

Roof Characteristics of the Springfield (No. V) Coal in Indiana

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Introduction

In Indiana the Springfield (No. V) coal is the most persistent seam with the largest in situ reserve and greatest mineable potential. Approximately 95% of the remaining in situ 11.7 billion tons of Coal V estimated by the Indiana Geological Survey has to be extracted by underground mining methods. By virtue of its being in the median stratigraphic position among the major mineable seams, the bulk of the reserve occurs in the shallow underground mineable category, which is less than 600 feet deep.

In any method of underground coal extraction, the nature of the roof above the coal seam is one of the key factors in determining the economic mineability of the seam.

In the present study an attempt has been made to formulate the basic characteristics of the Coal V roof in Indiana and to define their variabilities on a regional scale. The specific details of the localized target areas for mining have not been discussed here primarily due to the lack of extensive data control and the uniqueness of each mine-block.

Geology of the Roof

The various lithologic units overlying a coal seam in a composite form are collectively called the roof of the seam. Geologically a roof can be divided into two categories—immediate or primary and main or secondary. Immediate roof can be defined as the lithostratigraphic unit which lies directly above the coal seam. The main roof which overlies the immediate roof usually is composed of multiple lithostratigraphic units. The total thickness or upper limit of the main roof can be defined either, by the direct influence of the uppermost lithostratigraphic unit can have on the stability of the roof system, or the lithostratigraphic unit used as the foundation for the roof support mechanism. In general, the immediate and the main roof constitute a heterogenous geological condition. The homogenous geologic condition in a roof system exists when the immediate roof is very thick and extends vertically beyond the zone of influence. In the heterogenous roof system the two categories are not always complimentary of each other.

To be consistent for the purpose of generalization, a fixed 10 feet zone above the coal seam has been adopted as an index of evaluation. Several hundreds of these '10 feet zones' above the coal seam from representative geographical distribution have been utilized to define the litho and chronostratigraphic variabilities.

The immediate roof of Coal V in Indiana can be defined as a member of the Petersburg Formation which shows lithologic variations geographically over the Indiana coalfields. Except for a few localized areas where the Alum Cave Limestone overlies Coal V, the immediate roof is considered to be time parallel or formed contemporaneously. The total range of changes in the immediate roof is probably caused by changes in the depositional environment. As is shown in Figure 1, the immediate Coal V roof in Indiana is predominantly black shale. Although the black shale for mapping convenience has been characterized as a

