overall.	No subsidence observed.			
West Virginia	400-800 ft.	Overburden:								
		Coal seam: No. 6								
		Parting:								
	Ave. 66"	Coal seam: Pittsburgh No. 8	11 Room and Pillar sections plus one retreat longwall. Headgate: 120's 120' center, 80' x 80' center at middle block, tailgate 60'x60' center. 600' face. 7600 ft. long. 10 entries 16 ft.wide.	Firm limestone, 8" drawslate.	8" clay followed by fireclay.	45% overall.			Undermining	Extensive workings, ventilated through 3 double compartment shafts provided with 4 exhausting ventilators. Production is 1.6 M.T. per year.
Kentucky	375'	Overburden: Waterbearing sandstone and limestone.	Room and pillar, same as below.	Limestone	Fireclay	50% in panels. 45% Overall.	[illegible] 11 working heaving and p[illegible] 9 workings are wet, causing	Possible coal reduction due to dry workings.	Overmining.	Presence of fault systems disturbs coal and inhibits smooth advance. Farmland, aquifers, and oil and gas wells prohibit pillar extraction.
	34"	Coal seam: No. 11								
	125'	Parting: Mostly sandstone.	Room and pillar. 7 entry mains with 120' coal barrier. 60' x 80' panels. 26' wide.	Drawslate and shale.	Fireclay	55% in panels. 50% Overall.				
	Av 64"	Coal seam: No 9								
Kentucky	0 to 1000'	Overburden: Sandstone and shale.								
	Av 43"	Coal seam: Elkhorn No. 2	Room and pillar. 6 entries, 60' x 60' x 20' mains and panels.	Weathered, weak drawslate.	Hard blue slate.	65% to 70%	Requires two more men per section due to overmining due to roof support requirements. Loss of 5 to 7% of coal compared to lower seam is due to previous mining of lower seam.	Bad top when panning pillar lines left in bottom seam.	Overmining.	Mains and submains are columnized. Competent parting reduces interaction effects. Seams can probably be worked in any order without affecting costs or recovery.
	180'	Parting: Sandstone and shale.		Bone coal.	Hard slate.	85 to 90% in panels.				
	Av 39"	Coal seam: Elkhorn No. 1	Room and pillar. same as above.			80% Overall.				
Tennessee	0 to 550'	Overburden: Sandstone and shale.								
	Av 60'	Coal seam: Dirty Mary	Room and pillar. 3 entries, 70' x 70' x 20'.	Banded shale Separated from coal when underlying seam collapsed.	Shale. Uneven mining has cause cracks.	80 to 85% for pillars. 60 to 65% for panels. 50 to 55% Overall.	Parting rolls between remnant pillars and gob. Entry development in upper seam causes floor cracks along pillar ribs. Side support is needed to prevent sloughing.	Heavy roof and side support costs. Loss of coal during retreat mining and dilution from roof slate.	Overmining.	Mine personnel feel that best results could have been achieved by simultaneous mining with columnization of pillars. Advance of upper seam 1 to 2 years of the lower seam would be best. Inferior upper coal seam quality could then be better marketed through blending.
	60' to 70'	Parting: Shale and sandstone.								
	35" to 36"	Coal seam: Windrock	Room and piller.	Shale	Soft fireclay.					

TABLE 16 (Continued)

LOCATION	COLUMNAR STRATIGRAPHIC DESCRIPTION		TYPE AND METHOD OF WORKING	NATURE OF IMMEDIATE ROOF	NATURE OF IMMEDIATE FLOOR	RECOVERY WITH RESPECT TO MINING SYSTEM EMPLOYED	MINING PROBLEMS AND EFFECTS ON FUTURE/SUBSEQUENT OVER/UNDER/SIMULTANEOUS MINING	EFFECTS ON COST	NATURE OF FUTURE/SUBSEQUENT MINING	DISCUSSIONS/CRITIQUE/REMARKS
	THICKNESS	DESCRIPTION								
1	2	3	4	5	6	7	8	9	10	11
Letcher County KY	Avg. overburden from surface 800.	Big black mountain formations. Straitfield contortable gently sloping in north-south direction. Overburden overlay (Upper Taggart) seam about two-thirds shale to sandy shale. The balance sandstones, thin coal seams and fireclay. The sandstone beds occur throughout, varying in thickness from few inches to up to 40'.	Room and pillar. Drifts from outcrop on mountain side. Driven N-S along the seam slope. 6 entries each 20' wide at 70 ft x 70 ft centers in upper reaches and 80' x 80' in deeper reaches, with 500 ft coal barrier on either side. No gas detected 5/7 entry panels at 70 ft x 70 ft centers with 20' wide entries and 100 ft coal barriers between panels. Bleeder chain pillars left for ventilation of pillared out panels.			90-95% in pillars. 70-75% in panels. 60-65% overall.				All main, submain, main and submain and panel barriers columnized. Both first mining and pillar workings are done without consideration of other overlying or underlying seams. Both first mining as well as pillar workings are accomplished without any intersection difficulty. Mine personnel at the mine feel that with partings more than 100 ft. The workings in one seam, do not have any affect on mining conditions, resource recovery or production costs. With partings of more that 200 ft, it is felt that mining lower seam first may actually have beneficial effects while mining overlying seams. As the overlying seam workings are likely to be dry and coal easy to work.
	U. Taggart Coal seam Interburden 200 ft	48" (average) Mainly sandy shale and sandstone, with a bed of sandstone about 35 to 40 ft thick lying almost directly below U. Taggart seam and thin inferior coal bed.		Immediate Roof-competent shale	Immediate floor-fireclay to sandy clay.					
	'B' seam Interburden 330' to 350'	40" - Average Mostly shales, include 3-4 beds of sandstone, 20 ft to 40 ft thick.	Room and Pillar. Drift from outcrop on mountain side. Driven N-S along the seam slope. 6 entries each 20 ft wide at 70' x 70' centers in upper shallow portion and 80 ft x 80 ft centers in lower deep reaches with 500 ft coal barrier on either sides.	Immediate roof-tough competent shale.	Immediate floor-hard fireclay.	Pillar working minimal. No estimate possible with limited experience.				Mine personnel were further of the opinion that whenever a number of seams are available in mining area, simultaneous production from all the seams should be planned because: (1) this facilitates proper blending, of all coals, thus better unit price realisation, with flexibility of meeting consumer quality specifications. (2) Each seam should have its independent outlets and ventilation, so that any mishap or accident will not affect all the seams. This arrangement paid off in the explosion mishap of 1976. (3) More flexibility of man power utilisation because rearview sections can be maintained with least extra capital expenditure. (4) Possible reduced pumping costs. because the water make-up underground depends on surface area, annual rainfall, natural drainage, and seepage underground. Seepage underground depends on induced surface breaks, and is most likely source of extra water make-up. If mining one seam after another seams is done, mining of first seam will produce enough breaks, for seepage on most of the rainfall below and retained in the previously worked seam and this will have to be pumped. Also excessive wet conditions will have its effect to machinery breakdown, maintenance, productivity, etc. Wet workings are also likely to deteriate, roof, floor and pillar, with resultant increased costs.
	Imboden seam	Average thickness - 72"	Room and pillar. Drift from outcrop on mountain side. Driven N-S along the seam slope. 6 entry mains each 20' wide at 70' x 70' centers in upper shallow portions and 80' x 80' centers in lower deeper reaches with 500' coal barrier on either side.	Immediate roof-shale.	Immediate Floor-shale	85-90% in pillars. 70-75% in panels. 60-65% overall.				At present both first and pillar working in the lowest Imbode seam are by far ahead of other seams workings. 'B' seam being thin has only one operating section and working are far behind in this seam.

TABLE 16 (Continued)

LOCATION	COLUMNAR STRATIGRAPHIC DESCRIPTION		TYPE AND METHOD OF WORKING	NATURE OF IMMEDIATE ROOF	NATURE OF IMMEDIATE FLOOR	RECOVERY WITH RESPECT TO MINING SYSTEM EMPLOYED	MINING PROBLEMS AND EFFECTS ON FUTURE/SUBSEQUENT OVER/UNDER/SIMULTANEOUS MINING	EFFECTS ON COST	NATURE OF FUTURE/SUBSEQUENT MINING	DISCUSSIONS/CRITIQUE/REMARKS
	THICKNESS	DESCRIPTION								
1	2	3	4	5	6	7	8	9	10	11
Kentucky	Av 700 ft.	Overburden: Sandstone 30 - 80 ft. thick, shale 20 to 50 ft. thick, fireclays.					Dry workings due to drainage to lower seam.	Savings on common slope, surface facilities.	Overmining	Mains and submains columnized. Some sinking of pillars from wet floor in No. 9 seam (lower seam) and floor heave. No pillar extraction planned due to prime farmland and aquifers.
	58"	Coal seam: No. 9	Room and Pillar 60' x 60' pillars 24' wide rooms.	Laminated shale.	Firm, dry fireclay.	50% in panels 45% overall				
	85 ft.	Parting: Sandstone and shale.								
	58"	Coal seam: No. 11	Room and Pillar same as above.	Jointed limestone	Dry fireclay.	Same as above.				
Kentucky	550 ft.	Overburden: Sandstone 25 to 60 ft. thick, shale 20 to 40 ft. thick.						Savings from common slope, ventilation, and surface facilities. Improved O.M.S. expected due to better understanding of geology.	Overmining	Columnization of mains and submains. Mine boundaries are fixed by major faults on all sides. Little interaction due to sufficient parting.
	58"	Coal seam: No. 11	Room and Pillar	Jointed limestone	Dry fireclay.	50% in panels. 42% overall	No. 11 is more watery due to overlying water bearing sandstone. Some piller sinking in No. 9 due to wet fireclay.			
	80 to 90 ft.	Parting: Sandstone and fireclay.	60' x 60' 24 ft. wide rooms.							
	58"	Coal Seam: No. 9	Room and Pillar	Laminated shale.	Fireclay.	50% in panels 45% overall				
Kentucky	370 ft.	Overburden: 35 ft. alluvium, water bearing sandstone, shale and limestone.								
	54"	Coal Seam: No. 11	Room and Pillar 60' x 60' pillars, 24' wide rooms.	Limestone	Fireclay	50% in panels 45% overall	Excessive water due to faults.	No effects.	Overmining	
	70 ft.	Parting: Sandstone and shale.				Same as above.	Pillar sinking from soft floor. Potholes due to roof failure in No. 9 seam.			
	58"	Coal seam: No. 9	Room and Pillar same as above.	Limestone	Fireclay					
VIRGINIA	300'	Overburden: Sandstone and shale.								
	45" to 49"	Coal Seam: Pocahontas No. 5	Room and pillar.	Drawslate and shale	Sandy fireclay.		No. 3 seam can only be blended with other seams due to poor quality. Recovery will be 15% less than No. 5 because high production costs for better recovery would not be economically sound.		Simultaneous Mining. No. 3 Seam logs No. 5 Seam workings.	All mains and submains are columnized or superimposed.
	75' to 320'	Parting: Slate and shale								
	Average 65"	Coal Seam: Pocahontas No. 3	Room and pillar.	Same as above.	Same as above.					
WEST VIRGINIA	200' to 1000'	Overburden: Shale and strong sandstone.								
	60"	Coal Seam: Pocahontas No. 4	Room and pillar, 7 main entries, 80' by 80' by 20' panel	Strong shale.	Shale.	90% in panels excluding barriers and bleeders.			Simultaneous [illegible] No. 3 kept 6 months ahead of No. 3 for strata stabilization.	All mains and panels are columnized. Longwall operations in No. 3 are planned for 1980.
	20'	Parting: Shale and sandstone.								
	50"	Coal Seam: Pocahontas No. 3	Same as above.	Drawslate, shale and sandstone.	Firm shale.	85% as above.				

TABLE 16 (Continued)

LOCATION	COLUMNAR STRATIGRAPHIC DESCRIPTION		TYPE AND METHOD OF MAKING	NATURE OF IMMEDIATE ROOF	NATURE OF IMMEDIATE FLOOR	RECOVERY WITH RESPECT TO MINING SYSTEM EMPLOYED	MINING PROBLEMS AND EFFECTS ON FUTURE/SUBSEQUENT OVER/UNDER/SIMULTANEOUS MINING	EFFECTS ON COST	NATURE OF FUTURE/SUBSEQUENT MINING	DISCUSSIONS/CRITIQUE/REMARKS
	THICKNESS	DESCRIPTION								
1	2	3	4	5	6	7	8	9	10	11
Kanawha County W VA	0-150 ft	Overburden: Shandstone and shales.	Some sections pillared and some sections only first mined. Simultaneous mining with lower Winifrede seam.			About 60%	No effects of the mining in either seam over thought to have been experienced.		Simultaneous mining with lower seam lying 140 ft below.	No columnization of pillars attempted. No flooded areas in the upper seam. No other effects experienced.
	60"-72"	Coal seam: Belmont (Stockton-Lewiston).								
	140 ft	Parting: Shales, sandstones.	Room and pillar. Entries on 50' centers, 70 ft wide; rooms on 80' centers, 30-40 ft wide.	0"-14" shale overlain by beds of sandstone up to 75 ft.	Fairly firm shale.	65% overall.	Same as above			
	30" to 78" with 1/2" to 15" partings.	Coal seam: Winifrede (Dorothy).								
	280-320 ft Av 300 ft	Parting: Mostly sandy shale with sandstone beds; coal seams, and a 50 ft thick sandstone bed directly beneath the Winifrede.	Room and pillar. Entries on 45 ft and 50 ft centers 70 ft wide; rooms on 50 ft centers, 40 ft wide. Pillars left in place.	Mostly sandstone, excellent roof.	Gray shale firm.	75%	None.			
	42" to 54" Av 44"	Coal seam: No. 2 gas.							Undermining.	No columnization of pillars attempted. No flooded areas in upper seams.

TABLE 17 Southern Appalachia; Alabama, Tennessee, and Georgia.

LOCATION	COLUMNAR STRATIGRAPHIC DESCRIPTION		TYPE AND METHODS OF WORKING	NATURE OF IMMEDIATE ROOF	NATURE OF IMMEDIATE FLOOR	RECOVERY WITH RESPECT TO MINING SYSTEM EMPLOYED	MINING PROBLEMS AND EFFECTS ON FUTURE/SUBSEQUENT MINING OVER/UNDER/SIMULTANEOUS MINING	EFFECTS ON COST	NATURE OF FUTURE/SUBSEQUENT MINING	DISCUSSIONS/CRITIQUE/REMARKS
	THICKNESS	DESCRIPTION								
1	2	3	4	5	6	7	8	9	10	11
Alabama	0' to 500' 34"	Overburden: Shales and sandstones (no drill ing available) Coal seam: Thompson	Room and pillar entries 12' wide rooms on 40' centers, 30' wide; most pillars left; some sparsy pillar recovery.	Slate	Sandy shale	50% approx.	No columniation attempted other than mains. Both seams were driven to the dip and entries on the strike.			
380' average 36" to 50" Average 39"	Parting: Shales and sandstone conglomerate Coal seam: Woodstock	Room and pillar, pillars left in place; rooms 30' wide on 60' centers, breaks on 60' centers; 50' wide curtain pillar between room entries.	Sandy shale-sandstone	Fireclay fairly hard, underlain by dark shale.	62%		Undermining		(After Stemple, 1956)
Alabama	0' to 160' 30" to 36" plus 2" parting	Overburden: Shale and sand stone with the sandstone lying in a bed 50' to 60' thick, about 30' to 35' above the upper seam. Coal seam: Pratt	Room and pillar; 3 entry mains on 50' centers, 12' and 20' wide, breaks on 70' centers, leaving 35' x 70' chain pillars; 3 entry butts, 45' centers, room widths, rooms on 45' centers, 30' wide, breaks on 60' and 70' centers; pillars left.	Brownish, 3' to 17' thick, overlain by shale up to 30' thick. In some places about 1" coal appeared over the drawslate.	Fireclay, firm when dry; underlain by sandy shale or sandstone. Slippery and bad.	60% in areas mined	No difficulties encountered attributable to two seam mining except two instances, where excessive retraction in the lower seam caused a squeeze, resulting in cracks in the surface. Three were evidenced in the upper seam only as hairline cracks, with a slight sweeping of the entry.	Costs were no greater in either seam than they would have been had each seam been mined alone.	Overmining with simultaneous production from two seams	In one section where the upper seam was mined about 1 to 2 years before the lower seam. No difficulty was encountered in the lower. Pillars not columnized but certain cross entries turned on seam projections. Main not superimposed. Mains in two seams are parallel about 150 ft apart. (After Stemple, 1956)
	55' to 75' Av 65'	Parting: Predominantly sandy shales, some sandstones; the unmined Nickel Plate coal seam 18" to 24" thick midway in the interval; usually a good bed of sandstone between the Pratt and Nickle Plate coal seams.		Variable: 3" to 12" drawslate in some places, shale or sandstone in others. Main top is normally shale, up to 10'-12' thick.	Soft fireclay; deteriorates badly when wet.	60% in the old workings 65% elsewhere				
	48" to 66" with 5" to 9" of parting	Coal seam: America								
Alabama	0'-1150' 38" to 40"	Overburden: Predominantly sandstones, massive bed, up to 80' thick. Also fireclays, coals and shales. Coal seam: Chatham	Almost entirely longwall. Mains driven to dip, entries turned on strike, main barriers left in place.	Normally firm shale.	Slate, about 6" underlain by sandstone.	85%	No difficulties or disturbance reported. Main and cross-entries appear to be superimposed but pillars not columnized.		Undermining	Subsidence measured over a surface line was 2.3 ft maximum . . 1.9 ft average.
	30' to 80' Av 48' coal - 12" rash - 6" coal - 30" shale- 12" coal - 18"	Parting: sandstone conglomerates, and slates and sandy shale. In one place 56' of a total of 70' was sandstone lying in two beds. Coal seam: Clark	Part longwall, part room and pillar.	Sandy shale about 2' thick, overlain by sandstone.	12" shale underlain by 19" coal, then by slate and shale.	60% approx				(After Stemple, 1956)
Alabama	0' - 200' 52" coal plus 9" bone	Overburden: Sandstones and sandyshales many thick bedded up to 50' thick. Coal seam: Pratt	Part longwall, panels between 3 place entries on 60' center, 40' wide, 400' apart; part room and pillar, 3 place entries, 50' to 60' centers, 20' wide, rooms on 40' and 60' centers, 25' and 40' wide, pillars left in.	Slate. Normally good.	Slate	70-75% overall	No difficulties or disturbances reported		Undermining	Known surface cracks are outside the Pratt outcrop. (After Stemple, 1956)
	450' to 470' Coal - 36" Rash and bone 24" Coal 48"	Parting: Some fairly thick and heavy sandstones. Several coal seams including one 2' or more above the lower seam. Sandy shales, shales and fireclays. Coal seam: Mary Lee	Room and pillar, 9 entry mains, 3 entry butts, 30' centers, 25' wide, pillars left in place.	Sandy shale 2' thick or more, overlain by coal (not too good).	Sandy shale	50% approx				
Alabama	0-900' Average 59"	Overburden: Chale and sandstone, 50' to 60' thick sandstone, lying 100' or so above the upper seam. Coal seam: America	Room and pillar, entries on 72' centers 30' wide, rooms on 16' centers, 40' wide pillars left in place.	8' to 10' shale overlain by sandstone.	Fireclay	60% approx	Over the robbed areas of Lower Mary Lee seam, mining in upper seam, the America, as well as in the top most seam, the Pratt (lying 500' above the America) was complexly disrupted by top falls, caved entries, ecr., due to the falls made in the Lower Mary Lee seam.		Varied. Some times upper, sometimes lower seam mined first. Occasionally, both seams mined simultaneously.	In the partial mining sections, no disturbance in either seam, with the pillars in both standing up very well. Some surface cracks over robbed areas of Lower Mary Lee seam. (After Stemple, 1956)
	300' to 400' 32" to 84" Average 54"	Parting: Sandstones and shales. Some very hard sandstones in fairly thick beds. (30' to 40') Coal seam: Mary Lee	Room and pillar same centers and widths as for upper seam. Pillars pulled in two areas of about 800' x 1000' only.	10' to 12' slate overlain by hard sandstone.	Hard sandy shale	60% approx			Primarily simultaneous mining.	

TABLE 18 Midwestern United States; Illinois, Indiana, Iowa, and Western Kentucky.

LOCATION	OVERBURDEN STRATIGRAPHIC DESCRIPTION		TYPE AND METHOD OF DEVELOPMENT	NATURE OF PREPARED ROOF	NATURE OF IMMEDIATE ROOF	RECOVERY WITH RESPECT TO MINING SYSTEM EMPLOYED	MINING PROBLEMS AND EFFECTS ON FUTURE/SUBSEQUENT OVER/UNDER/POTENTIALLY MINING	EFFECTS ON COST	NATURE OF FUTURE/SUBSEQUENT MINING	DISCUSSIONS/FREQUENCY/REMARKS
	THICKNESS	DESCRIPTION								
1	2	3	4	5	6	7	8	9	10	11
Indiana	40' to 50'	Overburden: Coal seam: No. 5 Parting Coal seam: No. 6					Heavy grades at entry crossed over unbreached chain pillars in No. 6 bed. Foreman and miners did not know that area beneath had been worked out until after much of the area in No. 5 had been worked. The roof in upper bed was bad in places but was not regarded as unusual. Evidence in places where the roof fell, that condition was caused by effects of removal of bottom seam		Overmining	
Indiana		Overburden: Coal seam: Parting: Coal seam:	Room and Pillar			72%	Upper bed had been mined 2 years before, getting about 72% extraction. When lower bed was mined, a panel in upper bed squeezed. Two days later, panel in lower bed squeezed from effects of squeeze in bed above. Squeeze in lower bed closed rooms and entries. Ordinary squeeze originating in lower bed did not close entries but rooms only.		Undermining	
Illinois	200 ft. Av 54"	Overburden: Sandstone and Limestone. Coal seam: No. 6	Room and Pillar 60' x 60' pillars with 20' wide rooms. 6 entry mains.	Jointed limestone	Dry fireclay		Colonization not possible due to unknown old workings in lower No. 5 seam.	Possible increase for roof support, but may be offset by dry conditions.	Overmining	Closer roof bolt spacing anticipated.
	90 ft. Av 62"	Parting: Sandstone and shale. Coal seam: No. 5	Room and Pillar	Laminated shale	Fireclay					

TABLE 19 Western United States; Colorado, Utah, and Wyoming.

LOCATION	COLUMNAR STRATIGRAPHIC DESCRIPTION THICKNESS	DESCRIPTION	TYPE AND METHOD OF MINING	NATURE OF IMMEDIATE ROOF	NATURE OF IMMEDIATE FLOOR	RECOVERY WITH RESPECT TO MINING SYSTEM EMPLOYED	MINING TECHNIQUES AND EFFECTS ON FUTURE / SUBSEQUENT OVER / UNDER / SHIFTING/FOOL MINING	EFFECTS ON COSTS	NATURE OF FUTURE / SUBSEQUENT MINING	DISCUSSIONS / CRITIQUE / REMARKS
1	2	3	4	5	6	7	8	9	10	11
Utah	5' 10' to 20' 9' to 16'	Overburden Coal seam: Parting Coal seam:					100 acres of coal lost due to mining of lower seam			
Utah	Up to 2000 ft 6" to 5.5" 2' to 60' 6' to 10'	Overburden: Coal seam: Upper Sunnyside Parting: Coal seam: Lower Sunnyside	Room and pillar extensively worked in the past Room and Pillar	2' to 3' sandstone			Under present pillars of upper seam extremely poor roof conditions. Under a cover of 500' to 1400', room drivage for retreat mining, subsiding remnant pillars extremely difficult because of violent bounces and inability to hold 2' to 3' cap rock		Underground	Pillar remnants in upper seam in the form of barrier, chain and abandoned room pillars. No difficulty in driving entries under worked out upper seam. (After Peperakis, 1968)
Utah	2500' 4' to 6' 3-45' 5 1/2' to 16'	Overburden: predominantly sandstone A massive bed up to 200' thick, 150 ft above the seam Upper seam Parting: Lower seam	Room and pillar extensively worked in the past	Shales, sandy shales, rider seams and laminations	Sandstone strong 20 to ft		Problems caused due to subsiding workings, serviceability and delays along haulage and tail entries due to shattered roof. Tail entry bottom heaving, roadway floor dinting. Cap rock broken along the face causing dilution, bouncing and sloughing of coal face in presence areas due to overlying remnant pillars. Pushing out of coal face resulting in pinning of coal face plough.			(After Peperakis, 1968)
Orchard Valley near Paonia, Colorado	900' to 2000' 76' 80' 13' 80' 17'	Overburden: Present cover - 1000 ft Coal seam "B" seam Parting Coal seam: "C" seam Parting: Coal seam "A" seam	Present: Room and pillar entry mains - 125' x 100' pillars with 200' barriers. Panels, 5 entry, 60' x 80' x 20' wide 80' x 80' x 20' wide. Planned - longwall and mining of pressure			First working only				(After Goodrich, 1979)
Wattis Utah 83' Average 93' 88' 73' 99' Average		Overburden: containing thin unmineable coal seam underlain by a parting of 282' Coal seam: Wattis Parting: Coal seam: Third seam Parting: Contains two unmineable bind rooves - second seam Coal seam: Hiawatha	Five Heading panels, fairlow and rooms at 80' centers 19' wide roof holes at 4' centers and 4' long	Mostly sandstone with some strata of shale or siltstone and small amount of dense rock up to 1' in few places. Generally good top.	Good Good Good	Overall mean recovery of 75-80% in previously mined seams 90% Expected		Planned capital expenditure of $14m from 2,900 T.P.D. to 5,000 T.P.D. (1 SMPY)	Mining from top to bottom Production simultaneous from all seams with coordinated mining activities in three seams.	In the past all three seams been mined by room and pillar work. No super position of entries or barriers had been attempted, resulting in poor road areas, with no uniform mining conditions. Present workings are to recover as much coal as possible by working small blocks of coal, barrier and chain pillars, with a view to reach virgin coal areas as a rehabilitation program. Small faults and dikes are common throughout the property. Dikes have also burned out considerable coal. (After Jackson, 1978)
UTAH	16.5' Average 3100' 85' 25'	Overburden: Massive sandstone Coal Seam: Upper O'Connor Parting: Sandstone Coal Seam: Lower O'Connor	Room and pillar. 5 to 7 main entries, 80' by 80' by 20', 4 entry panel. Room and pillar. 80' by 50' by 18' entries.	Weak shale and slate. Prevalate.	Coal. Coal.	42% during development. As above.	Wet conditions due to water bearing sandstone. Sandstone overburden causes pillar crushing when over 600'.	No change in coal cue to multiple seam working.	Simultaneous Mining.	Colonization of entries. Present workings are only in upper seam. The seams are thick, and only the top part of each is developed. Final pillar retraction may bring recovery to 55% overall.
WYOMING	0' to 1600' 6', 8', 12.5' respectively. 95' to 110'	Overburden: Sandstone and shale. Coal Seam: Shale and sandstone. Parting: Shale and sandstone.	Room and pillar, 7 mains, 50' by 20' to 50' by 100' depending upon depth, 710' to 300' coal barriers	Sandstone.	Shale.	57%, 55%, 52% respectively during development.	Pillar weighting at depth.	No change in cost with production.	Bottom seams developed after top seam. 500' lag distance .	All entries and barriers are columnized. Top seam abandoned due to bad roof and deteriorating fireclay floor. Seams split but are then not mined due to this parting.
Wyoming	100' to 200'	Overburden: Sandstone and shale Coal seam: USCS 50 Parting: Coal seam: USCS 25	Room and Pillar. Pillars 80' x 80' with 20' wide entries.			40 to 50% Planned.			Longwall planned for 1981. 450 ft. face, 5,000 ft. long. Simultaneous mining planned, no problems anticipated.	

TASK 2

DEFINITION OF TECHNICAL PROBLEMS

1.0 INTRODUCTION

Every mining operation is unique and distinct, with its own set of problems related to the conditions that exist at the mine. Problems may be created by the rate of mining, the amount of water present, the type of rock comprising the roof and floor, or the thickness of parting between coal seams. All of these problem areas affect mining performance, and have an impact on future mining. In order to analyze the technology of multiple-seam mining, it is first necessary to review mining methods currently used, along with existing problems that must be dealt with for successfully mining multiple seams. Mining performance can then be ascertained on the basis of production economics, recovery ratio, number of employees and equipment required.

Analysis requires composite plans to mine all coal seams in proper sequence using the best available technology suited to specific conditions. New methods of extraction, such as shortwall and advancing or retreating longwall, and methods of reducing problems of interaction from workings in superjacent or subjacent seams need to be examined. Mining interaction between coal seams can be reduced by:

- Superposition of entries, pillars, and panels when room-and-pillar mining.
- Total extraction of pillars, with over 90% resource recovery.
- Driving of roadways under old gobs in order to achieve drivage through destressed areas when longwall mining.

The objective of this task report is to analyze present multiple-seam mining technology and then present ways to improve industry performance under specific geologic situations. This is done through the compilation of general operational plans. The procedures presented in the plans use either existing technology, or technology that can be developed through short-term research and development, as per the requirements of this study.

The investigation entailed a study of all major coal regions of the United States, which was divided into 5 geographic areas, (Northern Appalachia, Central Appalachia, Southern Appalachia, the Interior Province, and the Rocky Mountain Coal Province) each with 3 modes of mining:

overmining, undermining, and simultaneous mining. This gave a total of 15 locales. However, during the study it was recognized that the seam interactions and technologic problems resulting therefrom, were very similar in all of the geographic regions. Besides, very little multiple-seam mining data exist for the Interior and Rocky Mountain Coal Provinces. Hence only very general type comments could be made. Since these were often repetitive of those for Appalachia, for which region there was more definitive information, it was decided to discuss the technologic problems as these relate to that region. Much of the data for this portion of the study came from the Central Appalachia area (Southwestern Virginia, Southwestern West Virginia, and Eastern Kentucky), but the information from mines in Northern Appalachia (Southwestern Pennsylvania, Northeastern West Virginia, and Ohio) and Southern Appalachia (Tennessee and Alabama) was very similar. This was also true of the mines visited in Western Kentucky, which is part of the Interior Basin. This report treats all of Appalachia and Western Kentucky as one region.

Hence the operational mine plans presented in the report are primarily based on the characteristics of the coal-bearing strata within Appalachia. However, we feel that these provide adequate insight to the problems of multiple-seam mining elsewhere in the country. Particular attention has been given to the following factors:

- Strata control
- Roof, floor cracks, and heaves
- Entry support
- Water percolation
- Influx of gas
- Loss of ventilating air
- Spontaneous heating

Foreign experience is also discussed briefly, since several European countries have used multiple-seam mining techniques for some time, and consequently have gained valuable experience. Although this experience is primarily related to longwall mining, it is useful in that this method of coal extraction is becoming more widespread in the United States.

2.0 STRATA REACTION TO MULTIPLE-SEAM MINING

Past experience has clearly demonstrated that mining over or under isolated pillars, or small groups of pillars, left in a coal seam are the primary causes of disturbance in the coal seam being mined. Thus, if such areas of disturbance can be anticipated, because of prior knowledge of existing conditions, appropriate precautions can be taken to avert difficulties.

Strata behavior is affected also by the method of mining. Essentially, two types of rock failure occur as a result of stress relief, related to the mining method. In longwall mining, large areas are mined and the subsequent caving is accompanied by progressive subsidence which extends upward towards the surface, thus disturbing all the beds overlying the seam. In room-and-pillar mining, breaks in the overlying strata occur with difficulty and such failures, caused by stress concentrations, are localized near the pillar line. Pillar-line stresses can be transmitted to both under- and overlying strata, due to the pressure ellipse formed. This is discussed later in this section.

2.1 Working Above A Mined Seam

While developing workings above a seam that has been previously mined, the strata that have settled on either side of the workings will induce cracks in the roof beds over the new entries in the upper seam. These are caused by pillars left in the lower seam, either within the workings or at the property lines. Figure 5 shows some examples of where stress cracks are likely to develop.

The most severe fracturing could occur about 100 to 300 feet beyond the isolated pillar left in the lower seam, since the strata acts as an unsupported cantilever beam and can bend 100 to 300 feet before fracturing. The severity of disturbance is dependent upon the nature and thickness upon of the strata and the thickness of coal, e.g. extraction of a thicker lower seam will create more disturbance. Figure 6 schematically illustrates such cantilever behavior of strata during subsidence.

The behavior of subsidence is dependent on the nature of rock which fills the goaf area. For example, strength of sandstone is higher, so it reduces the amount of total subsidence. Also because of its slow rate of compaction final subsidence occurs after an extended period. Shale however, has a faster compaction

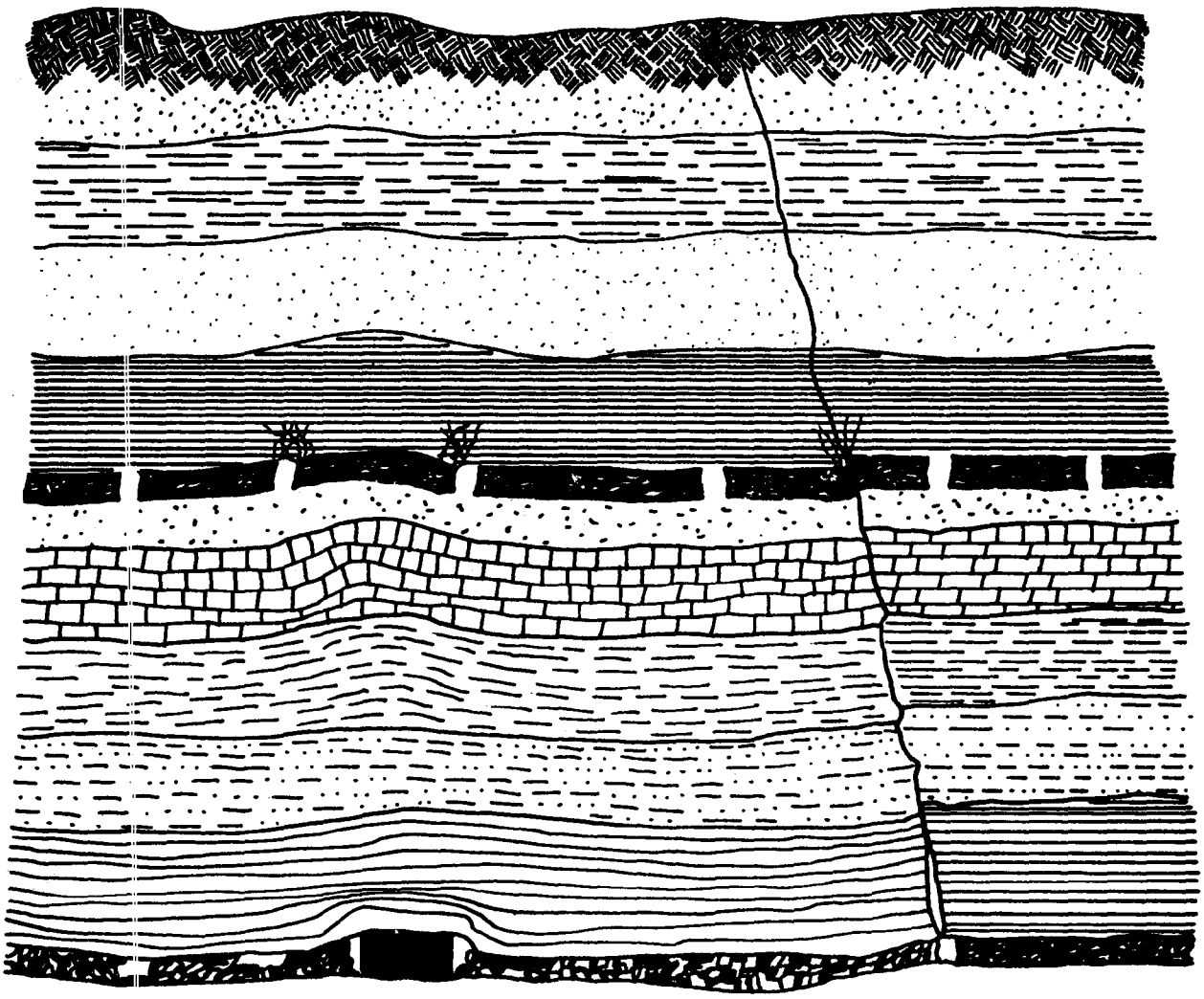


Figure 5 - Disturbance in Upper Coal Seams
(after Stemple, 1956).

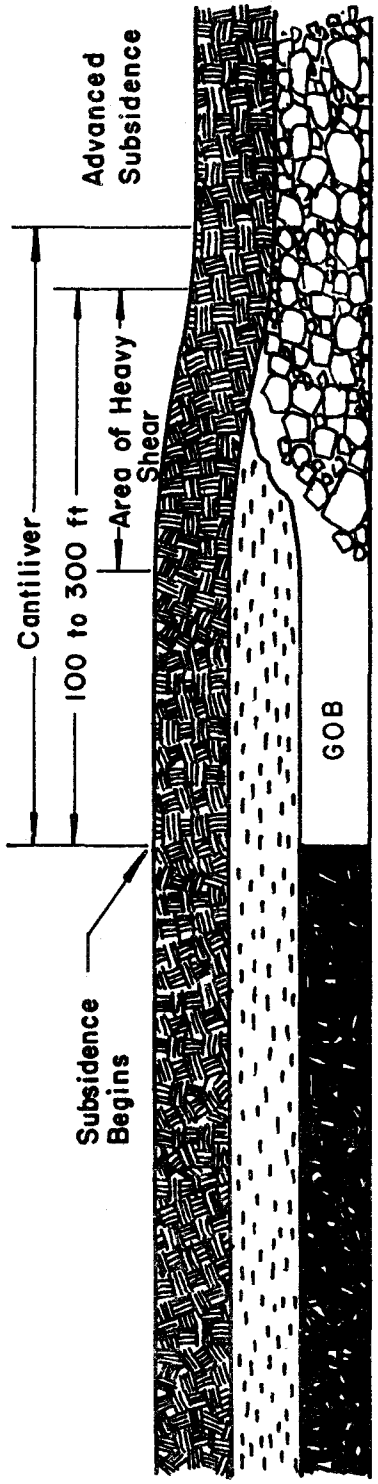


Figure 6 - Cantilever Action of Strata

rate and due to its lower strength subsidence will be more rapid and more severe than with sandstone. A measure of compaction may be obtained from the swell factor, which is a ratio of the loose weight of rock excavated or caved to that of the weight of rock in place. The reciprocal of this ratio is the percent swell. The swell of sandstone is 40 to 60 percent compared to about 33 percent for shale. This indicates that the initial subsidence with sandstone rock is less. It is also evident that sandstone deteriorates less rapidly than shale, which disintegrates quickly when exposed to groundwater.

When mining above a worked-out seam, the influence of the parting of the superjacent seam is important in defining conditions that may exist during mining (from Mining Handbook, 1975). Figure 7 shows the likelihood of influence on the upper seam based on the deformation of the rock mass above the lower seam previously mined, where d is the vertical distance and m is the seam thickness. Obviously as the vertical distance increases, the likelihood of influence decreases, and the strongest influence is when the vertical distance is less than 5 times the seam thickness.

2.2 Working Below A Mined Seam

Mining below a worked-out area presents problems of induced stresses due to remnant pillars similar to those when mining above, but to a lesser degree. One major difference is that mining below is more affected by increased stresses from overburden thickness. When mining under existing remnant pillars, where overburden is significant (about 450 feet), disturbance due to the weight of the overburden may be anticipated. Assuming rock in place weighs 160 lb/ft^3, 450 feet is equivalent to 500 psi. This force approaches the compressive strength of the coal mass (600 to 1,200 psi, see Singh, 1981). Thus causing deformations in the coal seam. Figure 8 shows coal workings where squeezing of pillars has taken place in the lower seam. This creates difficulties in keeping haulageways open (Zachar, 1952). Fracturing in the roof occurs when the floor is strong, and floor heave will occur if the roof strata are strong. These conditions occur when remnant pillars in the upper seam transmit excessive forces from overburden weight vertically downward, and result in stress concentrations and consequent ruptures in the workings of the lower coalbed. Figure 9 illustrates the arch stresses that can develop in undermining. The intention here is to examine mining conditions in view of the pressure arch theory. When excavation occurs the overlying strata distribute the weight to either side of the open space thus forming an arching line of stress which is the resultant of forces in equilibrium. The arch defines the supported material above it and allows the easy removal of material below it. Characteristics of overlying strata affect the shape of the arch necessary to maintain equilibrium. A large span indicates the occurrence of excessive weight at the limits of the excavation, so that crushing may

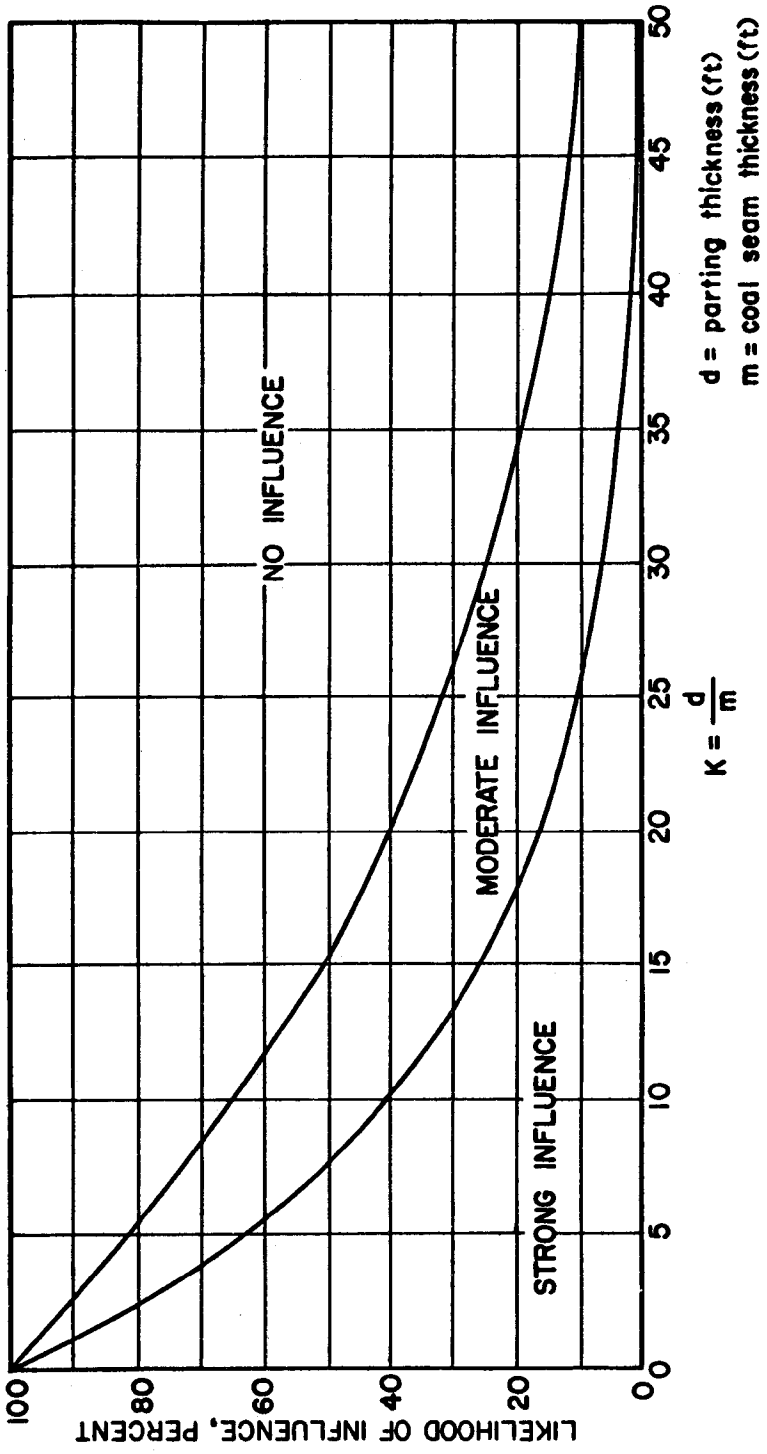


Figure 7 - Likelihood of Seam Influence (after Mining Handbook, 1975).

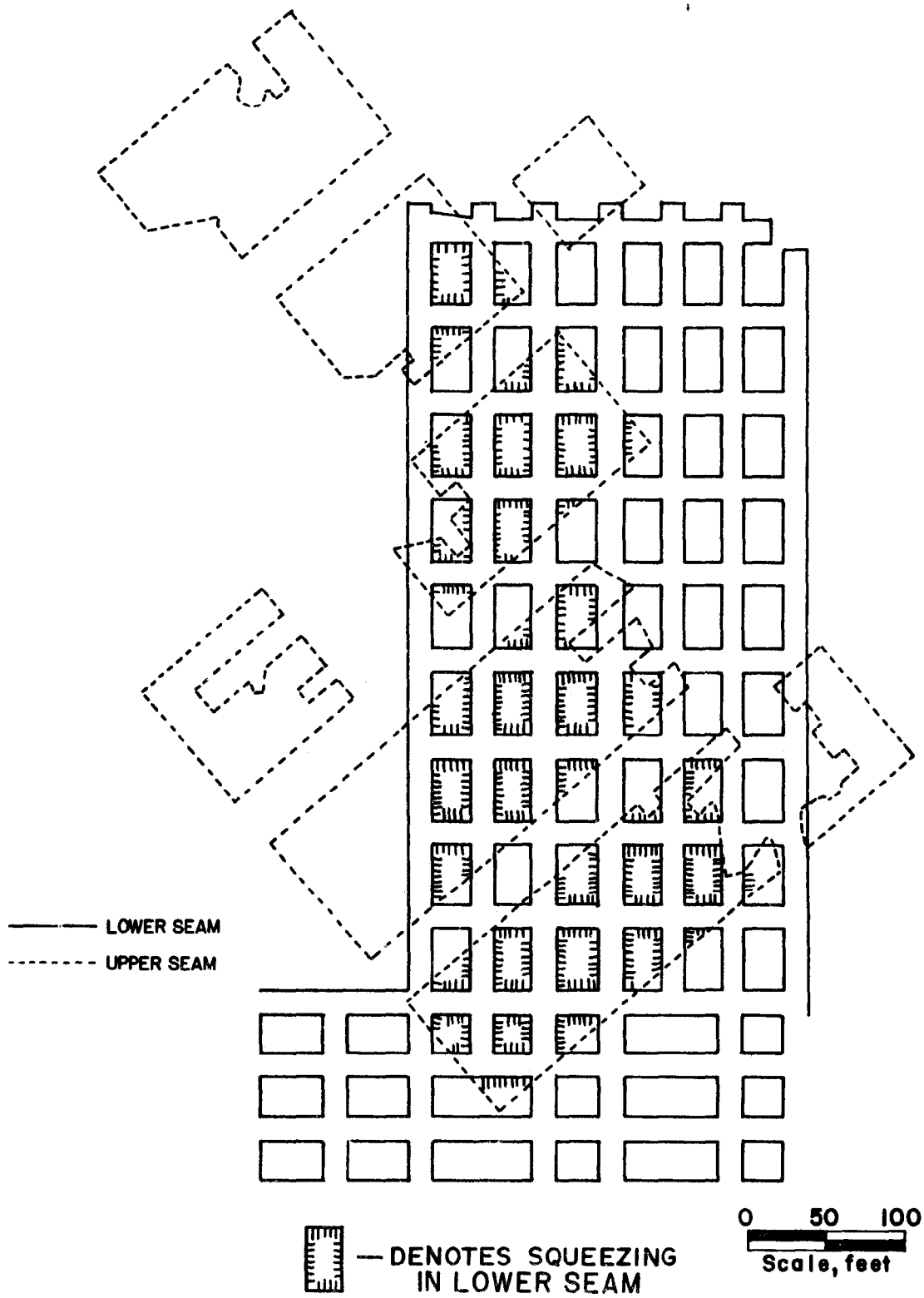


Figure 8 - Squeezing from Remnant Pillars in the Upper Seam.

