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Geologic Investigation of Roof and Floor Strata: Longwall Demonstration, Old Ben Mine No. 24

Robert A. Bauer

Philip J. DeMaris

April 1982

Illinois Department of Energy and Natural Resources
STATE GEOLOGICAL SURVEY DIVISION
Champaign, Illinois

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GEOLOGIC INVESTIGATION OF ROOF AND FLOOR STRATA: LONGWALL DEMONSTRATION, OLD BEN MINE NO. 24

FINAL TECHNICAL REPORT: PART I

by

Robert A. Bauer and Philip J. DeMaris

Principal Investigators:

Heinz H. Damberger
Harold J. Gluskoter (to 6/78)

April 1982

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This report represents work on a program
that was originated by the Interior Department's Bureau of Mines
and was transferred to the Department of Energy on October 1, 1977.

Illinois State Geological Survey
Natural Resources Building
615 East Peabody Drive
Champaign, IL 61820

CONTENTS

TABLES

FIGURES

ABSTRACT

In-mine mapping of three longwall panels at the Old Ben No. 24 Mine has revealed both major and minor roof-stability problems and multiple areas of concentrated coal balls within the Herrin (No. 6) Coal Member. The roof-stability problems are related to three interacting factors: variations in roof lithology, various structural features, and mining plan. Major roof-stability problems are rare at the longwall face, but more common in the longwall support entries. Several major falls have occurred in areas where potential problems were identified previously during mapping. Lesser roof-stability problems are associated with "rolls" (linear shale bodies in the top of the seam) containing compaction faults and with a tectonic fault zone running perpendicular to the face of the second panel.

A distinctive roof type has been identified in this mine; the roof type varies between Energy Shale and Anna Shale/Brereton Limestone over a short distance. Other mines with this type of transitional roof can expect similar roof problems.

Large deposits of coal balls within the seam repeatedly interfere with orderly development of support entries and damage longwall equipment. The second and third panels have been shortened to avoid areas of coal-ball concentrations. The distribution of coal balls is strongly correlated with roof lithology; thus the association of roof and coal balls has been used successfully to predict locations of coal balls in unmined areas.

ACKNOWLEDGMENTS

This report is based on detailed geologic investigations in the Old Ben No. 24 Mine near Benton, Illinois, in conjunction with the longwall coal mining demonstration project. This work was supported by the U.S. Bureau of Mines Grant G0166207 from September 1976 to March 1978, and by the Department of Energy Grant ET-76-G-01-9007 from April 1978 to December 1979. The work was administered under the technical direction of the Pittsburgh Mining Technology Center with James R. White, and later, Mary Ann Gross as Technical Project Officers.

We wish to thank the officials and employees of the Old Ben Coal Company and of their No. 24 Mine for valuable information and assistance. We also wish to thank W. John Nelson and John T. Popp of the Illinois State Geological Survey for assistance in underground mapping and Peter R. Johnson for petrographic study of the Herrin (No. 6) Coal seam in the study area. We are grateful to Tom Phillips of the University of Illinois, Botany Department, for identification of the plant material in the coal balls found in the mine. We also thank Sue M. Rimmer for clay mineral analyses of roof, floor, and in-seam materials.

INTRODUCTION

In the 1960s and early 1970s, ten attempts at longwall mining were made in southern Illinois in the Herrin (No. 6) Coal Member. All attempts were abandoned before the completion of one entire panel. The most serious problems were related to the chock supports, which were inadequate to hold the roof at the face. Since geologic conditions encountered during these first attempts were not documented, how geologic conditions related to the stability problems is not entirely known. Moroni (1974) described several of the longwall attempts of the Old Ben Coal Company; Harrell (1974) described similar attempts by Freeman Coal Mining Company.

In 1975, the U.S. Bureau of Mines and the Old Ben Coal Company began a longwall demonstration project on a cost-sharing basis. The Illinois State Geological Survey, with financial support from the U.S. Bureau of Mines and later the U.S. Department of Energy, documented the geologic conditions encountered during the longwall mining demonstration.