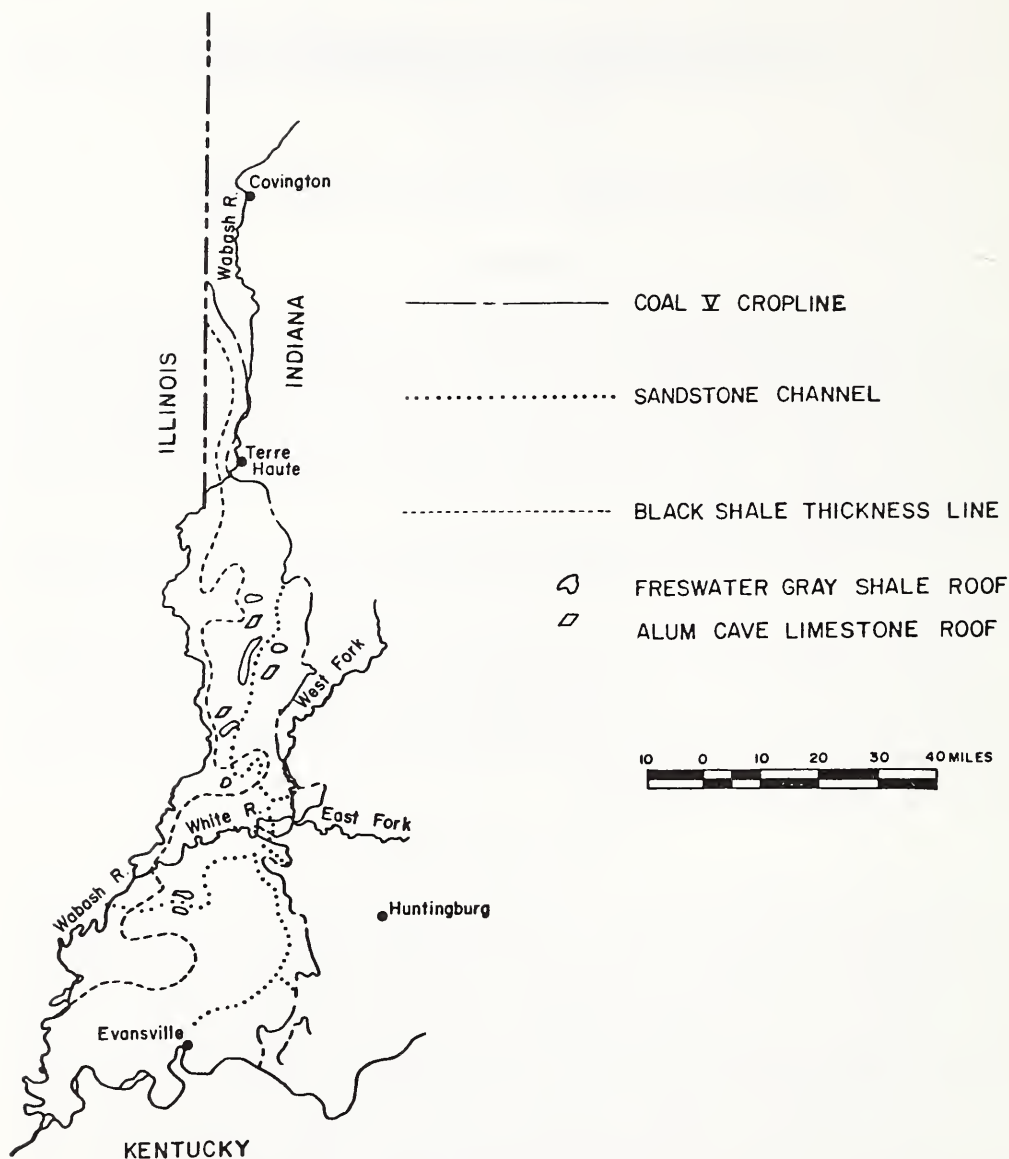


FIGURE 1. Geographical distribution of the immediate roof above Coal V in Indiana. (Black shale roof is present in the entire area, except gray shale and limestone locations.)

uniform member in the entire coalfield, close field examinations reveal that there are few distinctions in properties which can influence the mineability of Coal V. Also, as shown in Figure 1, a generalized thickness line delineating the "more than 3 feet and less than 3 feet" of black shale areas is presented. The characteristics which are prominent in these two divisions are tabulated below.

+3 feet	3 feet
1. typically massive	typically laminated
2. comparatively harder (bulk hardness)	brittle and breaks along the horizontal planes
3. silty	more clayey
4. typical area - Vermillion and northern Sullivan counties	Warrick County

units in the main roof for different geographical locations is shown. These represent best estimates of averages (based upon the available data) for any given area. These lithologic units are either members of the Petersburg or the Dugger Formation. Based on the number of lithologic units present in the remainder of the interval, a general approximation about the stability of the roof can be obtained (typically for Indiana coal fields). It is assumed here that each lithologic unit is adding one plane of weakness. Thus, the stability of the Coal V roof is inversely proportional to the number of lithologic units present in the main roof, or the stability of the Coal V roof = $K \times$ number of lithologic units present in the main roof. The value of K , constant of proportionality will vary from place to place depending upon the local geology, nature of lithologic units and the past history of mining. In this approximation, the orientation of excavation either parallel or perpendicular to the bedding planes has not been considered.

In Figure 3, different combinations of qualitative variations have been illustrated. Each combination gives an indication of the stability of the roof relative to the lithologic characteristics. Laterally, the lithologic variations for the members of the main roof are very abrupt and inconsistent. It is probable that during late Petersburg and early Dugger time, the depositional system was very active, variable and restricted.

Structure and Physical Properties

In the preceding section, the range of lithologic variations in the immediate and the main roof of Coal V in Indiana was described. A generalized geographical distribution of the rock types in these two categories of roof has also been presented. The physical characteristics and the sedimentary structures associated with these rock types will be briefly discussed here.

Black Shale: Typically, the black shale in Indiana is very dark to moderately dark, moderately hard and contains varying amounts of organic materials.

The laminated type of black shale which is rather brittle and breaks along horizontal planes is relatively smooth and even. The cracks are rather prominent and relatively less water sensitive than the massive type of black shale.

The massive type normally shows irregular cracks, lenses of silty materials and contains slightly coarser sediments. It is relatively more water sensitive than the laminated type. Near the contemporaneous sandstone channel in places, the normal sequence of lamination is disturbed and lenses of silty materials become more prominent.

The laminated black shale frequently parts unevenly along the horizontal planes, activated by the presence of fluids in exposed conditions. The massive variety is moderately competent except where it contains lenses of silty materials, irregular bandings, etc. The black shale roof type in Indiana can be considered more competent than the fresh water gray shale. **Gray shale (fresh water):** Light to moderately dark, massive, invariably silty, porous, moderately hard to soft and breaks unevenly. The gray shale in Indiana is typically inhomogenous, inconsistent and not very thick. Numerous lenses of fine grained sand are typically present. Close to the channel the gray shale shows distortion in restricted areas. Irregular, interconnecting cracks are common. Because it is typically water sensitive and disintegrates easily, the fresh water gray shale commonly exhibits poor roof conditions with a very limited holding capacity.