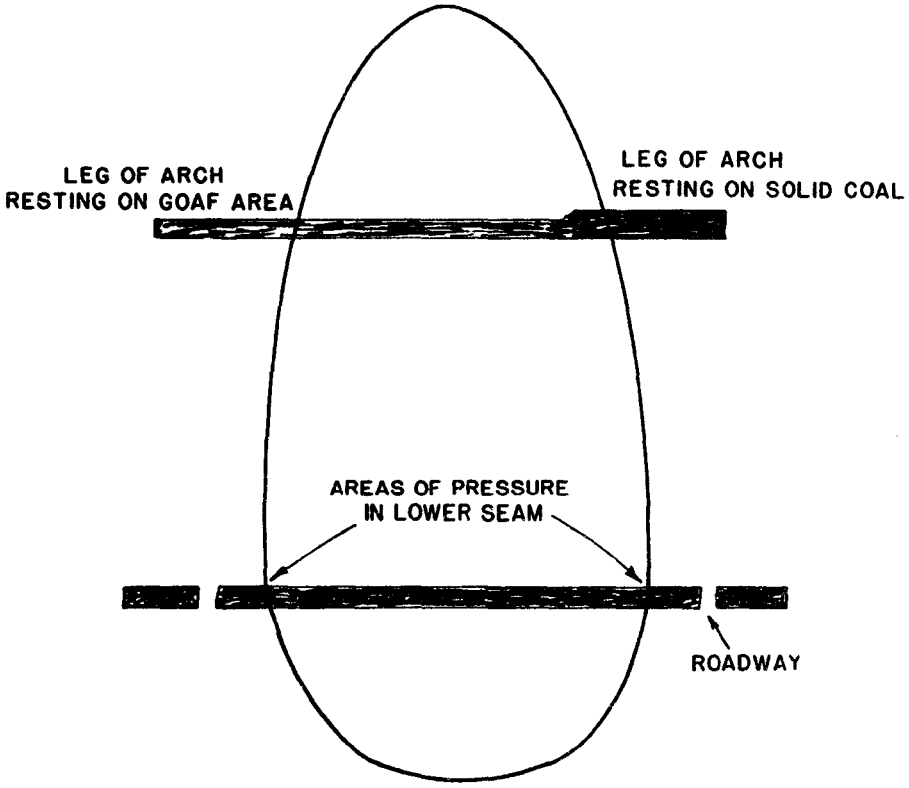


Figure 9 - Stress Result of Undermining.

(modified from Stemple, 1956)

occur in this area. Conversely, material falling above into the excavated area may fill the space so that one side of the arch will find extra support for stress forces and thereby create a narrower arch. The height of the arch is estimated to be twice its width for depths between 400 and 2,000 feet. The span (L) can be calculated by the following expression:

$$L = 0.15D+60$$

where D is the depth of working below the surface, in feet.

It is important to note that the pressure arch extends above as well as below a coal seam. Figure 10 is presented to show that the pressure arches formed in two coal seams indicate stresses that become additive and, therefore, create areas of excessive pressure.

In developing workings as in Figure 9 the stress areas in the lower seam may exist over the entries and haulageways where effects on mining are more severe. Consequently the placing of entries in destressed zones requires careful planning.

2.3 Simultaneous Mining

With simultaneous mining, one seam is mined slightly ahead of the other creating either an overmining or undermining condition. The only difference characterizing simultaneous mining is the time lapse between mining of the seams. Hence problems encountered are a combination of what has been previously discussed. When the lower bed was mined first, bumps in the floor, weighting of pillars, and fractures in the upper strata occurred over remnant pillars. With ample time allowed for stability of strata little difficulty was encountered. When the upper seam was mined first no deleterious effects existed except where parting thickness was 40 to 50 feet whereupon high pressure areas existed under large remnant pillars. Generally results of past experience have not been favorable for parting thickness less than 165 feet.

The mining of one seam will have strong influence on the other when simultaneous mining is practiced. Figure 11 shows the zone of influence from the upper seam upon the seam below. The zone extends downward from the mining face at an angle of 45° to a limit (z) equal to Unrug,1980):

$$\frac{2G_eS}{\pi P_1}$$

where G_e = mean stress in the zone
S = width of the mined zone in the upper seam
P_1 = primary overburden stress.

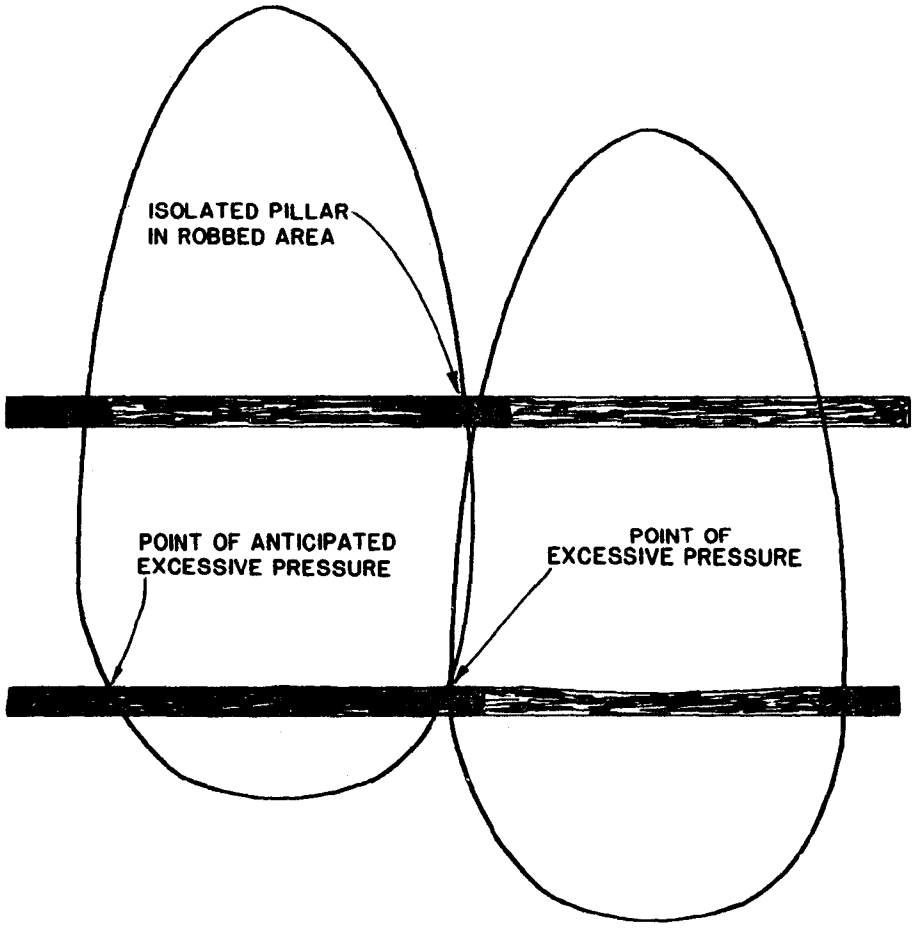


Figure 10 - Cumulative Effect of Stress.
(modified from Stemple, 1956).

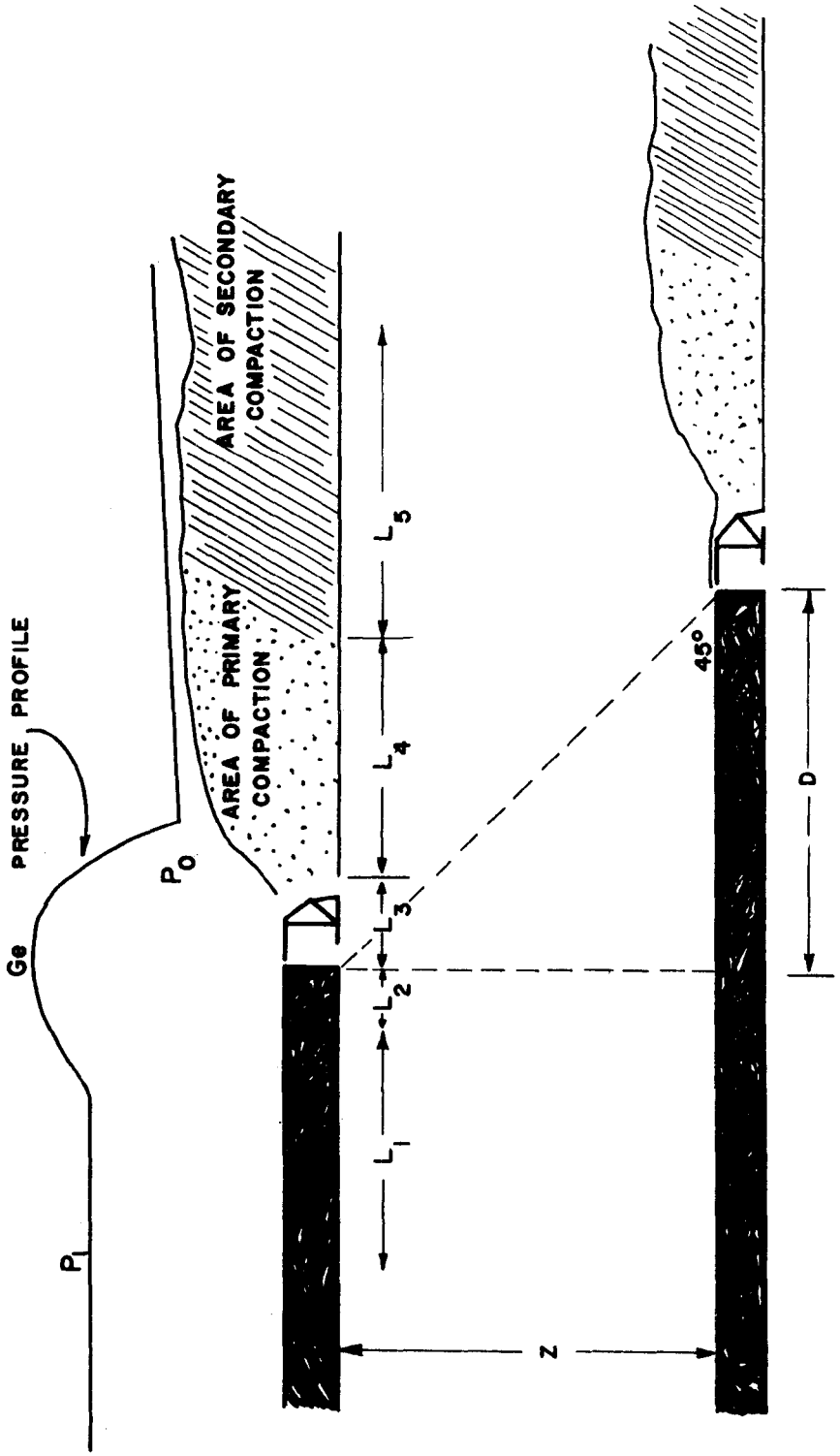


Figure 11 - Zones of Influence.

(Based on Unrug, 1980).

Hence, if the parting is thick enough, then the influence limit may not reach the lower seam. However, the distance D is the minimum distance the lower seam should be behind the upper seam advance. If the parting is less than the influence limit, then pressures will cause poor roof conditions. Figure 11 also illustrates a series of zones L_1 to L_5 defined as:

L_1: zone of the seam not influenced by mining, as it is located ahead of mining and stresses here are equal to the primary overburden stresses

L_2: disturbed zone along the mining front, where exploitation pressures (G_e) due to excavation are encountered

L_3: zone of exposed roof, whose distance is determined by backfill or caving methods and the support system applied

L_4: zone of gradually compacting gob or backfill, where roof support is not yet complete because the gob material reaction is less than the primary stress which will later grow from P_o (point of lowest stress) to P_1

L_5: zone of compacted material, where full support exists similar to that as before mining.

Whenever the roof is weak, the lengths of zones L_3 and L_4 are relatively small due to immediate caving and quick secondary compaction, consequently the exploitation pressure G_e is moderate. In competent rock zones L_3 and L_4 are large in that caving is slower, leading to slower primary compaction and higher stresses. Generally when two adjacent seams are mined with an adequate advance of one beyond the other so as to avoid mutual influence of the mining faces, then the advanced mining face will have normal conditions and the lagging face will have lower exploitation pressure regardless of the relative positions of the seams.

2.4 Multiple-Seam Subsidence Effects

Subsidence is always of concern when mining, and the subject becomes of greater concern when mining multiple seams in that the additive subsidence effects must be considered. Research in the area of subsidence history and prediction has been somewhat limited in the United States but extensively conducted in Europe (Great Britain, West Germany, Belgium) where subsidence experience is almost entirely the result of multiple seams. The degree of subsidence is dependent upon the mining method used. For example, complete extraction by longwall methods removes the problem of continued subsidence and a degree of uncertainty as to the extent which exists with room-and-

pillar mining due to its slow yielding pillars (Bise, 1980).

When discussing subsidence effects, there are several basic areas of concern:

- Lost property value due to uncertain stability
- Damage to buildings
- Surface damage to farmland from ground movement
- Coal lost in place so as to prevent subsidence.

The lost coal is not usually emphasized, but the coal company can suffer damage by having to leave coal and thereby loose money (Bise, 1980). Coal may also need to be left if prime farmland, gas wells, or aquifers are present.

Subsidence, or surface collapse, is caused by excavation of minerals by underground mining methods, and this activity forms a "trough" or depression. The extent of surface subsidence depends on the extent of mining and on the thickness of the coal seam. Maximum subsidence occurs when a minimum width of seam has been removed. This is called the critical width. Larger extractions are called supercritical, while smaller widths are termed subcritical. The terminology is illustrated in Figure 12. The surface area affected by excavation is usually larger than the seam area excavated as shown by the line extending from the edge of excavation to the surface point of zero vertical displacement, thus defining the angle of draw. This line is a function of the geologic strata and fracturing.

Experience in Great Britain where 90 percent of coal production is the result of longwall mining and where multiple-seam operations are common, has shown subsidence to be 45 percent of the coal seam height with partial packing and about 90 percent of the coal seam height when caving is practiced. The relationship of calculated subsidence for a given coal thickness is proportional to the extraction width and depth of the coal seam, as shown in the following equation for longwall conditions, when extraction is below the critical width, and where maximum subsidence is expected to occur.

$$\frac{S}{M} = f\ (\frac{W}{H})$$

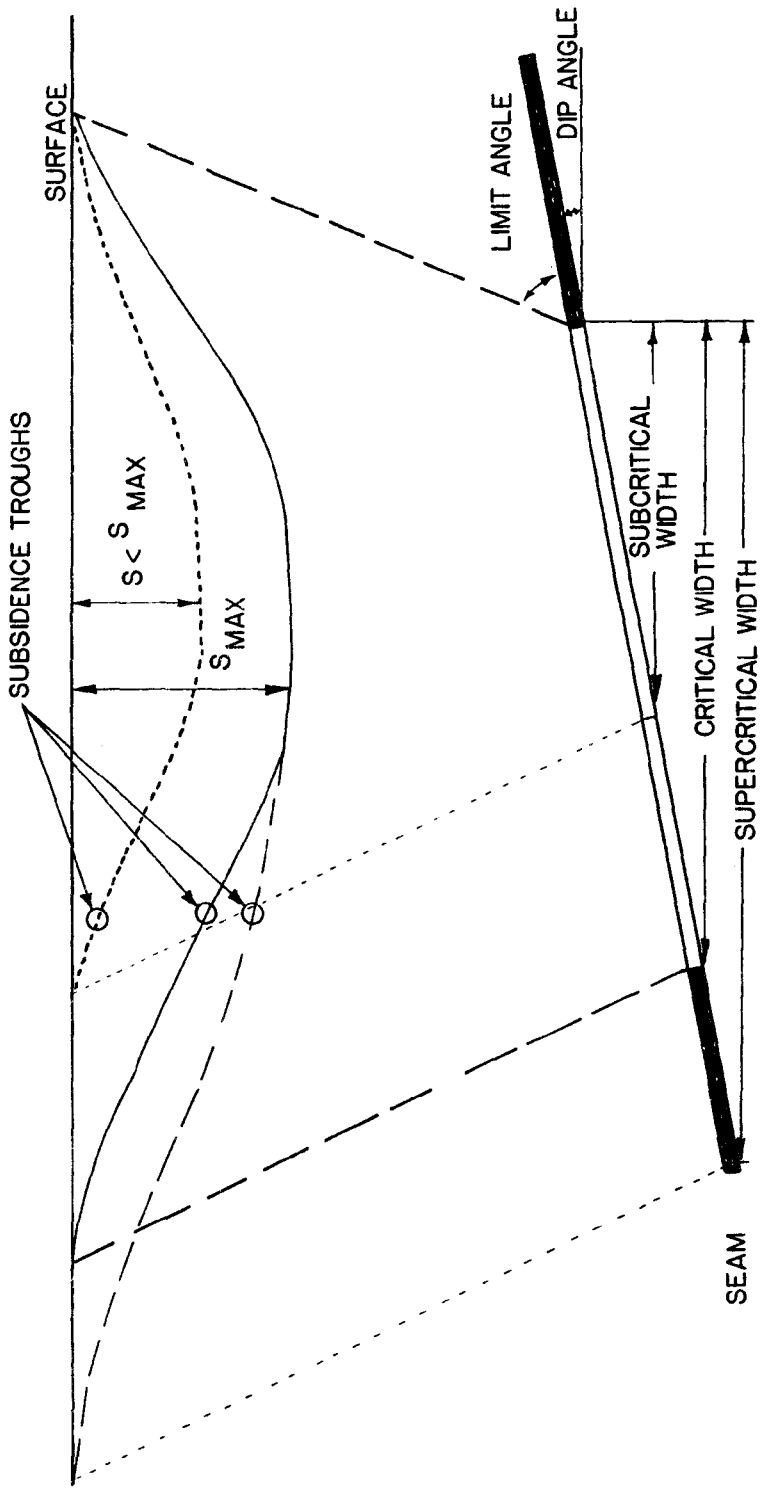


Figure 12 - Subsidence Terminology (after Singh, 1978)

S = Calculated subsidence

M = Coal seam thickness

W = Extraction width

H = Depth to coal seam

Obviously maximum subsidence can only equal the coal seam thickness. Excavation beyond the critical width will always create maximum subsidence and the above relationship does not apply.

According to Kohli and Peng (1980) subsidence observed in the Appalachian region is somewhat less than that predicted by British estimation methods. They feel the difference lies in the longwall panel layouts and in geologic conditions.

Another way to cope with subsidence is as in West Germany's Sophia Jacoba mine where subsidence compensation to property owners amounts to over 5 million dollars per year. Mining is under densely populated areas and a bonus plan is being implemented by paying individuals who will incorporate special steel foundation reinforcement in new construction (Harrold, 1979).

Foundations for new construction can be designed to be either flexible or rigid in order to reduce distortion caused by ground movement. The foundation is kept in contact with the ground as subsidence progresses. Usually a 6-in. layer of compacted sand is laid on the bedrock and covered by building paper to separate the sand from the reinforced concrete slab poured on top. The finished foundation is level with the ground surface. The sand layer minimizes the strain transmitted from the ground to the concrete slab and the sand takes the shape of the deformed ground. The structure above ground should be very light so as to deflect and follow vertical ground movement.

Rigid structures permit the structure to span the subsidence area by using heavy structural elements that sustain high shear forces and moments. Releveling jacks are installed at critical points in the foundation so as to keep the structure horizontal. Long buildings may be separated into smaller units by a 2-inch gap extending into the foundation so as to reduce strain on the overall structure. Generally the long axis of the building should parallel the subsidence contour lines so as to induce uniform strain on the structure (Singh, 1978).

Because of the relatively recent introduction of multiple-seam mining in the United States little subsidence history exists for such cases. Our experience may differ somewhat from foreign experience in that our mining methods and geology differ. In this country, the economics of mining certain properties or sections over others dominates other considerations because of our private enterprise system. Further, if the coal seams which lie above or below a seam being worked are operated by different companies, complications may arise in the coordination of the work in the various seams.

3.0 MINING ABOVE A PREVIOUSLY - WORKED SEAM (OVERMINING)

3.1 Overburden

For this overmining investigation the mines visited included Peabody's Camp No. 11, Camp No. 2, and Republic Steel's No. 4 mine among others. The data for this part of the study came from 21 mines. Here, overburden averages about 500 feet in depth and is composed of alluvium, sandstone, shale and limestone. Coal thickness generally ranges between 36 and 60 inches and the seams are essentially flat lying. Often the coal is overlain by prime farmland, or an aquifer, or is intersected by oil or gas wells, and special care is needed so as not to disturb the surface.

3.2 Roof, Floor, and Parting

Roof layers can be shale, sandstone combined with jointed limestone, or occasionally draw slate. The floor can be composed of sandstones, slate, or hard shales. Fireclay is also common, and is stable until wet, then it deteriorates. These same rocks compose the partings between coal seams, with partings ranging from ten to several hundreds of feet in thickness.

The study of mining problems associated with parting thickness shows that they are similar for thicknesses less than 180 feet. Partings greater than this will have little influence on the mining of multiple seams (Stemple, 1956). A generalized stratigraphic section is presented in Figure 13.

3.3 Mining

The decision to mine above a worked-out area may frequently be due to the location of the best quality or the thickest coal seam as the lower seam. Mining is predominantly room-and-pillar with 4 to 7 main entries, generally 18 ft in width and on 60-ft centers; and 3 to 5 panel entries up to 25 ft wide on 80-ft centers, and upto 2,500 ft long. Columnization of pillars in successive coal seams is not always practiced, although full superposition of entries and columnization of pillars is common.

Time lapse from the extraction of the bottom seam to the start of mining the top seam may vary from 2 to 30 years depending on market demand. A typical mining plan appears in Figure 14. Mines can be either shaft or slope entry, depending on the depth of overburden.

Extraction varies from 45 to 90 percent depending on the degree of subsidence prevention neccesary. Wider pillars are needed to prevent damage if the surface is prime farmland,

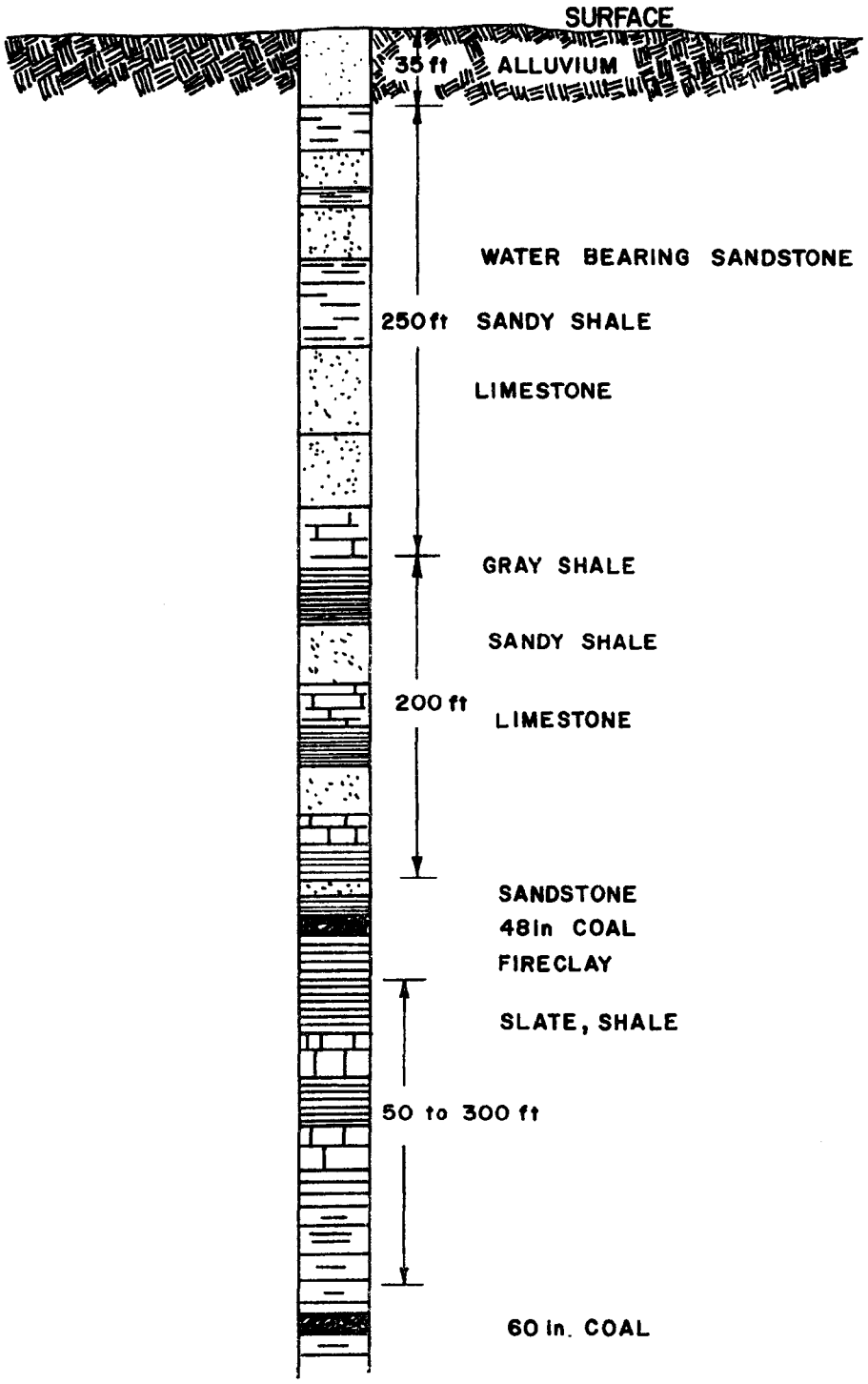


Figure 13- Generalized Stratigraphic Section of Overmining

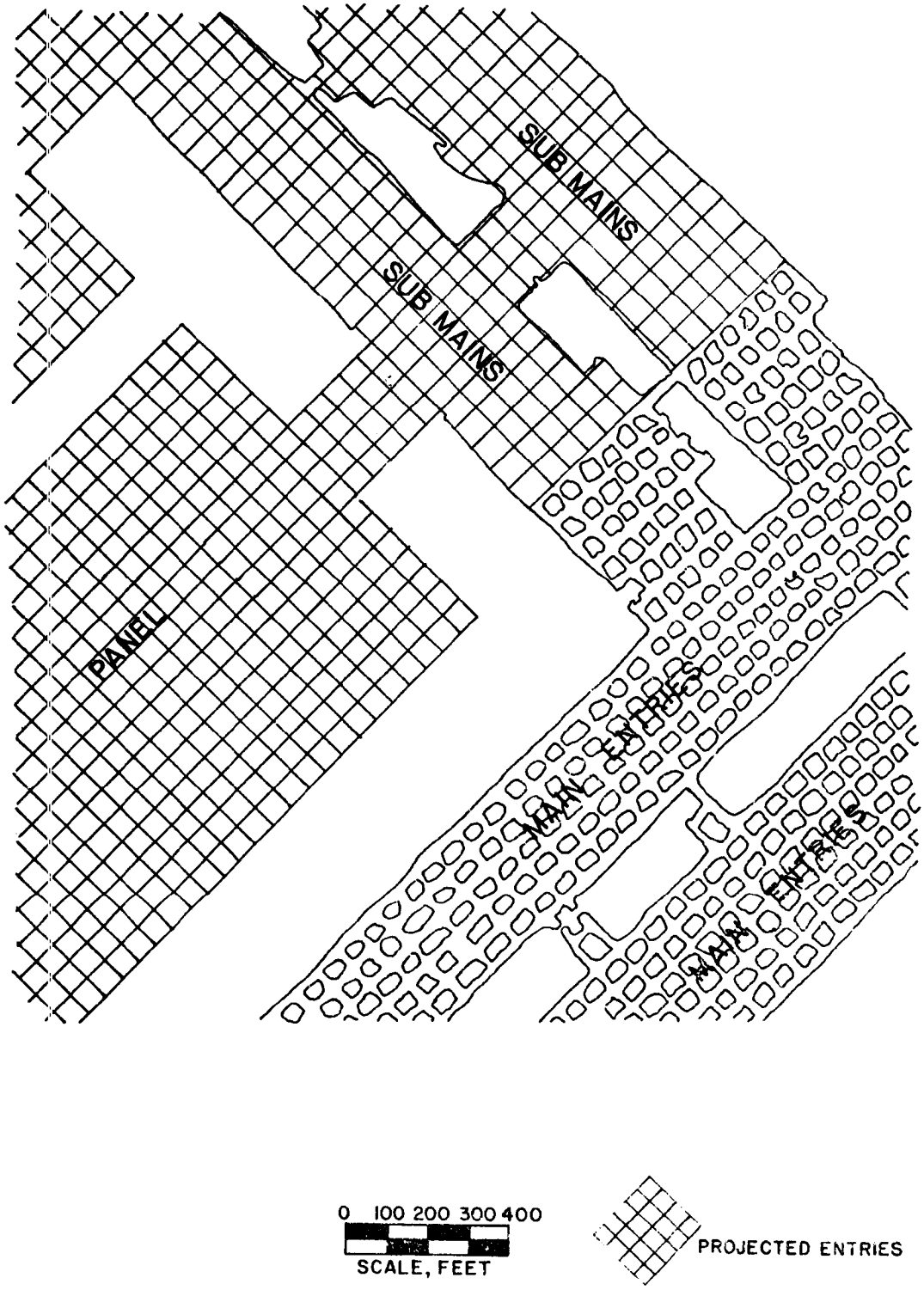


Figure 14 - Typical Mine Plan for Top Seam in Over Mining

or if a gas-field exists in the area. An aquifer present in the rock strata above also dictates that extra care be taken to prevent subsidence.

Longwall methods will be discussed in a later section. For conventional room-and-pillar mining, however, many techniques have been tried both intentionally and unintentionally with varying success. Overmining operations can include the following options:

- Develop the lower seam first
- Develop and pillar the lower seam completely
- Develop and columnize the pillars in each seam
- Completely mine the lower seam and then the upper seam after allowing time for subsidence

3.4 Problems

Data from numerous overmining operations have been examined, and associated problems have been recognized in order to determine if any given set of problems can be linked to particular sets of conditions. This examination showed that the same problems exist but vary in degree, depending upon the parting thickness between coal seams. From a knowledge of past experience, successful operations are possible even with narrow partings of 10 feet if conditons permit. Unfortunately, incorrect techniques were often employed resulting in the sterilization of considerable quantities of coal. Parting thicknesses greater than 180 ft did not usually interfere with the mining of the upper seam if prior mining of the lower seam was done with care. Also 25 ft will permit mining the upper seam provided the lower bed is less than 8-ft thick (Holland, 1951). In Appalachia, the Redstone coal seam has been successfully mined over the Pittsburgh seam with parting thicknesses of 19 ft. The parting is composed of competent limestone and superposition of entries was practiced (Eavenson, 1923).

3.4.1 Geologic Problems

If the lower seam is developed but pillars are left to support the upper seam, then the lower seam workings which remain idle and open for long periods will be subject to roof falls and caving. In addition, these pillars induce

stresses through the parting to the seam above and have some effect on conditions even if the parting is 200 ft or more. The top seam reacts to these stresses resulting in cracking of the roof and floor. The upper seam excavation directly above the lower seam pillars will most likely squeeze, and bumps can occur in the floor. These conditions have forced the abandonment of mining in these areas. If, on the other hand, pillars in the lower seam have been extracted below workings in the upper seam, excessive roof falls can occur, especially near rolls in the upper seam (Stemple, 1956).

Successful operations have completely mined the bottom seam and waited for periods varying from months to many years before mining the upper seam. During this time, which is dependent on the nature of the parting, the ground should settle toward stability. The upper seam may become slightly fractured, but extraction has not been difficult. Optimum lag time is learned by experience, however two years in most cases has proved adequate. Occasionally a time lapse of 15 to 20 years was practiced, but this was due to market and capital cost problems rather than strata instability.

3.4.2 Hydrologic Problems

The presence of water in a mine can have a significant effect on mining necessitating water control systems and equipment that can operate in wet floor conditions. The absence of water can indicate that heavy fracturing has taken place in both the coal seam and the rock strata beneath facilitating the drainage of water. Cracks up to 3 in. wide have been reported, and sometimes they can be readily filled with pulverized rock during mining. If water cannot be drained off, it can have a detrimental impact, creating a muddy floor and adversely affecting haulage.

Most often the floor material is fireclay or slate which may be firm when dry but deteriorates quickly when exposed to water. Wet floor can cause sinking of pillars and promote crushing, spalling, and floor heave. In overmining, water percolating through cracks in the upper seam can have these effects on the lower seam and thus further causing poor mining conditions in the upper seam. This then reinforces the need for pillaring the lower seam first so that water will not create additional problems.

3.4.3 Roof Support

Roof support is another area that is highly dependent on planning and foresight when mining multiple coal seams.

Because of the high probability of roof fracturing, roof bolting or other support will be more extensive in the upper seam even if pillaring of the lower seam was done systematically, so as to achieve uniform subsidence. Columnization of pillars in the main entries aids roof support although this is difficult to achieve and cannot always be accomplished if equipment for mining each seam is of different size. If pillars are not completely under each other, the existing over- or underhang promotes shearing of the pillars which reduces their effectiveness. The advantage of columnization is that it helps to keep the main haulageways open. The thicker the underlying coal seam, the more severe may be the rock behavior upon extraction because of higher extraction pressure and cantilever action. Areas of disturbance occur where coal may be left, such as at the property line. A shear zone is then created from this point and angles upward to the superjacent seam. Disturbance is then caused by the overlying strata being supported by the remaining lower coal, but being allowed to collapse over the gob.

To aid the stability of thin partings (i.e. < 8 ft.), only the best quality coal is mined (Stemple, 1956).

3.4.4 Impact on Future Mining

The handling and occurrence of many of the problems discussed can have a strong impact on future mining possibilities ranging from no effect to that of possibly losing the entire coal seam in the area. It should be noted that in many cases where problems were severe, it was because several operating companies were involved, each mining a different seam. Usually, there was no coordination or cooperation between the companies which often led to a permanent injunction against mining, leading to the abandonment of many acres of coal.

As discussed earlier, fracturing of the parting and upper coal seams is common and of varying degree. Cracks leading to the surface can permit the entrance of surface water causing inrushes that can affect rock stability and mining performance. Another prevalent characteristic resulting from overmining is the time lag necessary for rock settlement. This is the time period between the pillaring of the lower seam to when development begins in the upper seam. This time can vary from as little as 3 months to as much as 15 years; but 2 years is common. The optimum time lag is dependent upon the nature of rock strata.

Future mining of the uppermost seam will result in less recovery if prime farmland, gas wells, or inhabited structures exist in the area. In these and similar instances, subsidence cannot be permitted to occur, so larger pillars need to be left in place. This restriction, however, would also apply in the case of single-seam mining.

4.0 MINING BELOW A PREVIOUSLY-WORKED SEAM (UNDERMINING)

4.1 Overburden

In Appalachia, typically, overburden thickness for undermining conditions ranges from 300 to 2,300 feet. The material is predominantly shale with interlying sandstone beds and some sandy shales and fireclays. Coal thickness generally ranges from 48 to 61 inches and the seams are generally flat lying. Judging from the amount of overburden it becomes obvious that undermining is practiced because the top seam is more readily minable or of better coal quality. Mines from which data were collected included Island Creek's Fies No. 9 and 11 mines, Hamilton 1 and 2 mines, Bishop Coal Company's Bishop Mine, and Consolidated Coal Company's Jenkinjones mine. In all, 23 mines were studied for this section.

4.2 Roof, Floor, and Partings

The immediate roof is generally composed of slate having varying degrees of strength, with sandstones and sandy shale and occasionally jointed limestone or strong shale. The immediate floor is mostly soft to firm shale with some fireclay and sandstone. Partings are composed of this same material in varying degrees of thickness from as little as 20 feet to as much as 350 feet. Mining problems are basically the same for any thickness less than 150 feet (Stemple, 1956). Parting thickness in undermining conditions, however, is not as much related to problems encountered as is the total thickness of overburden. Narrow partings and large overburden can cause a limited extraction ratio to be achieved because of the greater stresses imposed by the overburden weight. A generalized stratigraphic section is presented in Figure 15.

4.3 Mining

Undermining is generally practiced when the top coal seam is thicker, of better quality, or has easier access. Mining is predominantly room-and-pillar with 6 to 10 main entries, 16- to 30-feet wide and on 50- to 70-foot centers. Panel entries number up to 6, with rooms up to 72 feet on center and 36 feet wide. Main barrier pillars range from 120 to 200 feet in thickness and are frequently superposed. Time lapse from the extraction of the top seam to the start of mining of the bottom seam may vary considerably, but the passage of time has not shown to minimize the disturbance of strata and, therefore, presents little advantage. As with overmining methods, access can be by either slope or shaft, depending on overburden depth. With undermining, the means

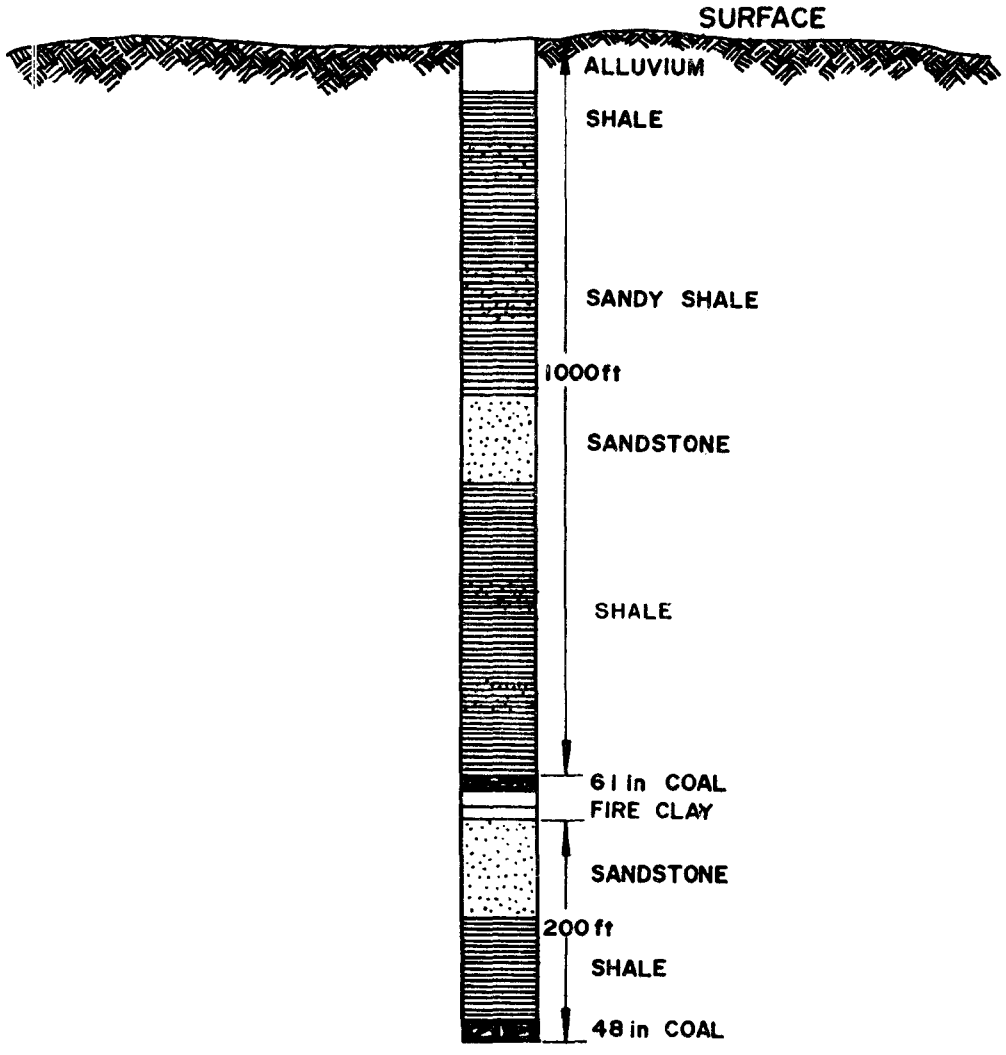


Figure 15 - Generalized Stratigraphic Section in Undermining.

of access must be extended to the bottom seam. The typical plan view would be similar to Figure 14.

Extraction ratio varies from 60 to 90 percent depending on strata and mining operations. For coventional room-and-pillar mining, many variations in operation exist. Mining below a worked-out seam provides the following options:

- Develop the top seam first, then the lower
- Both develop and mine pillars in the top seam first
- Develop and columnize the pillars in each seam
- Develop and partially recover the top seam, leaving enough coal to support overburden; then develop and mine pillars in the lower seam.

From the available mine data it appears that undermining operations are generally larger than the overmining operations. There are more work entries and panel entries for more crews and possibly for the dilution of larger amounts of gas released. Working below a prior-mined seam permits the gas to migrate into the void above.

4.4 Problems

Data from several undermining operations have been examined and associated problems have been recognized in order to determine if any given set of problems can be linked to different sets of conditions. Problems in undermining operations depend upon the amount of overburden, the nature of the strata, and the parting thickness. Other problems may be dependent upon haphazard removal of coal by randomly leaving remnant pillars in the upper seam. Successful operations have dealt with partings as thin as 20 feet. Partings greater than 150 feet generally have less effect on mining conditions unless the overburden is considerable. Overall, however, with the top seam mined first the threat of inundation is great, a condition that is ever present in undermining situations.

4.4.1 Geologic Problems

The geologic problems are dependent on the nature of the partings, roof, and floor of the lower seam. The

severity of the resultant condition is dependent upon how the mining of the upper seam was done. For example, if pillars are left in the upper seam, stresses are transmitted through the strata to the subjacent seam. If the top strata fracture to the degree where they cannot support themselves, the stress imposed by them is increased accordingly.

As previously mentioned, the nature of the roof and floor greatly influence the kinds of problems that result from undermining. A hard roof and soft floor in the upper seam coupled with a strong floor in the lower seam will create complete roof failure and pillar squeezing in the bottom seam. If pillars are left in the top seam, overburden pressure may be transmitted by the roof onto pillars which would not fail due to the heaving of the soft floor. The pressure can only be relieved by the failure of the lower coal seam and roof, since the strong floor is not likely to heave. This problem is compounded with an overburden greater than 300 feet. On the other hand, if the bottom seam floor is soft, heaving will result but will not greatly affect coal recovery (Zachar, 1952). Experience in these conditions was obtained by mining the Pittsburgh seam under the mined Sewickley seam in West Virginia. Most often damage has occurred in parting intervals of 20 to 110 feet, and failure occurred in the roof or floor depending on which was weaker. In some instances coal may have to be abandoned or require extensive roof support for recovery. Oddly enough, time allowed between the mining of seams for strata stabilization has little influence, probably due to the combined effects of overburden and parting.

4.4.2 Hydrologic Problems

Water build up in the superjacent coal seam is always a potential hazard with undermining conditions. Water can either percolate continually through the intervening strata to the bottom seam or it can collect in the worked out top seam and then inundate the bottom seam with disastrous results. As noted for overmining conditions water will percolate to the bottom seam creating dry conditions in the upper seam albeit possibly worsening conditions below. With undermining, water will continually be a problem unless the parting is several hundred feet thick, where operations under these conditions seldom have had water problems. In any type of coal mining, wet roof or floor will cause structural difficulties. A clay floor when wet can expand and create heaves which can impair haulageways. One operation when threatened with inundation, drilled a hole into the seam above which allowed water to be drained at a controlled rate ahead of pillaring.

4.4.3 Roof Support

Many of the techniques desirable for better roof support in overmining conditions apply equally well to undermining. Mining history has shown columnization attempted in varying degrees but mostly with partings of 35 to 90 feet. Superimposing main entries is more common. However it cannot be ascertained how well columnization was practiced because it is difficult to accurately determine pillar placement, and if not done correctly, can be of no help. Generally, columnization has been helpful although the extraction ratio has not been higher as a consequence. In one instance a room in the lower seam was driven under every other room in the upper seam in order to achieve better roof support. As much as 40 percent of lower seam coal has been left in place to prevent strata breakage and possible flooding (Stemple, 1956). It appears that fracturing of coal and parting is more likely with undermining because stress release occurs in the form of strata fracturing, pillar squeezing, or floor heaving. This then leads one to expect that if coal is obtainable, roof support will most likely be more extensive than with overmining. This may be necessary to combat the same problems that affect overmining, but the problems can become more severe if not dealt with in an adequate manner. The problems of operation are definitely compounded with water inflow and increased depth, when mining the bottom seam.

4.4.4 Impact on Future Mining

It has been shown that severe stresses exist close to pillar lines and can be transmitted to underlying strata through standing pillars. The amount of fracturing is dependent upon overburden strata thickness; if too thick, this can cause the sterilization of large amounts of coal. Roof control is a major obstacle to mining the bottom seam. This is again dependent upon parting thickness and nature of rock. Columnization can help extraction and if cognizance of the potential problems is realized, undermining can be successful. The problems outlined are more severe with less than 50 feet of parting, and gradually decreased with increased parting thickness up to 150 feet. Beyond this thickness few problems exist unless circumstances are unique. And unlike overmining, time delay between mining coal seams is of little advantage, which indicates that coal recovery in the lower seam can take place more readily after upper-seam mining is complete.