This report summarizes the observations made by Illinois State Geological Survey staff during geological mapping, sample collection, and testing conducted in connection with the three longwall demonstration panels and other selected areas in the Old Ben Coal Company No. 24 Mine. It also contains information from past State Geological Survey investigations and drill hole logs. Our tasks and goals were

1. to map lithologic variations and geologic structures in roof, floor, and coal in and around the longwall panels and other locations in the mine (methodology generally follows that discussed in Krausse et al., 1979a; 1979b);

2. to relate geological features to the stability of the roof during the longwall mining operation;

3. to drill several boreholes into the roof and floor and conduct mechanical strength tests on the cores;

4. to study the nature and occurrence of coal balls found in the coal seam in the demonstration area for the purpose of predicting other coal-ball occurrences.

GEOLOGY OF HERRIN (NO. 6) COAL MEMBER AND ASSOCIATED STRATA IN FRANKLIN COUNTY

This longwall demonstration project was conducted in the Illinois Basin Coal Field at the Old Ben No. 24 Mine, which is located in southern Illinois within Franklin County and operates in the Herrin (No. 6) Coal Member (fig. 1) of the Carbondale Formation of the Pennsylvanian System (fig. 2).

A large river was contemporaneous with the deposition of the peat that is now the Herrin (No. 6) Coal. The position of the river is now represented by the sediment-filled Walshville channel, located about 7 miles west of the longwall site. Shale splits within the coal seam along the channel indicate that the river associated with the Walshville channel remained active throughout deposition of the Herrin peat (Johnson, 1972). Furthermore, an investigation of the thickness and type of strata below the Herrin (No. 6) Coal showed that the river responsible for the Walshville channel was active even before deposition of coal-forming peat began in Franklin County. The thickness of the interval between the Herrin (No. 6) Coal and the next major coal seam below, the Springfield (No. 5) Coal Member, varies greatly in the county. The interval is thinnest near to and thickens away from the channel. The thickness of the interval was used as an indicator of the relative topography upon which the peat forming the Herrin (No. 6) Coal was deposited. Whereas the Herrin peat may have been slightly time transgressive, the effect within the study area was judged to be insignificant. Further investigation of strata below the Springfield (No. 5) Coal showed that no variations in thickness existed that might have influenced these upper units.
In western Franklin County the interval between the Herrin (No. 6) and the Springfield (No. 5) Coals thins abruptly within a mile-wide, crescent-shaped depression that has both ends terminating near the Walshville channel; it appears to be an abandoned meander (fig. 3). The coal is thickest in the meander (fig. 4). Shape, location, and increased coal thickness all indicate that the meander was formed and abandoned before peat deposition began.

After deposition of peat ceased, the river persisted a while, forming the first layer on top of the coal—a gray silty shale called the Energy Shale Member. This shale, believed to be an overbank deposit of the river, is found in several large lobate deposits along the former course of the river; they all thin away from the channel. The next layer deposited on the gray shale, or directly on the coal where the gray shale is missing, is a black carbonaceous shale known as the Anna Shale Member. The Anna Shale here is a widespread, black, highly carbonaceous shale averaging 2.8 feet thick with a low-diversity marine fauna suggestive of a restricted environment. Where the Energy Shale exceeds about 35 to 45 feet in thickness, the Anna Shale generally pinches out.