Alum Cave Limestone: It is a light colored, argillaceous, 4 to 5 feet thick, moderately hard to hard limestone with an uneven fracture pattern. Typically, it occurs in two benches: The lower bench is thinner, compact and even. The two benches

**Variations in the Roof Lithology of Coal #V
(First Ten Feet)**

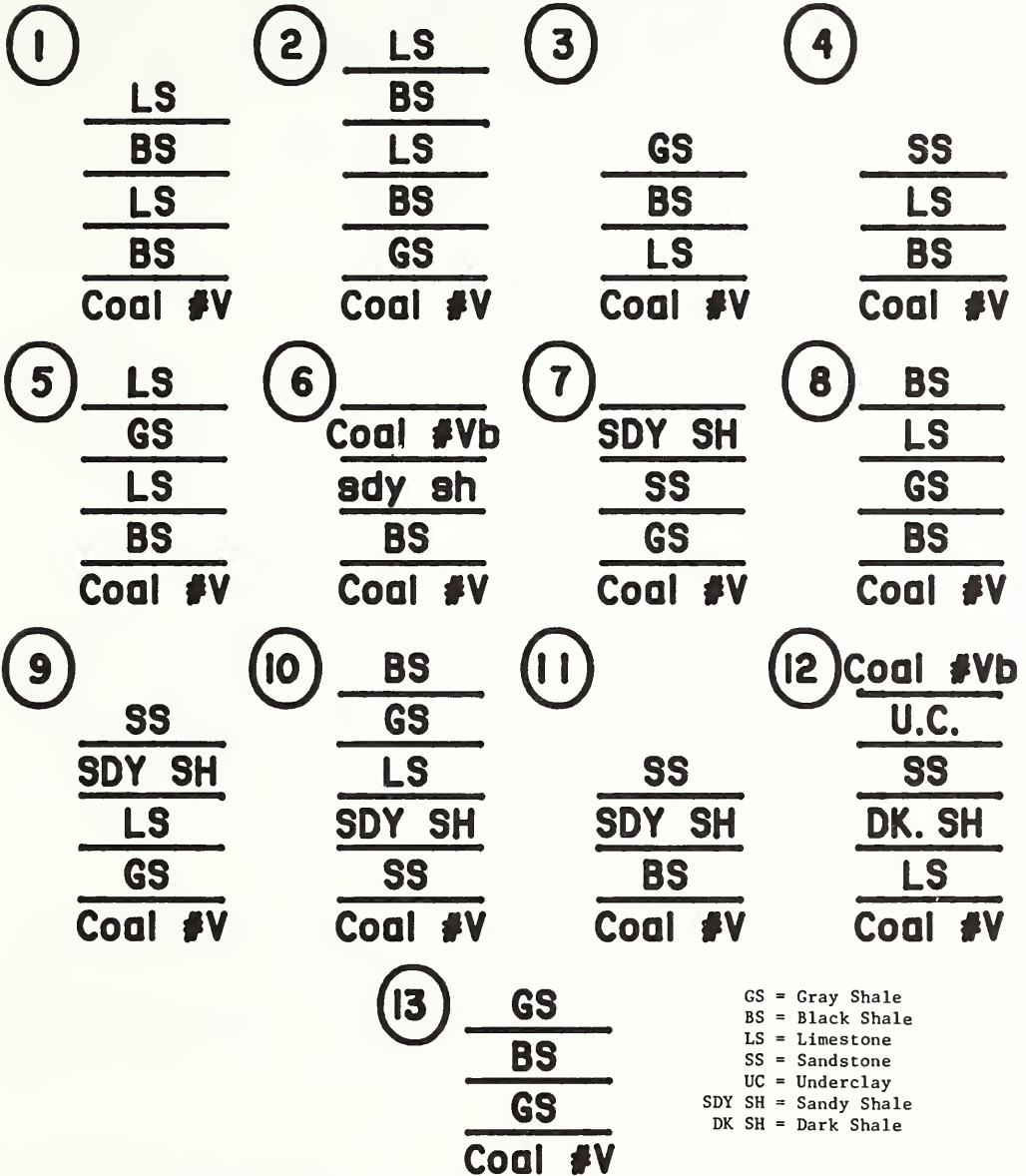


FIGURE 3. Various lithologic combinations present in the first ten feet above Coal V in Indiana.

are typically separated by black or marine gray shale. The upper bench is normally shaley, less compact and uneven. Generally the fractures are irregular, intersecting and unevenly distributed, and the shaley areas are moderately water sensitive. If the lower bench is reasonably thick (> 2 ft.), and consistent, the Alum Cave affords good roof conditions in underground mining.