5.0 SIMULTANEOUS MINING

5.1 Overburden

Simultanous mining operations in the Appalachian region generally have overburden thicknesses between 75 feet and 1,000 feet. Occasionally the thickness will vary by this amount at a single operation. The overburden is composed predominantly of sandstones shales and fireclay. Coal thickness is between 30 and 73 inches and the seams are generally flat lying. Access to coal seams can be either by shaft or slope, with the seams most often numbering two to three. This part of the study included 10 mining operations.

5.2 Roof, Floor, and Parting

Roof layers are usually shale, draw slate, or sandstone that can be strong or fractured. Floor is generally composed of shale or sandy shale, and fireclay. These rocks also composed the parting material which can be from 60 to over 300 feet in thickness. The parting thickness has a considerable bearing on problems at thicknesses below 165 feet (Hasler, 1951). Larger partings are associated with fewer problems because seam interaction is reduced, but for simultaneous mining many factors need to be considered in that simultaneous mining can take one of two forms. Simultaneous mining can be either in an overmining mode or an undermining mode, and the problems associated with each are different. Simultaneous mining in the undermining mode refers to the top seam advancing ahead of the bottom seam, while the overmining mode implies that the lower seam is advanced ahead of the upper seam. A generalized stratigraphic section appears in Figure 16.

5.3 Mining

Simultaneous mining has several inherent advantages from the outset. The biggest advantage is that it permits the mining of a marginal-quality coal seam by blending it with a high quality seam above or below. Common practice for operation is room-and-pillar with each seam being treated as a separate mine, that is, each seam has its own ventilation, pumping system, and production facilities, but may have a common slope or shaft. Surface facilities could also be common to both seams. The mine layout has 5 to 7 main entries at 50-foot centers and 20 feet in width. Rooms are 20 feet in width with pillars of 70 x 70 feet. Columnization may be practiced in varying degrees, or not at all. For example, main entries and panel barriers may be

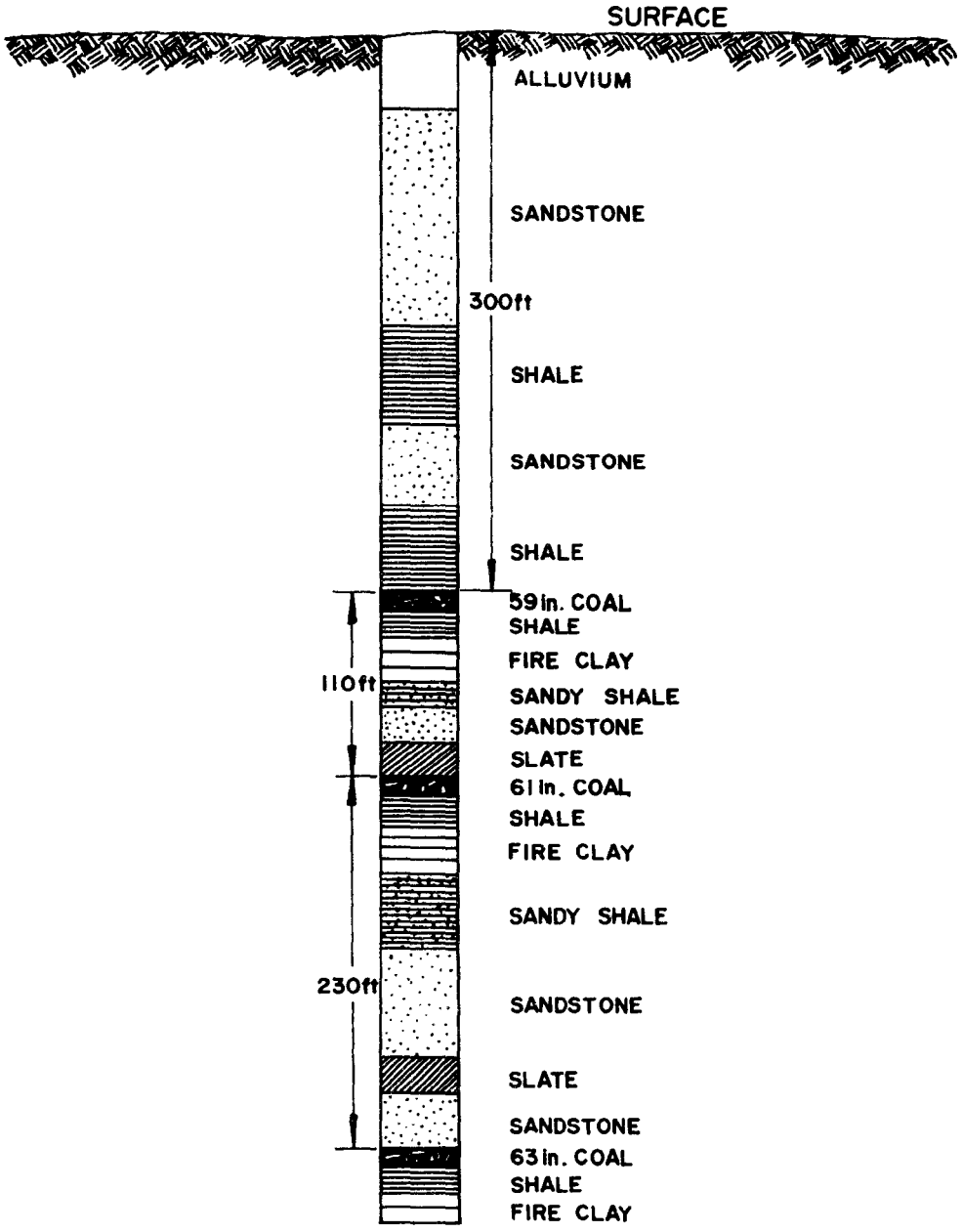


Figure 16 - Generalized Stratigraphic Section in Simultaneous Mining

columnized but this is not always successful with narrow partings, and close proximity of mining faces. Operations not columnizing pillars can still be successful. The time lapse of extracting one seam after another ranged from 6 months to several years. Differences of seam advance are usually 100 to 150 feet and is governed by economics and market demand (Stemple, 1956). As previously discussed, the amount of advance should be equal to, or exceed, the depth of influence between coal seams. In most instances of simultaneous mining the upper seam was kept in advance. There are no cases where several seams are advanced at the same rate.

The extraction ratio varied from 60 to 90 percent for all sequence of seams mined, and remained nearly uniform for all seams mined on a given property. Average extraction was about 77 percent.

As mentioned, room-and-pillar mining for simultaneous operations can be undermined or overmined. Overlying seams have not been mined directly over each other, but are preceded by a time lapse.

The rates of mining coal seams simultaneously is highly dependent upon coal quality for mixing and on market conditions. From the data gathered it appears that the undermining mode of simultaneous mining is most common. This may be due to the fact that the upper seam is thicker or of better quality coal and therefore, is advanced first. Access and investment recovery is quicker because coal is closer to the surface.

5.4 Problems

Due to the variety of geologic conditions and mining techniques it is difficult to correlate problems and successes since they are site specific. Each mining situation is unique; a successful method at one mine may prove inefficient at another. As for other modes of mining, parting and overburden thickness, and nature of strata influence the success of the mining operation. It is safe to say that problems for simultaneous mining are similar to those for overmining and undermining, but may be compounded when these methods are practiced at the same operation.

5.4.1 Geologic Problems

Geologic problems are site specific in that strata can range from laminated shale to thick, competent sandstone. Problems are compounded when overburden thickness is substantial. Lag time between the mining of two seams

is critical from two viewpoints: coal mixing and rock stability. The time may need to be lengthened in order to allow for strata settlement, but this may not be possible due to coal quality demands. One cause of interference with production is the existence of want areas, which are local disturbances where coal is not present due to washouts, squeezes, or rolls. These areas may be geologically replaced by sand or clay, neither of which offer much support. If the strata are competent enough no interaction should occur between seams, but case studies substantiating this are rare. As a rule extraction of pillars in the lower bed can cause damage in the upper bed if parting thickness is less than 165 feet. Pillaring in the upper bed can cause floor heave in the lower seam if parting thickness is less than 45 feet (Hasler, 1951). The damage may be in the form of coal squeezing or bumping, which can lead to abandoning the coal. Remedying this condition implies leaving more coal for support. Since the problems are complex, extra care is needed in the mine planning stage; consideration should give to geologic conditons. There are several instances where simultaneous mining was halted in favor of overmining due to severe interreaction of coal seams.

5.4.2 Hydrologic Problems

Because of the increased potential of strata subsidence and cracking from simultaneous mining the danger of water inflow to the bottom seam may be a hazard. However, water buildup in the upper seam should not occur as in undermining, since the water percolates to the bottom seam rather than be impounded. At worst, the pumping system for the lower seam needs to be of larger capacity. On the other hand, the top seam could remain relatively dry so that equipment could operate better and the floor could remain more stable. Case studies do not indicate that water is a problem.

5.4.3 Roof Support

Roof control problems can become complicated with simultaneous mining. Pillar recovery in the lower seam can cause settlement in the floor of the upper seam and loosen timbers (Stemple, 1956). Caving may be postponed by using roof bolts, at added expense. Extra stress could be induced in roof bolts, causing them to fail, if their spacing is too wide. Depth of coal is critical; excessive rock pressures can prevent successful roof bolting. This would be an important factor in future mine operations, when mining at greater depths will be more common. Columnization has been tried with varying success. It is used more extensively in simultaneous mining than in over- or undermining.

Depending on conditions, main entries, submains, and panels may be superposed. Panel barriers may also be columnized. Columnization and superposition of workings is best when parting thickness is relatively small (Stemple, 1956).

In the past the mining industry believed that subsidence could be entirely avoided if large pillars of coal were left in place. Passage of time, however, has proved that pot-holes develop on the surface above the areas excavated between pillars. Now the occurrence of subsidence has become accepted and it is realized that uniform subsidence will do less damage and is more desirable. Studies of subsidence from old mines have shown that sinkholes occur with diameters up to three-quarters of the width of the entries below. One study of sinkholes resulting from mining of the Pittsburgh seam in West Virginia states that they are caused by weak remnant pillars, surrounded by stronger pillars, which crush under the overburden loads after long periods of time; or they can be caused by strata falling out and filling the excavated area between pillars. Sinkholes can occur even where the overburden is greater than several hundred feet (Gray, 1977).

5.4.4 Impact on Future Mining

Simultaneous mining, by its very nature, tends to take advantage of many coal seams in the area. Resource recovery is more efficient, since poor quality seams that would not otherwise be mined can be mixed with a good quality seam and still meet market demands. However, mining must be done with care or else large amounts of coal will have to be abandoned due to resulting problems. Overall, recovery appears to be slightly higher than with undermining or overmining. The economic conditions, however, are examined later, in Section 8 of this task. The effects of simultaneous mining are dependent upon the degree of cooperation between mining companies, if several are active in the same area. With no cooperation it is certain that large amounts of coal will be lost, possibly along with considerable subsidence.

6.0 FOREIGN EXPERIENCE

Europe has been mining coal longer than the United States, and has less coal resources. As a result, the more readily minable seams in Europe have been depleted causing present mining to take place under much more overburden than that occurring in the United States. Because of the past extent of mining, the interaction of new and old workings is practically unavoidable, and every coal face may be expected to interact with another seam at least once during its working life (King, 1972). Consequently European experience in dealing with multiple-seam mining is extensive. However, this experience in the U.S. is complicated by a legacy of indiscriminate extraction, that has been left for present and future operators to contend with, and which hinders efforts to optimize mine layouts and efficiency (Spedding, 1976). The bulk of available literature in English deals with operations in the United Kingdom and West Germany. Considerable experience exists in both these countries. Poland also has resulted in much multiple-seam experience, although there is little information in English. Although multiple-seam mining is conducted in France, Belgium, Holland, India, USSR, China, and other countries, the experience is similar to that for United Kingdom, West Germany and Poland. Hence only these are discussed here.

6.1 United Kingdom

In the United Kingdom, conditions are favorable for longwall mining in that roof and floor strata are not strong, and depth generally exceeds 900 feet and can reach 3,800 feet. Generally conditions consist of a moderately strong mudstone roof underlain by a stronger coal seam which, in turn, is underlain by a weak mudstone. The result is that the strata pressure is high very close to the longwall face line. These pressures have been measured and lie 3 to 6 feet ahead of the face. As a consequence shearing machines are used rather than plows, and mining performance is slightly hindered as a result (Whittaker and Pye, 1975).

A British longwall face may be between 165 to 1,000 feet long, and travels 2,400 to 3,000 feet during its life (Whittaker and Pye, 1975). The extracted region behind the longwall is allowed to cave; stowing is rarely done. For multiple seams roadways are driven under gobs where a destressed zone exists. It is believed that vertical pressure on an extracted region can return to cover load pressure only if the width of the extraction to height of strata (overburden) ratio if greater than 1.2 to 1.4. Consequently completely destressed areas are only achieved with this ratio. Figure 17 shows the effect of the width-to-height ratio on the pressure arch.

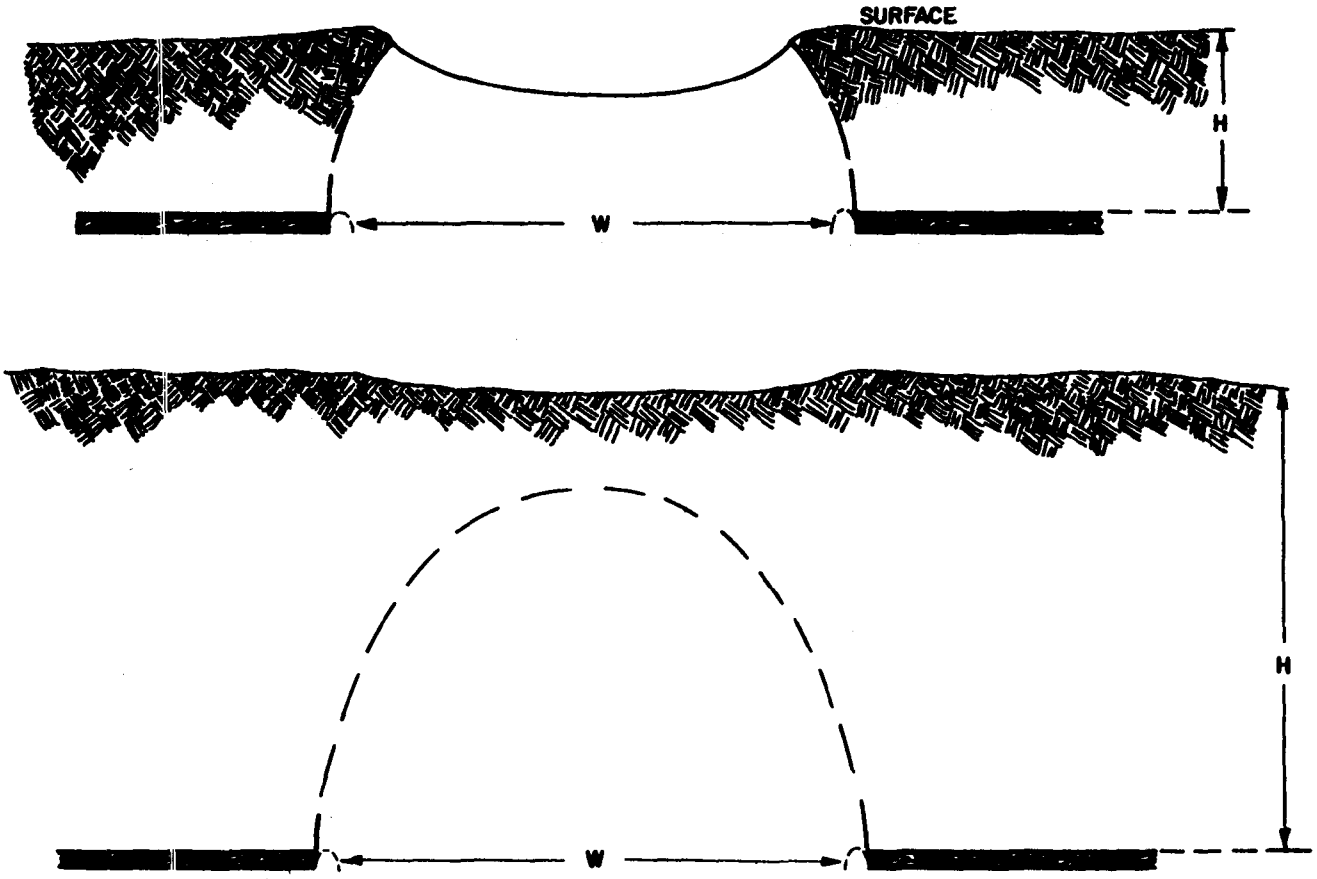


Figure 17 - Influence of W/H Ratio On The Pressure Arch (after Whittaker and Pye, 1975).

Conventional development methods for longwall extraction are to drive two or more entries, whereupon flank faces are taken as shown in Figure 18. These methods have proven successful for providing stability in entries in shallow to moderately deep conditions of less than 1500 feet. However, in deep mines the method is wasteful of reserves in that substantial pillar widths are needed between the entries and flank faces. Also, high stresses occur in the isolated pillars created for service roadways, causing interaction problems and entry instability in the areas the pillars are supposed to protect.

British experience with the advancing longwall method is extensive, since high pressures because of depth prohibit retreating techniques. The development entries necessary cannot be kept open for the time interval needed to mine the panel, since they are driven first along the entire length of the panel.

Additionally, the advancing method is versatile enough to be successful under a variety of geologic conditions. Several methods are used for developing panels for longwall faces, which are illustrated in Figure 19. Figure 19a is limited to shallow workings of less than 1,000 feet or where coal thickness is less than 38 inches. In deep workings, gate problems occur because of roof deterioration from rib shear fracturing and floor heave due to pillar loads on the floor shale. To reduce rib fracturing the gate entries can be offset by 6 feet towards the waste as in Figure 19b, where packwalls are built for added support. This creates even floor lift which does not greatly hinder mining efficiency but the method is labor intensive. Figure 19c permits maximum rates of advance, while separate roof drivages give long-term stability to roadways. Gate roadways are driven ahead of the coal face and yieldable arches are erected behind the face in the gob area before complete caving is allowed. For maximum stability these drivages should be 180 feet behind the face and 60 feet inside of the gate roadways, based on past experience. This method is used when long-term stability is needed and where high strata pressures in weak strata formations have a deterimental effect on roadways (Whittaker and Pye, 1975).

Conventional advancing longwall is illustrated in panels in Figure 20. Experience indicates that in order to protect gate roadways against deformation, the distance between panels should be the length of the panel divided by 10. If simultaneous working of panels is practiced this rule is only

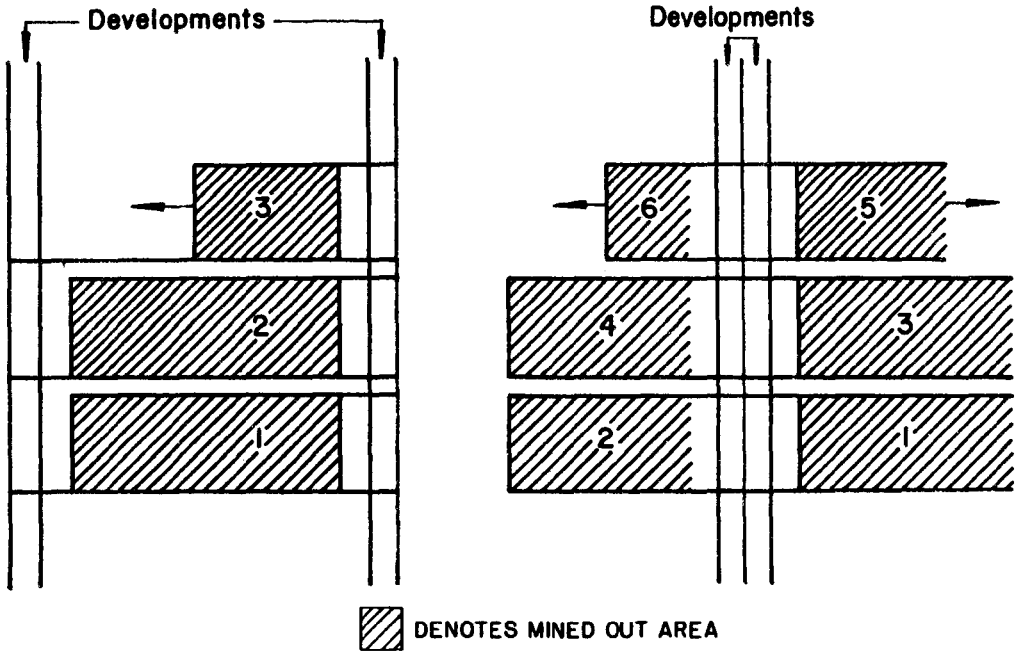


Figure 18 - Double- and Triple-Entry Development for Longwall Extraction (after Whittaker and Pye, 1975).

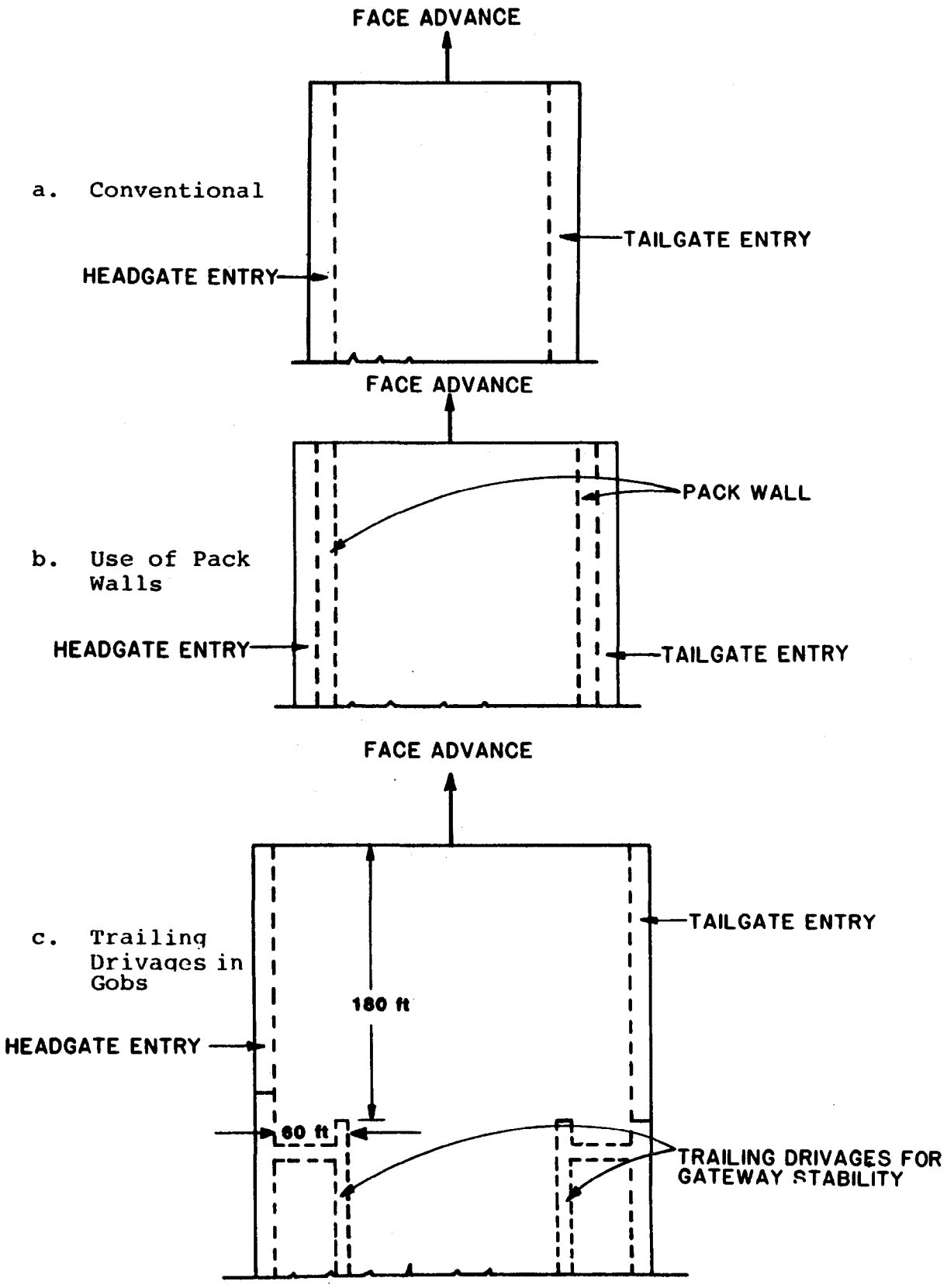


Figure 19 - Longwall Development Panels (after Whittaker and Pye, 1975).

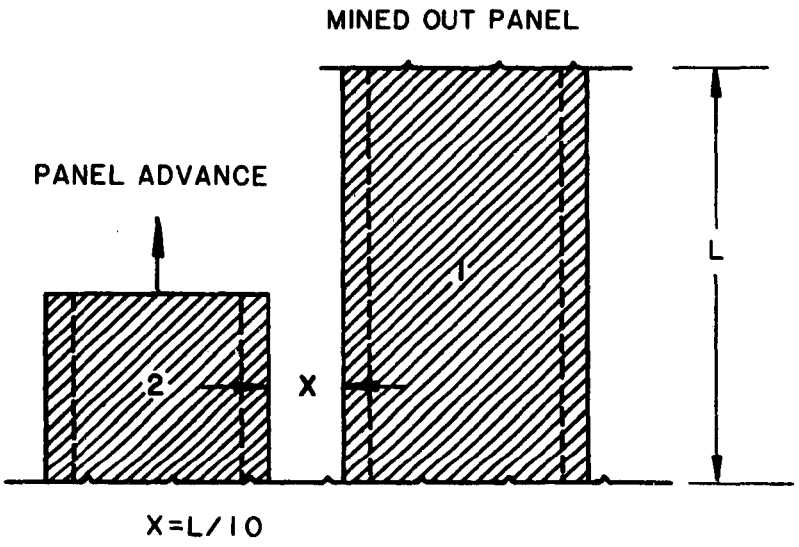


Figure 20 - Conventional Advancing Longwall (After Whittaker and Pye, 1975).

valid for lengths up to 1800 feet. Roadway closure occurs due to the yielding of rib pillars if the distance between panels is 10 to 65 feet (Whittaker and Pye, 1975).

The multiple-seam interaction discussed is evident in partings up to 450 feet and can be classified into three types:

1. Stress fields due to old or current workings
2. Active strata displacement in workings from other current workings
3. Changes produced by current workings upon old workings.

To help eliminate these interactions, often pillars in successively descending seams are increased in size to ensure that roadways are below gob areas (Dunham, 1978). In order to plan for multiple-seam interaction it is beneficial to have mine maps of old workings available for study. Mine plans have been a requirement in the United Kingdom since 1911, thus enabling present mine operators to have fairly accurate knowledge of old workings that can affect mines today. Principal maps required are a five-year development plan, a layout plan, and a working-face development plan, as shown in Figure 21. The five-year plan outlines mining strategy that is the most effective and efficient. The plan takes into account known restraints and obstacles such as mine boundaries and geologic conditions. The layout plan outlines the best means of achieving good operational results, and is basically a document of instruction that follows statutory requirements and company policy. The working-face development plan details the requirements for mining a face. This plan includes a detailed method of working, equipment to be used, roof support, etc.

All these plans are the result of collective discussions between management and engineers. Any future addition or corrections must be approved by designated people in charge, and these changes are made known throughout management. Assigned areas of responsibility and system of required discussion and approval help to avoid judgment error and assure successful control over mining as well as problems that may arise. New face-end systems are being developed to increase longwall production and improve safety (Fennelly, 1980).

6.2 West Germany

The Ruhr, Saar and Aachen coalfields of West Germany are relatively more complex than those in the United States. In some areas 60 to 80 minable seams exist, the mining sequence being determined by strata control problems. Working conditions are complex becuase of changing dip, excessive faulting, and changing coal quality. The surface

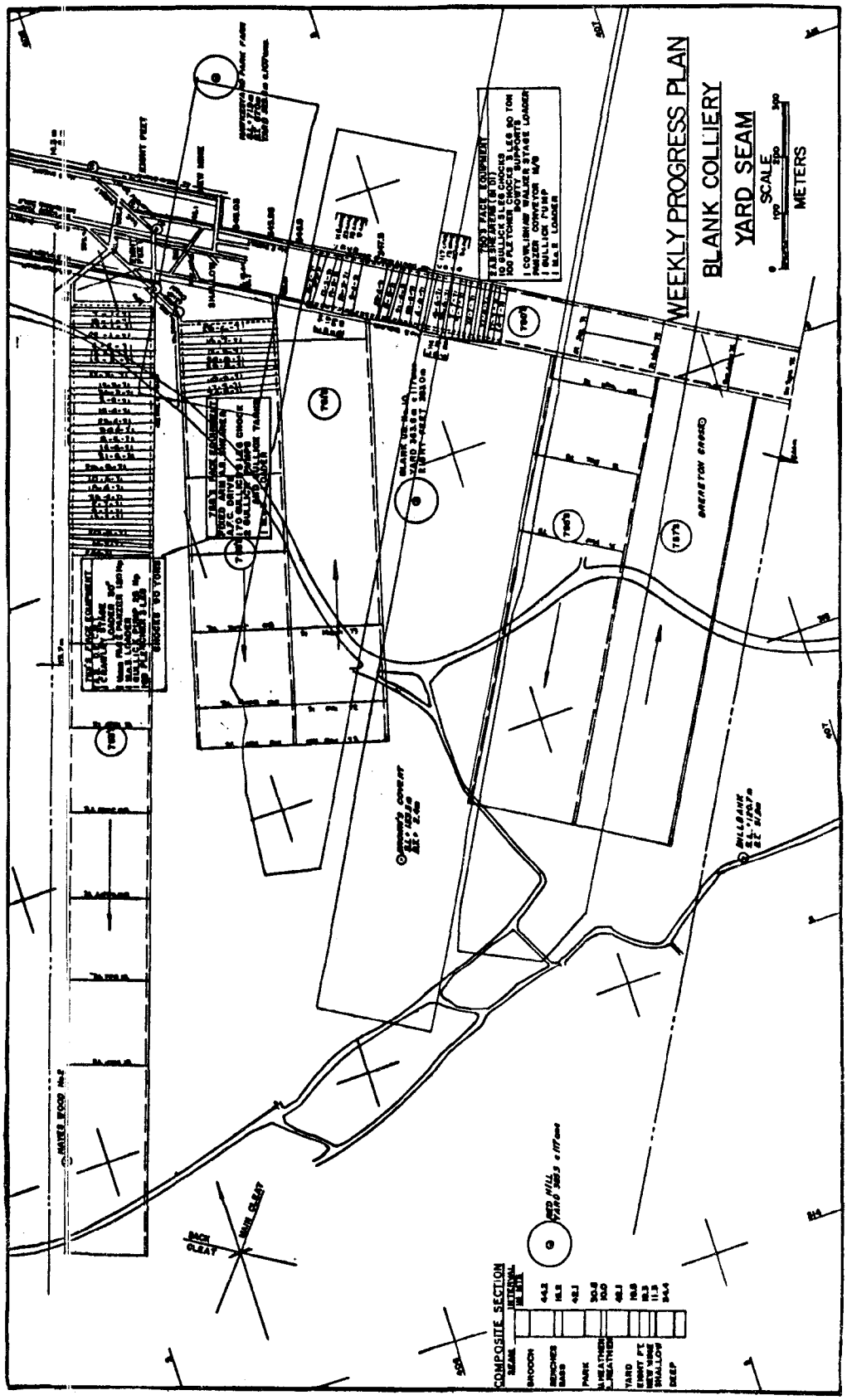


Figure 21 - Typical Development Plan for a British Coal Mine

is often heavily populated and uniform, and controlled subsidence is demanded, hence the leaving of pillars is avoided. To produce these conditions high productivity is needed. All underground production is the result of longwall operations. Average mining depth is about 2,600 feet, and panels are of short length due to the frequency of fault zones and the difficulty of maintaining long entries because of excessive pressures (Klaer, 1972).

When compared to conditions in the United Kingdom, coal in West Germany is softer and is bounded by a hard roof and floor, creating stress areas up to 30 feet behind the face. As a result a plow system is used which produces better coal sizes upon cutting.

Generally an advance system of mining is used because of increased productivity although a retreat system is used when possible due to a faster face advance results in saving two weeks over the life of the panel. Thus overall costs are reduced by about 10 percent. In order to achieve success good roadways are important. These are mostly supported by arches, with timber accounting for 20 percent of the support. Roadways are arched whenever the following conditions exist (Schliesing, 1974):

- Seam thickness is less than 4 feet
- Where roof falls occur during drivage
- Where the floor is soft and base plates find no resistance
- Where there is a lack of plain partings in the roof.

Figure 22 illustrates the conventional longwall retreat method. Experience has demonstrated that between panels a 12-foot barrier is necessary to be stable, although its thickness does not greatly affect roadway conditions on the right-hand side of the advancing face 2 provided an arched profile is used. The left-hand gate, looking at the face, is not affected by strata pressure interacting with the working of face 1 (Whittaker and Pye, 1975).

Single-entry longwall systems are being developed in Europe based on the success of the double-entry system in order to improve ground control, ventilation, resource recovery, and development cost savings. However, because of regulations, the system is only being tried in the United States on an experimental basis

Over the years a Strata Control System (Jacobi, 1980) has been developed in West Germany. This system helps to predict strata behavior at greater depth and under new conditions, this was not possible hithertofore. Considerable new face technology has also been developed lately (Kundel, 1980; Benthaus and Schuesmann, 1980).

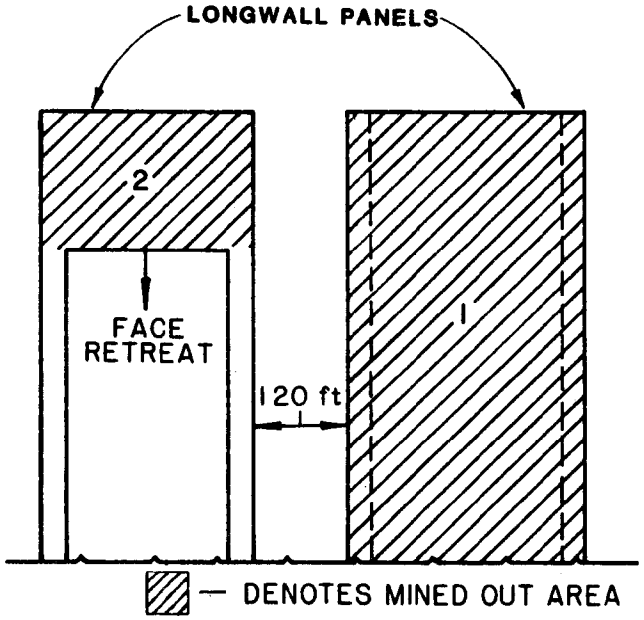


Figure 22 - Conventional Longwall Retreat (after Whittaker and Pye, 1975).

6.3 Poland

European experience also includes backfilling of the gob in order to aid in subsidence control by decreasing its severity. Hydraulic backfilling, effected by pumping sand slurry in the gob areas after mining, is practiced in about 30 percent of the underground coal mines in Poland. The technique is used if the surface must be protected and if sufficient sand deposits exist nearby. Coal mines in Poland average 10,000 tons per day at an average depth of 650 m Coal is a major export of Poland and high recover is stressed, consequently the upper coal seams with quicker access are exploited first. Often neighboring mines will share an access shaft to decrease development work by 40 percent. Simultaneous mining is commonly practiced, with production obtained from the upper seam as the lower seam is being developed. Where partings are less than 300 feet strict survey control is employed to achieve columnization for both advancing and retreating longwall systems.

To avoid future problems brought about by remnant pillars, a single-entry system is used which reduces the number of pillars. The single entry is shared for two adjoining panels thus increasing mining efficiency and enabling close to 100 percent extraction which can lower the possibility for unwanted differential subsidence (von Schonfeldt, 1980).

The industrial philosophy in Poland is different than in western countries in that Polish mines are more labor intensive. Longwall faces average 2000 tons per day and 3.2 tons per man-shift. Where hydraulic backfilling is practiced, 30 percent less output per man-shift can be expected.

Backfill packs up to 70 percent of the seam thickness. For best results, the following grain size mix is recommended:

10%	less than 0.1 mm
90%	between 0.1 to 2 mm
0-10%	between 2 to 40 mm

The sandfill process starts at the surface where sand is dumped into a hopper. It is then mixed with water to form a slurry which enters a basalt-lined pipe to the shaft. Coal refuse from the preparation plant is also incorporated in the sand mix. The slurry is transported to a series of nozzles at each longwall panel, as shown in Figure 23, where it is

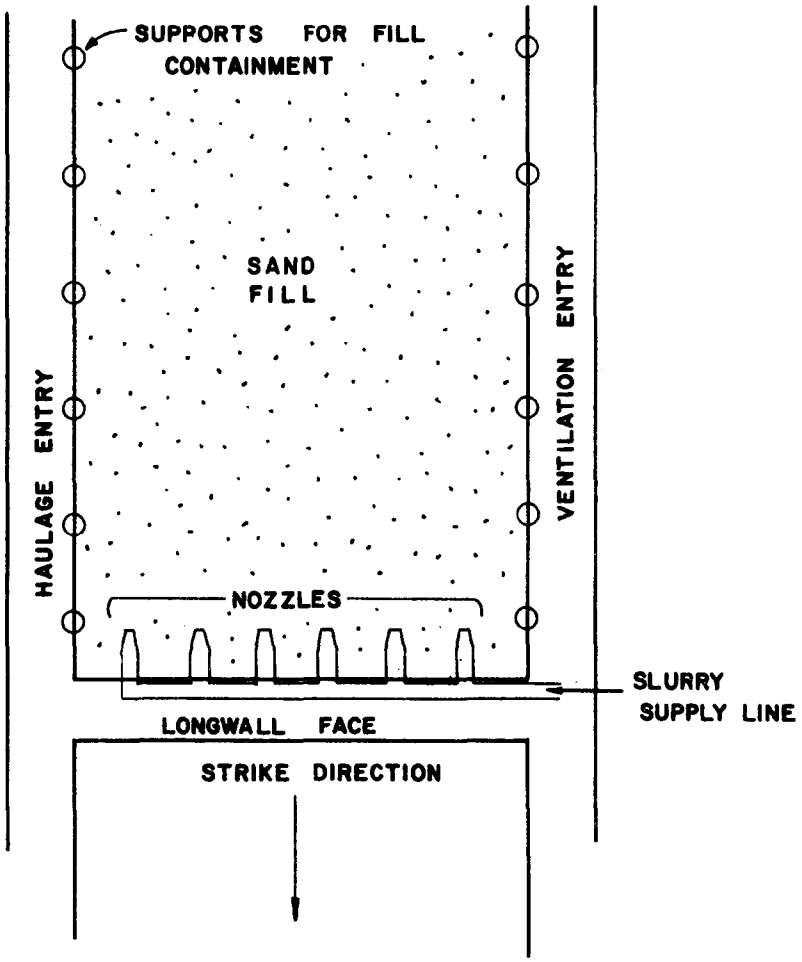


Figure 23 - Plan View of Polish Sand Stowing Technique

sprayed in the gob area just behind the working face. Posts and screens are used to contain the sand. The water flows out of the area as shown in Figure 24. The water then travels in a series of ditches and is brought to settling areas developed for this purpose in rock. After primary settlement, the water is pumped to the surface where it can be recycled. Provisions for the underground settling chambers are made to facilitate cleaning of sediment and to accomodate any possible inrushes of groundwater. The hydraulic sand-stowing process is very expensive even when sand is immediately available in the area. For these reasons its applicability in United States coal mines is doubtful.

The sand-stowing technique is primarily used to slow the rate of subsidence that occurs after mining. The sand fill gradually compacts from pressure buildup of overburden trying to fill the void created by mining. With 70 percent of the excavation backfilled subsidence cannot approach the total seam thickness. The presence of fill material prevents major strata falls and immediate subsidence. With longwall mining, subsidence occurs but is uniform throughout the large areas of extraction, as discussed earlier.

The advantages of backfilling are evident for multiple seams where subsidence from each seam is additive, provided that parting thickness is not too great. It is clear that if subsidence is reduced by half when backfilling is used, then twice as much seam height can be mined before total subsidence will equal that when backfilling is not practiced. Ventilation efficiency can also improve when backfilling is practiced. The compacted backfill in the gob areas will prevent air circulation there and thus keep fresh air coarsing through the face areas as intended, so that gas and dust can be diluted and carried out of the mining area faster. This also reduces ventilation costs.

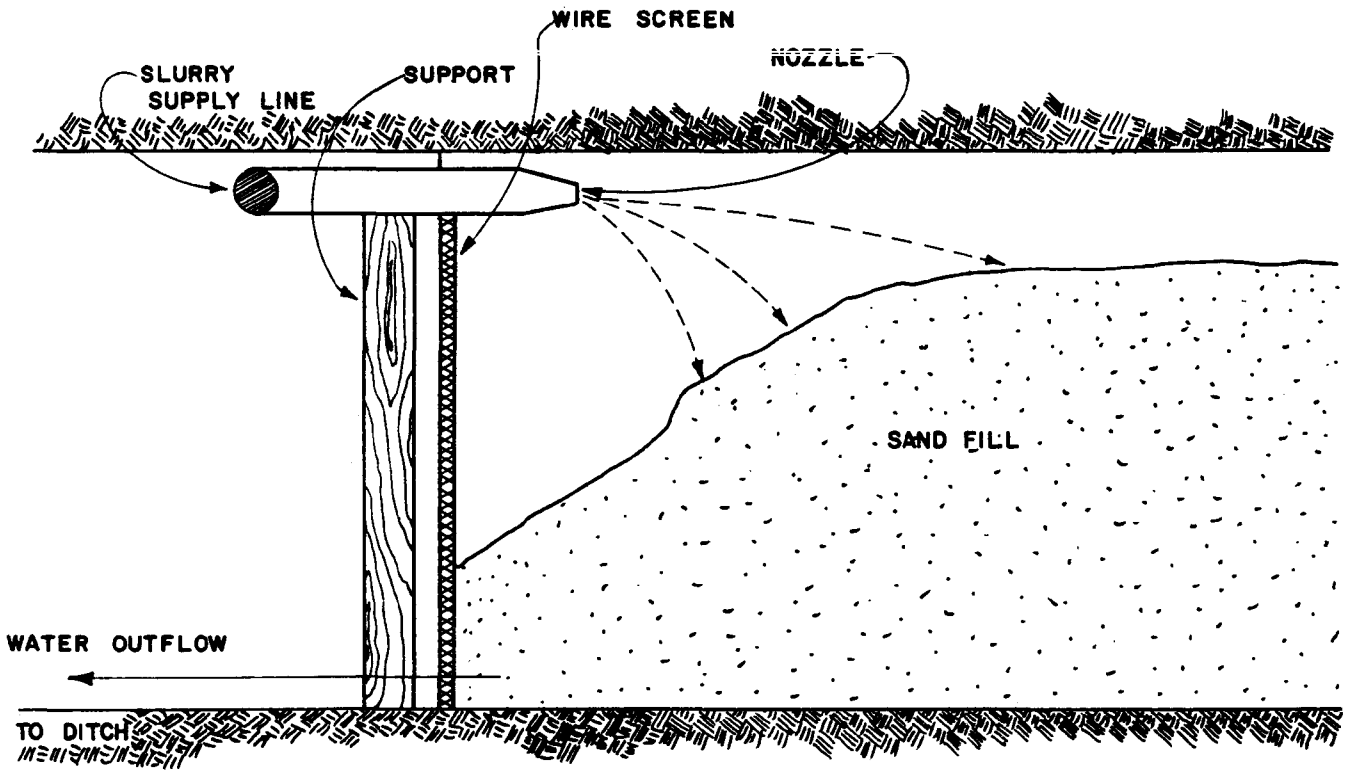


Figure 24 - Cross-Section of Polish Sand Stowing

7.0 LONGWALL MINING SUMMARY

Longwall mining in the United States is not widespread and few operations are conducted in multiple-seam conditions. In Appalachia, one large operation was studied, this being Consolidation Coal Company's Ireland Mine. It had one retreating longwall face with plans for further expansion. Current mining is over worked-out areas. Figure 25 illustrates a typical longwall retreat system as practiced in the United States. In the last 10 years longwall mining has grown from 13 faces to nearly 100 faces. A major advantage of the system is its high extraction ratio, even at great depths.