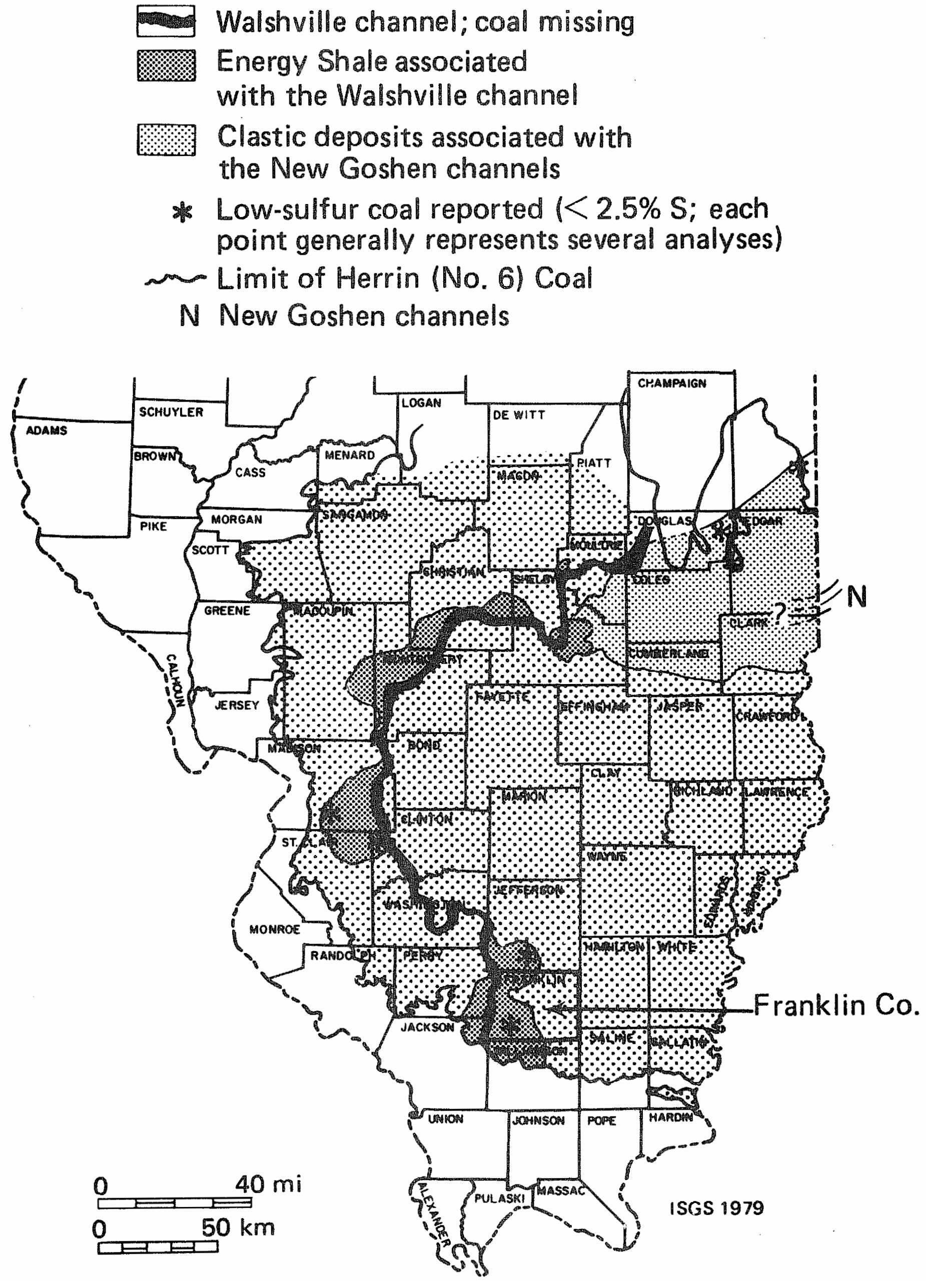


Figure 1

Distribution of the Herrin (No. 6) Coal Member in southern Illinois, and the location of the study area, Franklin County. (From Treworgy and Jacobson, in press.)