Discussion

From the data presented in the preceding sections, it is evident that local roof variations are locally more pronounced compared to variation on a regional scale in Indiana. Hence, based on the regional trends we can devise a scheme

of assessment which can be applied to determine the competency of a roof system in a given localized area. This scheme may be helpful as a first approximation in the early stages of exploration where very little detailed information is available.

This is a semiquantitative scheme based on the comparative weight factors on a scale of one to ten, assigned qualitatively without any bias. Even with some degree of bias the gross result will remain unaffected. The various parameters in the assessment are given below.

1.) Nature of the immediate roof—the most favorable (realistic) situation in Indiana can be at least three feet thick, Alum Cave Limestone without any inclusion of shaley materials (compressive strength > 10,000 PSI). A relative scale of competency based on the megascopic characters for assigning weights, in decreasing order of preference is as follows:

					soft fresh water
				compact sandy	gray shale
Lithologic units:	(> 3 ft.)	limestone finegrained sandstone	hard black shale	shale	shale
Weight :	10	8	6	4	2

Homogeneity and thickness are two variables which should also be considered while assigning weights in this category. Thick and homogenous lithologic units are favorable unless the units are composed of incompetent soft materials.

2.) Depth is also an important parameter. Because, the same marginally competent materials at shallower depth may not be competent at a substantially greater depth. Also, groundwater seepage, structural features and discontinuities would increase the susceptibility to failure at greater depths. An example of a simplified scale of weights based on depth is given below:

Depth (ft.) :	200	400	600	800	1,000
Weight :	10	8	6	4	2

3.) Number of unit beds present in the main roof is an important parameter to be weighted. In general, the fewer number of units in the main roof, the more stable the system is for underground mining. In the case of the multi layered main roof situation, the effect of weakness is cumulative to the process of deformation. Weights can be assigned in the inverse order to the number of units.

Number of lithologic units in the main roof :	10	9	8	7	6	5	4	3	2	1
Weight :	1	2	3	4	5	6	7	8	9	10

Geologically, if the changes are not gradational, by addition of one more units in the system, the homogeneity is decreased to some extent and thus the probability of failure increases.

4.) Lithologic nature of the units present in the main roof is also important and should be weighted accordingly. For example, if in a main roof system the lithologic units are alternating fresh water—soft gray shale and coarse grained loosely cemented sandstone, then this category should be given lower weights. The weights can be assigned as in the immediate roof (parameter 1).

5.) Position of the relatively incompetent bed and the arrangement of the lithologic units in order of competency in the main roof system is also an important parameter.

There can be three orders of arrangement—vertically increasing order of com-

petency, vertically decreasing order of competency and irregular order. Each one has its own merits and demerits and should be evaluated with respect to the immediate roof and the basal unit of the main roof. If the basal unit is thick, then a vertically decreasing order of competency can withstand the overlying load, but if the basal unit is thin, then a vertically increasing order of competency is needed for support. In the case of an irregular order, the position of the most incompetent bed in the system is important. In Figure 3, 13 lithologic combinations are shown and weights can be assigned in the following manner.

Combination :	1	2	3	4	5	6	7	8	9	10	11	12	13
Weight :	8	6	8	8	6	4	4	6	4	6	6	6	2

5.) The density of cracks, joints and fractures present in the unit area should also be considered. Length and orientation of the cracks are critical. Under pressure, the cracks tend to connect and create roof falls. Also the presence of fluid in these cracks increases the chances of failure. If under pressure, the cracks connect with each other, the bulk permeability of the rock is increased which reduces the in situ compressive strength. Hence, if the cracks are close together and oriented at angles to one another where two sets of cracks intersect, these should be assigned lower weights.

6.) Water sensitivity is also an important parameter which is detrimental to the roof stability. Typically, the clayey shale and loosely cemented sandstone are the most susceptible to water. The expendable clay minerals like montmorillonite, if present, will swell and reduce the compressive strength. The weights should be assigned, based on the results of field water sensitivity test.

Based on the above parameters, a semiquantitative estimate of the roof stability in a given area can be determined which bears directly on whether the reserve has potential for detailed analysis.

Conclusion

Interpretation of geological variables to determine the stability of roof, unless quantified, does not represent the sensitivity of correlation. Qualitative judgements do not properly verify the factor of risk and the uncertainties associated with the projected inferences. The present study needs refinements in order to be effective at the final stages of mine planning.

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