7.1 Geology

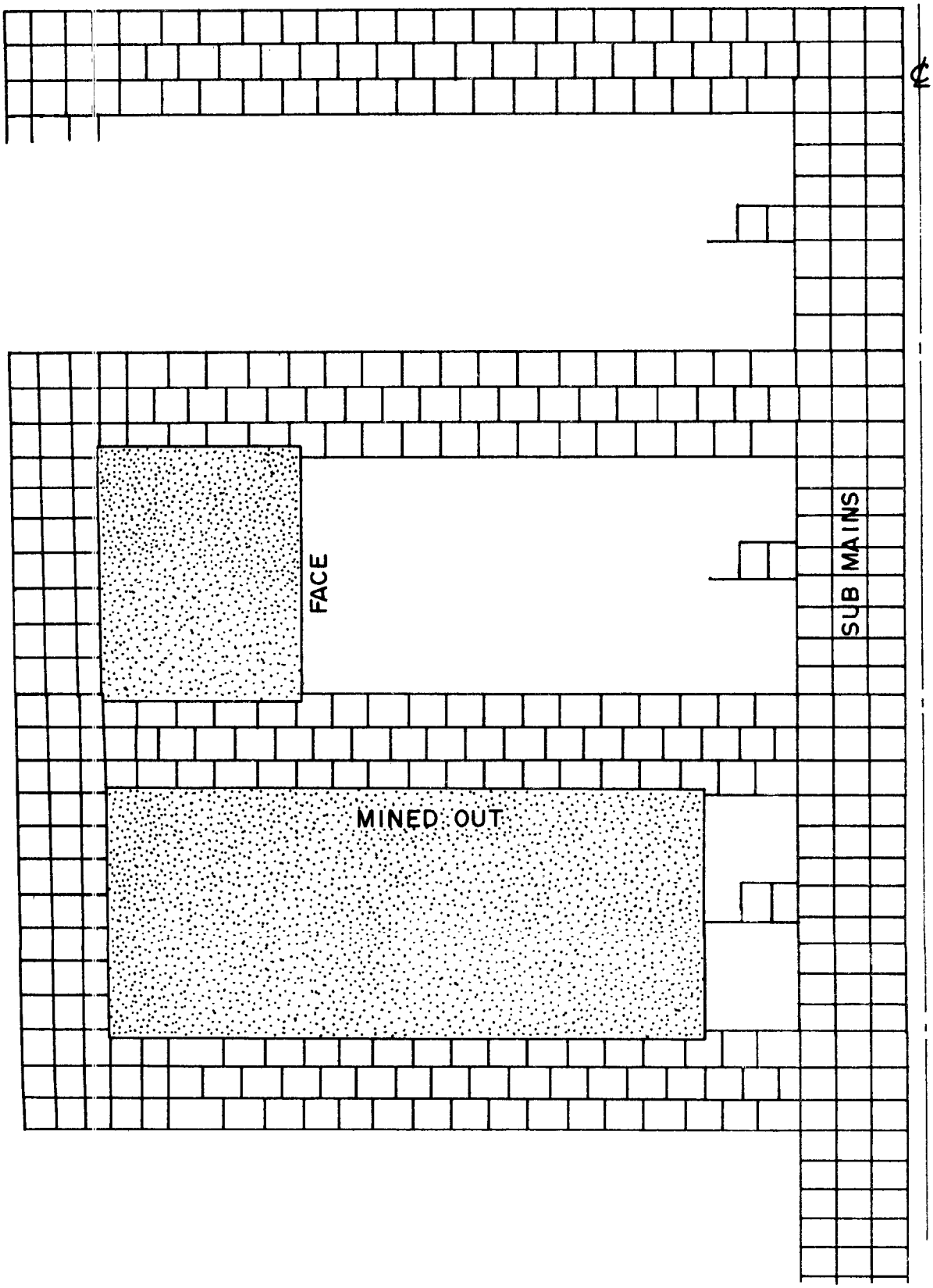
The coal seams average 5 to 6 feet thick and occur in multiple-bedded strata having bands of soft slate and hard veins of clay and shale. Overburden varies from 400 to 800 feet in thickness consisting of draw slate overlain by massive strong limestone. The floor consists of clay rock underlain by strong fireclay. The coal seams are level with occasional undulations.

7.2 Mining

The typical mine layout utilizes 10 main entries and 6 submain entries 16 feet wide and 80-foot centers. Butt panel entries are 90 degrees off the submain , using 4 entries on 120-foot centers for the headgate entry, 80-foot centers for the middle block, and 66-foot centers for the tailgate entry. Panels are 5400 feet deep with a face 440 feet long. Other systems used in the U. S. have variations in the size and number of panel entries.

7.3 Problems

The most urgent problem with longwall mining is the large amount of respirable dust generated by the shearing machines. The high production rates possible with longwall methods may also liberate large quantities of methane, which requires increased ventilation. This may necessitate more shafts to accomodate the air. The firm fireclay floor remains dry and permits excellent haulage. However the drawslate in the roof cannot be supported and therefore is mined during entry drivage. This drawslate band is not mined in longwalling and therefore rejects are reduced from 20 to 10 percent. Since the mainline haulage entries will be standing for 30 years, resin bolts are used for long-life roof support (Mason, 1979). Abandoned old workings below have had little influence on present mining and it does not appear that old workings are a major consideration for mine planning.



NO SCALE

Figure 25 - Typical Longwall Retreat System

Subsidence resulting from longwall mining occurs over a short time span, since there are no pillars which deteriorate over several years before subsidence is realized as with room-and-pillar methods.

For reasons of ventilation and means of escape, single-entry systems as practiced in Europe are not permitted under U. S. regulations. As discussed earlier, the remaining pillars needed for entry drivages can have a detrimental influence on future undermining, creating problems similar to those encountered in room-and-pillar operations.

Single-entry longwall is being tried at Kaiser's Sunnyside, UT, mine. A design for a single-entry is being prepared for a Jim Walter's mine in Alabama under a Bureau of Mines Contract (No. H0292015). Mid-Continent Resources has worked two panels using advancing longwalls with two entries on the headgate side and one on the tailgate end.

8.0 PRODUCTION PERFORMANCE

Based on the data collected during the mine visits and the literature review, it was possible to generalize many of the factors that measure the performance of mining multiple seams. Extraction ratios and output per man-shift are important measures of performance since they are greatly affected by mining conditions. Coal left in place for added roof support is reflected in a lower extraction ratio. Output per man-shift is an indicator of how difficult the conditions are when mining coal. Extra miners, needed for extensive roof support or roadway grading when bumps occur, lower the output per man-shift.

The data collected are presented in a series of graphs comparing the mining of both the top and bottom seams. Data from each mining operation are plotted and the data points are connected vertically to aid interpretation. In some instances the data points for both seams are coincident. Most graphs form a pigtail which reflects upon the nature of the parting, a significant factor in multiple-seam mining.

8.1 Extraction Ratio

8.1.1 Mining Above a Worked-Out Seam

Figure 26 illustrates in a general sense the relationship of percent extraction against parting thicknesses common in Appalachia which vary from a few feet to nearly 300 feet. Specific attention was given to the extraction in each of two individual seams; a situation that was most common in the study. As discussed, parting thickness is the common denominator for creating many of the structural problems that may be associated with mining above a worked zone. Generally, extraction is slightly greater in the lower seam which is taken first. As can be expected, the extraction ratio falls off as the parting is less or if the nature of the parting is weak. Obviously the nature of the rock is of more significance when the parting is thin than when it is over 200 feet, as seen in the graph.

One reason why extraction is less in the upper seam is that wider pillars will be needed to prevent subsidence if valuable land exists on the surface. Other causes for lower extraction are the fracturing of the upper seam and bumps created by pillars left in the lower seam. Intense fracturing can inhibit productivity and may lead to abandonment of an area if the conditions are too severe.

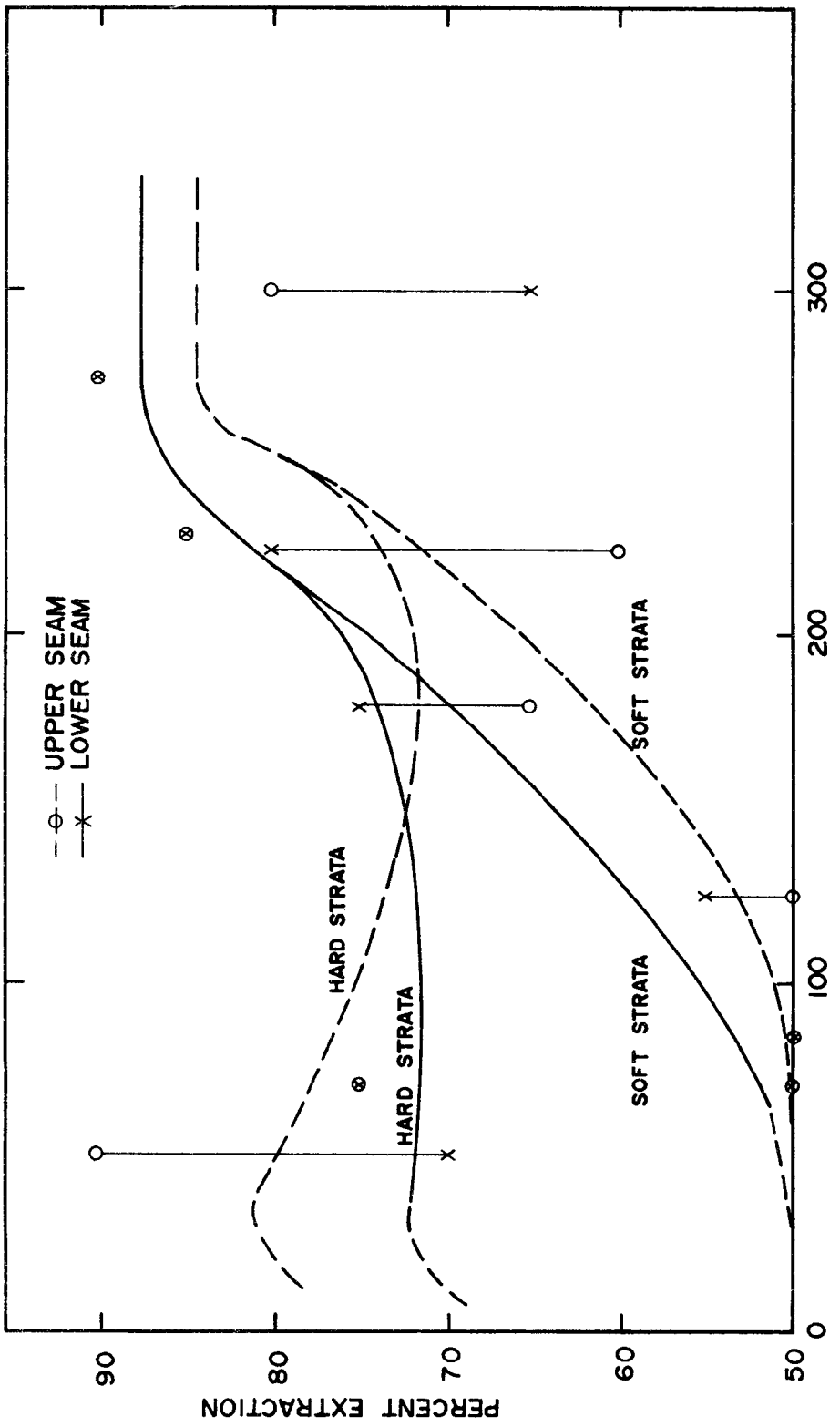


Figure 26 - Effect of Parting Thickness on Extraction When Mining Above a Worked-Out Seam.

8.1.2 Mining Below A Worked-Out Seam

Figure 27 depicts the effect of parting thickness on extraction ratio based upon past experience when mining below a worked area. The graph develops a pigtail which separates because of the influence of the nature of parting, i.e. hard and soft strata. Extraction is slightly higher in the lower seam which in this instance is mined second. Optimum extraction in hard strata occurs with partings of 50 to 200 feet. Beyond that the extra thickness adds greatly to the need for support due to added weight. Top seam extraction is lower because generally large parting thicknesses occur where heavy overburden exists and, as mentioned, the preservation of the surface is important when farmland, aquifers, or gas wells are present. Not only the parting, but the combination of parting and overburden are the primary concerns. If the overburden is thin and substantial pillars must be left, the stresses are transmitted to the bottom seam which adversely affect extraction. If more data were available they might indicate that the extraction ratio for larger partings may level off.

8.1.3 Simultaneous Mining

Simultaneous mining in either the overmining or undermining mode is practiced by keeping the faces within several hundred feet of each other. The parting thickness is an important parameter in that stress conditions will seldom be relieved due to strata settlement if mining faces are too close. Figure 28 shows how extraction relates to parting thickness for simultaneous mining. Unfortunately data for simultaneous mining do not exist for as many cases as for the overmining and undermining methods, but the data available clearly illustrate that with soft strata extraction in both top and bottom seams is relatively low. The extraction is affected nearly equally in both the seams, as demonstrated by the existence of a single set of curves.

It should be pointed out that simultaneous mining operations are conducted for the most part so as to enable blending of the coal to obtain a final desirable coal quality. Hence the extraction ratio is not only reduced due to reasons of roof support but is also affected by economic reasons--to achieve the coal mixing ratio desired. If a planned ratio of seam excavation is to be achieved, the extraction of two seams will reflect this goal. The advance of one seam cannot be permitted to get too far ahead of the other. For example, with two seams of equal thickness, each

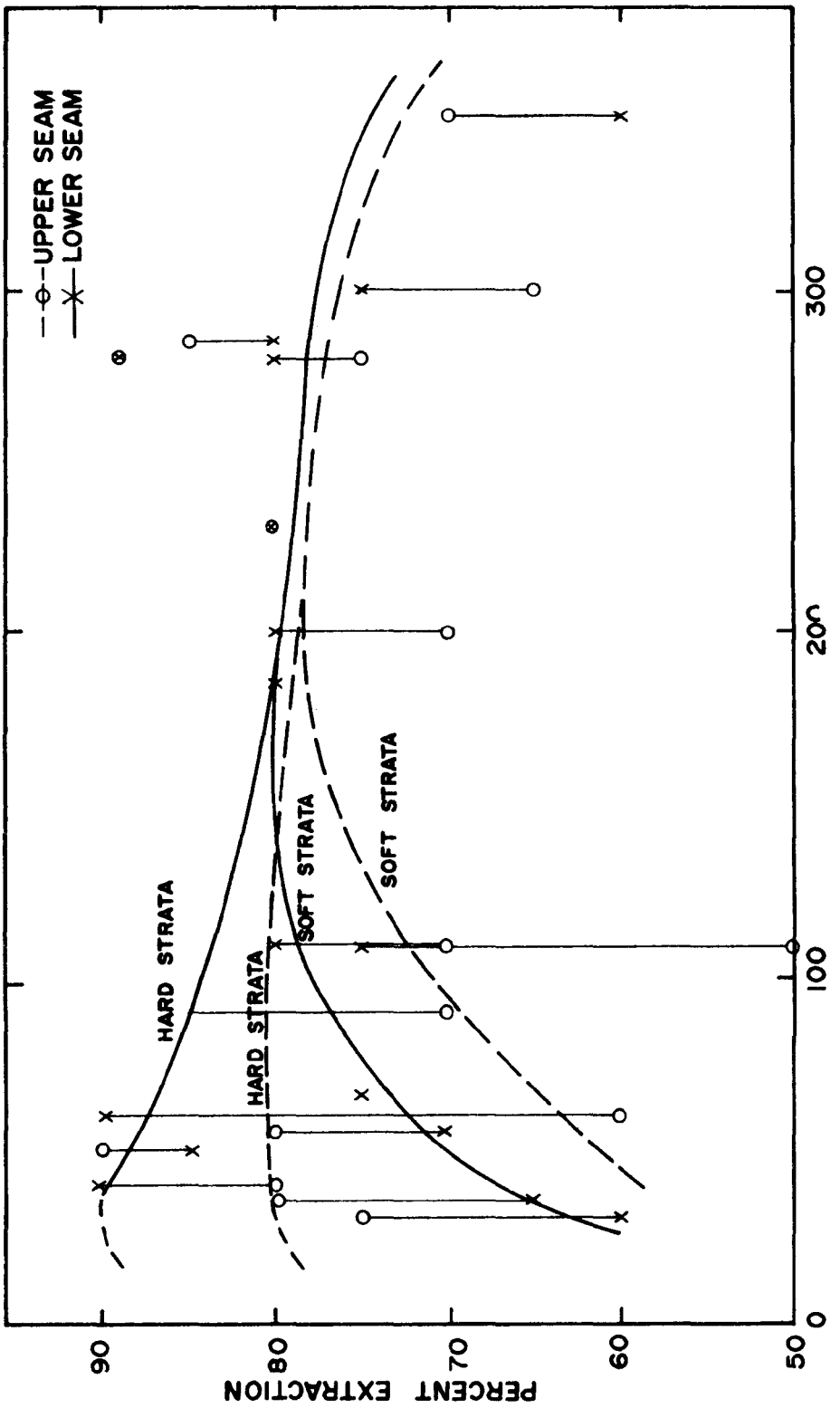


Figure 27 - Effect of Parting Thickness on Extraction When Mining Below a Worked Seam.

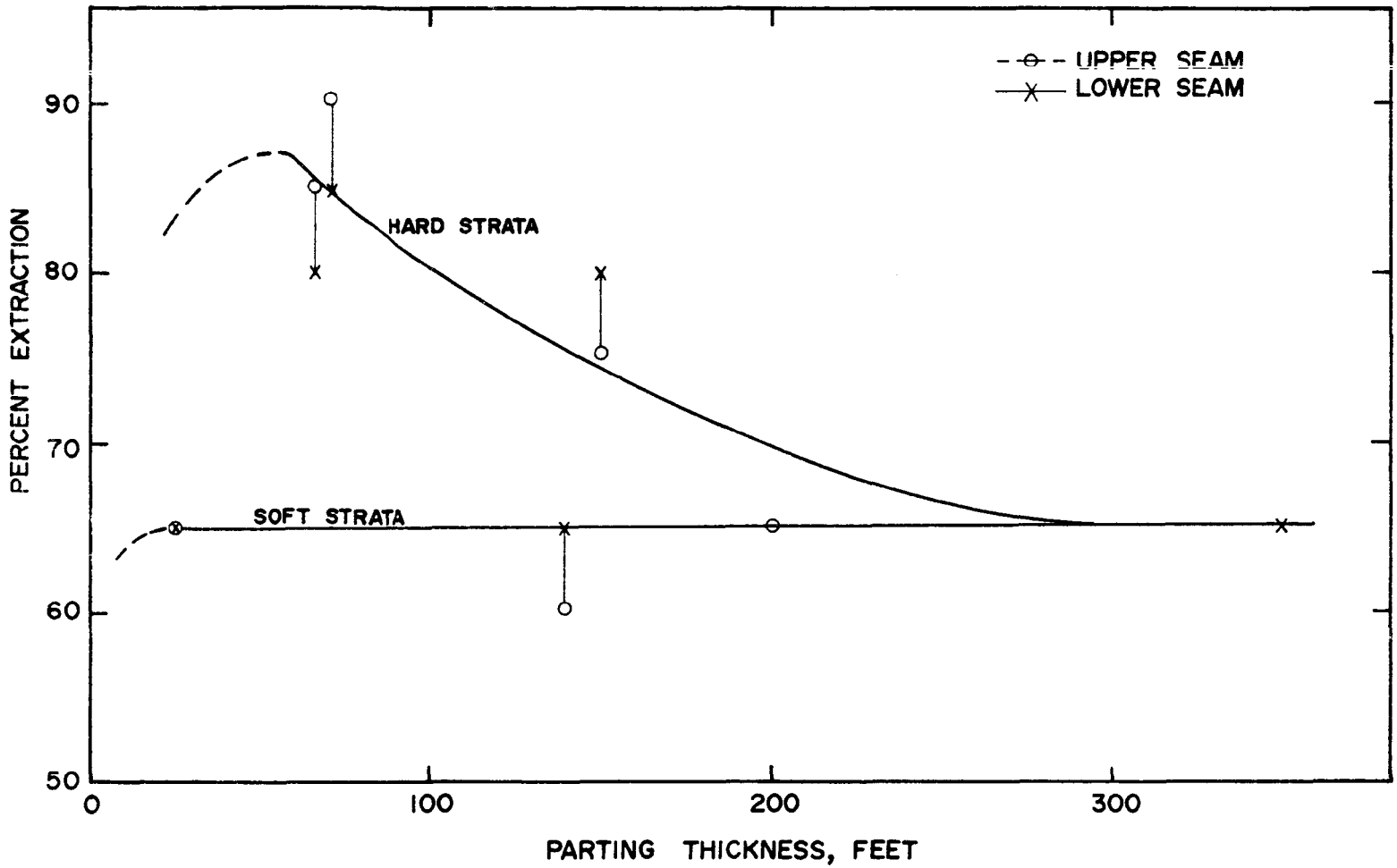


Figure 28 - Effect of Parting Thickness on Extraction With Simultaneous Mining.

seam must be advanced in proportion to the mixing ratio for the desired product. Obviously, faults and want areas will affect this production plan.

8.2 Output per Man - Shift

Figure 29 is an attempt to illustrate coal production in terms of output per man-shift (for underground workers only) for different methods of multiple-seam mining. The majority of data shown were obtained from field visits since this type of information was rarely discussed in the literature. The graph is essentially a frequency diagram showing the tons per man-shift as a percentage of the available data for each mode of mining. Each mining method has a range of output per man-shift, hence some overlapping may be expected. Although the graph shows the highest output is obtained when mining below a worked seam, and the lowest with when mining above a worked area, in general, the two methods are nearly equal with an expected output to be around 14 to 15 tons per man-shift. This is based on the available information only from Appalachia. The analysis could change if more information were available, especially in the case of simultaneous mining (where data were severely limited).

8.3 Operating Costs

In addition to extraction ratio and output per man-shift, production performance needs to be measured in several individual phases of the mining operations. Because of the many variables that can influence mining operations, differences between them are difficult to quantify. However, sufficient information was obtained to examine the operating costs of ventilation, pumping, roof support, and coal haulage, and to see how these costs change with mode of mining, coal seam thickness, and production rate.

8.3.1 Ventilation Costs

Ventilation cost can increase significantly with the presence of leaks due to cracks in the rock strata. These cracks can be induced by the mining operation. Poor roof conditions may require steel beam supports which add resistance to the airways. This must be compensated by extra horsepower at the main mine fan or by the addition of auxiliary fans. Costs were first examined on a cost-per-ton basis for several coal seam thicknesses and production rates. These costs were then plotted in relation to each different form of multiple-seam mining and the results are shown in

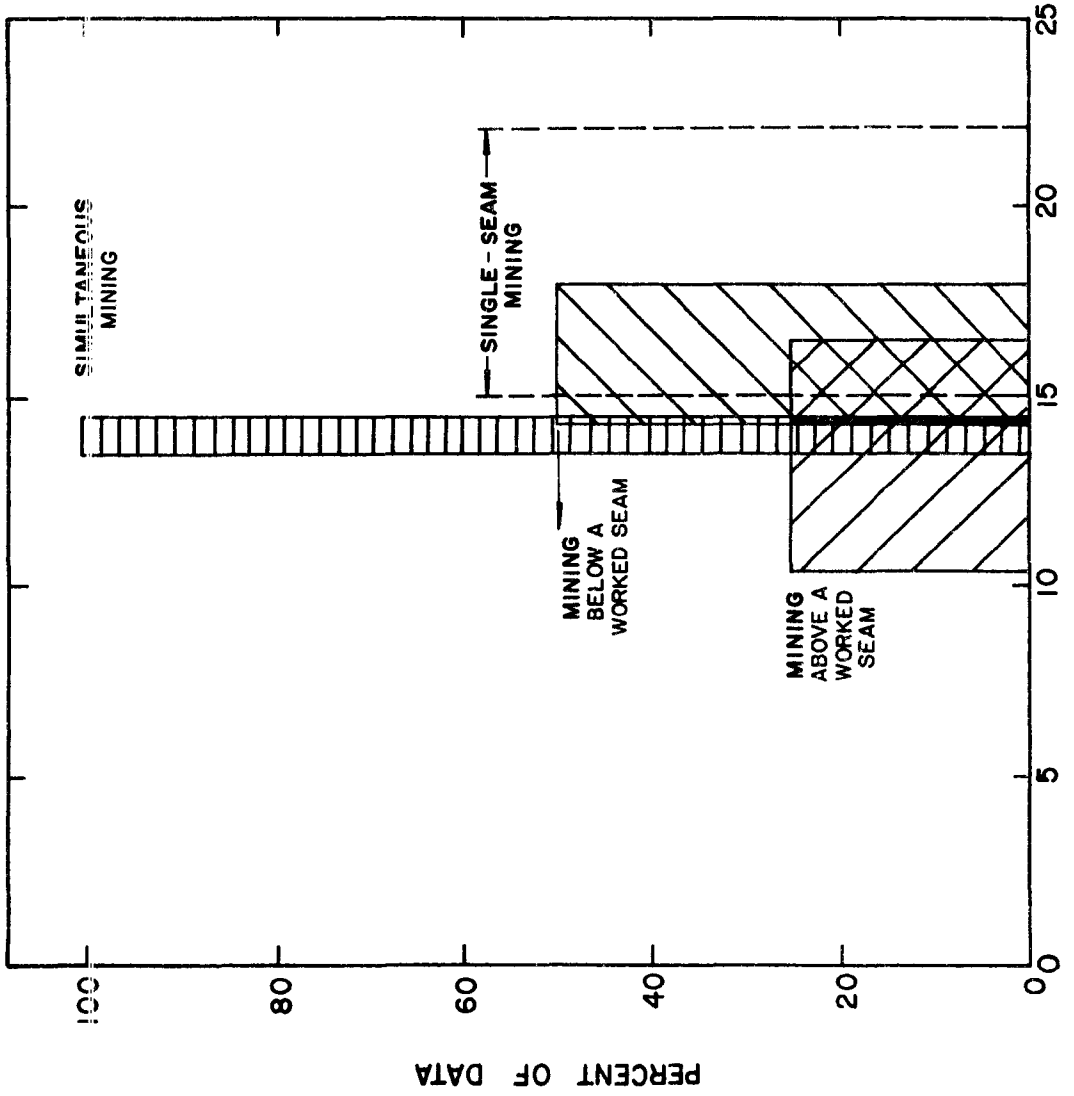


Figure 29 - Underground Output per Man-Shift for Various Mining Methods.

Figure 30. Overmining and undermining both increase ventilation cost by about 12 percent in that both mining systems cause fracturing in rock strata because of remnant pillars and strata settlement. Air leakage can occur in an upward or downward direction, because leakage is created by the higher-pressure air in the ventilated seam escaping to a lower-pressure nonventilated seam whether it be above or below. Consequently the losses for each of the mining methods are nearly equal.

The ventilation system for simultaneous mining is somewhat different. Generally each coal seam is ventilated independently so if any ventilation shut down were to occur due to a major roof fall or market slow-down, both seams would not be affected. Even if the strata are fractured the pressure difference between seams would not be as great as with overmining or undermining so the extent of air migration would be considerably less. The ventilation cost with simultaneous mining closely parallels that of single-seam mining, since each seam is ventilated independently.

8.3.2 Pumping Costs

Studies show that the pumping cost per ton varies with total coal production, but is not directly dependent upon coal seam thickness, as shown in Figure 31. Each multiple-seam mining method, however, has significantly different associated pumping cost. Overmining pumping cost is minimal since the mined-out lower seam accepts water flow from above creating a dry floor in the top seam. Thus little need exists for a pumping system in the upper seam. Undermining however, has the inherent danger of sudden inundation from possible water buildup in the upper coal seam. A larger capacity pumping system needs to be employed to offset the danger, and drill holes may be used to let accumulated water above drain into the lower seam at a controlled rate. Generally water handling will be significantly greater with undermining conditions. Simultaneous mining can take advantage of water handling only on one level if an overmining mode is followed. Several seams can be mined while dry, and only one pumping system will be needed in the lowest seam. This reduces equipment, maintenance, and labor costs, even if power costs remain unaltered. The pumping cost may be spread over the combined coal production of several seams, thus lowering the overall pumping cost per ton. Under- and overmining pumping costs are shown to be linear with respect to coal production but this may be due to the lack of detailed cost histories.

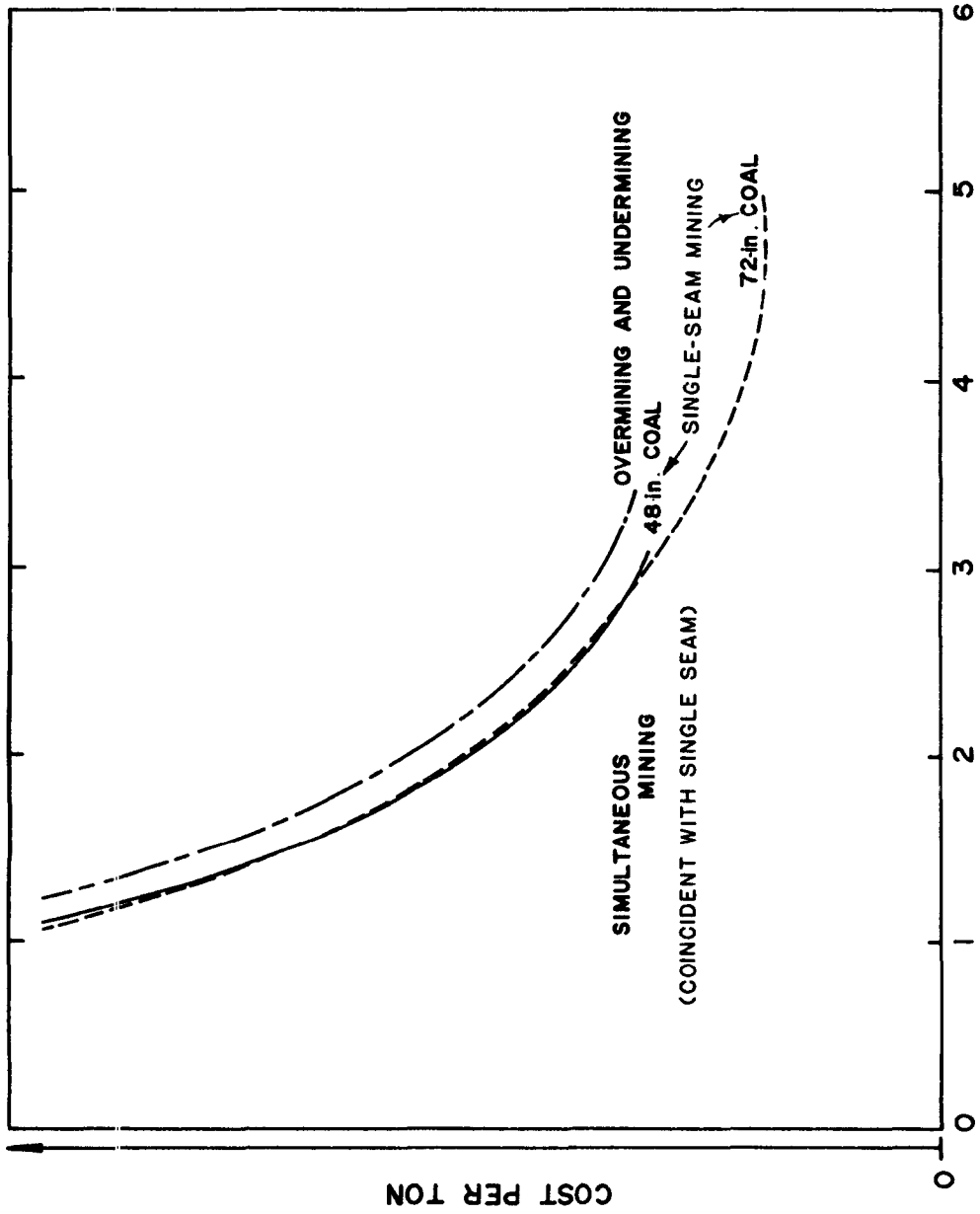


Figure 30 - Effect of Coal Production and Mining Method On Ventilation Costs.

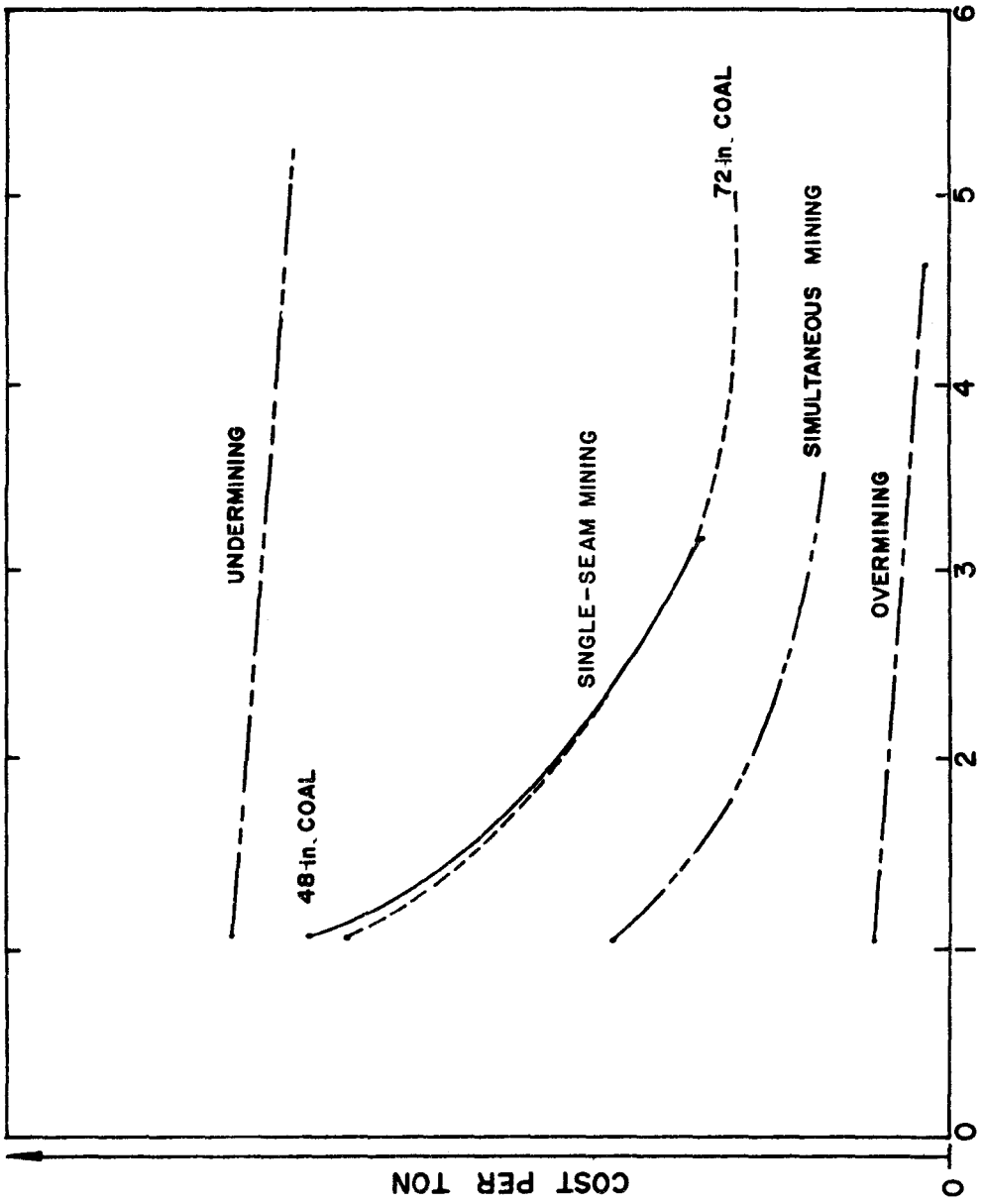


Figure 31 - Effect of Production and Mining Method On Pumping Costs.

8.3.3 Roof Support

Roof support costs are difficult to quantify and hence field data are not readily obtained. For preparing Figure 32 it was assumed that the costs involved would be directly proportional to the roof-bolt machine costs. There are of course other factors such as injuries from rock falls, lost production, and equipment damage which are difficult to assess on a general basis. Studies have shown that in general, roof support costs are higher for multiple-seam mining operations. Each operation has its own set of problems to contend with based on the local geology. The mine operators generally report either no difference in cost or between 10 and 20 percent increase in roof control cost while mining multiple seams. Because data are limited and complicated by other factors, all multiple-seam mining techniques were lumped together and therefore reflect the general higher cost per ton over that of single-seam mining. The mining technique, nature of parting, time lapse between mining, and other parameters all have an effect upon roof support costs. As noted earlier in this report, the nature of the floor, its susceptability to squeezes, bumps, and deterioration when exposed to water, are also critical factors.

8.3.4 Coal Haulage

Coal haulage is greatly influenced by poor roof conditions which may result in rock falls in haulageways, and the presence of water which may swell a shale floor or cause slippery conditions that may be difficult to negotiate with rubber-tired equipment. Hence coal haulage costs for multiple-seam mining can differ from single-seam mining. The benefits of multiple-seam mining however include a common haulage shaft or slope which can be depreciated against more coal in the case of multiple seams, especially if parting thicknesses are not great. In single-seam mining coal haulage cost decreases with coal thickness and increases with production, as is reflected in Figure 33. Industry figures are not definitive, especially since there are many systems or combinations of haulage systems used in coal handling. Generally materials handling costs of multiple-seam systems should be about equal to those of single-seam mining. The savings of extending an existing shaft or slope for an increased amount of total coal production can be offset by haulage inefficiencies due to worse roof conditions or the presence of water. Simultaneous-mining operations do not generally have these severe problems. The cost curve for simultaneous mining is likely to be less than overmining or undermining by the extent of savings effected by improved roof and water control.

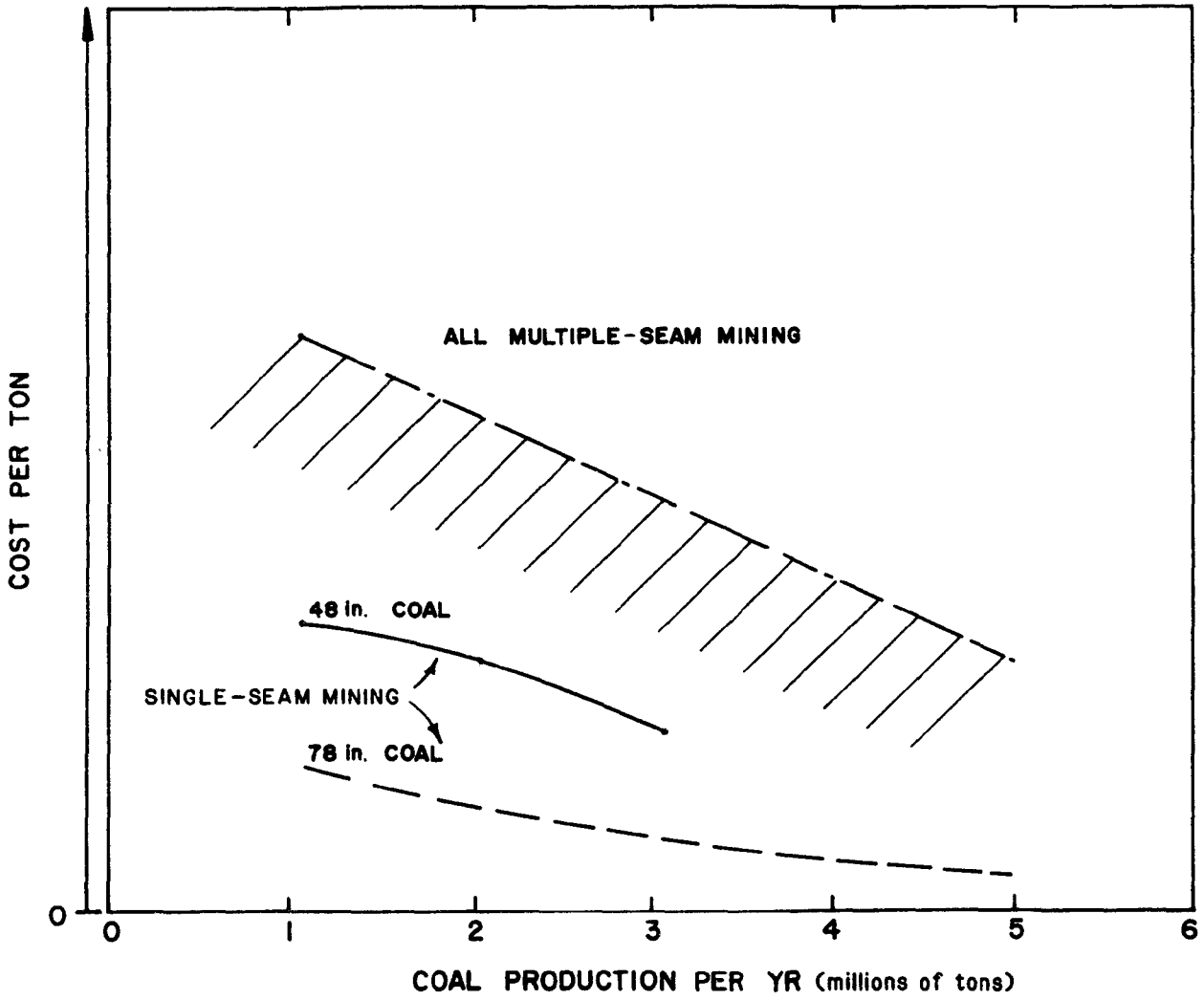


Figure 32 - Effect of Production and Mining Method On Roof Support Costs.

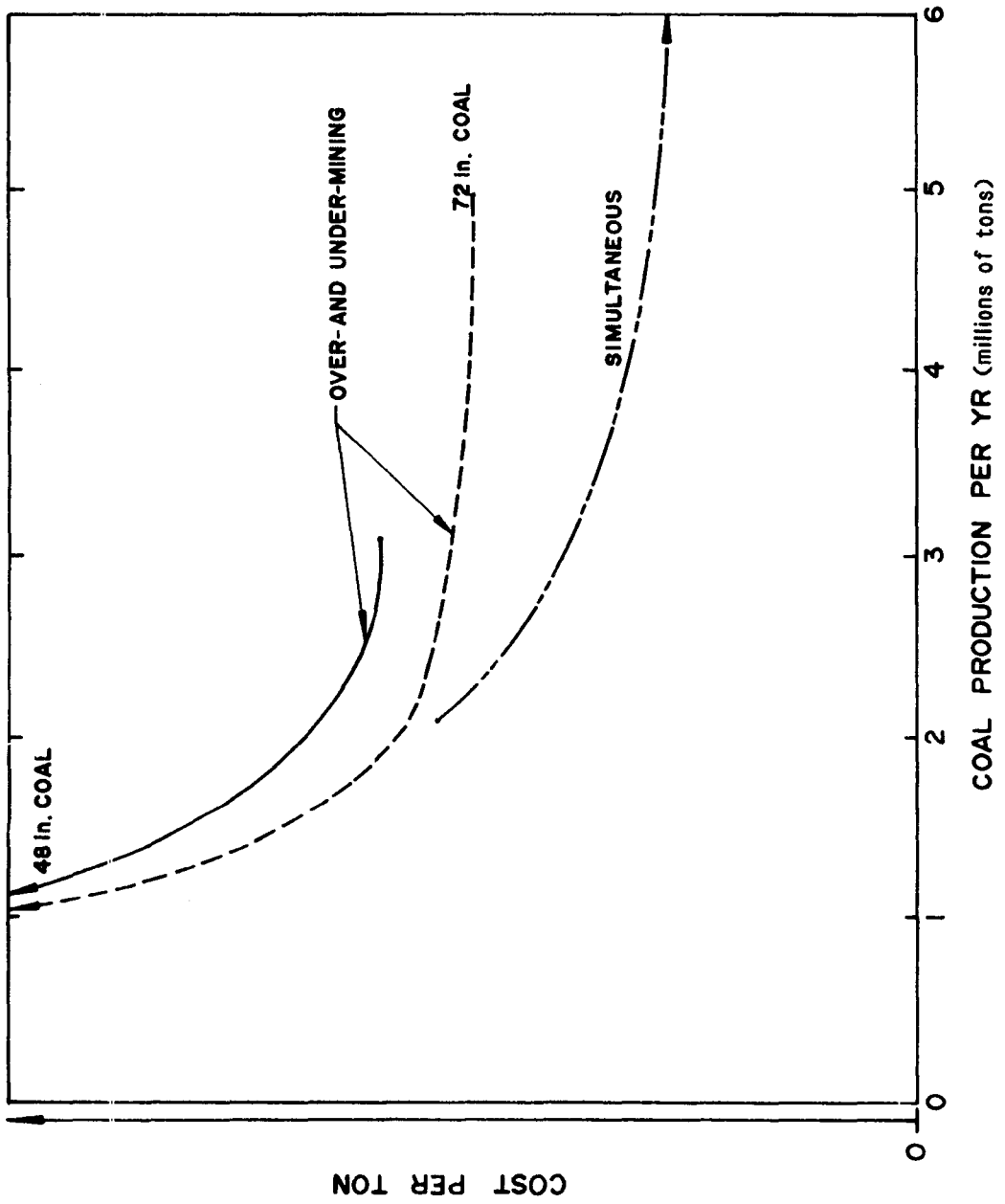


Figure 33 - Effect of Production and Mining Method On Coal Haulage Costs.

8.4 Spontaneous Heating

Most coals in the United States are not conducive to spontaneous combustion. Hence, this is not a serious problem, especially in the Appalachian or Interior coal fields. Some coals in the West, however, do experience this problem.

All precautions that need to be taken when mining single seams of coal liable to spontaneous heating also should be observed when mining multiple seams. This includes sizing panels so that these can be mined within the incubation period of the coals, leaving adequate barrier pillars around the panels, completely sealing off the panels after they have been mined, keeping access open to the panels at all times, regularly monitoring the atmosphere within the sealed panels, and providing adequate ventilation while mining to absorb heat generated by the exposed coal. In addition, with multiple-seam mining care needs to be exercised that air is not introduced into sealed, worked-out panels through cracks in the strata. Hence close control is required over the ventilation air in the second seam to be mined. Leakage out of this seam needs to be stopped immediately. The need to leave pillars does introduce stress problems in multiple-seam mining as discussed earlier, but these can be dealt with in the same manner as barrier and other pillars.

8.5 Methane Control

Methods used for methane control in multiple-seam operations are similar to those for single-seam mining. Adequate ventilation is necessary. Care needs to be taken that gas pockets do not form, especially in the upper seam. This situation is likely to develop when the upper seam has been previously mined and is no longer being worked. Unless the old workings are regularly checked, gas accumulations may go undetected.

Gas emissions , in general, may be expected to increase in deeper coal seams. Also rapid rates of advance will release larger quantities of gas. These situations, however, also occur with single seams.

8.6 Bumps

The occurrence of bumps in multiple-seam mining may be expected, especially if isolated pillars are left in the seams. Bumps occur when these pillars get overloaded and fail suddenly. The subject of bumps has already been discussed in various sections of this report, under strata control, but is worthy of special mention here because of the safety hazard they pose during mining. Elimination

of pillars, of course, eradicates bumps, but this is not always feasible. Hence when pillars need to left, these should be of adequate size to withstand the loads to which they may be subjected in the future. It should be borne in mine that pillars will deteriorate with time, and may be subjected to increased loads with the mining of subsequent seams.

9.0 OPERATIONAL PLANS FOR IMPROVED PERFORMANCE

Detailed examination of the operational plans used in multiple-seam mining has led to this summary of successful techniques used to deal with the problems encountered. Some of the factors associated with improved performance include enhanced productivity, higher resource recovery, and reduced detrimental effects of future mining. The improved methods are discussed separately for room-and-pillar and longwall mining, with some procedures being applicable to both methods.

9.1 General Considerations for Improved Performance

There are many successful techniques that apply to any type of multiple-seam mining whether it be overmining, undermining, or simultaneous mining and which can be used for both the room-and-pillar or longwall methods.