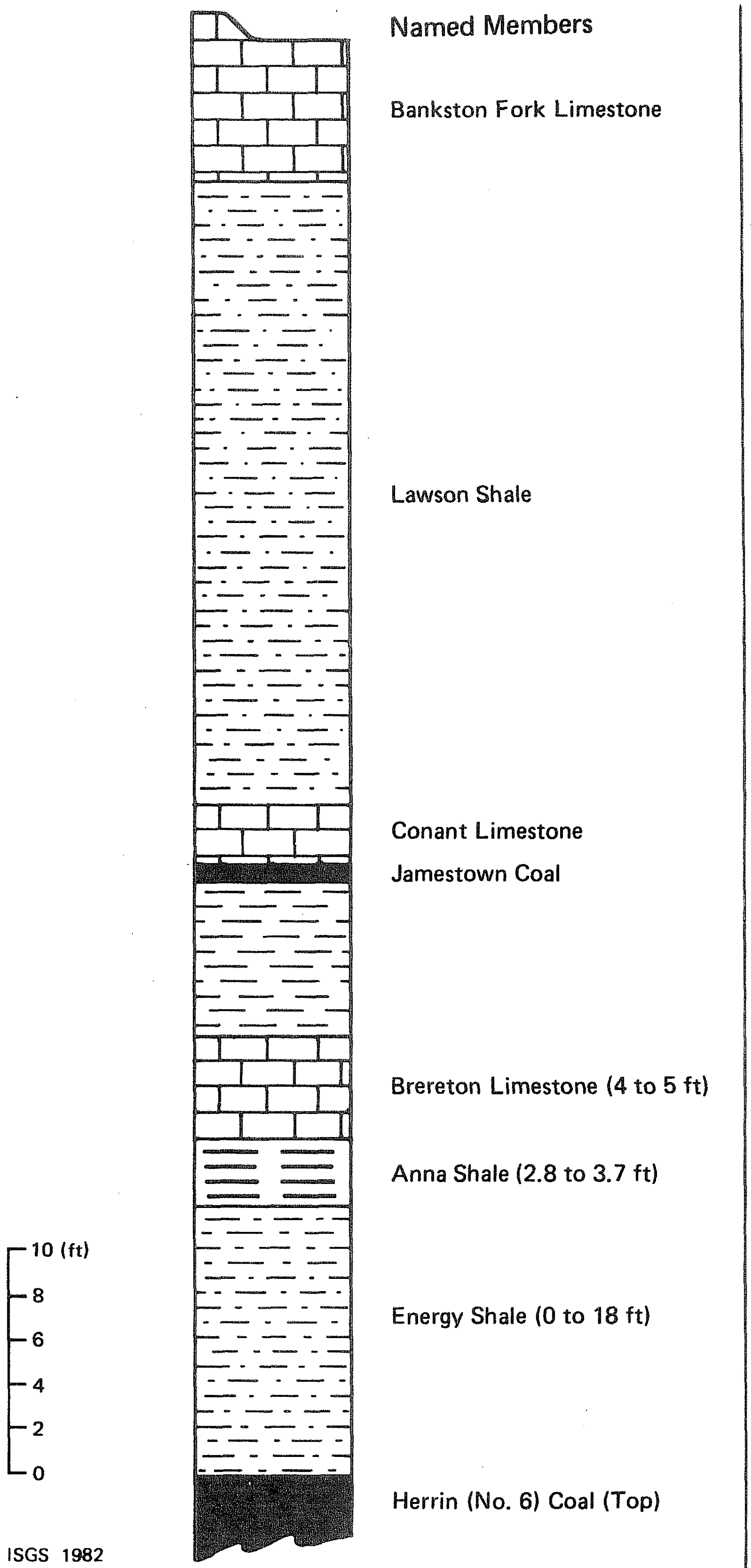