A time lapse between mining of successive seams is necessary to relieve stress buildup in rock strata and to allow time for settlement. This time is more beneficial to mining above a worked seam and simultaneous mining and may vary from as little as 6 months to as much as 2 years or more, depending on conditions. Time lapse for mining below a worked seam has not proved as advantageous. The duration is greatly reduced with simultaneous mining, with a distance between the advancing faces in the two coal seams at least equal to the parting thickness, so as to prevent interaction of the stress concentrations around the faces. Roadways driven under or over destressed areas in a seam stand longer and require less roof maintenance. One method to assure this is to widen pillars with increased depth of mining, to assure that drivages are over or under gob areas. This practice is best suited for moderate parting thicknesses, of 100 to 200 feet, where seam interaction does exist. With thicker partings the advantage of this technique is less noticeable. When parting thickness is thin it is best to employ superposed roadways over roadways and pillars over pillars i.e. columnize. Columnization has proved successful and is necessary, when parting thickness is less than 50 feet. Although superposition of main haulageways is desirable, it may not be feasible to achieve complete columnization in that pillars in different seams may be in line but not directly underneath each other, especially if the seams are not exactly horizontal.

Attempts should be made to attain complete extraction. Remnant pillars left in either sub- or superjacent seams can greatly interfere with mining by creating fractures,

heaves and squeezes. There are a few case histories where pillars that cannot be safely mined were blasted so that they will have no interaction with mining above or below. This practice of pillar blasting, however may be extreme. Complete extraction creates rapid, uniform subsidence which is more desirable than that caused by deteriorating pillars.

For successful simultaneous mining a parting thickness of at least 165 feet is necessary. In the past, lack of cooperation and coordination between mining companies, each mining different seams in the same property, has led to the abandonment of extensive reserves. To avoid such losses mining of the property can be coordinated among the companies by mining only one seam first, and then mining subsequent seams sequentially. If the parting thickness is thin and not conducive to simultaneous mining, the coal seams may be developed on opposite sides of a property in order to prevent interaction between seams. Later this creates overmining and undermining conditions. This method of operation may necessitate extra portals and surface equipment but provides the opportunity for complete extraction of reserves.

Often, in Europe sand-stowing is practiced in order to gain added pillar support when mining deep seams. However this practice is labor intensive and not economically sound for use in the United States (Singh and Courtney, 1972).

In Poland improved shaft design permits mining of coal closer to the shaft, thereby allowing greater resource recovery and faster return on capital. Figure 34 shows a shaft profile with 60-degree influence lines defining where coal should be left in order to preserve shaft stability. Thus, for a shaft depth of 600 feet coal recovery is reduced in an area around the shaft with a radius of about 350 feet. Extensive coal recovery in this area may cause fracturing in the water-bearing strata above the shaft lining thereby flooding the mine. To prevent such an occurrence, a shaft lining has been developed that plugs inrushes from water-bearing strata. A cross section of this type of lining design is shown in Figure 35. Since this type of lining is expensive it is extended only to the first dry strata below the aquifer. Basically the lining is a series of concrete and thin steel walls that sandwich a bituminous seal formulated from asphalt and limestone fines so as to achieve a specific gravity of 1.3. If fracturing occurs at the lining-rock interface, the bituminous mixture flows into the

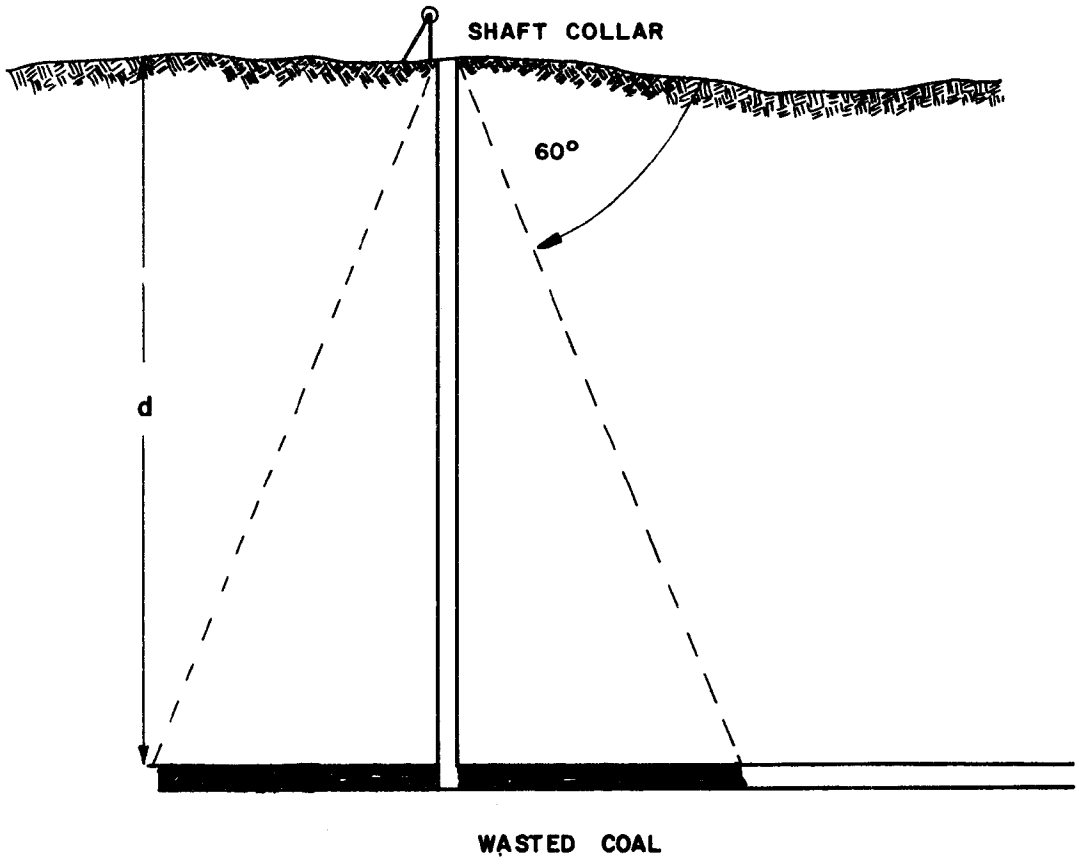


Figure 34 - Size of Coal Pillar for Shaft Stability

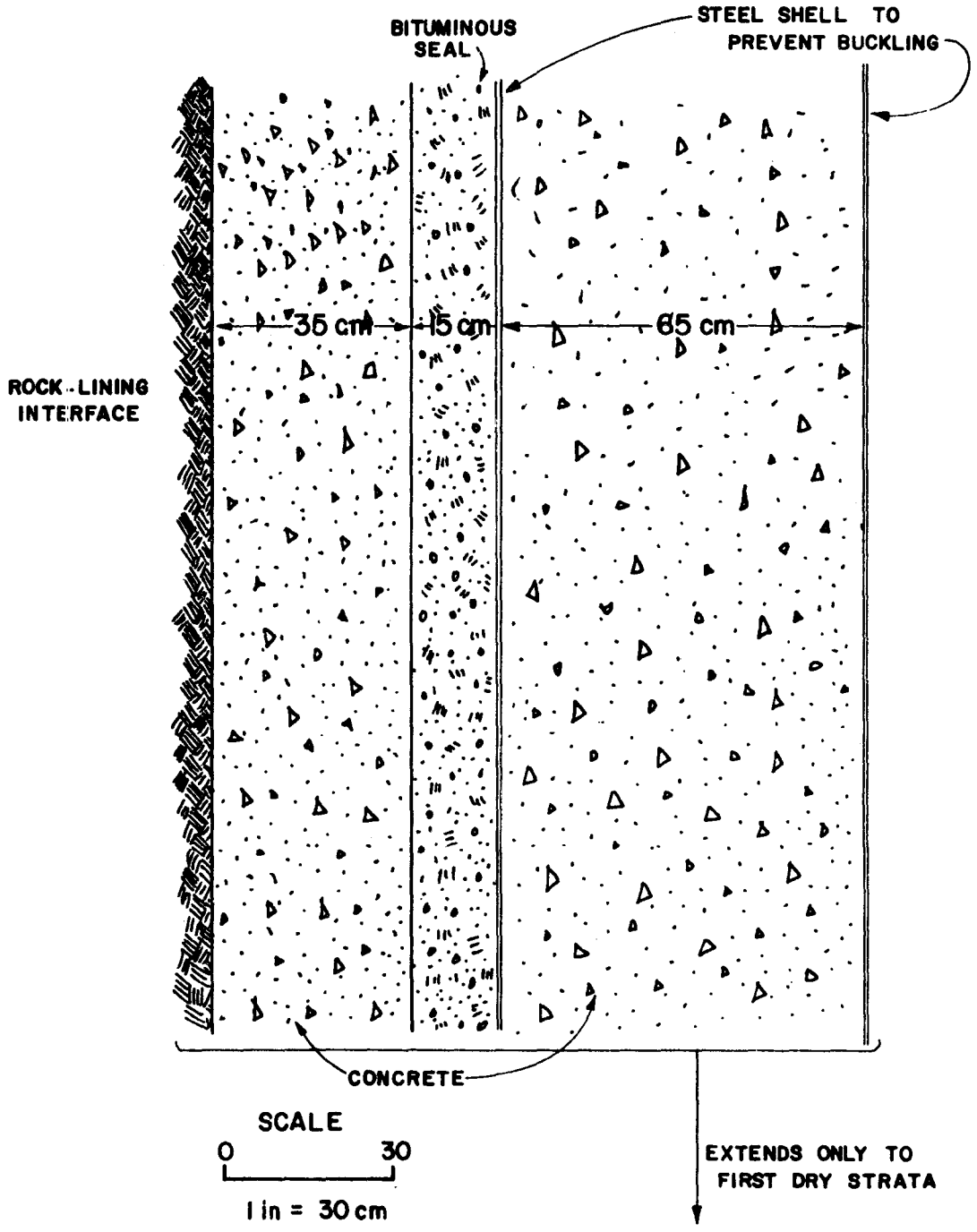


Figure 35 - Cross-Section of Polish Shaft Lining

cracks and seals them against flow of water. Such flowing action can be quite rapid, since even in the steady state the sealant is under relatively high pressures because of the weight of the sealant column above it.

The advantage of this shaft lining design is that mining can take place within 100 feet of the shaft at a depth of 600 feet. This is further aided by the fact that backfilling is practiced during mining. The application of this technique makes considerably more coal available than conventional shaft linings in a property where multiple seams occur.

9.2 Room-and-Pillar Methods

In addition to the general techniques discussed above, some techniques can specifically improve efficiency in room-and-pillar mining methods. Forming of long straight pillar lines helps to reduce shearing of overlying strata at barrier pillar edges and helps promote subsidence by roof bending rather than by shearing, thus reducing seam interaction.

Columnization of pillars and superposition of roadways are beneficial. Complete coal extraction is necessary to form destressed zones that have little interaction effect on sub- or superjacent seams.

Partial coal recovery has been successful in the past. This method involves the development of the top seam while leaving a regular pattern of unpillared coal to support the overburden. The technique diffuses the pressure applied to the lower bed so that the lower seam can be extracted with less difficulty. Case histories have shown that overall extraction is not reduced significantly and recovery may be increased since coal is not abandoned. Because of less seam interaction mining costs may be expected to improve.

Experience in Europe has led to the development of long narrow, parallel panels separated by permanent pillars. The width of panels and pillars is about 20 to 30 percent of the depth of mining. Extraction ranges from 40 to 70 percent. The resulting subsidence is 3 to 20 percent of the coal seam thickness (Brauner, 1973).

9.3 Longwall Methods

Much of the current longwall experience has come from European countries, but procedures and techniques that have been successful there may not be directly applicable to conditions in the United States. Nevertheless much can be

learned from European mine planning procedures. Table 20 lists factors that should be examined when laying out a panel in longwall operations. The table is essentially a summary of causes and effects of the following parameters on mine design:

- Reserves
- Depth
- Local geology
- Seam thickness
- Seam and panel interaction
- Working environment
- Surface subsidence

Consideration of the factors presented in Table 20 should be of some benefit to mine operators contemplating multiple-seam longwall operations.

Many of the adverse conditions created by the interaction of multiple coal seams can be successfully dealt with by longwall methods. Excavations with a width-to-depth ratio less than 1.2 to 1.4 induce low stresses and prevent the buildup of vertical pressure. Remnant pillars from previous mining, above or below, should be located such that the central axis of the pillars bisect the longwall face, as illustrated in Figure 36. The pillar interaction occurs in the gob areas and drivages are situated in the destressed zones on either side of the pillars. Thus a more even subsidence profile is produced on the surface (Whittaker and Pye, 1975).

An improved longwall method shown in Figure 37, extracts alternate panels. This permits maximum recovery of reserves. The gate roads for faces 1 and 2 may be reused for face 3 if they were designed for achieving maximum stability by remaining open for the longer time period (Whittaker and Pye, 1975).

A brief explanation of stress zones was presented earlier in this report, along with a discussion of advancing simultaneous mining fronts using the longwall method. To some degree subsidence is always to be expected, but harmonic extraction methods may be utilized to reduce surface strains. Figure 38 illustrates two seams of nearly equal thickness being mined, and the angle of break along which the overlying strata is ruptured. If this angle is known, the position of maximum tensile and compressive forces at the surface can be

TABLE 20 - Factors for Panel Layout

Layout Factor	Information Contribution	Effect on Plan
Reserves	Virgin areas	Sequence of extraction
	Value of reserves	Percentage extraction
	Location of reserves	Access cost; available working time
	Quality and working conditions	May require exploratory work
Depth	Roadway stability at depth	Solid drivages may not stand
		Retreat work may be ruled out because of floor lift
	Roadway shape at depth	Development time increased because of need for the more stable arched profile or for more supports
	Shallow depth	Rectangular profiles usually successful - always used in U. S.
Local geology	Rock type and conditions	Type and amount of support
		Virgin areas may require special precautions because of rock pressure problems
	Gradient	Direction of working
	Disturbed ground, e.g. faulting	May limit face length or require exploratory work or special support
Seam thickness	Thick	Mechanization more successful
		Increased convergence; more difficult roof control
		Panel width possibly reduced
	Thin	Strata control on face usually no problem
		Less interaction effect on neighboring seams
		Roadways can be smaller
		Face ends; special support measures
Seam and panel interaction	Old workings	Require knowledge of all previous surrounding workings and their relative location
	Old gobs	Gives maximum protection to both faces and roadways
	Rib edges and remnant pillars	Difficult strata conditions met by faces crossing old rib edges
		Roadway deformation increased in neighborhood of remnants
Working environment	Gas emission	Special measures may be required
	Spontaneous combustion	Influences method of working and percentage extraction
	Water in neighboring aquifer	Direction and limit of working; goaf support measures may be required; percentage extraction affected
	Water	Working conditions made more difficult, pumping arrangements
Surface subsidence	Shallow workings	Localization of strain and tilt, possible opening of fissures and surface cracks
	Industrialized area	Partial extraction may be required
	Special surface structures	Protection pillars may be necessary (size 0.3 to 1.0 x depth)
	Low lying topography	Partial extraction can control surface subsidence

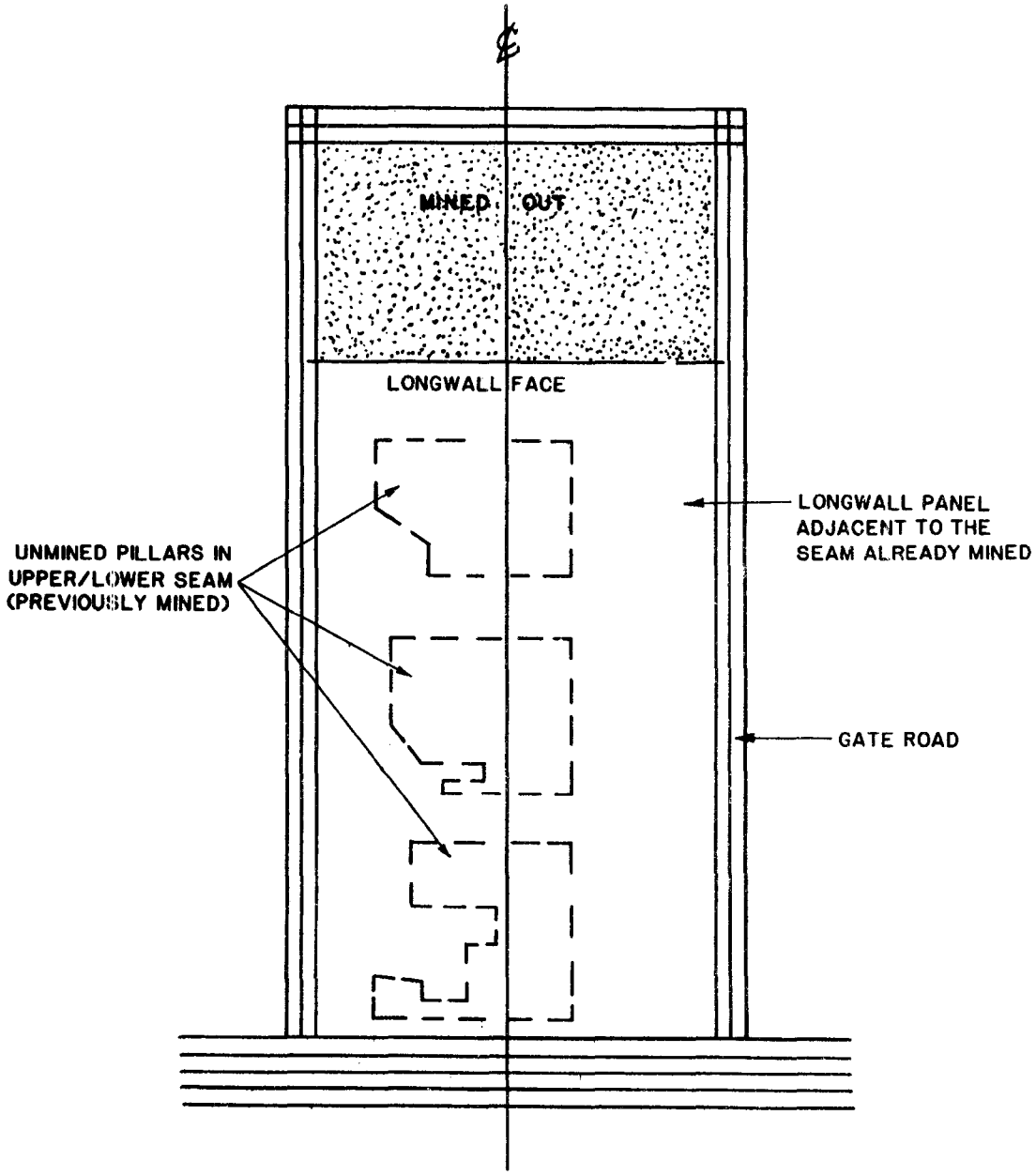


Figure 36 - Longwall Face Orientation with Respect to Pillar Line

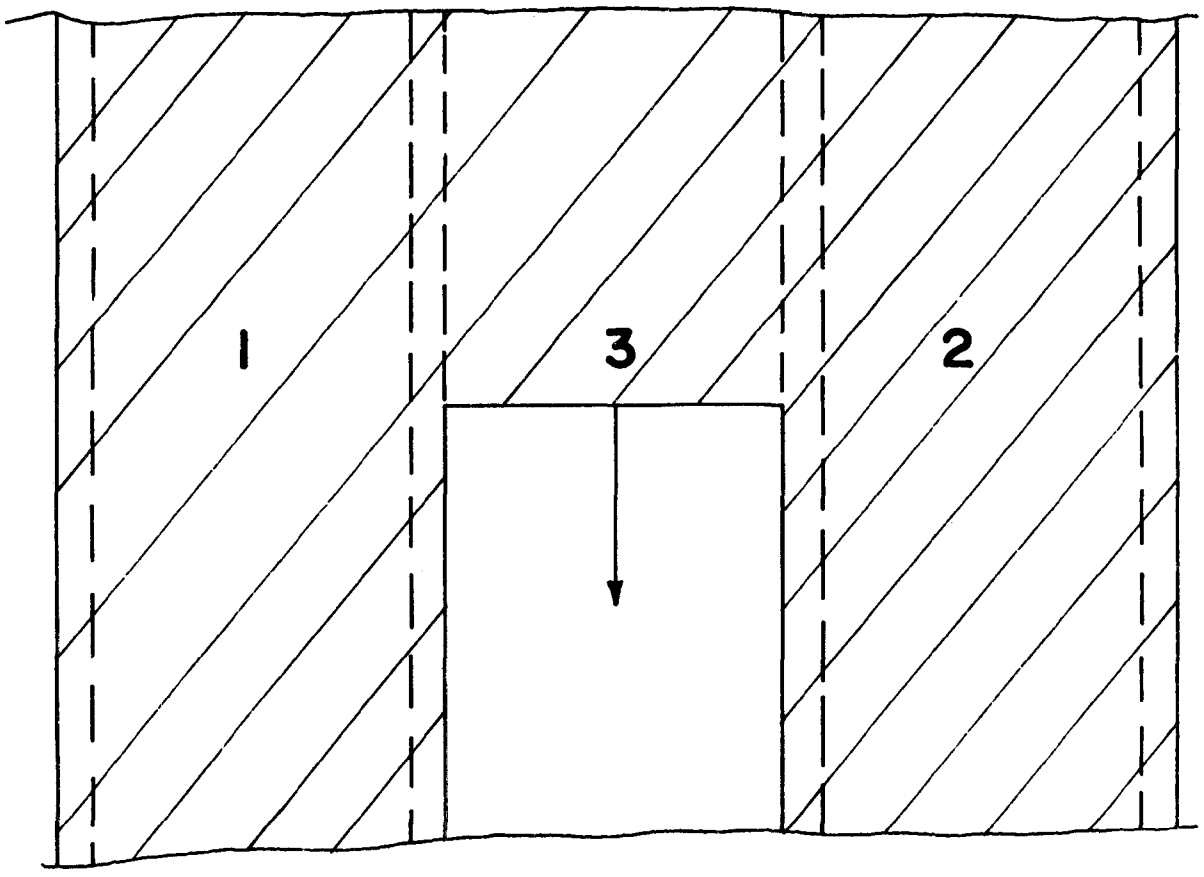


Figure 37 - Longwall Extraction of Alternate Panels

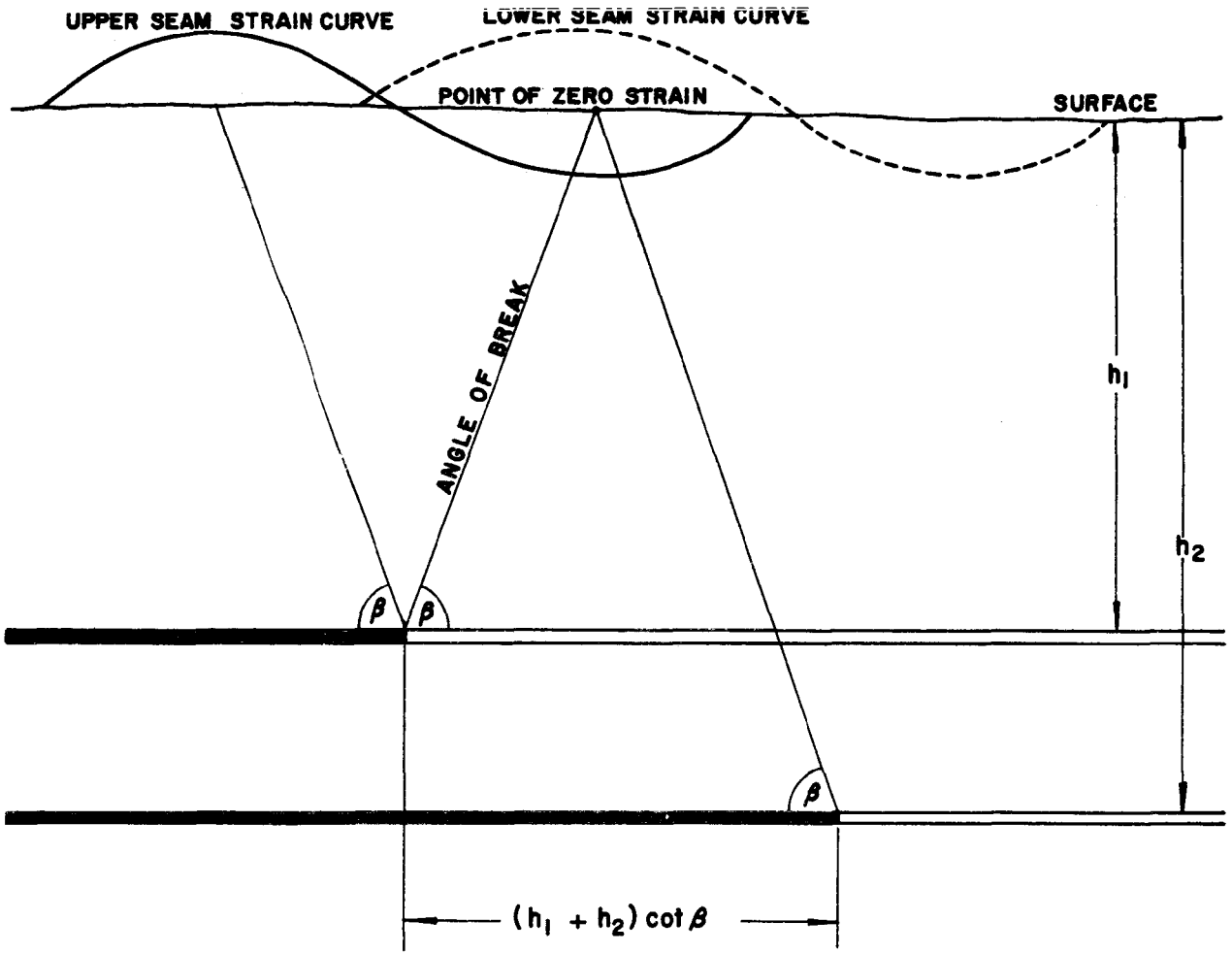


Figure 38 - Harmonic Extraction

located. The horizontal distance between mining fronts, given by (h_1+h_2) cot β, results in the maximum extension of the surface due to one working face and the maximum compression from the other face coinciding. These strains nullify each other resulting in minimal traveling surface strains in that area. In practice such reduced strain areas are difficult to achieve because geologic irregularities make the prediction of the angle of break difficult. However in areas where large surface strains cannot be tolerated (because of the existence of critical structures), use of the method may prove worth while. It will, of course, take time to gain sufficient experience with the local rock conditions before a successful application can be expected. With single-seam mining under a structure which needs to be protected from damage due to expected subsidence, longwall panels may be staggered with one face ahead of the other by one-fourth of the critical width (i.e. width of extraction causing maximum subsidence). In such a case, the adjacent panels need to border each other without any pillars, directly under the surface structure to be protected, as shown in Figure 39 The tensile strain over the right panel is small at the edge of the panel, and the compressive strain behind the face is offset partially by the tensile strain from the left panel. Strain under the structure will then be kept to a minimum (Peng, 1978). The location of pillars beneath the structure, as mandated by the three-entry system used in U. S. longwalls, does not permit the use of such a scheme. In fact, the existence of pillars intensifies the tensile strains and would tend to amplify the damage that may occur.

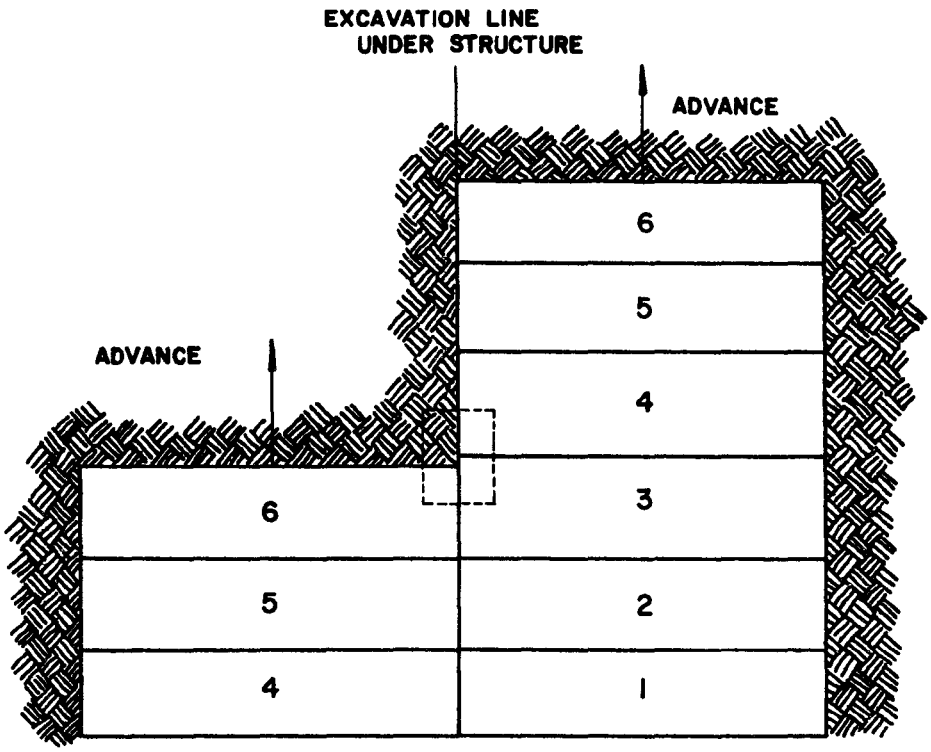


Figure 39 - Mining Under Surface Structures

10.0 CLOSURE

It is evident from the preceding discussion that the nature and extent of any problems encountered in multiple-seam mining are site specific. It is difficult to predict the conditions that will exist at a site, but it is possible to hypothesize the nature of the circumstances that are likely to exist. The degree of difficulty is dependent upon overburden thickness, nature and thickness of the parting, thickness of coal seams, and time lapse between mining of the seams. Problems most associated with multiple-seam mining are roof fracturing and bumps resulting from high stresses, haulage inefficiencies due to floor heaves, water inundations from accumulations in an abandoned upper seam, gas pockets, ventilation losses due to leaks, and disruptions. Spontaneous heating is not a major problem in the Appalachian and Illinois coalfields, but is a matter of concern in the western regions.

When mining above a worked-out seam (overmining) subsidence begins in the lower coalbed and works up to the surface, although this will not always affect the upper bed. Generally no significant effects related to productivity and overall extraction will be noted if the parting thickness is greater than 180 feet, provided the lower seam is less that 8 feet thick (Stemple, 1956). However, success in mining can only be assured if extraction in the lower seam is complete, otherwise the parting thicknesses of 30 feet and seams less than 8 feet thick, with careful planning which included columnization of pillars, and long straight pillar lines. A time lapse after lower seam mining tends to stabilize the upper beds and facilitate later mining. When compared to single-seam operations mining costs may be expected to be higher for thin partings and gradually decrease with increasing parting thickness set after which costs stabilize and may be only insignificantly different. This rate of change is illustrated in Figure 40.

When mining below a worked-out seam (undermining), seam disturbance may be expected when parting thickness is less than 100 feet, and is almost certain when the thickness is less than 65 feet. The limits of disturbance are influenced by overburden depth and nature of strata; time lapse between mining has little advantage. Possibly the ratio of overburden thickness to parting thickness is proportional to the likelihood of disturbance.

Difficulties are likely to develop with simultaneous mining if the parting is less than 165 feet. For narrower partings, the upper seam should be advanced 100 to 150 feet ahead of the lower seam and columnization of pillars is advisable. Partial mining of the poorer quality seam first and maximizing recovery in the high quality coalbed can lead to good recovery with reduced problems.

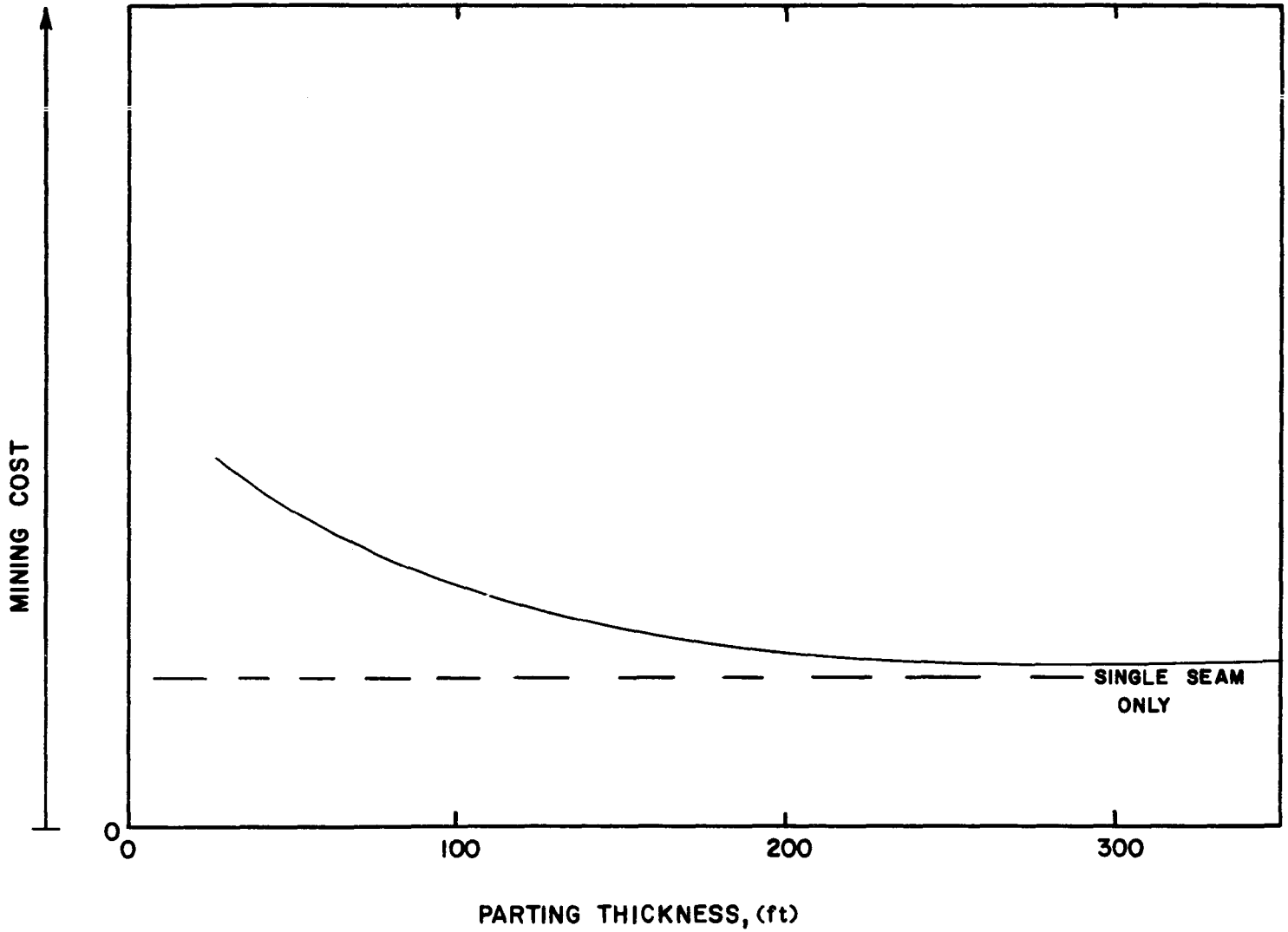


Figure 40 - Overmining Costs Relative to Parting Thickness

European experience demonstrates how difficult mining conditions may be addressed, and provides some techniques for dealing with problems related to longwall mining and increased depth. Drivages in destressed zones are imperative for good roof control. Toward the same goal, longwall faces should be oriented to advance perpendicular to the pillar lines that may exist in seams either above or below. Complete extraction is important not only to achieve maximum resource recovery but also to help reduce seam interaction.

Figure 41 summarizes the potential problem severity for the three modes of multiple-seam mining for parting thickness-to-coal ratios ranging from 5 to 40. The graph shows that for overmining conditions, success can be realized with small parting ratios even though greater potential for problems exists. The parting ratio is almost doubled before the same success may be expected for undermining conditions. However, the problem potential decreases faster than that for overmining as the parting ratio increases. Simultaneous mining requires the highest parting thickness-to-coal ratio before mining success may be expected. In all of these modes of multiple-seam mining the problem of interaction is greatly reduced when the parting thickness-to-coal ratio exceeds about 40.

It was noted during this investigation that extraction ratio, which serves as a measure of mine performance, varies with the thickness and nature of parting. This ratio also varies somewhat with the mode of multiple-seam mining practiced, but is not significantly different for any particular mode of operation. It was also observed that the output per man-shift (OMS) for underground workers is relatively close when comparing overmining, undermining and simultaneous mining, and that this output is only slightly less than for single-seam mining. It may be concluded that even though certain phases of mining are affected by multiple-seam conditions, the additional costs incurred to cope with the problems resulting therefrom do not significantly add to the selling price of coal.

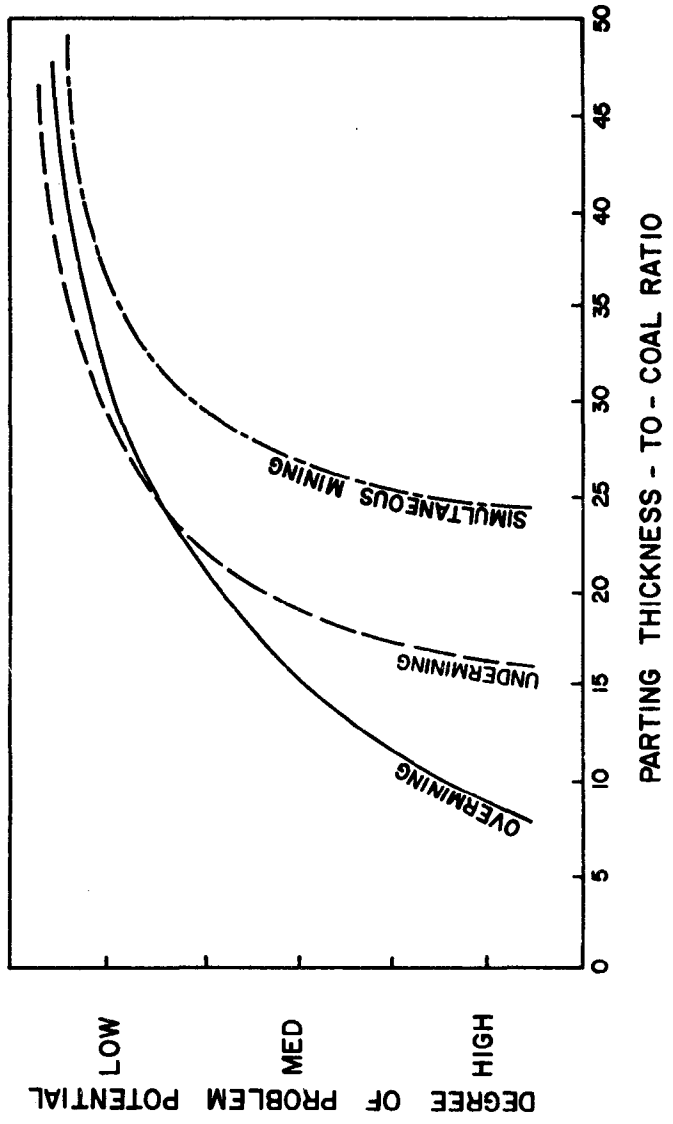


Figure 41 - Multiple Seam Problem Potential

TASK 3

EVALUATION OF REGULATORY AND OTHER INSTITUTIONAL CONSTRAINTS

1.0 INTRODUCTION

The United States has four to five times as much energy reserves in its coal resources, than it has in all other resources combined. With prospective energy needs, Government experts and private economists declare that the nation will have to double its coal production within a decade. Consequently, it is anticipated that multiple seam mining, which has been practiced to a limited extent in the United States for over 100 years, will increase rapidly.

Multiple-seam mining can present problems and can affect the coal recovery of overlying or underlying seams. The maximization of coal recovery has become based on a composite plan for the mining of all existing minable seams on a property while using the best available technology. This is becoming an important factor which is reflected in the requirements of prior approach for mining plans which are then examined by federal and various state government agencies for maximum recovery with a minimum of environmental damage. Only if these criteria are met will a lease or permit be awarded.

The purpose of this investigation is to identify the problems posed by mining regulations, and by other indirect sources such as organized labor, which are applicable to underground multiple-seam coal mining, taking into account existing technology as practiced in the United States and Europe. This technology can include shortwall; advancing or retreating longwall; superposition of entries; driving of roadways under old gobs in order to achieve drivage through destressed areas; or the use of harmonic extraction of two or more seams.

Multiple-seam underground mining of coal can be affected by several state and federal agencies in the areas of

- Resource Recovery
- Leasing
- Environment
- Health and Safety
- Mining Operations
- Organized Labor

but it appears the Department of Energy itself has no direct role in regulatory effects in this area.

Regulations and restraints applicable to auger mining have not been included in this work, as auger mining is not generally considered underground mining, but an extension of surface mining.

Specific pertinent regulations and proposed regulations have been cited in their entirety to fully indicate their context.

2.0 INDUSTRY REACTIONS

Along with the procurement and study of federal and state regulations, a search was undertaken of all recent U. S. mining journals, trade magazines, conference proceedings, and so on, to try to find the overall industry reaction to coal mining regulations as they apply to multiple seams. Sources were examined from 1970 to date.

Nearly all of the industry reactions referred to so-called over-regulation of the coal mining industry with extreme federal and state involvement, too many investigations for grant of mining permits, too many departments and agencies required to be contacted for approval, and too many permits required annually. Prolonged and costly delays in obtaining permits as well as the heavy cost of implementation were also cited.

It becomes clear that the industry was particularly concerned with the suspension of federal leasing, emergency leasing of federal lands, and the delay in the formulation of policies with respect to long-term leasing. Several articles also were concerned about wildcat strikes, especially in mines controlled by the UMWA. The complaints and fears of operators apply to coal mining in general and not specifically to multiple-seam mining.

However, in none of these articles are the authors specific about how the regulations that might affect multiple-seam mining affected them. In general, specific regulations have been met or variances obtained, at increased overall cost.

3.0 RESOURCE RECOVERY REGULATIONS

3.1 General

The responsibility of assuring maximum resource recovery has been left to the United States Geological Survey (USGS) of the Department of the Interior. Before a mining permit for the mining of coal by underground methods is granted, the Lessee is required to submit a detailed application to the USGS Mining Supervisor, showing the location, method, and extent of mining operations, including related activities necessary and incidental to the mining operations, along with steps to be taken to reclaim disturbed areas, to mitigate adverse impacts, and to meet necessary performance standards and requirements.

These applications are required to be examined by the Mining Supervisor, with a view to assure the extraction of the coal resource to the maximum extent possible, taking into account existing technology, commercially available equipment, the cost of production, the quality and quantity of the coal resource, minimization of waste of the coal resource and damage to any remaining coal formation and other mineral resources.

3.2 Maps and Plans

In order to assure maximum resource recovery certain input information is required by the Mining Supervisor and Title 30, Chapter II, § 211.10 Exploration and § 211.12 Mine Maps, and Mining Plans, outline the general and specific requirements.

3.2.1 Exploration and Mining Plans

The regulations which affect multiple-seam underground coal mining are:

> § 211.10 (7) Suitable topographic maps or aerial photographs showing:
>
> (iii) Cross sections and plan views of the land to be affected, including the actual area to be mined, showing elevation and location of drill holes and depicting the following information: the nature and depth of the various strata of overburden; the nature and thickness and extent of any coal, or if rider seams above the specific coal proposed to be mined; the nature of the strata beneath the coal to be mined for a vertical distance of at least 20 meters beneath the base of the coal seam; the location of the next known deeper coal seam below the deepest seam to be mined and representative characteristics thereof; the

location of any other mineral values encountered; hydrologic data and other information relevant to the mining plan; all mineral crop lines and the strike and dip of the coal to be mined within the area of land to be affected; location and extent of known surface and underground mine workings, oil or gas wells, and water wells within ¼ mile of the affected lands, the location of aquifers; the estimated elevation of the water table, and potentiometric surface; the location of spoil, waste, or refuse areas, and sequence of placement and topsoil preservation area; the location of all impoundments of water treatment facilities; constructed or natural drainways and the location of any discharges to any surface body of water on the area of land to be affected or adjacent thereto; and cross sections of the anticipated final surface configuration that will be achieved pursuant to the operator's proposed reclamation activities.

3.2.2 Mine Maps

The regulation which affects multiple-seam underground coal mining is § 211.12 (a) and § 211.12 (b).

§ 211.12 Mine maps.

(a) General requirements. The operator shall maintain accurate and up-to-date maps of the mine, drawn to scales acceptable to the Mining Supervisor. All maps shall be appropriately marked with reference to government landmarks or lines and elevations with reference to sea level. Before a mine, or section of a mine, is abandoned, closed, or made inaccessible, a survey of such mine or section shall be made and recorded on such maps and a copy shall be furnished to the Mining Supervisor. All excavations in each separate bed shall be shown in such a manner that the production of coal for any royalty period can be accurately ascertained. Additionally, the maps shall show the name of the mine; the name of the lessee; the lease, permit, or license serial number; the lease boundary lines; surface buildings; dip of the bed; true north; map scale and explanatory legend; location surface elevation, depth and thickness of the coal, and total depth of each borehole; auger holes; improvements; reclamation completed; topography, including subsidence resulting from mining; and the geologic and hydrologic conditions as determined from outcrops, drill holes exploration or mining; water

monitoring stations and such other information as the Mining Supervisor may request. Copies of such maps shall be properly posted to date and furnished, in duplicate, to the Mining Supervisor annually, or at such other times as he may request.

(b) Underground mine maps. Underground mine maps shall, in addition to the general requirements of paragraph (a) of this Section, show all mine workings; the date of extension of the mine workings and a coal section at each entry face; the location of all surface mine fans; the position of all fire walls, dams, main pumps, fire pipelines, permanent ventilation stoppings, doors, overcasts, undercasts, permanent seals, and regulators; the direction of the ventilating current in the various parts of the mine at the time of making the latest surveys; sealed areas; known bodies of standing water, either in or above the workings of the mine; areas affected by squeezes; the elevations of surface and underground levels of all shafts, slopes or drifts, and the elevation of the floor, or bottom of the mine workings, at regular intervals in main entries, panels or sections, and sump areas. Any maps submitted to the Mining Safety and Health Administration for the purpose of showing, and which in fact show, any of the specific data required by this subparagraph shall be acceptable in fulfillment of the requirements hereof.

The requirements for maps showing all seams are the minimum needed for the purpose and do not present any undue hardship to the lessee or operators.

3.3 Mining Sequence and Method

Regulations of the Geological Survey, which directly effect the mining of multiple seams by underground methods, are provided in CFR Title 30, Chapter II:

§ 211.32 Multiple-Seam Mining

(a) Sequence of mining. In general, the available coal in the upper beds shall be worked out before the coal in the lower beds is mined, and simultaneous workings in an upper coal bed shall be kept in advance of the workings in each lower bed. The Mining Supervisor may authorize mining of any lower beds before mining the available coal in each known upper bed.

(b) Protective barrier pillars in multiple-seam mining. In areas subject to multiple-seam extraction, the protective barrier pillars for all

> main and secondary slope entries, main haulageways, primary aircourses, bleeder entries and manways in each seam shall be superimposed, regardless of vertical separation or rock competency; however, modifications, exceptions, or variations of this requirement may be approved in advance by the Mining Supervisor.

The provision on mining sequence does not spell out the conditions when such permission may be granted by the Mining Supervisor. The "Maximum Economic Recovery" (MER) under Federal Coal Leasing, discussed in Section 4.2.1 of this report, requires the assessment of "MER" on the basis of individual seams. Thus one mining sequence may be more beneficial overall than another, but would require special consideration.

The provision on protective barrier pillars requires that all barrier pillars for all main and secondary slope entries, main haulageways, primary air courses, bleeder entries, and manways in each seam shall be superposed regardless of vertical separation or other conditions. These requirements ideally suit the working of horizontal and moderately pitching coal seams by room-and-pillar methods, but do not permit columnization normal to the bedding planes as practiced for pitching seams.

The requirements also do not permit drivages or entries through destressed zones over or under a worked-out seam, when these are specifically driven away from zones of abutment pressures.

These superposition provisions are the most specific regulatory or institutional constraints on multiple-seam underground coal mining that were found during this work. Provisions for remnant pillars are discussed at greater length in Section 7.0 of this task.

4.0 LEASING REGULATIONS

4.1 General

The United States Geological Survey estimates that a large part of Alaska and Rocky Mountains Land and all of the Outer Continental Shelf beyond state jurisdiction are controlled by the federal government. In real terms, it controls 760 million acres, one third of all U. S. land, and it holds mineral rights on another 63 million acres.

The federal government now owns more than 96% in Alaska (62% after final agreement on state selection and settlement of native claims); 86% of all lands in Nevada; 67% in Idaho; 65% in Utah, 52% in Oregon; 48% in Wyoming; 45% in California; and 44% in Arizona. Only four states - Connecticut, Iowa, Maine and New York - contain less than 1% federal lands. It has been estimated that publicly controlled land contain 33.8% of all known coal and 70% of all known low-sulfur coal resources. ("The Mining Record," Feb. 7, 1979).

4.2 Management of Federally Owned Coal

Leasing of federally-owned coal is presently in a state of flux as court decisions have temporarily halted leasing and the Bureau of Land Management has proposed entirely new regulations.

The Bureau of Land Management (BLM), Department of Interior, is responsible for the management of federally-owned coal. In proposed CFR Title 43 - Coal Management; Federally Owned Coal, there are some references dealing directly and indirectly with multiple-seam underground coal mining. These proposed regulations are stated and evaluated below:

4.2.1 "Maximum Economic Recovery" (MER)

Part 3400 - Coal Management - General, Sub part 3400. Introduction, General, Section § 3400 0-5 Definitions:

> (ee) "Maximum economic recovery" or "MER" means that all portions of the coal deposits within the lease tract shall be mined that have a private incremental cost of recovery (including reclamation, safety and opportunity costs) less than or equal to the market value of the coal.

Thus each seam must be assessed individually as well as collectively, providing multiple scenarios for lease bidders.

However, based on comments received on the proposed Coal Management Rule Making, and to conform to the definition of "Known Recoverable Coal Resource Area" or "KRCRA" used in the Geological Survey usage, the Secretary of Interior has clarified that the definition of:

> Maximum economic recovery has been revised to reflect the decision of the Secretary to assess coal seams on the basis of their individual profitability rather than their collective profitability.

In accordance with this definition, coal seams are leased individually in a given area. Thus different seams may even be worked by different operators. A seam that proves uneconomical to operate under present conditions, will not be developed, even though it could become economic in the future, or can be profitably mined along with other seams. This policy is based on immediate benefits and essentially considers only single-seam mining.

4.2.2 Leasing

Proposed Part 3400 Subpart 3420 - Competitive Leasing, Section

> § 3420.0-6 Policy, states:
>
> All leases except those issued under the provisions of Part 3430 of this title shall be issued competitively. There shall be special opportunity lease sales for qualified public bodies and for small businesses. Before each sale, the Department shall evaluate and compare the method or methods of mining that will achieve the maximum economic recovery of the resource. The Department shall receive fair market value for all coal leased.
>
> Before leasing of federal coal lands can be accomplished, preliminary tract delineation is required to enable the BLM to determine the effect that mining a particular coal seam will have on the rest of the area. In Proposed Part 3420, Subpart 3420-Competitive Leasing, Section § 3420.4-3 Preliminary Tract Delineation, Subsection (C), outlines the delineation procedure:
>
> (c) The potential tracts shall be delineated in accordance with § 3471.1-2 of this title and by seam(s) or coal bed(s). More than one potential tract may be delineated for a specific coal bed or potential mining unit.

The BLM carries out economic evaluation on coal leasable areas through the Geological Survey before accepting bids. These evaluations determine fair market value and assist in the determination of the MER.

This is detailed in Proposed Part 3420 - Competitive Leasing, Subpart 3422 - Lease Sale, Section.

> § 3422.1-1 Mineral evaluation and comments on fair market value and maximum economic recovery.
>
> After announcement of the regional lease sale schedule, and in any case not less than 30 days prior to the publication of a notice of sale, the authorized officer shall:
>
> (a) Solicit public comment on the fair market value of the tract or tracts proposed to be offered. Such solicitation shall ask for comments on these items which affect the appraisal such as the terms and conditions of similar market transactions, the quality and extent of the coal resource, the price that the mined coal would bring in the market place, the cost of producing the coal, the interest rate at which anticipated income streams should be discounted, depreciation and other accounting factors, the value of the surface estate (if private surface), the mining method or methods which would achieve maximum economic recovery of the coal and any other items which might effect the appraisal of the tract or tracts. Such comments will be solicited for a period of not less than 30 days. The authorized officer shall forward a copy of all comments to the Geological Survey.
>
> (b) Request from the Geological Survey and evaluation including a coal resource economic value (CREV) and a maximum economic recovery (MER) determination. Prior to issuance of the sale notice, the Geological Survey shall forward this evaluation to the authorized officer. This evaluation shall include the coal resource economic value, mining method evaluation, estimated recoverable reserves by bed, preliminary MER indication, coal quality assessment, royalty and lease bond recommendations; an estimate of reclamation fees that mining the tract would generate, and an evaluation of the public comments on fair market value and maximum economic recovery.

Thus, the appraisal of the coal lease must be done by seam and therefore will affect multiple-

seam operations by having various alternatives to consider.

After a successful bid is indicated, pre-lease requirements must be met and stated in Proposed Part 3420--Competitive Leasing, Subpart 3422--Lease Sales, Section § 3422.2 Notice of Sale, Subsection 6

> (2) Contain the pre-lease indication of maximum economic recovery by bed of coal to be mined as a guide to bidders even though this determination would not be a lease term, and would be subject to revision in the formal MER determination to be made in mine plan

MER must be indicated by seam which again may affect multiple-seam operations.

Noncompetitive leasing regulations are covered in Proposed Part 3430 of CFR, Title 43. The only regulation applicable to multiple-seam underground mining is Subpart 3430 - Preference Right Leases, Section § 3430.2-1. Intial Showing, Subsection (a), which states

> (1) Coal quantity shall be indicated by structural maps of the tops of all beds to be mined, isopachous maps of beds to be mined and interburden; and, for beds to be mined by surface mining methods, isopachous maps of the overburden. These maps shall show the location of test holes and outcrops. An estimate of the measured and indicated reserves for each bed to be mined shall be included.

Multiple-seam operations must therefore file additional maps in conformity with this section.

4.2.3 Lease Modifications

The BLM has made the conversion from single-seam mining to multiple-seam mining available in their coal mining leases. This is shown in Proposed Part 3430, Subpart 3432-Lease Modifications, Section.

> § 3432.2 Availability.
>
> (a) The authorized officer may modify the lease to include all or part of the lands applied for if he determines that: (1) the modification serves the interests of the United States; (2) there is no competitive interest in the lands or deposits; and (3) the additional lands or deposits cannot be

developed as part of another potential or existing independent operation.

The BLM also has the reverse of the above clause. These regulations from Proposed Part 3450 - Management of Existing Leases, Subpart 3452 - Relinquishment. Cancellation and Termination read

§ 3452.1-1 General

Upon a satisfactory showing that the public interest shall not be impaired, the lessee may surrender the entire lease, a legal subdivision thereof, an aliquot part thereof (not less than 10 acres), or any bed of the coal deposits therein. A partial relinquishment shall describe clearly the surrendered parcel or coal deposits and give the exact acreage relinquished (see 43CFR 3475.5 (c).

Proposed Part 3470 Coal Management Provisions and Limitations, Subpart 3475 - Lease Terms, Section § 3475.5. Logical Mining Unit, Subsection (C), states:

(c) If, under the provisions of § 3452.1, the authorized officer accepts the relinquishment of any coal deposits in a lease, the LMU reserves shall be adjusted. When the Mining Supervisor is determining the LMU reserves, the lessee shall be consulted about any coal deposits subject to the lease which the lessee does not intend to mine. The lessee shall also be consulted about the rights the lessee is prepared to surrender to decrease the LMU reserves upon which the requirements of diligent development, continued operation, and production in commercial quantities will be based.

4.2.5 Emergency Leasing

Proposed Part § 3425.1-4, Emergency Leasing, reads:

(a) An emergency lease sale may be held in response to an application under this Subpart if the applicant shows:

(1) That the application involves an existing mining operation that has been producing coal for at least two years before the date of application, and either: (i) the Federal coal is needed within three years to maintain an existing mining operation at the current average annual level of production, or new contracted level of production to supply coal for contracts signed prior to the effective date of these regulations, as substantiated

by a complete copy of the supply or delivery contract, or both; or (ii) if the coal deposits are not leased they shall be bypassed in the reasonably foreseeable future, and if leased, some portion of the tract applied for shall be used within three years, as substantiated by the proposed production levels stated in a mining sequence plan submitted as part of the application for lease; and

(2) That the need for the coal deposits shall have resulted from circumstances that were beyond the control of the applicant or that he could not have reasonably foreseen and planned for in time to allow for consideration of leasing the tract under the provisions of § 3420.4 of this title.

(b) The extent of any lease issued under this section shall not exceed 8 years of recoverable reserves at the rate of production under which the applicant qualifies in subsection (a) (1) of this section.

(c) No lease shall be issued under this section if:

(1) the applicant holds an existing lease issued under this section.

(2) such an existing lease and the application are related to the same mining operation; and

(3) the number of years of reserves (at the calculated rate of production) leased in accordance with subsection (b) of this section is greater than the number of years that have passed since the issuance of such an existing lease.

The section authorizes the issuance of a lease in response to any application of a pre-existing mine provided they meet special needs and requirements. The amount of recoverable reserves leased will not exceed 8 years of production in order to maintain an existing operation at the current average annual level of production. Eight years may be inadequate in some instances.

4.3 Comments and Conclusions

The proposed BLM Leasing regulations provide that all seams in a lease area be assessed individually for their economic potential, and not necessarily collectively. Further, the

coals on a lease area may be leased to different parties, and their individual bids may well differ in favorability to the government, therefore, the lease terms may require mining only certain seams or only one seam, and perhaps even different operators in vertically adjacent seams.

In addition, the BLM must be notified and approve of intent to mine or not to mine seams originally not included or included in the lease, emergency leasing provisions may allow a mining firm to mine an additional seam of federal coal if not already leased or operating a lease, but for a period of 8 years only.

The proposed leasing arrangements whereby each seam must be considered individually and not necessarily collectively has the potential for great impact on multiple-seam underground coal mining and could lead to both mining and leasing delays and difficulties.

5.0 ENVIRONMENTAL REGULATIONS

5.1 Mine Drainage and Dust

An examination of pertinent federal and state environmental and reclamation regulations, including those of the Office of Surface Mining of the U. S. Department of Interior, revealed that no provisions deal with multiple-seam mining either directly or indirectly. All regulations are written on the basis of a single permit for a mine, no matter how many seams or portals are active. Thus environmental control regulations for mine drainage and other impacts from multiple-seam mining do not differ from those for single seam-mining.

5.2 Surface Effects from Underground Mining

The Office of Surface Mining of the U. S. Department of the Interior regulates surface effects from underground mining in two ways: effects of the surface plant and facilities and effects of subsidence.

This arises from the following definition of surface coal mining operations:

CFR Title 30, Chapter VII, Part 700-General

§ 700.5 Definitions:

> Surface Coal Mining Operations means: (1) Activities conducted on the surface of lands in connection with a surface coal mine or subject to the requirements of Section 516 surface operations and surface impacts incident to an underground coal mine, the products of which enter commerce or the operations of which directly or indirectly affect interstate commerce. Such activities include excavation for the purpose of obtaining coal including such common methods as contour, strip, auger, mountaintop removal, box cut, open pit, and area mining, the uses of explosives and blasting, and in-situ distillation or retorting, leaching or other chemical or physical processing, and the cleaning, concentrating, or other processing or preparation, loading of coal for interstate commerce at or near the mine site: provided, however, that such activities do not include the extraction of coal incidental to the extraction of other minerals where coal does not exceed 16 2/3 per centum of the tonnage of minerals removed for purposes of commercial use or sale or coal exploration subject to Section 512 of the Act; and (2) The areas upon which such activities occur or where such activities

5.2.2 Subsidence

Since subsidence is a surface effect of underground mining, OSM has proposed that a Subsidence Control Plan be filed for mining, which would probably be required for each episode of non-simultaneous underground multiple-seam coal mining.

Proposed § 784.20 Subsidence Control Plan:

The application shall include a survey which shall show whether structures or renewable resource lands exist within the proposed permit and adjacent area and whether subsidence if it occurred could cause material damage or diminution of reasonably foreseeable use of such structures or renewable resource lands. If the survey shows that no such structures or renewable resource lands exist, or no such material damage or diminution could be caused in the event of mine subsidence, and if the regulatory authority agrees with such conclusion, no further information need be provided in the application under this section. In the event the survey shows such structures or renewable resource lands exist, and that subsidence could cause material damage or diminution of value or forseeable use of the land, or if the regulatory authority determines that such damage or diminution could occur, the application shall include a subsidence control plan which shall contain the following information.

(a) A detailed description of the mining method and other measures to be taken which may affect subsidence, including:

(1) The technique of coal removal, such as longwall mining, room and pillar with pillar removal, hydraulic mining or other methods; and

(2) The extent, if any, to which planned and controlled subsidence is intended.

(b) A detailed description of the measures to be taken to prevent subsidence from causing material damage or lessening the value or reasonably forseeable use of the surface, including-

disturb the natural land surface. Such areas shall also include any adjacent land, the use of which is incidental to any such activities, all lands affected by the construction of new roads or the improvement or use of existing roads to gain access to the site of such activities and for haulage and excavation, workings, impoundments, dams, ventilation shafts, entryways, refuse banks, dumps, stockpiles, overburden piles, spoil banks, culm banks, tailings, holes or depressions, repair areas, storage areas, processing areas, shipping areas and other areas upon which are sited structures, facilities, or other property or material on the surface, resulting from or incident to such activities.

5.2.1 Surface Plant and Facilities

As with mine drainage and dust, the effects of the surface plant are regulated solely on a permit basis. Thus, multiple-seam mining is not currently specifically affected except in terms of additional subsurface information proposed to be required.

Proposed Part 783 - Underground Mining Permit Applications - Minimum Requirements for Information on Environmental Resources:

Proposed § 783.14 Geology Description:

(a) Geology of the strata down to and including the stratum immediately below any coal seam to be mined shall be described for those areas to be affected by surface operations or facilities, including the following data resulting from analyses of test borings, core samplings, or outcrop samples.

Proposed § 783.25 Cross sections, Maps and Plans:

(c) Nature, depth, and thickness of the coal seams to be mined, any coal or rider seams above the seam to be mined, each stratum of the overburden, and the stratum immediately below the lowest coal seam to be mined.

(d) All coal crop lines and the strike and dip of the coal to be mined within the proposed mine plan area.

(e) Location and extent of known workings of active, inactive, or abandoned underground mines, including mine openings to the surface within the proposed mine plan and adjacent areas.

(1) The anticipated effects of planned subsidence, if any;

(2) Measures, if any, to be taken in the mine to reduce the likelihood of subsidence, including such measures as-

(i) Backstowing or backfilling of voids;

(ii) Leaving support pillars of coal; and

(iii) Areas in which no coal removal is planned, including a description of the overlying area to be protected by leaving coal in place.

(3) Measures to be taken on the surface to prevent material damage or lessening of the value or reasonably forseeable use of the surface including such measures as-

(i) Reinforcement of sensitive structures or features;

(ii) Installation of footers designed to reduce damage caused by movement;

(iii) Change of location of pipelines, utility lines or other features;

(iv) Relocation of movable improvements to sites outside the angle-of-draw; and

(v) Monitoring, if any, to determine the commencement and degree of subsidence so that other appropriate measures can be taken to prevent or reduce material damage.

(c) A detailed description of the measures to be taken to mitigate the effects of any material damage or diminution of value or forseeable use of lands which may occur, including one or more of the following as required by 30 CFR 817.124-

(1) Restoration or rehabilitation of structures and features, including approximate land-surface contours, to premining condition.

(2) Replacement of structures destroyed by subsidence.

(3) Purchase of structures prior to mining and restoration of the land after subsidence to condition capable of supporting and suitable for the structures and forseeable land uses.

(4) Purchase of non-cancellable insurance policies payable to the surface owner in the full amount of the possible material damage or other comparable measures.

(d) A detailed description of measures to be taken to determine the degree of material damage or diminution of value or forseeable use of the surface, including such measures as-

(1) The results of pre-subsidence surveys of all structures and surface features which might be materially damaged by subsidence.

(2) Monitoring, if any, proposed to measure deformations near specified structures or features or otherwise as appropriate for the operation.

The Pennsylvania Bituminous Coal Mine Subsidence and Land Conservation Act of 1966 requires additional maps and other information for multiple-seam operations:

Section 5. Permit; application, map or plan; bond or other security; filing.

(a) Before any bituminous coal mine subject to the provisions of this act is opened, reopened, or continued in operation, the owner, operator, lessor, lessee, general manager, superintendent or other person in charge of or having supervision over such mine or mining operation shall apply to the Department of Mines and Mineral Industries, on a form prepared and furnished by the department, for a permit for each separate bituminous coal mine or mining operation, which permit, when issued or reissued shall be valid until such mine or mining operation is completed or abandoned, unless sooner suspended or revoked by an order of the Secretary of Mines and Mineral Industries, as hereinafter provided. As a part of such application for a permit the applicant shall furnish, in duplicate, a map or plan of a scale and in a manner in accordance with rules and regulations of the

Department of Mines and Mineral Industries showing the location of the mine or mining operation, the extent to which mining operations presently have been completed, and the extent to which mining operations will be conducted under the permit being requested. Such map or plan shall show the boundaries of the area of surface land overlying the mine or mining operation, the location and/or designation of all structures in place on the effective date of this act which overlie the proposed mine or mining operation, the name of the record owner or owners of said surface structures, the location of all bodies of water, rivers and streams, roads and railroads, and the political subdivision and county in which said structures are located. Such map or plan shall include, in addition to the information specified above, such information on the character of the mining operation, overburden, rock strata, proximity of and conditions in overlying or underlying coal seams and other geological conditions as the Secretary of Mines and Mineral Industries, by rules and regulations, shall direct. The map or plan must set forth a detailed description of the manner, if any, by which the applicant proposes to support the surface structures overlying the bituminous mine or mining operation. Upon receipt of such application in proper form, the Secretary of Mines and Mineral Industries shall cause a permit to be issued or reissued if, in his opinion, the application discloses that sufficient support will be provided for the protected structures.

In addition this Pennsylvania act requires:

Section 6. Repair of damage or satisfaction of claims: revocation or suspension of permit; bond or collateral.

(a) If the removal of coal or other mining operations by a holder of a permit granted under section 5 causes damage to structures set forth in section 4 of this act evidence that such damage has been repaired or that all claims arising therefrom have been satisfied, shall be furnished to the Secretary of Mines and Mineral Industries within six months from the date that the holder of such permit knows, or has reason to know, such damage has occurred or, at the option of the permit holder, within such period there shall be deposited with the Secretary of Mines and Mineral Industries as

security for such repair or such satisfaction a sum of money in an amount equal to said damage or the reasonable cost of repair thereof, as estimated by a reputable expert. In default of the filing of such evidence or such deposit, the Secretary of Mines and Mineral Industries shall suspend or revoke said permit.

(b) No permit revoked or suspended pursuant to this section shall be reissued or reinstated until the applicant shall have furnished satisfactory evidence to the Department of Mines and Mineral Industries that the damage for which the permit was revoked or suspended has been repaired or all claims arising therefrom satisfied, in accordance with subsection (a) above.

This provision may result in repair of surface structures two or more times rather than once after all mining has ceased, unless mining seams simultaneously.

6.0 HEALTH AND SAFETY REGULATIONS

6.1 Department of Labor - MSHA

The Mine Safety and Health Administration (MSHA) has two indirect provisions dealing with multiple-seam underground mining. Both are in CFR Title 30, Chapter I, Part 75 - Mandatory Safety Standards - Underground Coal Mines.

6.1.1 Map Provisions

The first provision requires operators of coal mines to have up-to-date maps and included on these maps location of mines above and below their operation.

Subpart M-Maps

§ 75.1200 Mine map.

(Statutory Provisions)

The operator of a coal mine shall have in a fireproof repository located in an area on the surface of the mine chosen by the mine operator to minimize the danger of destruction by fire or other hazard , an accurate and up-to-date map of such mine drawn on scale. Such map shall show:

(i) Mines above or below;
(j) Water pools above;

The provision has been provided for determing the mining conditions and should present no hardship to an operator, if the mines below or above are under the same management.

6.1.2 Provisions for Operating Under Water

The second provision is a safety measure for inundations and a coal mining operation which has an abandoned mine full of water above its operations. Therefore, this provision as stated below can indirectly affect multiple-seam mining.

Subpart R - Miscellaneous

§ 75.1716 Operation Under Water

(Statutory Provisions)

Whenever an operator mines coal from a coal mine opened after March 30, 1970, or from any new working section of a mine opened prior to such date,

> in a manner that requires the construction, operation, and maintenance of tunnels under any river, stream, lake, or other body of water, that is, in the judgment of the Secretary, sufficiently large to constitute a hazard to miners, such operator shall obtain a permit from the Secretary which shall include such terms and conditions as he deems appropriate to protect the safety of miners working or passing through such tunnels from cave-ins and other hazards. Such permits shall require, in accordance with a plan to be approved by the Secretary, that a safety zone be established beneath and adjacent to such body of water. No plan shall be approved unless there is a minimum of cover to be determined by the Secretary, based on test holes drilled by the operator in a manner to be prescribed by the Secretary. No such permit shall be required in the case of any new working section of a mine which is located under any water resource reservoir being constructed by a Federal agency on December 30, 1969, the operator of which is required by such agency to operate in a manner that protects the safety of miners working in such section from cave-ins and other hazards.

The provision provides safeguards when mining below an abandoned worked-out seam which may be full of water. In such case, the Secretary has the powers to prescribe conditions, which may be required for safe working of a seam.

6.1.3 Inspection Provisions

MSHA has the authority to conduct inspections in coal mines, as given by Public Law 91-173, Title I-General, Inspections and Investigations:

> Sec. 103. (a) Authorized representatives of the Secretary shall make frequent inspections and investigations in coal mines each year for the purpose of (1) obtaining, utilizing, and disseminating information relating to health and safety conditions, the causes of accidents and the causes of diseases and physical impairments originating in such mines, (2) gathering information with respect to mandatory health or safety standards, (3) determining whether an imminent danger exists, and (4) determining whether or not there is compliance with the mandatory health or safety standards or with any notice, order, or decision issued under this title.

> In carrying out the requirements of clauses (3) and (4) of this subsection, no advance notice of an inspection shall be provided to any person. In carrying out the requirements of clauses (3) and (4) of this subsection in each underground coal mine, such representatives shall make inspections of the entire mine at least four times a year.

As the last line of this paragraph states, 4 inspections as a minimum must be made each year, in each coal mine. Inquiries to MSHA Regional Offices indicated that a multiple-seam operation can be inspected in two ways:

- The minimum number of required inspections in each seam, as if each seam were a mine, or
- Some number of inspections in each seam totaling to the minimum number of required inspections for a mine.

Since such inspections are costly and time-consuming for the operator he would want the overall minimum number at his operation. On the other hand, an inspection resulting in closure would close the entire inspection unit whether seam or mine, so that seam-wise inspections are preferable.

MSHA Regional Offices differ in their interpretations, some consider multiple-seam mines a single inspection unit, while others let the mine operator decide.

6.2 State Agencies

Table 21 shows the ways in which underground coal mining is regulated in each of the 50 states. All states are included for the sake of completeness, even though some states effectively have no coal mines or reserves for geologic reasons. Underground coal mining may be regulated in many ways, as indicated in Table 21 , and these categories are:

- All Mining - all mining in a state, regardless of commodity or method, is regulated by the same set of regulations.
- All Coal Mining - all coal mining in a state, regardless of method, is regulated by the same set of regulations.
- Underground Coal Mining - the mining of coal by underground means is regulated by a specific set of regulations.
- Subsidence Separately - surface subsidence resulting from underground mining is regulated by a specific set of regulations.

Investigation of State Regulations Pertaining to Underground Coal Mining

State	All Mining	All Coal Mining	Underground Coal Mining	Subsidence Separately	Anthracite Separately	MSHA Only
Alabama	0	●	0	0	0	0
Alaska	●	0	0	0	0	0
Arizona	●	0	0	0	0	0
Arkansas	●	0	0	0	0	0
California	●	0	0	0	0	0
Colorado	0	●	0	0	0	0
Connecticut	0	0	0	0	0	●
Delaware	0	0	0	0	0	●
Florida	0	0	0	0	0	●
Georgia	0	0	0	0	0	●
Hawaii	0	0	0	0	0	●
Idaho	0	0	0	0	0	●
Illinois	0	●	0	0	0	0
Indiana	0	0	●	0	0	0
Iowa	0	0	0	0	0	●
Kansas	0	0	0	0	0	●
Kentucky	0	●	0	0	0	0
Louisiana	0	0	0	0	0	●
Maine	0	0	0	0	0	●
Maryland	0	0	0	0	0	●
Massachusetts	0	0	0	0	0	●
Michigan	0	0	0	0	0	●
Minnesota	●	0	0	0	0	0
Mississippi	0	0	0	0	0	●
Missouri	●	0	0	0	0	0
Montana	0	0	0	0	0	0
Nebraska	0	0	0	0	0	●
Nevada	0	0	0	0	0	0
New Hampshire	0	0	0	0	0	●
New Jersey	0	0	0	0	0	0
New Mexico	●	0	0	0	0	0
New York	●	0	0	0	0	0
North Carolina	0	0	0	0	0	●
North Dakota	0	0	0	0	0	0
Ohio	●	0	0	0	0	0
Oklahoma	●	0	0	0	0	0
Oregon	●	0	0	0	0	0
Pennsylvania	0	0	●	●	●	0
Rhode Island	0	0	0	0	0	●
South Carolina	●	0	0	0	0	0
South Dakota	0	0	0	0	0	●
Tennessee	●	0	0	0	0	0
Texas	0	0	0	0	0	●
Utah	0	●	0	0	0	0
Vermont	0	0	0	0	0	●
Virginia	0	●	0	0	0	0
Washington	0	0	0	0	0	0
West Virginia	0	0	●*	0	0	0
Wisconsin	●	0	0	0	0	0
Wyoming	0	●	0	0	0	0
	14	7	3	1	1	21

*NOTE: Including Proposed Regulations Governing Longwall Mining

● = Regulations
0 = No Regulations

- Anthracite Separately - the mining of anthracite is regulated by a specific set of regulations.
- MSHA Only - the state does not regulate underground coal mining in any fashion, but such regulation is left to MSHA.

It should be noted that MSHA regulates underground coal mining in every state whether or not the individual state does as well.

In Table 21, the solid circles indicate that a particular state regulates underground coal mining in the fashion indicated.

Reviewing the 26 sets of State regulations shown in Table 21, only three direct and indirect regulations dealing with multiple-seam underground mining appeared.

6.2.1 Health and Safety Provisions

Indiana Code 22-10, Coal Mining Laws of Indiana, Section 22-10-1-4,

Subsection (c) states:

> "When two (2) or more veins are worked in the same mine, they shall be so operated that no danger will occur to the miners in either vein."

Which is the only direct mention of mining more than one underground coal seam.

6.2.2 Map Provisions

Within the different state regulations two indirect regulations are worth commenting about. One deals with maps, which is the same as the MSHA regulation. This regulation was found in the Coal Mining Laws of Alabama, Coal Mining Laws of Colorado, Coal Mining Act of Illinois, Coal and Clay Mining Laws of Kentucky, Pennsylvania's Bituminous Underground Coal Mining Laws, and West Virginia's Underground Coal Mining Laws.

An example of this is Coal Mining Laws, State of Colorado, Article 30, Section 34-30-101, Maps required-certified, which states

> (1) The owner of each coal mine shall make first, a map of the surface of the property; second, a map of the underground workings of each and every seam of coal worked in the same mine; third, a final and complete map of every mine about to be abandoned or closed indefinitely.

6.2.3 Right-of-Way Provisions

The second indirect regulation deals with "Tunnel, Right-of-Way" found in Pennsylvania's Bituminous Underground Coal Mining Laws and Coal Mining Laws of Colorado. The "Coal Mining Laws, State of Colorado" also give a good example of this regulation in Article 31, Section 34-31-101. Tunnels - rights-of-way - condemnation.

> (1) The owner or his agent of any coal lands lying on two or more sides of the property of another shall have the right to enter and cross such adjoining or intermediate claims or property with such drifts, tunnels, and crosscuts as may be necessary for the practical or economical mining and development of his own property and for the purpose of extracting and removing coal there from. Such drifts, tunnels, crosscuts, and entries for the mining and development of coal shall not exceed six hundred sixty feet in length and shall not enter or cross any adjoining or intermediate claims or property which are operated at the time of entry or may reasonably be expected to be operated in the future either as a coal mine or as a part of an operating coal mine.
>
> (2) Neither shall such drifts, tunnels, crosscuts, or entries for coal mining enter a seam of coal which it may reasonably be expected will be operated or mined in the future. Any such drifts, tunnels, crosscuts, or entries driven for the development of coal lands or which cross coal lands must conform to all pertinent laws relating to coal mines, and in no event shall such tunnels, drifts, crosscuts, or entries for coal mining be driven or maintained across any intermediate property if they interfere with the operation of said intermediate claim or property, nor if such drifts, tunnels, crosscuts, or entries for coal mining will interfere with the ventilation of any operations then or thereafter to be conducted in said intermediate property, nor if said drifts, tunnels, crosscuts, or entries for coal mining will damage the surface of said intermediate property or any seams of coal lying above said drifts, tunnels, crosscuts or entries. In the construction of such drifts, tunnels, crosscuts, or entries for coal mining, no barrier pillars may be removed or destroyed without the consent of the owners of such barrier pillars.

6.3 Comments

The provisions for preparation of maps and plans for all seams, irrespective of whether these are being worked by the same operator or different operators is for better and accurate information.

6.4 States not Having Laws Affecting Underground Multiple-Seam Mining

Applicable undergound coal mining health and safety regulations having no multiple-seam provisions are State of Alaska Mine Safety and Conservation Regulations; Mining Code of the State of Arizona; Mining Laws of the State of Arkansas; State of California Mine Safety Order; Minnesota Statutes; New Mexico Mine Safety Code for All Mines; Rules and Regulations of the State of New York; Underground Mining Operations; Mining Laws of Ohio; Oklahoma Mining Laws; Pennsylvania Anthracite Coal Mine Act; South Carolina Mining Act; Mines and Mining Laws and Regulation (Tennessee); General Safety Orders Utah Coal Mines; Mining Laws of Virginia; Mine, Pit and Quarries (Wisconsin); and Laws of the State of Wyoming.

7.0 MINING OPERATIONS

7.1 General

Various federal and state regulations affect multiple-seam mining methods by requiring that pillars be left unmined for different reasons. The leaving of such pillars can significantly affect the strata control and other aspects of overlying or underlying mines consequent upon subsidence.

Because of the importance of remnant pillar effects on mining operations overlying or underlying one another the question of remnant pillars have been dealt with in this separate section.

7.2 Safety Separation Pillars

7.2.1 MSHA Safety Separation Pillars

The following are the regulatory provisions CFR Title 30, Chapter I, that require the leaving of pillars in various mining operations for the mine life.

Section §57.3 - Ground Control Sub-Section §57.3-29

Shaft pillars should have sufficient strength to protect operating shafts.

Section § 57.11-1 - Surface and Underground:

Mandatory - Safe means of access shall be provided and maintained to all working places.

For underground mines, those provisions have been further elaborated in § 57.11-50.

§ 57.11-50 Mandatory

Every mine shall have two or more separate, properly maintained escapeways to the surface from the lowest levels which are so positioned that damage to one shall not lessen the effectiveness of the others. A method of refuge shall be provided while a second opening to the surface is being developed. A second escapeway is recommended, but not required, during the exploration or development of an ore body.

In addition to separate escapeways, a method of refuge shall be provided for every employee who cannot reach the surface from his working

place through at least two separate escapeways within a time limit of one hour when using the normal exit method. These refuges must be positioned so that the employee can reach one of them within 30 minutes from the time he leaves his workplace.

For underground coal mines, these provisions have been further clarified in §75.1704 and §75.1707.

§ 75.1704 Escapeways

(Statutory Provisions)

Except as provided in § 75.1705 and 75.1706, at least two separate and distinct travelable passageways which are maintained to insure passage at all times of any person, including disabled persons, and which are to be designated as escapeways, at least one of which is ventilated with intake air, shall be provided from each working section continuous to the surface escape drift opening, or continuous to the escape shaft or slope facilities to the surface as appropriate, and shall be maintained in safe condition and properly marked. Mine openings shall be adequately protected to prevent the entrance into the underground area of the mine of surface fires, fumes, smoke, and floodwater. Escape facilities approved by the Secretary or his authorized representative, properly maintained and frequently tested, shall be present at or in each escape shaft or slope to allow all persons including disabled persons to escape quickly to the surface in the event of an emergency.

§ 75.1707 Escapeways; intake air; separation from belt and trolley haulage entries.

(Statutory Provisions)

In the case of all coal mines opened on or after March 30, 1970, and in the case of all new working sections opened on or after such date in mines opened prior to such date, the escapeway required by this section to be ventilated with intake air shall be separated from the belt and trolley haulage entries of the mine for the entire length of such entries to the beginning of each working section, except that the Secretary or his authorized representative may permit such separation to

be extended for a greater or lesser distance so long as such extension does not pose a hazard to the miners.

7.2.2 State Safety Separation Pillars

Various states also have remnant pillar regulations discussed in detail below.

Coal Mining Laws of the State of Colorado, Title 34 Article 26, - Roof Control:

> 34-26-115-(1) (b) Each coal mine and every separate coal seam worked in the same mine, whether such coal mine or seam is worked by shaft, slope, or drift, shall have at least two properly equipped and properly maintained openings available for exit for all persons working in such mines, and one of these openings may be the main delivery shaft or opening and the second opening or escapement may be a shaft, slope, drift, or underground passageway to an available outlet of a contiguous operating mine, and such outlet of a contiguous mine and approaches to such outlet shall be maintained in good condition.
>
> (2) In mines opened on or after March 21, 1951, all vertical shafts shall be separated by not less than one hundred fifty feet of distance, and shaft pillars extending not less than one hundred fifty feet from the shafts shall be established. Only the neccessary entries and passageways for the operation of the shaft bottom pumping station, and waiting rooms may be excavated through this shaft pillar. Sufficient pillars shall be under main rock slopes throughout their entire length, but in no case shall the coal pillars left beneath the slopes be less than seventy-five feet on each side of the slopes. Where main slopes are driven in the coal seam, they shall be separated by not less than a fifty-foot pillar of coal, and flanking pillars of at least seventy-five feet in width shall be left alongside of slopes throughout their entire length where minimum distance and size of supporting pillars have been prescribed.

The Coal Mining Act of the State of Illinois, Article 19:

> Section 19.02. In mines sunk after July 1, 1911, the first escapement shaft shall be separated from the main shaft by such extent

> of natural strata as may be agreed upon by the State Mine Inspector of the district and the owner of the property, but the distance between the main shaft and the escapement shaft shall not be less than 500 feet nor more than 2,000 feet; except that in mines employing 10 men or less the distance between the hoisting shaft and the escapement shaft shall not be less than 250 feet.

The act does not prohibit dividing the distance between escapement, and consequently development with room-and-pillar is done in the intervening area.

The Coal Mining Laws of Indiana, Indiana Code 22-10 Section 87. IC 22-10-11-4:

> (B) The distance between shafts at any mine opened after March 8, 1955, shall be not less than one hundred fifty (150) feet, and the distance between drift or slope openings at such mines shall be not less than fifty (50) feet.

The New Mexico Mine Safety Code for All Mines, Article 9-Safety Regulation Escapeways in Coal Mines:

> 63-9-1. ESCAPEWAYS-REQUIREMENTS. Every underground coal mine shall have two (2) or more ways of escape to the surface so arranged and equipped that people can escape quickly. In coal mines hereafter opened, such ways of escape shall be spaced by at least fifty (50) feet of ground unbroken, safe by crosscuts, throughout their length if drifts or slopes and by at least two hundred (200) feet if shafts so that damage to one from any source shall not thereby lessen the effectiveness of the other as a means of escape....

The Bituminous Coal Mining Laws of Pennsylvania for Underground Mines, Article II-N, Section 290-Mine Openings or Outlets - Subsection (a) -

> The distance between two shafts shall not be less than two hundred feet, and the distance between the openings to the surface of the slopes shall not be less than one hundred and fifty feet, and the distance

between drifts shall not be less than fifty feet.... The passageways between said two shafts shall at all times be maintained in safe and available condition for the employees to travel therein, and the pillars in entries between said shall not be removed....

The laws in Subsections (d) and (g) go on further to define the number and position of such entries and separation of these entries by coal pillars.

(d) Every gassy mine shall have at least four main entries, two of which shall lead from the main opening and two from the second opening into the body of the mine; provided, that every new gassy mine, projected to open up a large acreage with main entries five thousand feet or more in length shall have at least five main entries, two of which shall lead from the main opening and two from the second opening into the body of the mine and the fifth, which may be connected with an opening to the surface or with the intake airway at or near the main intake opening shall be used exclusively as a travelingway for the employees.

(g) The intake and return entries shall be kept reasonably drained and reasonably free from refuse and obstructions of all kinds, so that persons may safely travel therein throughout their whole length, and have a safe means of egress from workings in case of emergency. Said entries shall be separated by pillars of coal of sufficient strength.

The West Virginia Mining Laws - 22, Article 2 Coal Mines:

Section 22-2-60. Accessible outlets; safe roadways for emergencies.

(a) No operator or mine foreman of any coal mines shall employ any person to work in such mine, or permit any persons to be in the mine for the purpose of working therein unless they are provided with two openings or outlets to each seam, separated by natural strata, such openings to be not less than three hundred feet apart, if the mine be worked by shaft; if the mine be

> worked by shaft and slope, such openings shall be separated by one hundred feet of natural strata; and not less than fifty feet apart at the outlets, if worked by slope or drift; but this requirement of a distance of three hundred feet between openings or outlets to shaft mines shall not apply where such openings or outlets have been made prior to the effective date of this article.

These federal and state laws require coal pillars of various sizes and positions for support and service of coal mines, through the entire life of the mine.

7.3 Pillars Required for Ventilation Purposes

7.3.1 MSHA General Ventilation Pillar Regulations

Abandoned areas where pillars have been wholly or partially extracted are required to be continuously ventilated by means of bleeder entries, as is required by the provisions of Part 75.

> § 75.316-2 Criteria for approval of ventilation system and methane and dust control plan.
>
> (e) Bleeder entries, bleeder systems, or equivalent means should be used in all active pillaring areas to ventilate the mined areas from which the pillars have been wholly or

partially extracted, so as to control the methane content in such areas. Bleeder entries or bleeder systems established after June 28, 1970. Should conform with the requirements of this § 75.316-2.

(1) Bleeder entries shall be defined as special aircourses developed and maintained as part of the mine ventilation system and designed to continuously move air-methane mixtures from the gob, away from active workings and deliver such mixtures to the mine return aircourses. Bleeder entries should be connected to those areas from which pillars have been wholly or partially extracted at strategic locations in such a way to control airflow through such gob area, to induce drainage of gob gas from all portions of such gob areas and to minimize the hazard from expansion of gob gases due to atmospheric pressure change.

(2) Bleeder systems shall include any combination of bleeder entries, bleeder entry connections to any area from which pillars are wholly or partially extracted and all associated ventilation control devices. Such systems should extend from active pillar line of such gob to the intersection of that bleeder split with any other split of air and shall not include active workings.

(f) (1) Bleeder entries developed after June 28, 1970 should be adequately maintained and free of water to permit safe travel or, if such bleeder entries cannot be traveled without exposing the mine examiner to undue hazard, such bleeder system should be designed and maintained so that bleeder entry performance can be evaluated for adequacy and continuity by a means approved by the Coal Mine Safety District Manager.

At present, recovering pillars without bleeder entries can not be done, as is explicit from the provisions of:

§ 75.318 Pillar recovery without bleeder system.

(Statutory Provisions)

Where areas are being pillared on March 30, 1970 without bleeder entries, or without

bleeder systems or any equivalent means, pillar recovery may be completed in the area, to the extent approved by an authorized representative of the Secretary, if the edges of pillar lines adjacent to active workings are ventilated with sufficient air to keep the air in open areas along the pillar lines below 1.0 volume per centum of methane.

The regulation thus requires leaving at least two lines of chain pillars around an area, from where pillars have been or are being wholly or partially recovered.

7.3.2 State General Ventilation Pillar Regulations

The Coal Mining Laws of the State of Alabama provide:

Section 16. Coursing of Air.

(a) Two available openings to the surface are required from each seam or stratum of coal worked. In drift or slope mines these openings provided after the effective date of this Act must be separated by not less than forty feet of natural strata, and all crosscuts between them shall be closed with stoppings of fireproof material. In shaft mines these openings provided after the effective date of this Act must be separated by not less than two hundred feet of natural strata. The second opening may be made through an adjoining mine. Until these provisions are met, not over five men in a drift, ten men in a slope and twenty men in a shaft shall work in the mine at one time, and no additional development shall be permitted until the connection is made to the second opening. In mines wherein final pillar robbing operations necessitate closing the second opening, the above limitations as to the number of men permitted to work will apply until mine is worked out and abandoned.

This regulation also requires that the intake and return airways must be separated by natural strata having a width not less than 40 ft in case of slope and 200 ft in case of shaft mines.

7.3.3 Air Velocity and Beltway Regulations

7.3.3.1 MSHA Air Velocity and Beltway Regulations

There are limitations on the velocity and position of belt haulageways. These are provided for in Part 75, Section 75:

§ 75.326 Aircourses and belt haulage entries.

(Statutory Provisions)

In any coal mine opened after March 30, 1970, the entries used as intake and return air courses shall be separated from belt haulage entries, and each operator of such mine shall limit the velocity of the air coursed through belt haulage entries to the amount necessary to provide an adequate supply of oxygen in such entries, and to insure that the air therein shall contain less than 1.0 volume per centum of methane, and such air shall not be used to ventilate active working places. Whenever an authorized representative of the Secretary finds, in the case of any coal mine opened on or prior to March 30, 1970, which has been developed with more than two entries, that the conditions in the entries, other than belt haulage entries, are such as to permit adequately the coursing of intake or return air through such entries, (a) the belt haulage entries shall not be used to ventilate unless such entries are necessary to ventilate, active working places, and (b) when the belt haulage entries are not necessary to ventilate the active working places, the operator of such mine shall limit the velocity of the air coursed through the belt haulage entries to the amount necessary to provide an adequate supply of oxygen in such entries, and to insure that the air therein shall contain less than 1.0 volume per centum of methane.

Similar restrictions on velocities are also provided for trolley haulage systems. These are enumerated in Part 75, Subsection:

§ 75.327 Aircourses and trolley haulage systems.

(Statutory Provisions)

In any coal mine opened on or after March 30, 1970, or in the case of a coal mine opened prior to such date, in any new working section of such mine, where trolley haulage systems are maintained and where trolley wires or trolley feeder wires are installed, an authorized representative of

the Secretary shall require a sufficient number of entries or rooms as intake aircourses in order to limit, as prescribed by the Secretary, the velocity of air currents on such haulageways for the purpose of minimizing the hazards associated with fires and dust explosions in such haulageways.

§ 75.327-1 Velocity of air.

Unless a higher velocity is approved by the Coal Mine Safety District Manager, the velocity of the air current in the trolley haulage entries shall be limited to not more than 250 feet a minute. A higher air velocity may be required to limit the methane content in such haulage entries or elsewhere in the mines to less than 1.0 per centum and provide an adequate supply of oxygen.

These restrictions, require splitting air in such a way that at least one clear and straight roadway, in addition to the main air intake, have limited air velocity available for use as a trolley and/or belt haulageway.

7.3.3.2 State Air Velocity and Beltway Regulations

Bituminous Coal Mining Laws of Pennsylvania for Underground Mines, Article II, Sec. 242-Ventilation Requirements state in Subsection:

(c) Where belt conveyors are installed, main stoppings and regulators shall be so arranged as to reduce the quantity of air traveling in the belt conveyor entry to a minimum for effective ventilation and to provide an intake air split as an escapeway from the face area to the main air current.

This regulation requires that belt conveyors be in a natural airway with the provision of a separate air split for use as an escapeway from the face.