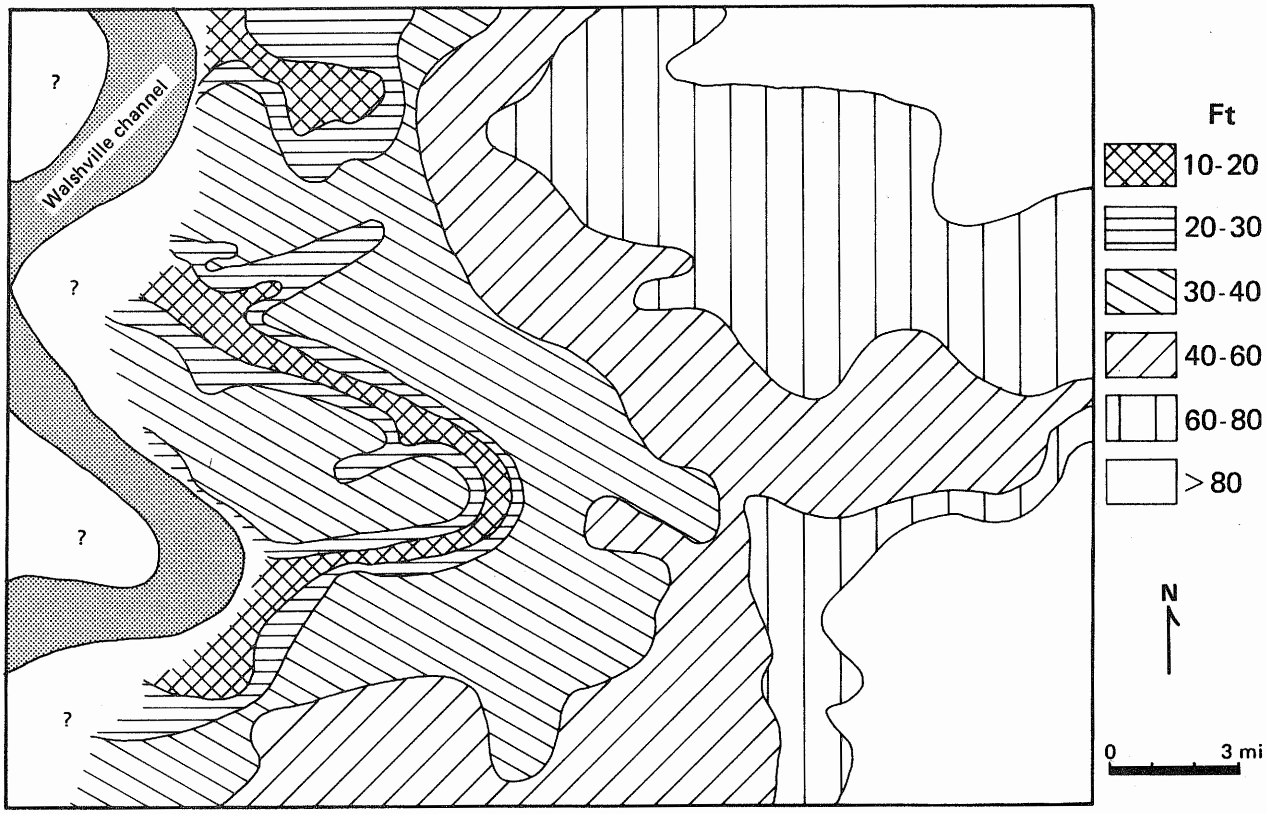