7.3.4 Abandoned Area Ventilation Regulations

7.3.4.1 MSHA Abandoned Area Ventilation Regulations

Specific requirements for underground coal mines can be deduced from the requirements in Part 75, Subsection 75.330-1, Plan for sealing abandoned sections.

§ 75.330-1 Plan for sealing abandoned sections.

For approval the plan for isolating each set of cross entries, room entries, or panel entries shall include the following:

(a) A mine map at a scale not more than 500 feet to the inch which is sufficiently detailed to illustrate the mining system employed, depth of cover and dimensions of barrier pillars left in place bordering such areas, the proximity of all active workings, and the proposed location and sequence of construction of all necessary mine seals required, when mining is complete in a mining area. Such map shall illustrate the location of such mine seals as may be required should mining conditions necessitate abandonment of a mining area prior to the scheduled completion date.

(b) A detailed drawing or drawings of proposed explosion-proof seal construction which shall meet the requirements of §75.329.2. Such drawings shall show the pillars in which the seals will be erected and such pillars shall be of sufficient size and number to protect the seals. These provisions in effect require that the workings be arranged to provide for bleeder ventilation during recovery of pillars and arranged in panels with solid barriers of coal so that they can be sealed. The seals should be so located that they are always accessible to measurements and drainage of water and gas.

7.3.4.2 State Abandoned Area Ventilation Regulations

Bituminous Coal Mine Laws of Pennsylvania for Underground Mines, Article II, Section 247.

> Section 247. Unused and Abandoned Parts of the Mine.
>
> In a gassy mine all workings which are abandoned after the effective date of this act, or the dates such mines became a gassy mine, whichever is later, shall be ventilated. Return air may be used to ventilate such areas. The plan of ventilation of abandoned and unused parts of the mine shall be approved by the mine inspector in the district.

This provision requires such areas to be continuously ventilated in gassy mines.

West Virginia Mine Laws - Act 22. Article II.

> Section 4, Subsection
>
> (h) In all mines a system of bleeder openings or air courses designed to provide positive movement of air through and/or around abandoned or caved areas, sufficient to prevent dangerous accumulation of gas in such areas and to minimize the effect of variations in atmospheric pressure shall be made a part of pillar recovery plans projected after the effective date of this article.
>
> (i) If a bleeder return is closed as a result of roof falls or water during pillar recovery operations, pillar operations may continue without reopening the bleeder return if at least twenty thousand cubic feet of air per minute is delivered to the intake of the pillar line.

Thus positive air movement through and/or around abandoned or caved areas is required.

7.5 Mining Methods

7.5.1 Room And Pillar Methods

7.5.1.1 MSHA Room and Pillar Methods

The general principles of planning and development are provided in Section 75:

> Subsection §75.330 Sealing abandoned sections
>
> (Statutory Provisions)

In the case of mines opened on or after March 30, 1970, or in the case of working sections opened on or after such date in mines open prior to such date, the mining system shall be designed in accordance with a plan and revisions thereof approved by the Secretary and adopted by such operator so that, as each working section of the mine is abandoned, it can be isolated from the active workings of the mine with explosion-proof seals or bulk-heads.

General guidelines for pillar recovery are outlined in Part 75, Section 201, Subsection:

§ 75.201-2 Pillar recovery methods.

In addition to those criteria set forth in

§ 75.200-11 which may be required in the roof control plan, the following shall apply to pillar recovery:

(a) The overall pillar recovery system shall be designed to minimize the possibility of outbursts or squeezes. The manner and sequence of recovery shall be included in the roof control plan submitted for approval.

(b) Where full pillar recovery is being done, extraction shall be such as to allow total caving of the main roof in the pillared area.

(c) During partial pillar recovery sufficient coal shall be left in place to support the main roof to the extent that the possibility of undue forces overriding the working places will be minimized.

(d) A combination of full and partial pillar recovery shall not be conducted on the same pillar line.

(e) If full extraction of pillars is being done and physical conditions such as standing water, adverse roof conditions, and falls of roof, or law requirements concerning oil and gas wells or surface subsidence dictate that some pillars of coal are to be left in place, a sufficient amount of coal shall be left to support the main roof so as to minimize the possibility of undue forces overriding the working places.

(f) Where full recovery of pillars is planned, the design of the pillars shall be compatible with the planned method of extraction.

General guidelines, for mining operations just before the abandonment of a mine are given in Part 75, Section 1706 - Final Mining of Pillars.

§75.1706 Final mining of pillars

(Statutory Provisions)

When only one mine opening is available, owing to final mining of pillars, not more than 20 miners shall be allowed in such mine at any one time, and the distance between the mine opening and working face shall not exceed 500 feet.

7.5.1.2 State Room and Pillar Methods

There are no applicable state regulations on this subject that are more specific or more stringent than MSHA regulations.

7.5.2 Longwall Mining Regulations

7.5.2.1 MSHA Longwall Mining Regulations

The federal regulations do not have any specific regulations which give any guidelines for longwall mining methods.

7.5.2.2 State Longwall Mining Regulations

Only one state, West Virginia, has attempted to provide regulations for longwall mining. These Proposed Rules and Regulations Governing Longwall Mining Within the State of West Virginia were published for comments from interested persons on December 10, 1979.

Definitions of a few terms are given in Proposed Chapter 22, Article 2, are reproduced below:

3.02 "Longwall Working Section" - The term Longwall Working Section shall mean all areas three hundred (300) feet outby the longwall working face.

3.03 "Longwall Section Last Open Crosscut" - The term Longwall Section Last Open Crosscut shall mean the first open crosscut outby the caving line.

3.04 "Caving Line" - The term Caving Line shall mean the line on the roof formed by the rear most projection of the roof support canopies once the longwall section has started retreating.

Chapter 22, Article 2, Section 5, Subsection 5.01. Paragraph (I)

SECTION 5. PLANS FOR LONGWALL MINING APPROVAL BY THE DIRECTOR OF THE DEPARTMENT OF MINES

5.01 (I) Ventilation Plan, which shall include the complete section and face ventilation system, showing ventilating controls and bleeder systems.

A review of these rules indicate that they are exclusively meant for longwall retreat mining and do not cover advancing longwall mining.

These also require a bleeder system for ventilation of caved areas.

7.6 Pillars for Special Supports

7.6.1 MSHA Special Pillar Support Regulations

Occasionally, pillars and chain of pillars are required to be left in place for safety and geological or technological reasons. Examples for these exigencies are enumerated in Part 75, Section 75. They are:

§75.1700 Oil and gas wells.

(Statutory Provisions)

Each operator of a coal mine shall take reasonable measures to locate oil and gas wells penetrating coalbeds or any underground area of a coal mine. When located, such operator shall establish and maintain barriers around such oil and gas wells in accordance with State laws and regulations, except that such barriers shall not be less than 300 feet in diameter, unless the Secretary or his authorized representative permits a lesser barrier consistent with the applicable State laws and regulations where such lesser barrier will be adequate to protect against hazards from such wells to the miners in such mine, or unless the Secretary or his authorized representative requires a greater barrier where

the depth of the mine, other geologic conditions, or other factors warrant such a greater barrier.

The "depth of mine" and "other factor" provisions may possibly result in non-superposed pillars in multiple-seam mining.

§ 75.201-2 Pillar recovery methods.

(e) If full extraction of pillars is being done and physical conditions such as standing water, adverse roof conditions, and falls of roof, or law requirements concerning oil and gas wells or surface subsidence dictate that some pillars of coal are to be left in place, a sufficient amount of coal shall be left to support the main roof so as to minimize the possibility of undue forces overriding the working places.

7.6.2 State Special Pillar Support Regulations

There are no state special pillar support regulations that are more specific or stringent than MSHA regulations.

7.7 Ground Support and Subsidence

If mining is conducted below surface bodies of water (such as rivers and canals, dams and natural lakes, ponds or tanks), prime farmlands, surface structures, public and private roads, railway lines, or urban and industrial areas, no subsidence or damage to the surface and surface structure is permitted.

Permanent support is required to be provided by leaving enough coal in the form of pillars. These pillars are required to be of such size and strength so as to give support permanently.

The effect of coal recovery on each seam is the same, and multiple-seam mining has no effect on recovery, nor have any rules or laws been found that affect working of multiple seams.

7.8 Concurrent Surface and Underground Mining

The Office of Surface Mining proposed regulations for concurrent surface and underground mining require barrier pillars between each seam and the surface:

Proposed CFR Title 30, Chapter VII, Part 818 - Special Permanent Program Performance Standards - Concurrent Surface and Underground Mining,

§ 818.15 Additional performance standards.

In addition to the requirements of 30 CFR 816 and 817, each person who conducts combined surface and underground mining activities shall comply with the following:

(a) A 500-foot barrier pillar of coal shall be maintained between the surface and underground mining activities in any one seam.

This provision could result in non-superposed pillars when contour strip mining exists in multiple seams that are also being mined underground.

7.9 Discussion

There are no specific federal or state regulations that regulate multiple-seam mining, but many provisions do have considerable impact on multiple-seam coal mining.

The means of ingress and egress require the maintenance of at least two exits, one of which shall be in the intake airway. Since the belt and trolley ways are required to be in neutral or restricted air velocities, they cannot be used as a second escapeway and consequently a second escapeway is required. Thus the provisions of the law require at least three entries, separated and protected by coal pillars of sufficient strength and flanked by protective pillars of adequate size. As such, rows of at least four pillars are necessary for the maintenance of main and submain entries.

The law does not prohibit extraction of these chain pillars and barriers as final operation before abandonment of a mine or seam. The mains and sub-mains are always the first to be driven and are required to serve the mine throughout its life. The roof, floor, and pillars deteriorate in the majority of cases and consequently their extraction becomes costly, slow, and unsafe and so they are usually left in place.

The requirements for sealing abandoned sections and for continuous ventilation of all areas from where pillars have been wholly or partially recovered or are being recovered, and for bleeder entries or equivalent means, necessitates leaving at least one row of pillars around the panel barrier until such time as the panel is sealed.

Though the law does not prohibit partial or even full extraction of panel barriers and pillars left for bleeder ventilation as final operation before abandonment, the operating, economic, and safety considerations do not offer sufficient attraction for barrier recovery when both men and equipment need to be employed for extraction of one row of pillars situated between gobs of two adjacent panels.

In longwall workings, the entries used as intake and return airways have to be separated from belt and trolley entries. This requires the driving of at least three entries during development. Since pillars can not be extracted with the longwall face, due to both limitations of available machinery and ventilation of gob through bleeder airways, two rows of pillars are left unworked between successive longwall retreating faces.

Few experimental advancing longwall faces operated in the United States have been granted variances from these provisions of law, but in these cases, the gate entries are required to be divided into two entries for each head and tail gate, either by means of a row of closely spaced cribs with partitions or by building a pack-wall, cast in place. These packwalls have the same effect as leaving a row of pillars left between two successive longwall faces.

Working of contiguous seams with small partings has been successfully done by driving entries through the destressed zone lying above or below a previously mined seam. This necessitates driving entries in the subsequently mined seam and not vertically above or below the entries of previously-mined seams. Such drivage is not permitted by CFR Title 30, Chapter II, Section 211; Subsection 211.32 (b), which requires that the protective barriers for all main and secondary slope entries, main haulageways, primary air courses, bleeder entries, and manways in each seam shall be superposed.

8.0 UNIONS AND ORGANIZED LABOR

8.1 United Mine Workers of America

The 1978 Contract between the United Mine Workers of America and the Bituminous Coal Operators Association contains no specific provisions dealing with underground multiple-seam coal mining.

However, there are two provisions which might indirectly affect the start-up of a mine or operation in another seam where one seam is already being mined. Theses are:

> Article IA, Scope and Coverage, Section (f), Application of This Contract to the Employer's Coal Lands.
>
> As part of the consideration for this Agreement, the Employers agree that this Agreement covers the operation of all the coal lands, coal producing and coal preparation facilities owned or held under lease by them, or any of them, or by any subsidiary or affiliate at the date of this Agreement, or acquired during its term which may hereafter (during the term of this Agreement) be put into production or use.
>
> Article IA, Scope and Coverage, Section (h), Leasing, Subleasing and Licensing out of Coal Lands.
>
> The Employers agree that they will not lease, sublease or license out any coal lands, coal producing or coal preparation facilities where the purpose thereof is to avoid the application of this Agreement or any section, paragraph or clause thereof.
>
> Licensing out of coal mining operations on coal lands owned or held under lease or sublease by any signatory operator hereto shall not be permitted unless the work involved is performed by members of the United Mine Workers of America in the manner and to the extent permitted by law and that the licensing out does not cause or result in the layoff of Employees of the Employer: provided, however,that either the licensor or licensee, lessee or sublessee makes the appropriate payments provided by this Agreement to the United

Mine Workers of America Health and Retirement Fund and otherwise abide by the terms of the Agreement.

Thus, an Employer must have all his mines organized by the UMWA, and further, any other mines in the same lease must also be UMWA organized.

8.2 Organized Mine Units

It was noted during this project that some Employers, that is, mining companies, would have each different seam operation in a multiple-seam mining situation organized into a different "mine" with a different UMWA local, so that if a wildcat strike developed in one seam, the production of the others would not be affected.

9.0 TECHNOLOGICAL IMPACTS

The impacts of regulatory and other constraints have been evaluated for the application of multiple-seam underground mining technology as applicable to the United States.

9.1 Resource Recovery and Leasing for Maximization of Recovery

The proposed BLM leasing regulations provide that all seams in a lease area be assessed individually for their economic value. The coals in a lease area may be leased to different parties whose individual bids may differ. The lease terms may require mining certain seams, only one seam, or only a specific portion of a single seam, with perhaps different operators in vertically adjacent seams.

The BLM must be notified in order to approve the intent to mine or not-to-mine seam(s) originally not included or included in the lease. Emergency leasing provisions may allow an operator to mine an additional seam of federal coal, if not already leased or not being mined, but for a maximum period of only 8 years.

The proposed leasing arrangements, whereby each seam must be considered separately, has the potential for loss of an overlying seam which is uneconomical individually, but economical, if considered collectively with an adjacent seam. This may also be true for an underlying seam in close proximity to the seam proposed to be leased and mined.

The mining of coal in multiple-seam areas, calls for composite plans and proper sequencing of mining operations in each seam. The provisions for assessment of each seam separately and possible leasing of different seams to different operators, does not provide conditions conducive for the preparation of proper composite plans and sequence of operations.

Provisions of emergency leasing, by which the coal leased is restricted, are likely to lead to quick production planning and procedures.

9.2 Present Technology

The effects of various constraints for commonly used methods are briefly discussed. If should be noted that there is a certain amount of repetition in order to make each sub-section complete in itself.

9.2.1 Room-and-Pillar Mining Without Pillar Recovery

Mining of coal from two or more seams with room-and-pillar mining without pillar recovery is being done in seams up to six feet thick, and partings of 30 ft and above and in areas where no surface subsidence or damage to surface structures is desired.

This method leaves more than 50% of insitu coal reserves, including that left in barriers for surface support.

The USGS regulations concerning superposition of entries in multiple-seam mining, could lead to an impact in extra care in planning, mining, and surveying, if an operator strictly followed those requirements.

Since no environmental change takes place in the area of mining in this method, there is no impact from any of the provisions related thereto. However at mines where coal from different seams is stacked separately for blending, in order to satisfy consumer specifications, two separate stacking yards with related reclamation facilities are required to meet the provisions regarding surface area, dust control, and so on, but these will be operated as one permit.

The provisions for preparation of mine maps; prevention of imminent dangers such as inundations, explosions, and fire do not impose any hardships on the operator due to multiple-seam working. Further, if two or more seams are worked through common portals and the mine is treated as one mine for inspection purposes, there is a possibility of considerable savings in cost, time, and manpower to the operator from fewer overall inspections.

As no pillar recovery is planned, there is no effect from any provisions regulating the number of entries, their size, their position with respect to each other, or their ventilation.

The method has been widely used in this country and consequently both the mine management personnel and mine workers are quite intimately familiar with the consequences.

9.2.2 Room-and-Pillar Mining with Pillar Recovery

The mining of coal from two or more seams using room-and-pillar mining methods with recovery of pillars is currently practiced for seams with partings for 45 ft and above, and depths up to 900 ft in areas where surface subsidence can be tolerated.

The provisions for superpositioning of workings could lead to additional impacts for planning, mining, and surveying effort, if followed strictly. Environmental control regulations for mine drainage,ventilation, and other mine operations do not have any extra impacts on multiple seam mining with pillar recovery for subsidence.

As the extraction of pillars from each seam is done sequentially with a time gap, subsidence control plans for each seam will have to be prepared. This calls for the study and description of measures to prevent subsidence and to minimize the effects of subsidence.

The Pennsylvania Bituminous Coal Mine Subsidence and Land Conservation Act of 1966 also requires that the repair of damage or satisfaction of claims shall be completed within six months. This can result in repairs to a surface structure two or more times, unless the seams are mined simultaneously or within six months of each other.

The provisions for preparation of mine maps, and 4 inspections by MSHA relating to health and safety conditions do not impose any additional hardship on the operator due to multiple-seam working. If two or more seams are worked through common portals and the mine is treated as one mine for inspection purposes, there is a definite possibility of savings in cost, time, and manpower to the operator.

The previously-mined seam(s) may contain accumulations of water, or gas, or have fire in the gob. These conditions can give rise to damage associated with each, and to the related restrictions and permits.

The regulatory provisions for preventing these dangers are likely to affect recovery, productivity, and mining cost.

There is no federal or state health and safety legislation that has a specific effect on the mining of multiple seams with pillar recovery. These provisions do not prohibit extraction of chain pillars left for gob ventilation, panel barriers or pillars and barriers for maintance of sub-main and main entries, as the final operation. Only economic, operating, and safety considerations dictate leaving chain pillars and other pillars.

Both overmining and undermining of coal seams is being conducted in the United States. Opinions of mine management personnel differ on the question of workability of multiple seams, but it is generally believed that if the workings are columnized, then overmining can be done without much loss of recovery or increase in cost, provided the parting

is 100 to 120 ft. Undermining of a coal seam is possible if the parting is 50 to 60 ft.

9.2.3 Longwall Mining

The general trend towards the working of coal seams appears to favor longwall mining methods. Many of the longwall faces are working below another seam - some of which have been mined by room-and-pillar methods. The method is being used with partings as small as 30 ft.

It is provided in CFR Title 30, Chapter I, Part 75, Subpart C, that

> § 75.201-3 Longwall mining.
>
> Longwall mining shall be considered as a modification of the open-end method of pillar extraction and the support system for the longwall shall be approved on an individual basis.

Thus longwall mining is treated as a modification of a method of pillar extraction.

The environmental, health and safety, and mining operational provisions for longwall mining are essentially the same as for room-and-pillar mining and have been discussed earlier. No regulatory provisions exist which inhibit or prohibit multiple-seam mining by longwall methods.

9.3 New Technology

Based on the current state-of-the-art for the mining of multiple coal seams in European and British practice, possible regulatory and other institutional constraints to common extraction techniques are discussed.

9.3.1 Simultaneous Mining

Simultaneous mining is a method of working two seams where the line of extraction in the two seams is kept more or less vertically superposed. The line of extraction in the upper seam is sometimes kept slightly ahead of the lower seam working, with the distance being about one pillar length in the case of room-and-pillar workings where seams with 10-ft parting have been worked. The distance or stagger in case of longwall workings is from 20 to 150 ft, where seams with partings of up to 2 ft are reported to have been worked.

The environment, health and safety, and mining operation provisions do not alter simultaneous operations of two seams

and have no regulatory provisions that inhibit or prohibit multiple-seam mining.

Because the line of extraction in the upper seam with respect to workings is the same as for single-seam mining, strata control is easier. Because the line of extraction in the lower seam lies in the destressed zone of the upper seam gob, and with the parting working as a shield for lower seam operations, strata control problems are minimal. Consequently, a greater overall extraction ratio is achieved. Subsidence gradients are smaller than those associated with mining one seam at a time. This reduces the cost of reclamation and of damage claims, as well as the extra efforts for multiple subsidence-control plans and damage-claims settlements.

9.3.2 Backfilling

The backfilling of gob underground as a part of the mining operation is not generally practiced in this country. The method has been successfully employed where a seam is prone to spontaneous heating, roof conditions are particularly bad, or the parting is small. The method has also been used to extract coal from seams lying below populated areas. The longwall system seems to offer a more convenient set-up for backfilling than the room-and-pillar method.

No regulatory provisions exist that inhibit or prohibit multiple-seam mining with backfilling, except where the backfill may be likely to flow into an underlying mine.

The drawbacks of the system are that the backfilling operations are slow, they are labor intensive, and they require more co-ordination between face advance and other support facilities. Generally, backfilling is not able to keep pace with face advance, especially in thin and medium-thick seams.

The advantage lies in better roof control, smaller and more uniform subsidence gradients, giving better resource recovery.

Because of cost and profitability considerations, the management at most U. S. mines have not seriously considered using methods involving backfilling.

9.3.3 Single-Entry Longwall

This method has been successfully used in Europe for mining multiple seams of coal. In order to avoid increased stress concentration due to the presence of rib edges and interaction damage to roadways from superposition of rib

edges, the pillars in successively descending seams are increased in size to ensure siting of roadways in destressed gob areas.

The method has the advantages of reducing overall disturbances of virgin coal areas, eliminating bounce and interaction problems due to chain pillars leading to extraction ratios up to 90%,and producing uniform subsidence gradients with minimal or no punch out effects that are usually found with room-and-pillar or retreat-longwall mining practices.

The environmental control provisions for mine drainage and the like do not have any additional impact on the adoption of the advancing-longwall method for multiple-seam mining.

As the extraction of coal from each seam is done sequentially, with considerable elapsed time between seams, the approval of a subsidence control plan for each seam will have to be obtained. Also, the repair of surface damage and satisfaction of claims will have to be completed separately for each episode of mining for each individual seam.

As the method requires drivage of entries below the gob of worked out overlying seam(s), columnization of entries in each seam is not possible as required by CFR Title 30, Chapter II, § 211.32 (b), though obtaining the necessary variance is not likely to be a problem.

Provisions of health and safety and associated inspections impacting multiple-seam mining have no effect on the adoption of the method, but existing ventilation and escapeway provisions could not be specifically met. Provisions for the means of ingress and egress, keeping the belt and trolley ways in neutral but fresh air ventilated roadways. The ventilation of gobs by means of bleeder entries, are not practicable in the light of existing laws as has been discussed in Sections 7.3.1 and 7.3.2. However, variances have been granted in the past for experimental operations, provided that the head and tail gates are partitioned.

The method has given better recovery, less interaction problems, and more uniform subsidence gradients although it demands more manpower for the support and maintenance of gate roads. The resultant restricted size of entries increases ventilation costs, and restricts movement of heavy mining equipment. All of these increase the unit cost of production.

The method also has anticipated misgivings from mine labor working in single-entry longwall faces.

These factors are likely to hinder its adoption in the near future.

9.3.4 Harmonic Extraction from Multiple Seams

Harmonic extraction involves the phased and simultaneous extraction of coal using single-entry advancing-longwall faces in two seams so that horizontal compressive and tensile strains cancel each other. The concept is based on the principle that overlapping horizontal strains are additive and that proper positioning of extraction areas can produce a cancellation of surface effects by the addition of compressive and tensile strains.

Basically the harmonic method of extraction consists of single-entry longwall panels and has the same regulatory constraints and restrictions as the single-entry longwall method. The attitude of mine operators and mine workers was also likely to be the same as that for single-entry longwall working.

Subsidence data in the U. S. are not documented as well as in Europe, so the design of harmonic workings may be difficult. Further, the scheme has only been used in Europe only under special circumstances, a fact not fully appreciated in this country.

10.0 CLOSURE

As a result of this task investigation it has been determined that there are only a few specific direct regulatory or institutional effects on underground multiple seam coal mining. There are, however, several indirect effects.

The BLM has proposed that leases of federal coal be evaluated on an individual seam-by-seam basis rather than collectively, and furthermore that each area or seam have its economic return to the government maximized. It is conceivable, then, that some seams may not be leased for mining that would be economic if mined in combination with another seam, and that different seams may be leased to different lease holders.

In order to mine or not to mine a seam originally not included or included, respectively, in a lease, the BLM must be notified and approval granted, as proposed.

The Geological Survey requires that workings be superposed and that the upper seam be mined first. Recently, the USGS has started examining the proposed ratio of resource recovery more closely. This will impact both single- and multiple-seam mining.

In general, multiple-seam operations are considered as a single mine permit unit for environmental purposes, so that no additional impact is felt. However, in the area of subsidence, non-simultaneous multiple-seam mining may result in repetitive subsidence control measures as proposed by OSM, and repetitive subsidence repair as in Pennsylvania, all on the same lands. Pillars meant to separate surface mines from deep mines, as proposed by OSM, may not end up being superposed in multiple-seam operations near contour strip and similar surface mines.

Health and safety regulations do not specifically deal with multiple-seam operations, except that additional maps may be required for each seam, special permission is required when mining beneath water-filled workings, and each seam may be inspected as a single mine with more inspections resulting overall. Some states have special provisions restricting or altering right-of-way for one operation over or under another, while Indiana merely requires that no danger result in either seam as a result of mining in another.

Most agencies have requirements that remnant pillars be left for various reasons, including escapeways, ventilation, ground control, barriers, and so on, and the

deterioration of these with time may result in effects in overlying or underlying mines if they cannot be extracted in due course. Requirements for superposition of pillars may result in extra care in mining and planning.

Organized labor impacts multiple-seam mining in that if an employer is organized by the UMWA all of his operations, leases, and seams must also be UMWA-organized. However, some operations are purposefully organized into different locals by seam so that a work stoppage in one does not affect the others.

In general there are no severe technological or economical impacts on underground multiple-seam coal mining imposed by regulatory or institutional constraints that are likely to cause additional hardship, beyond that experienced by single-seam mines, except in the proposed BLM seam-by-seam lease evaluations, Geological Survey mining sequence and superposition provisions, proposed OSM and in-force Pennsylvania repetitive subsidence amelioration, various remnant pillar provisions, and similar labor organization in each seam. However, it was clear that these provisions are all readily relaxed for sufficient reason and no undue hardships are likely.

TASK 4

INTERPRETATION OF R & D NEEDS

1.0 INTRODUCTION

This task outlines plans for research and development for problem areas in multiple-seam mining which have surfaced during the performance of this project. In general, the six (6) major areas of concern are:

- Leasing and other regulations pertaining to multiple-seam mining
- Studies at operating mines under different multiple-seam mining conditions
- Effective ventilation and methane control
- Effect of parting behavior
- Economic studies
- Ground control investigations

In this report proposed areas of research are presented along with their relationships with each other. The objectives of this research are to achieve better resource recovery, either by improving the regulation and economic environment or by better control over the expected physical problems associated with multiple-seam mining. Figure 42 shows the interrelationship of the proposed areas of research. This research, if well planned, should cover a variety of multiple-seam mining conditions that exist in the United States. Subsidence studies in Europe, for example, have yielded results and prediction formulas that do not correlate well with United States experience. This might be expected because of the different geological conditions.

Leasing and operating regulations can help to improve resource recovery by treating multiple-coal seam collectively, and provide techniques for better working of the seams through superposition, columnization, and accurate mapping.

Tests at several operating mines under controlled conditions include accurate cost accounting of all mine operations and rock mechanics studies that will ultimately lead to better mining techniques and lower costs. Hopefully an economic model can be developed that will predict optimum mine designs for multiple seams in a variety of geologic conditions.

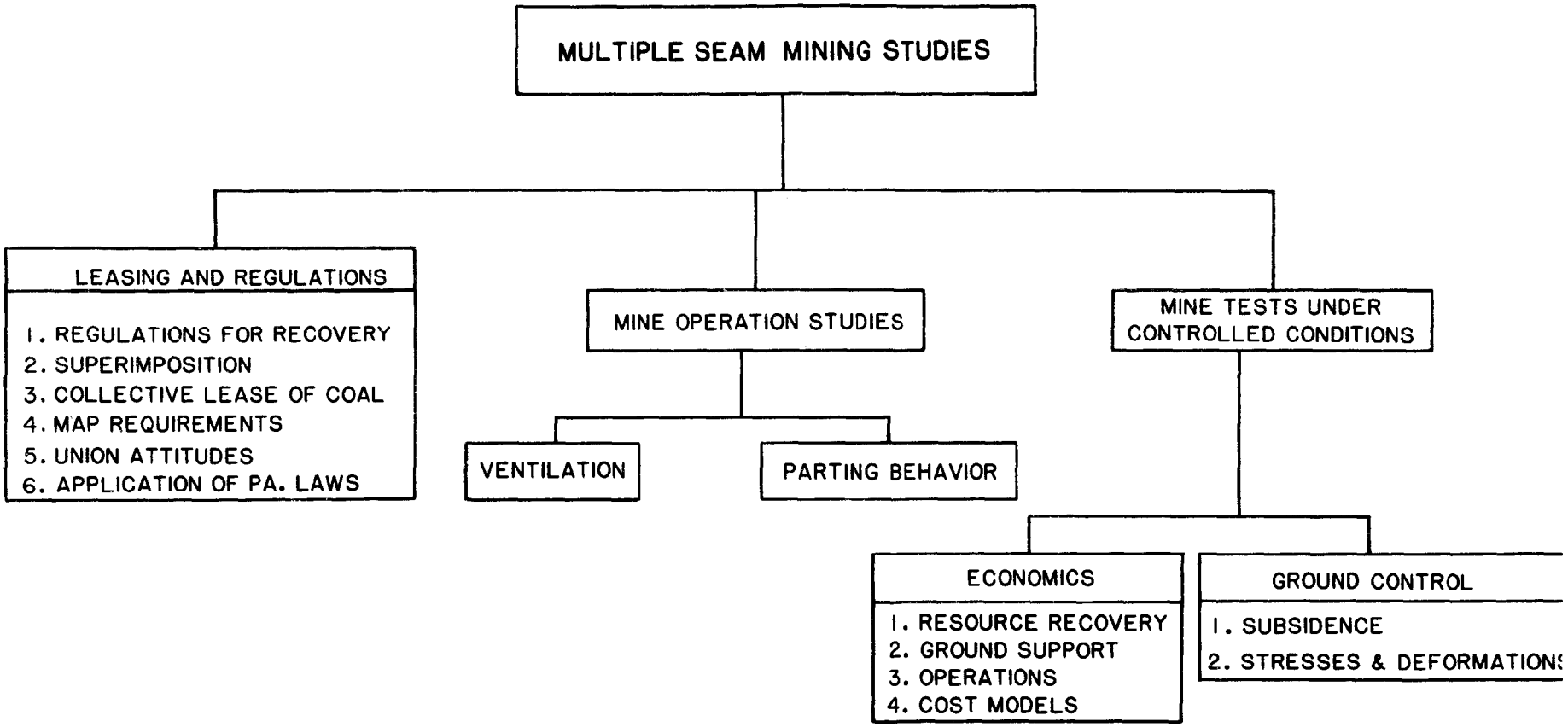


Figure 42 - Overview of Multiple Seam Mining Research Program

Field tests at operating mines can aid in coping with sub- or superjacent mined areas in coal regions where poor planning and execution in the past have created problems for contemporary operators. Tests under controlled conditions in existing mines may be expected to yield results much sooner than at mines which will exploit virgin coal, necessitating extensive development time before the studies of geologic behavior can be initiated. Although ventilation and parting behavior studies are specifically discussed in this report, other aspects of mining may also be examined. Besides, in research new results often raise new questions!

A general cost estimate for the proposed research is as follows:

• Leasing and Regulations	$ 150,000
• Ventilation study	200,000
• Parting Behavior study	350,000
• Mine tests under controlled conditions (4 mines)	4,000,000
TOTAL	$4,700,000

This report presents research programs that will lead to a better understanding of multiple-seam mining problems. There are many other areas where mining research is needed such as safety, equipment, coal haulage, groundwater control, and other mining elements, but these are common to both single-seam and multiple-seam operations and consequently are not discussed in the report.

2.0 STUDY OF REGULATIONS FOR MULTIPLE-SEAM MINING

2.1 Developing Specific Regulations

2.1.1 Regulations for Recovery

Regulations for resource recovery of multiple coal seams are few and are not specific enough to maximize coal recovery. Experience has shown that some methods are better than others for obtaining more coal. These methods should be indicated in the regulations since greater recovery is desirable. The section on, "Evaluation of Regulatory and Institutional Constraints" points out that mining plans are subject to approval of the Mining Supervisor in the U. S. Geological Survey, although specific judgement factors are not expressed. The primary concerns of the USGS are:

- Maximum coal recovery
- Reduced damage to surrounding coal
- Minimum damage to the surface

It would be desirable to identify the judgement factors used.

2.1.2 Superposition

For better coal recovery, superposition of roadways is mentioned in USGS regulations, but requiring drivages to be located under old gob areas or destressed zones is not. Perhaps more consideration should be devoted to this. It may also be suggested that longwall faces should be perpendicular to remnant pillar lines, which may be expected to help coal recovery by controlling remnant pillar stresses. If this is not feasible, the reasons therefor should be stated. Such techniques have demonstrated that impending problems can be averted or controlled thus lowering production costs.

2.1.3 Collective Leasing of Coal

Leasing should be reevaluated to include the possibility of requiring all minable seams in a property to be leased to a single operator rather than separately to multiple operators as is often done presently. Case histories have demonstrated that companies mining coal on the same property, need to cooperate with each other during the mining process. This cooperation must include preparation of mining plans for columnization, mining sequences, location of drivages, and so on, in order to minimize coal-seam interaction. Total disregard for other mines in a multiple-seam property has led to the forced abandonment of many acres of coal, often accompanied by extensive litigation.

To facilitate mine cooperation, a series of mine maps, as well as drill holes between mines to check survey accuracy, could be required.

In some regions of the country, with simultaneous mining, the practice is to operate the seams as different mines so as to avert wildcat strikes. The collective leasing of seams may influence this socioeconomic condition. Any proposed study of the regulations governing multiple-seam mining must take this into account.

2.1.4 Develop Mine Map Requirements

Maps can help identify where and when interaction problems may arise by locating the position of any over or under-workings that may be encountered. Any conclusions depend upon the degree of accuracy of such mine maps. A collection of maps will eventually build up a library of information available for new operations in an area. This will provide definitive data as regards "safe" areas and geologically disturbed areas. These could then be considered in mine design and operations.

The map procedures should ensure that all levels of management are involved and advised on problems that arise. Presently maps are required to comply with existing health and safety statutes. Separate maps are used for maintaining technical records or for formulating plans and business objectives for operations. The principal maps for such planning should include:

- A five-year development plan
- A layout plan
- A working-face development plan

These plans are an attempt to provide details for a mining operation and to delegate responsibilities for adopting and amending plans.

2.1.4.1 Five-Year Development Plan

This plan should outline the strategy for seam extraction having regard for known restraints and obstacles. The plan is the result of what is considered, at the time, to be the most efficient layout over a five-year period. The plan, at 500 scale, should include mine boundaries, workings in the seam, principal faults and other geologic disturbances, boreholes, yearly projection of workings, and areas where working rights are restricted.

The plan should be prepared jointly by the mine project and surveying staff after consultation with management. Approval of the chief mining or operating executive should be required for acceptance as a broad mining plan. Securing an agreement of a plan is by collective discussions between management and engineers, with the mine superintendent responsible for ensuring that the procedures adopted are complied with and maintained. Review and alteration of the plan should be made when necessary and updating is usually done periodically, annually as a minimum.

2.1.4.2 Layout Plan

This would define the best means of achieving the required operational results and secure a safe and efficient working of reserves to conform with statutory requirements and company policy. The plan would basically be a document of instruction and should be required to be signed by mine management and specialist engineers, of which the strata control engineer, or equivalent at any given mine is a key person particularly when multiple seams exist. The requirement for signatures is intended to certify that each person has examined the plan and that all necessary investigations have been carried out.

In practice, plans do change and provisions to permit this readily help to keep order in the plan. For example, if one area requires change a separate tracing should be made indicating the features involved along with a note explaining the changes. The tracing should be dated and signed upon approval and reference to it should be noted on the layout plan. If an urgent change is needed, the mine superintendent or mine manager should have the authority, although a copy must be sent to all appropriate persons and/or agencies concerned. The mine foremen or other staff, obviously, are responsible for implementing the amended procedure.

2.1.4.3 Working-Face Development Plan

Supplementing the layout plan, detailed plans should be required for the operating sections and faces and for development workings showing the methods of mining, equipment to be used for mechanization, support, methane drainage, and so on. These plans must conform to the agreed layout plan and be revised to take account of amendments. Working-face development plans and schedules are documents of instruction and should be signed by the mine superintendent or manager and his superiors.

Also required should be progress plans, which are weekly updates of the layout plan and contain the same type of information. The progress plan should show records of the progress of working faces and compare actual development with planned development, usually at 100 scale. This plan should include the old workings above or below since they should have appeared on the layout plan previously prepared and accepted.

The problems of old workings should also be addressed when the face design is agreed upon for the working-face development plan. The details should, preferably, include photographs of the entries before they are affected by old workings and as the face progresses more photographs may be taken to show damage or additional support required.

2.1.5 Union Attitudes

While evaluating regulations and suggestions for changes union attitudes must be considered. Although improved resource recovery is desirable, the safety and health of the workers must always remain the primary concern of the operator and the nation. Regulations should ensure that methane accumulation, excessive dust, or the possibility of inundation do not occur. Representatives of labor can provide valuable input in this regard. They could also suggest means for leasing of coal seams to be worked by single operators while presenting mechanisms for averting wildcat strikes which paralyze all operations.

2.1.6 Pennsylvania Mining Laws

Pennsylvania has the most specific set of coal mining laws applicable to underground multiple-seam operations.

Some studies have been conducted to evaluate their adaptability to other states. These evaluations need to be expanded to other areas based on the conditions in other states, and critically examined for applicability nationwide.

2.2 Program Implementation

Any alterations of laws can only be done by federal or state legislatures and agencies. However, background work to support legal revisions can be accomplished outside the governing bodies. Items that will need to be examined before any changes can be proposed are:

- Economic impact of the regulations
- Administrative implementation procedures

- Applicability of the regulation to certain regions and conditions.

In order to evaluate changes in existing regulations according to the above criteria, extensive mining experience is needed. Also, many state and federal agencies would need to be contacted including inspection, regulation, and permitting authorities. The regulation changes should not pose an economic hardship on mining operators, nor should it create a bureaucratic nightmare that could inhibit resource recovery. Finally the regulation change needs to be adaptable to the various mining conditions in the U.S.

For example, in investigating the need for current mine maps and plans existing mine plans need to be studied for their completeness and accuracy. Interviews with mine operators, particularly small operators, may be necessary to assess economic impact. It may prove beneficial to investigate foreign requirements for periodic mine plans, since more experience exists abroad than in the U.S. relating to multiple-seam mining. The United Kingdom, for instance, has had mine plan regulations since the turn of the century and these have proved invaluable to maximum resource recovery.

Currently available information suggests that it should be possible to develop a series of mine plans which define the physical mine layout over the life of the mine.

2.3 Program Procurement

The program tasks are listed in a time schedule in Figure 43 which is divided into two phases requiring a total of one year to complete. Phase I includes the following tasks:

- Examine the collective leasing of multiple coal seams
- Investigate regulations requiring the superposition of drivages
- Change existing regulations to include judgement factors to achieve maximum recovery
- Study of union attitudes for not leasing mines in a way to avert wildcat strikes.

This phase is best done internally by the Department of Energy, with the help of a consultant if necessary. To evaluate and consider regulatory alternatives requires coordination with MSHA, the Bureau of Mines, state agencies, and other

PROGRAM SCHEDULE FOR

STUDY OF REGULATIONS FOR MULTIPLE SEAM MINING

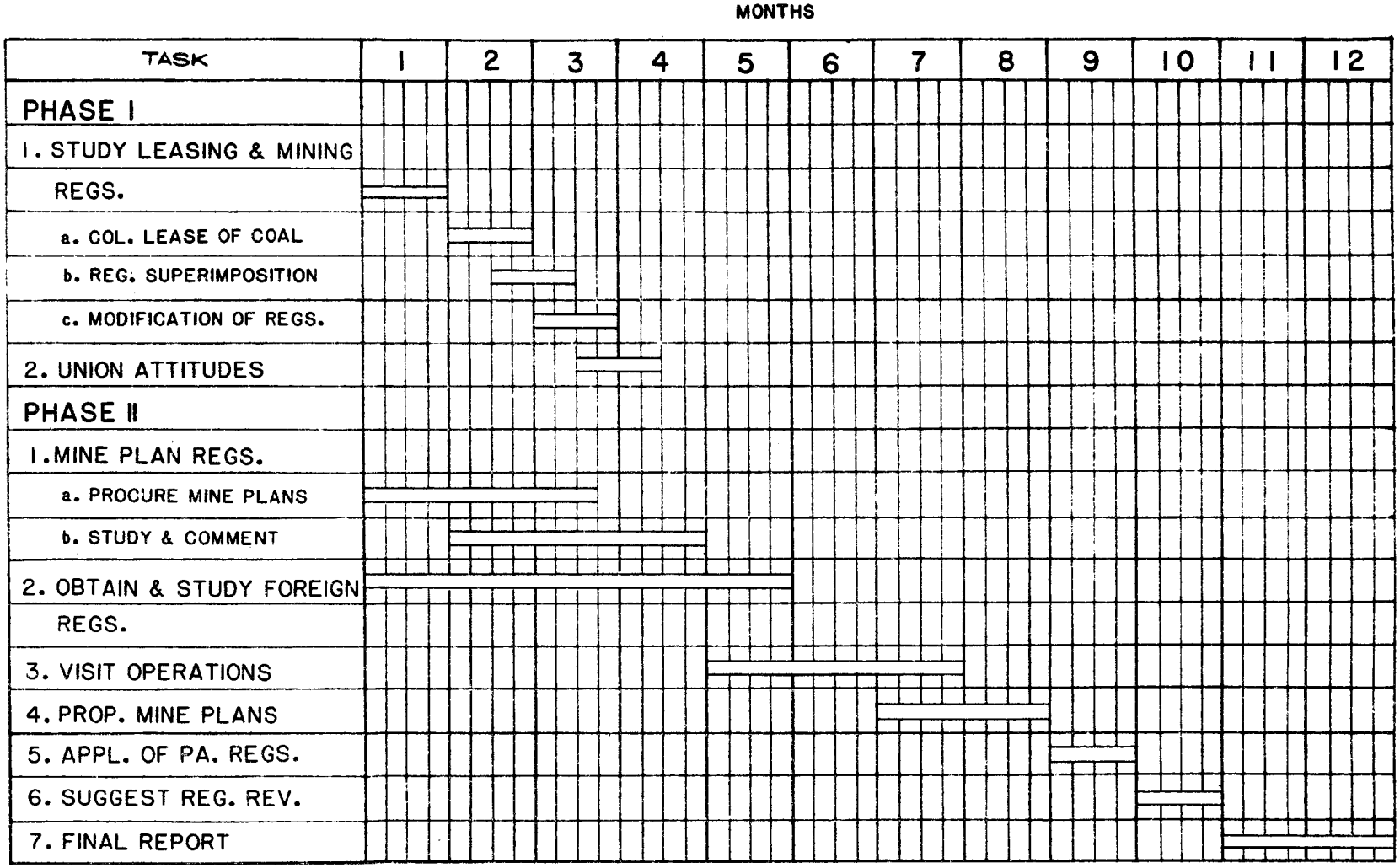


Figure 43 - Study of Regulations for Multiple-Seam Mining

government agencies, which can be done by the Department of Energy itself.

Phase II may be conducted by a consultant, selected with emphasis on the contractor's ability to work with mine operators and obtain the desired information. This phase will include:

- Collecting examples of mine plans currently used
- Study of mine plans for completeness
- Obtaining mine plans from other countries
- Visiting mines to discuss operators' ideas
- Propose mine plan requirements
- Applicability of adopting Pennsylvania multiple-seam mining laws nationwide.

Obtaining mine plans will have to be done through the mine operators or through state agencies that require an up dated mine map every year. Operations that are particularly well coordinated in their mining efforts may require a special visit to gain valuable information.

The program is estimated to cost $150,000 over a period about one (1) year.

3.0 DETERMINATION OF EFFECTIVE VENTILATION

The nature and thickness of the parting between coal seams has a significant effect on mining conditions. Stresses induced by multiple-seam mining can cause extensive fracturing that may lead to poor roof conditions, loss of ventilating air, or poor resource recovery.

It is desirable to know how much fresh air is migrating to a worked-out seam either above or below current workings. Air losses cannot be tolerated in the working areas where gas may be present and dust must be carried away. In order to study the behavior of parting thickness on ventilation it is suggested that a series of tests be conducted over a range of parting thicknesses from 20 feet to 100 feet where fracturing is almost certain to exist.

3.1 Ventilation Test

This test is best conducted in a long series of entries as shown in Figure 3.1, and with any mode of multiple-seam mining as long as an excavated area exists either above or below into which the ventilating air can migrate. The test area should be at least 1,500 feet long and blocked from the mine ventilation except for a small area where a blowing fan can be placed, and an open area at the end of the air course where quantity measurements can be taken. Stoppings in the test area can be erected at locations so as to assure that all the air flows throughout the test area. Basically a pressure chamber is simulated and any air migration will be reflected in the difference between the fan output and the measuring station. Other measurements may be taken along the roadways. The test requires the following steps to be taken:

- Install stoppings at strategic areas
- Define parting thickness by drill hole or survey map
- Install blowing fan of reasonably high capacity
- Accurately traverse the fan outlet to determine its performance
- Traverse the opening in the measuring station with vane anemometer, and compare volumes
- Repeat the procedure over a variety of parting thicknesses.

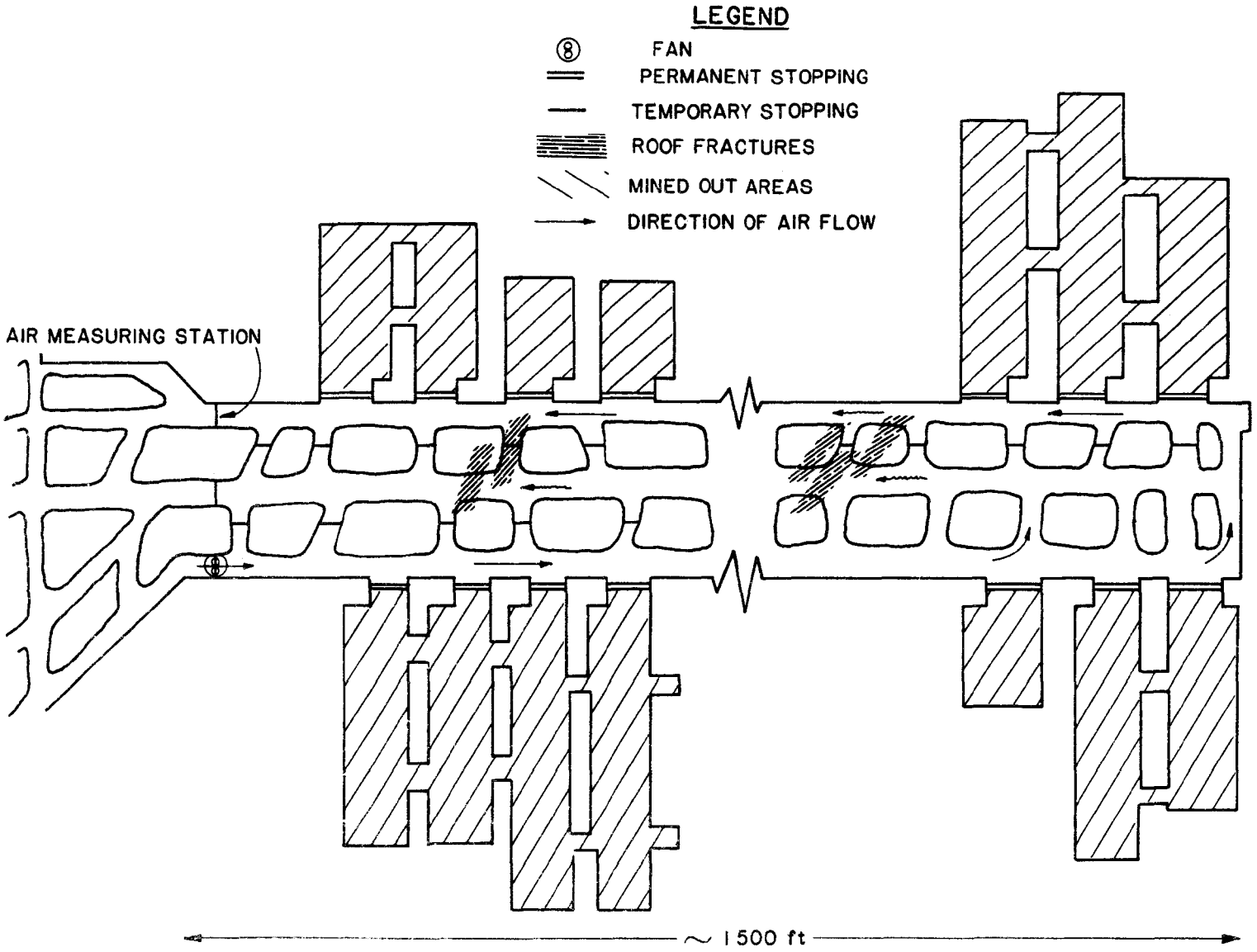


Figure 44 - Testing Ventilation Effectiveness

If significant volume differences exist, it may be possible to map roof (or floor) fractures in the test area with an infrared probeye viewer or other means. During testing, air samples can be taken to test for any increase in methane concentration. These tests would be conducted in the upper seam where methane is expected to migrate. Air leakage through the parting could also be determined using SF_6 (sulfur hexaflouride), as a tracer and a chromatograph, or a similar technique.

3.2 Program Procurement

It would be best to award the contract for this study on a competitive basis. This makes it possible for several mining companies to participate in the investigation. Many of them may already have a mine area similar to that desired. The mining companies may also have an appropriate fan on the premises which could greatly expedite the work. Since the tests need to be conducted over a range of parting thickness several mines would be required to perform the tests, particularly if the parting thickness at any one mine is relatively constant. The study, if it includes several mines, should be broadened to include both overmining and undermining situations.

The following schedule, Figure 45, shows a time estimate for the work previously outlined and the tasks involved. The bar chart (Figure 45) depicts the duration of each task and the time required for the preparation and submission of reports. An attempt has been made to initiate each task as early as possible and to overlap tasks whenever practical so as to ensure timely completion. The program is divided into the following tasks:

- Selecting mines that will cover a variety of geologic situations
- Finalizing agreements with mine operators to establish a degree of cooperation needed to carry out the tests
- Preparing the test site by installing stoppings in strategic locations, establish the parting thickness by drilling, and placement of the blower fan
- Performing air circulation tests
- Repeating the tests under a variety of parting thicknesses.

The program is estimated to cost $200,000 over a 13-month period. The schedule repesents the work carried out over several mines with work at each mine done sequentially.

PROGRAM SCHEDULE FOR

DETERMINATION OF EFFECTIVE VENTILATION

MONTHS

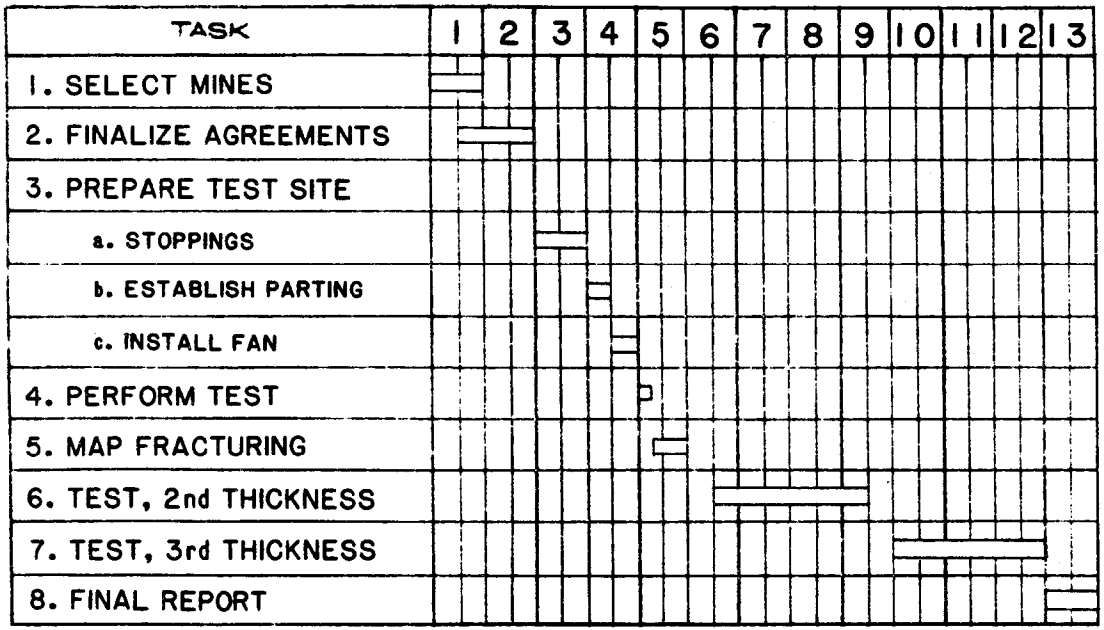


Figure 45 - Determination of Effective Ventilation

If testing for the varying partings were done concurrently the project could be completed considerably faster, but it may be preferable to have the same crew perform the measurements at each site.

4.0 INVESTIGATION OF PARTING BEHAVIOR

The stresses developed due to the strata reaction during multiple-seam mining have a significant effect on mine planning. It is, therefore, desirable to know the parting behavior more exactly. This information is especially useful for simultaneous mining where the difference in distance between mining fronts depends on the severity of influence of one seam on the other, through the parting. Testing the parting behavior should include coring the parting before and after mining a particular area so that rock testing can be compared on the basis of strength, degree of fracturing, and so on. These tests should be conducted under simultaneous mining conditions and can lead to estimates of coal seam interaction which influences the proximity of mining fronts.

4.1 Determination of Parting Behavior

Historically simultaneous mining has not been very successful with parting thickness less than 165 ft. The mining of one seam ahead of another creates a critical distance which is defined by the depth of overburden and by the nature of the parting. A study may be conducted under simultaneous mining conditions by coring the parting in an area ahead of the lagging mining front, and coring the the parting again sometime after this front has past under (or over) that location. Examination of the core would show if cohesion of the parting has been disturbed, which will be evidenced by a change in core fracture frequency with depth. Therefore, a graphical analysis of fracture frequency at depth could help define the limit of stress influence by one seam mined on the other. The graph obtained may be expected to be of the type shown in Figure 46. The increase of frequency is greater from 60 ft to 140 ft which may suggest that mining fronts between seams should be at 140 ft. This is based on rock behavior characteristics that define the zone of influence, which is the effective distance into the parting thickness where stress interaction is transferred from one coal seam to another. It is suggested that the distance between mining fronts should equal or slightly exceed the zone of influence.

To perform this program, core drilling needs to be conducted at different time intervals and for different parting thicknesses and rock varieties. In most simultaneous mining situations, the parting thickness does not vary greatly, but other factors that need to be considered include:

- Varying rock strata
- Method of mining (room-and-pillar, longwall)
- Differing time intervals (weekly, monthly, every 3-months)

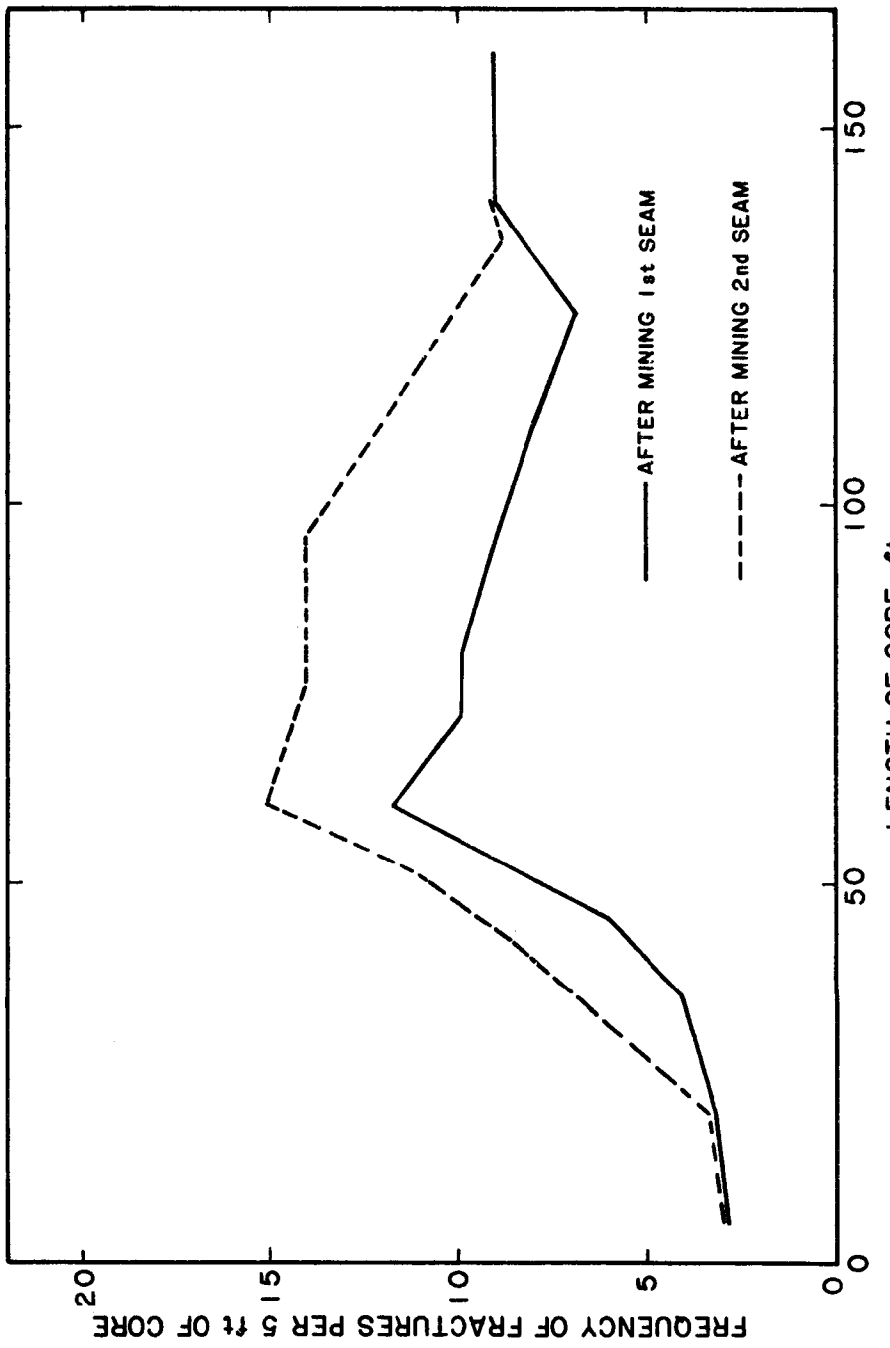


Figure 46 - Core Fracture at Depth

A systematic investigation of these parameters should result in reliable guidelines for estimating distance between mining fronts of different coal seams, for simultaneous mining. Another possible method of measuring parting reaction is with seismic refraction. The method involves measuring seismic pulses through the strata using an array of sensors. The change of pulse velocity can be related to the degree of rock fracturing.

4.2 Program Procurement

Since the work involves much core drilling and logging, it is suggested that competitive procurement procedures be followed. The proposing firms will be able to make their own arrangements with various mines and locations. Three (3) locations may be studied, the East, Midwest, and West. Experience in underground coring should be a requisite criterion for this program since space in the mine is confined, and good equipment, techniques, and efficiency are necessary to control costs and obtain reliable results. A list of the tasks to be performed is given in Figure 47 along with a schedule which depicts the estimated time for completion of each task and the overall program.

The tasks basically consist of:

- Selecting mines to cover a variety of parting thicknesses for longwall and room-and-pillar methods
- Finalizing agreements with the mine to determine responsibility and degree of cooperation
- Core drilling of the parting and logging of the core to determine fracture density
- Coring at prescribed time intervals to study the affect of ongoing mining.

The program is estimated to cost $350,000 over a 16-month period.

PROGRAM SCHEDULE FOR

INVESTIGATION OF PARTING BEHAVIOR

MONTHS

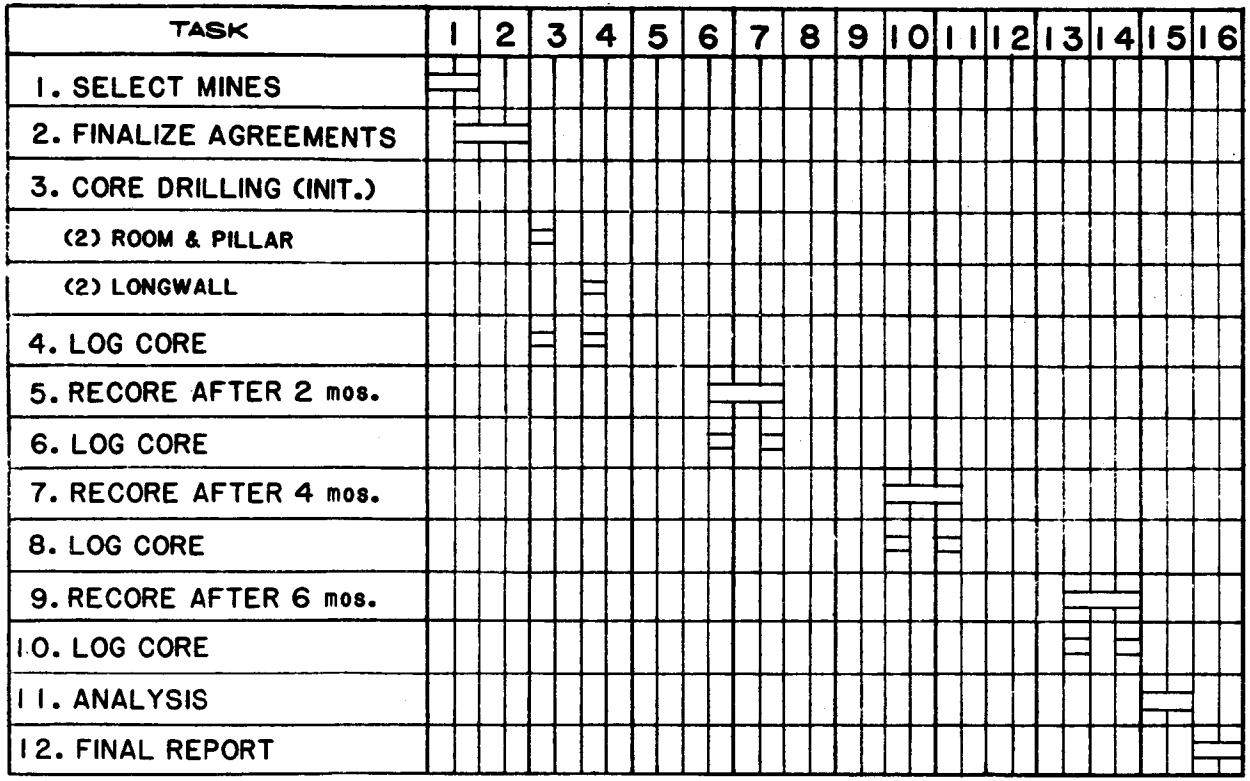


Figure 47 - Investigation of Parting Behavior

5.0 MINE TESTS UNDER CONTROLLED CONDITIONS

5.1 Necessity

During this study it was found that the method of record keeping at an operating mine is generally neither detailed enough nor in an appropriate format to positively identify cost changes caused by problems associated with multiple-seam mining. Indeed, often the cause of the problem is not definite but only suspected, and may be treated as a normal mining problem, not related to multiple-seam mining.

To better deal with multiple-seam mining problems and their solution it is desirable to study mining under controlled conditions at operating mines, i.e. in new sections of these mines preferably in virgin strata. These problems should be studied in a variety of geologic conditions so it may be desirable to utilize three mines, with one in Appalachia, one in the Interior Basin, and one in the West. Possibly a fourth mine may be selected in the Pennsylvania anthracite district where steeply pitching coal seams exist, and where the economic conditions are different to those in the bitumiuous coalfields. Arrangements need to be made with the mine management that all cost as well as technical information related to the sections under investigation should be made available to DOE. This is essential, since economic information is rarely released by private operators. Often the information presented is incomplete and sketchy.

5.2 Ground Control

5.2.1 Subsidence

Subsidence studies under controlled conditions, for a number of different mining techniques, should be conducted in the proposed mines. Accurate surveying can help to determine the changes or extent of control on subsidence due to columnization, splitting pillars upon recovery, and partial extraction mining. Adequate surface monitoring stations and the associated equipment are usually considered too expensive by private operators and hence not installed or monitored. DOE could fund such an activity in cooperation with operators.

5.2.2 Stress and Deformation

In addition to the subsidence data, pillar stress information is important. The use of optimum pillar dimensions for multiple-seam techniques would lead to maximum resource recovery and uniform, controlled subsidence. The measurement of in-mine deformations, loads, and rock properties

would be more valuable, if conducted along with subsidence measurements, in the same mines than if done elsewhere. Instrumentation that would provide useful information would include borehole extensometers, convergence stations, load cells under supports, stressmeters in pillars, and devices to measure pillar, floor, and roof deformation. Mines with various parting and coal thicknesses should be considered for these studies. The rate of secondary gob compaction may be determined by core testing at pre-determined time intervals. Such data would aid in mine design.

5.3 Economic Studies

As mentioned above, it is essential that all cost data must be made available to DOE or its research contractors. They would be in a position to identify specific problem areas, and isolate costs incurred to remedy each situation. Costs should be broken down for roof control, coal haulage, pumping, ventilation, and other operations.

5.4 Program Procurement

Because of the logistics of mining such as labor, supplies, power, etc., such a program should be contracted to firms with the requisite ground control and economic analysis capabilities. These contractors could either be mine operators themselves, or consultants who can arrange to work with suitable mines. The investigations should be performed in sections in virgin property since these are more suited to determining maximum resource recovery. These will not get affected by poorly-mined old workings which adversely influence mine planning. Virgin seams will also permit simultaneous mining which can have the mining front in either seam lead the other, so as to create over- or undermining conditions. The ideal location would be where the experimental sections could be developed in properties immediately adjacent to operating mines. This permits ready accessability without the need for new and expensive shafts or slopes to be developed.

Specific studies, such as the rock mechanics investigations or computer modeling, could be subcontracted, if necessary, by the prime contractor to specialist consultants. As mentioned earlier, possibly four such contracts throughout the country could be awarded, with each one being bid separately. DOE should coordinate all efforts for performing the work. The economic model also could be developed under an entirely sepcontract.

Realistically, the contracts will last over a number of years, and a preliminary estimate for the schedule might be 5 years each. A chronological order of research appears in Figure 48 which covers some highlights of possible work

PROGRAM SCHEDULE FOR

MINE TESTS UNDER CONTROLLED CONDITIONS

YEARS

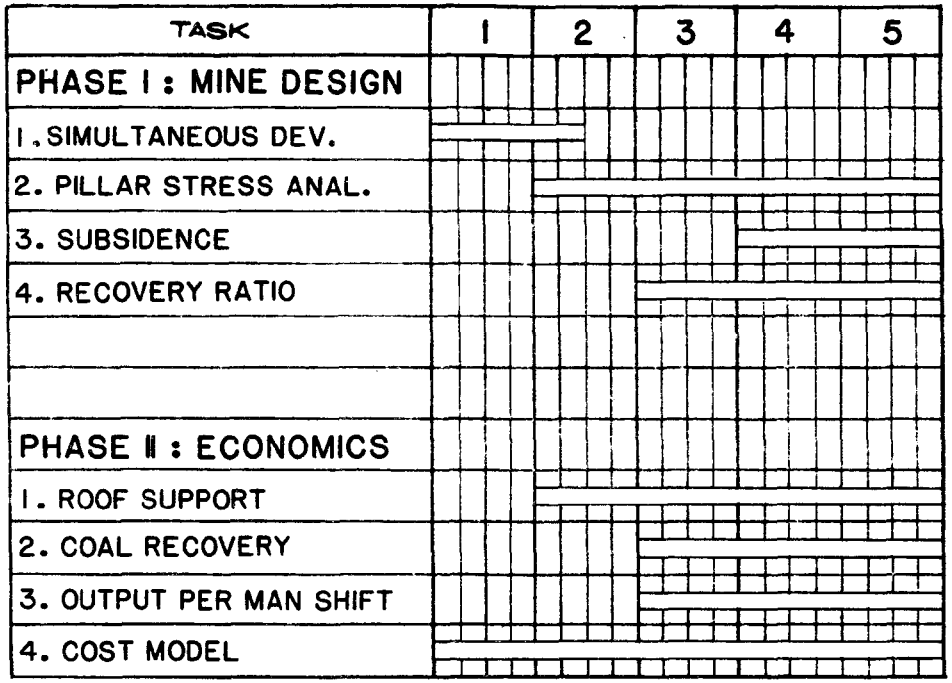


Figure 48 - Mine Tests Under Controlled Conditions

involved over two phases. The Phase I tasks include the physical measurements such as:

- Development of two coal seams, with two sections, one with the lower face in advance over the other in order to achieve overmining and the second with the upper face leading to get undermining conditions. Simultaneous mining may be attempted in a third section
- Pillar stress analysis and other rock mechanics investigations for the various mining methods
- Subsidence studies over the life of the sections
- Recovery ratio obtained by underground surveying and related to actual raw coal output.

Phase II is the economic analysis which will be ongoing from the section start-up. These tasks include, but are not limited to the following:

- Roof support costs under a variety of mining techniques
- Productivity analysis based on recovery and output per person-shift
- Costs of ventilation, pumping, haulage, etc. in relation to conditions
- Formulation of a computer cost model from data obtained from the various mines, representing varying conditions in the U.S.

The complete ground control and economic study program for each mining operation is estimated at $1,000,000 over a five-year period. Hence for 4 mines this totals $4.0 million.

6.0 CLOSURE

During the study of multiple-seam mining in the United States, six (6) areas which require attention were discerned, which related to:

- Leasing/regulations
- Union attitudes
- Ventilation/dust
- Parting behavior
- Economics
- Ground control and subsidence

These six (6) studies were carefully examined and integrated into a research program divided into 4 distinct parts:

- Study of regulations - which comprised of critically evaluating existing regulations with respect to leasing and mining methods, so as to maximize resource recovery; requirements for mine maps which clearly indicate that the workings of the various seams being mined are coordinated and that the damage to other seams and surface are minimized; attention is called to the effect of union attitudes on mining practices

- Ventilation investigations - which establish leakage of air from one working seam to the next; effects on dust; spontaneous combustion problems

- Examination of parting behavior - intended to determine the extent of parting thickness that is affected by undermining and overmining; it's influence along the seams; factors governing simultaneous mining

- Mine demonstrations under controlled conditions - which entail ground control investigations and economic modeling; determination of subsidence effects and their relationships to mining method, pillar loads, overburden thickness, nature of rock (floor and roof), and coal, mine geometry, and resource recovery; isolation of costs for each unit operation and it's sensitivity to changes; development of predictive cost models capable of analyzing unit operations, productivity changes, and effects on recovery; suggestions for optimal mining methods and designs.

The total research program is expected to cost less than $5,000,000 over a 5-year period, but as seen in the next task, this will make possible the recovery of coal worth considerably more.

TASK 5

COST/BENEFIT ANALYSIS OF R & D

1.0 INTRODUCTION

This task defines the benefit/cost ratio of the research and development plan presented in the previous section of this report. The benefit/cost ratio is a measure of the effectiveness of a new method, by comparing the value obtained against the value needed to achieve the improved method. For example, if $300,000 was saved as a result of a new method which cost $100,000 to implement, the benefit/cost ratio would be 3. It is by this means that the value of the proposed research and development program is evaluated. Each major part of the suggested research program is analysed with respect to its estimated benefit.

Figure 49 outlines the multiple-seam mining research program presented in Task 4. Each segment of the program requires a series of studies that are expected to improve resource recovery and reduce operational costs for mining multiple seams. Some areas of research will also benefit single-seam coal mining, e.g. the leasing and regulation study, or the ground control investigations. Figure 50 illustrates, each major category of the research program, as a percentage of total cost. The overall program is estimated to cost $4,700,000 over a 5-year period if the entire program, as suggested in the previous task, is implemented. The costs would evidently be reduced, if the number of mine demonstrations is reduced. This task report presents the benefit/cost relationship for each segment of the research program.

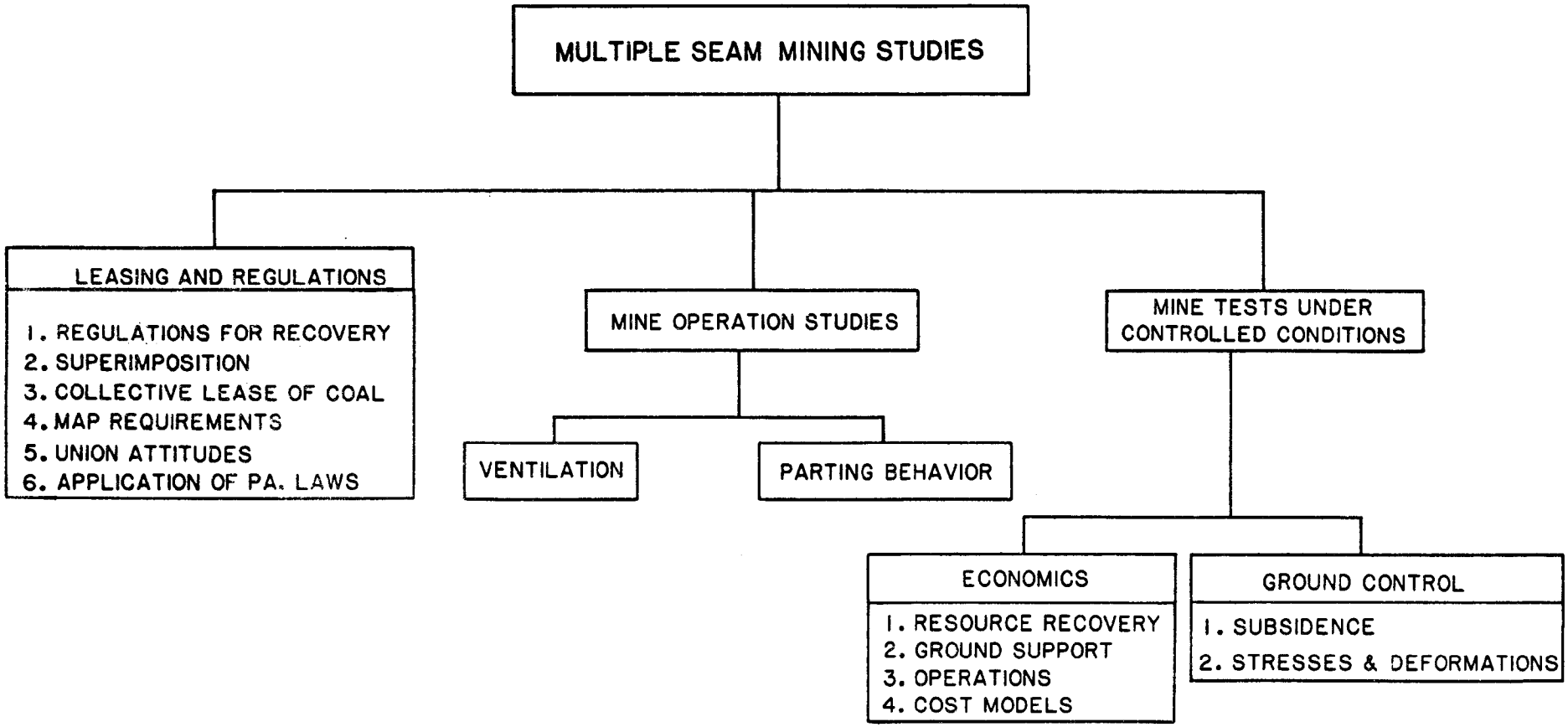


Figure 49 - Overview of Multiple Seam Mining Research Program

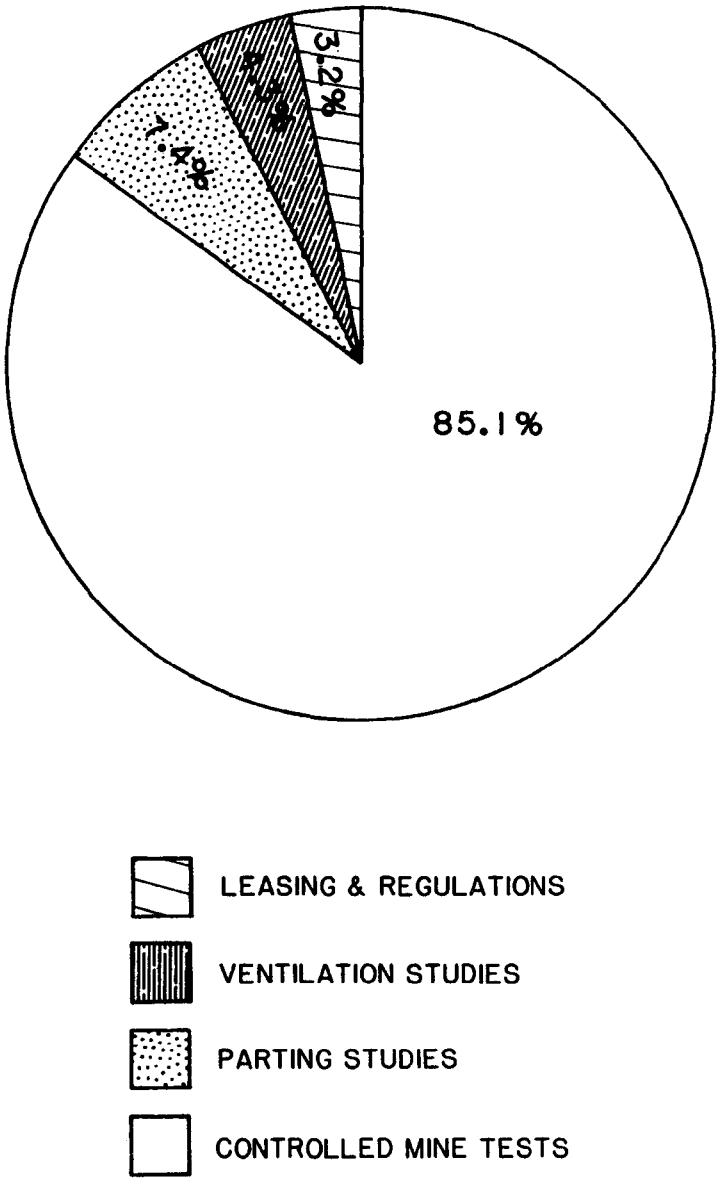


Figure 50 - Distribution of Funds Amount Segments of Research Program

2.0 LEASING AND REGULATIONS

Current leasing regulations are cumbersome and they tend to prolong the acquisition of coal resources by requiring considerable effort on the part of industry. Existing leasing requirements also do not adequately address maximum possible resource recovery. This has led to many acres of coal being abandoned in multiple-seam properties, many of which are operated by different companies which, knowingly or unknowingly, do not cooperate with each other. A research and development program has been proposed which includes examination of the following:

- Regulations for recovery
- Superposition requirements
- Collective leasing of coal
- Map requirements
- Union attitudes
- Application of laws

The cost/benefits of these topics are hard to quantify, in that all the factors are interrelated; hence the cost associated with each cannot be individually evaluated in dollars and cents. It is possible to estimate the costs incurred due to leasing regulations, however. If the leasing process were made more efficient, the mine property could be brought into production sooner. If, for example, the time period for procuring leases were reduced by 6 months, the capital requirements for mine start up would be reduced due to the elimination of the effects of inflation on equipment costs, for half a year. Thus for a 13% inflation rate, costs could be reduced by 6.5%. This would imply savings of millions of dollars for a large mine.

Figure 51 shows the reduced capital investment for different production rates. The graph dramatically shows the capital cost savings from the relatively small research program cost of $150,000. The savings reflected are only those from one operation. Consequently, a streamlined leasing program nationwide would free significant amounts of capital. In addition, the program will benefit both single- and multiple-seam coal leases, which increase the benefits of this research. Thus, for a one-million tons-per-year operation, a $3.3 million capital saving over 15 years amounts to $0.222 per ton of coal, which lowers the selling price correspondingly. Nationwide, these savings yields $149,924 per research dollar assuming 65% recovery.

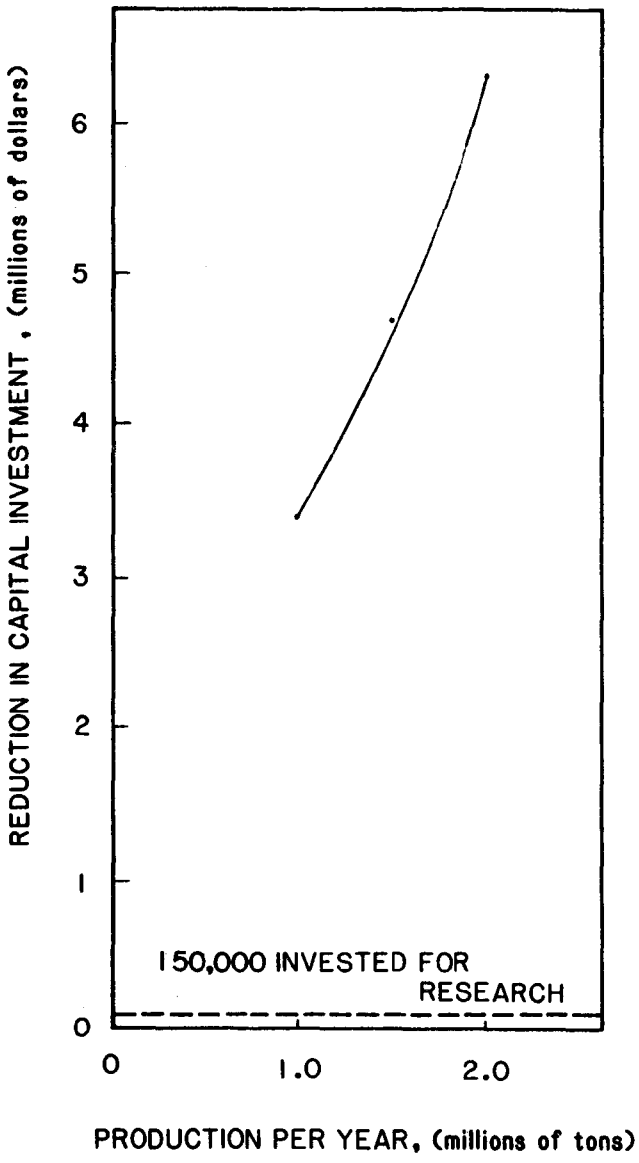


Figure 51 - Capital Investment Savings from Research

Regulations pertaining to improved coal recovery methods such as superposition of pillars, collective leasing, and map requirements are reflected in resource recovery economics and will be discussed in a later section of this report.

3.0 MINE OPERATION STUDIES

This segment of the research includes studies of the effects of multiple-seam mining on ventilation and parting behavior. Parting behavior directly influences both ventilation efficiency and roof support requirements. Investigation of these is important because it relates to the health and safety of miners. In the ventilation study, roof support is indirectly taken into consideration because falls of ground create more resistance in an airway. However, a separate study of the behavior of roof is merited also, since mining cannot progress without a safe roof.

3.1 Ventilation Study

The ventilation program outlined previously in Task 4 is estimated to cost about $200,000 or 4.3% of the total research program. The purpose of the ventilation study is to quantify the fresh air leakage through the disturbed rock strata between multiple seams under a variety of mining techniques and rock conditions. The results should help to correctly size the ventilation equipment needed to compensate for fresh air leakage, or to develop methods for reducing leakage.

This mining practice may partially offset the 12% higher ventilation cost estimated earlier (in the "Definitions of Technical Problems" section of this report) by reducing parting fractures that create savings of $0.097 per ton of the recoverable reserves subject to multiple-seam mining. This implies a total savings of $49,131 per research very worthwhile, and cost effective. Even a 1% improvement would imply a benefit/cost ratio of 4,103.

However, in addition to these very significant savings, what is really involved is a matter of much greater concern--the health of the miner. Besides, mining companies presently contribute money to a black lung fund, and if ventilation conditions improved, these contributions should be reduced. Black lung compensation is estimated at $18 per man per shift, resulting in $1.29 per ton (if output is considered to be 14 tons per man). A reduction in black lung compensation of even 5%, would have a major impact upon the costs entailed.

3.2 Parting Behavior Study

The program outlined in Task 4 for this investigation is estimated to cost $350,000 or 7.4% of the total research program. The study of parting behavior will aid in both roof control planning and ventilation design. If, as a result of this research, the rate of mining advance or time lag between mining coal seams can be planned to cause less severe parting reaction, roof control costs as well as roof fall accidents should decrease. Ventilation leakage will also be reduced, resulting in cost savings, as previously discussed.

Roof support costs have been estimated at 15% of total operating cost. These costs are about 15% higher when mining multiple seams than single seams, on the average. It is estimated that this increase can be reduced by 25% because of the parting behavior studies suggested herein. Better planning of pillars and uniform extraction can greatly reduce severe parting behavior when mining multiple seams. The parting behavior study should define the zone of influence of one mined seam on another, and thus provide a basis for establishing the mining advance rate for the seams. A less fractured roof will reduce support costs; the estimated cost savings per ton is expected to be about $0.152, yielding $43,993 saved per research dollar.

4.0 ECONOMICS

4.1 Resource Recovery

The extraction ratio, which serves as a measure of mine performance, varies with the thickness and nature of parting. This ratio also varies with the mode of multiple-seam mining practiced, i.e. overmining, undermining or simultaneous mining, but is not significantly different for the various modes. It may be recalled from earlier sections of this report that the output per manshift (OMS) for underground workers is relatively unchanged when comparing overmining, and simultaneous mining; this output is only slightly less than that for single-seam mining. These results are based on historical data. It should be noted that in the past much multiple-seam mining was done rather haphazardly, with little or no planning.

If the best multiple-seam mining technology is applied to an experimental multiple-seam mining operation the results would most likely be favorable, and both the extraction ratio and productivity may be expected to increase. It may be estimated conservatively that this would be on the order of 5% greater resource recovery. The Appalachian area alone is estimated to have over 66 billion tons of bituminous coal reserves amenable to multiple-seam mining. With 60 percent recovery, 40 billion tons are available. If an extra 5% of coal could be mined as a result of careful planning, this would yield 2 billion additional tons of coal in Appalachia alone, and a total of 7.8 billion tons for all United States coal subject to multiple-seam mining.

The estimated investment for the experimental mine program is 4.0 million dollars, implying an improved production of 1660 tons of coal per research dollar. Assuming that coal is produced at $27/ton, this implies a benefit/cost ratio of 44,820. For A 5% greater coal production and with $2.6 million being allocated to research related to resource recovery, the expected savings would be $0.904/ton of coal.

4.2 Ground Control

The importance of ground control in coal mining cannot be overemphasized. In Pennsylvania alone, damage claims resulting in approximately $0.01 per ton are paid each year. As more coal is mined and as urban areas spread, the problem of subsidence will become more costly. The proposed ground control program comprises one-third of the total cost of the program, or about 1.3 million. The subsidence program investigation essentially entails the

evaluation of an element of the mining program which improves resource recovery, while creating less disturbance both during and after mining. Subsidence is more severe with mining of multiple seams, since the effects from each seam are cumulative.

Estimating the cost/benefits are difficult, because of the prolonged time element involved. This makes determining the exact amount of subsidence damage intractable. Conservatively, an estimated 5% benefit applied to the total available recoverable reserves in the Appalachian region will result in a significant savings, viz. $35,100,000 or $108 per research dollar; $0.001 saved per ton of coal. Nationwide benefits would yield $39 per research dollar, with $0.001 saved per ton of coal.

5.0 CLOSURE

Figure 52 illustrates the major areas of the research program and their estimated cost savings. The graphs dramatically outline the extensive cost/benefits of the proposed research which include:

- Resource recovery
- Ground support
- Operations economics
- Cost models

This research program is quite broad, and the overall benefits to be expected may be larger than the sum of the individual elements.

The benefit/cost ratio is another expression for the dollars saved per research dollar, which is generally quite high. This is to be expected since tremendous quantities of coal are involved. Even a small increase in recovery amounts to considerable coal tonnage, thus offsetting research costs.

If the benefits of research are expressed as dollars saved per ton of coal, the total saved is $1.376 per ton. This is based on conservative estimates of the costs savings. It should be emphasized that these cost savings represent a significant portion of the extra costs involved when mining multiple seams. Consequently, these savings will bring the operating costs of multiple-seam operations much closer to those of single-seam mining.

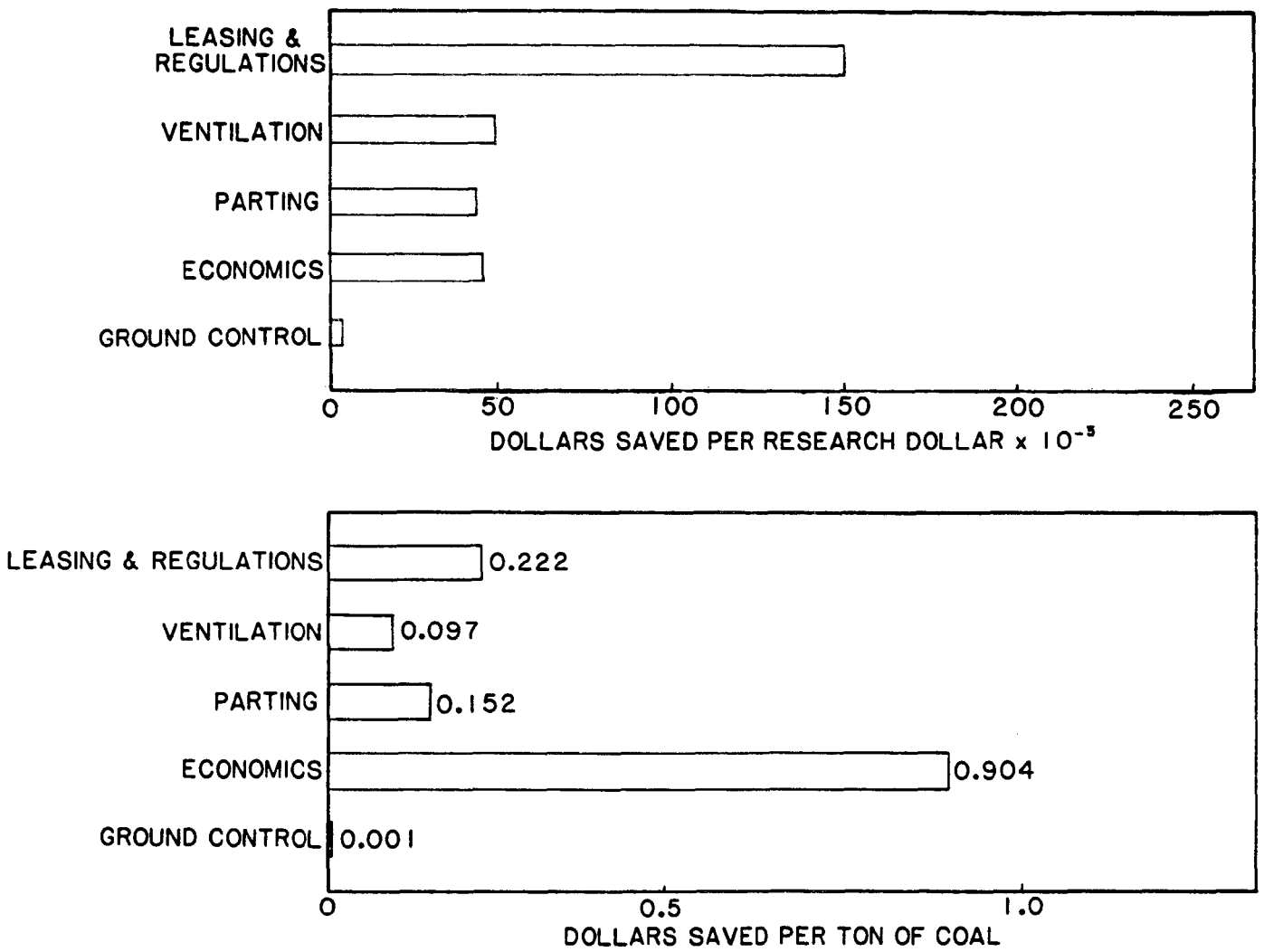


Figure 52- Dollars Saved Per Research Dollar and Per Ton of Coal Mined.

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