Figure 2
Composite stratigraphic section of the roof of the longwall panels, representing a portion of the Carbondale Formation, Kewanee Group, Pennsylvanian System.

Figure 3
Thickness of the interval between the top of the Springfield (No. 5) Coal and the the base of the Herrin (No. 6) Coal in Franklin County.

Figure 4
Generalized thickness (in feet) of Herrin (No. 6) Coal in Franklin County.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Walshville channel
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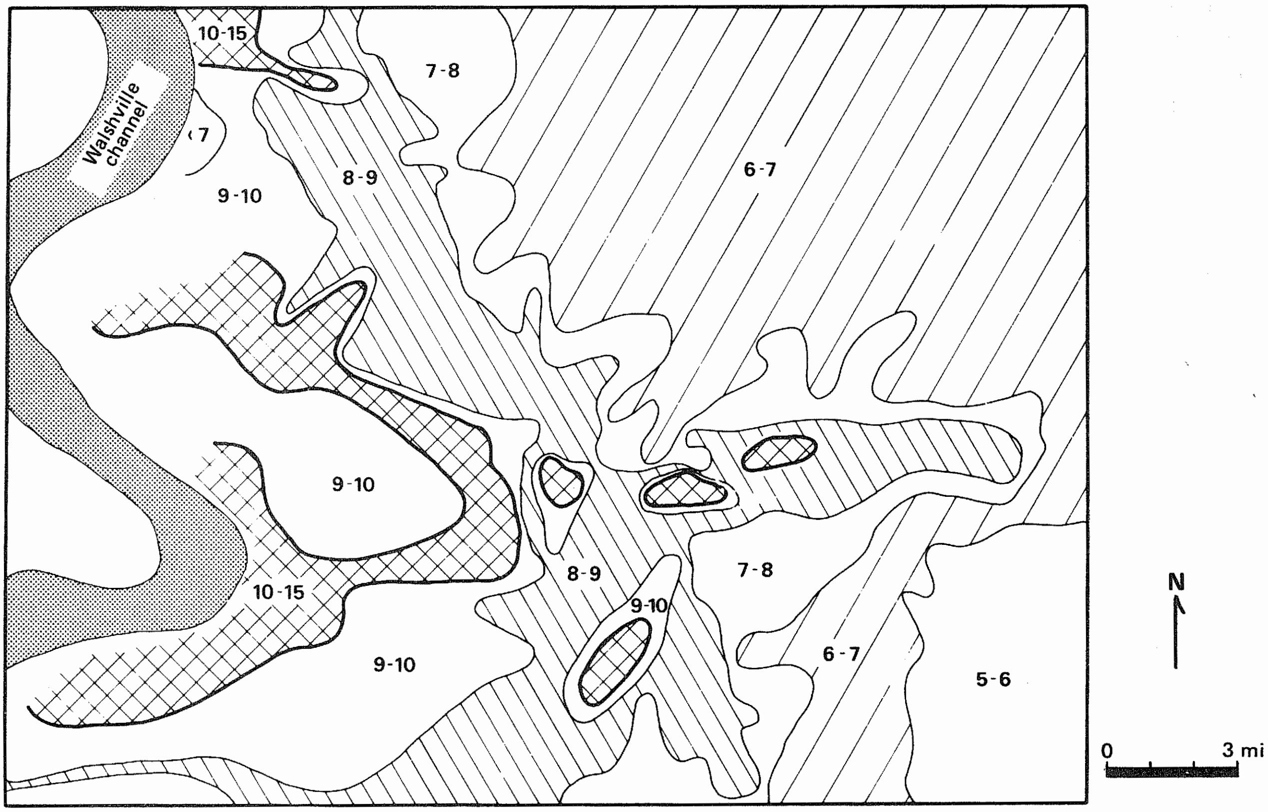
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Walshville channel
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The Brereton Limestone Member is the next younger unit. Here the Brereton Limestone is dark gray, fine grained, and argillaceous. It contains an open-marine fauna, averages 5.9 feet thick near the mine, and overlies the Anna Shale or the coal, if both the Energy Shale and the Anna Shale are absent. Where the Energy Shale is thicker than 35 to 45 feet, the Brereton Limestone also pinches out.

Each of these units may form the immediate roof within a small area; therefore, this type of roof is considered transitional between the thick Energy Shale roof found locally near the Walshville channel, and the Anna Shale/Brereton Limestone roof found well away from the channel. This variability was first recognized during in-mine mapping in Old Ben No. 24 (DeMaris and Bauer, 1978), and was defined as that area where the roof varied from Energy Shale to Anna Shale/Brereton Limestone and back to Energy Shale over a short distance. On the basis of further in-mine mapping and analysis of nearby drill-hole data we now recognize that Energy Shale was originally deposited over the Herrin (No. 6) and then partially or completely eroded. The term "transitional roof" has since been extended to include areas with similar variability, which were produced primarily by initial deposition (Nelson and Nance, 1980).

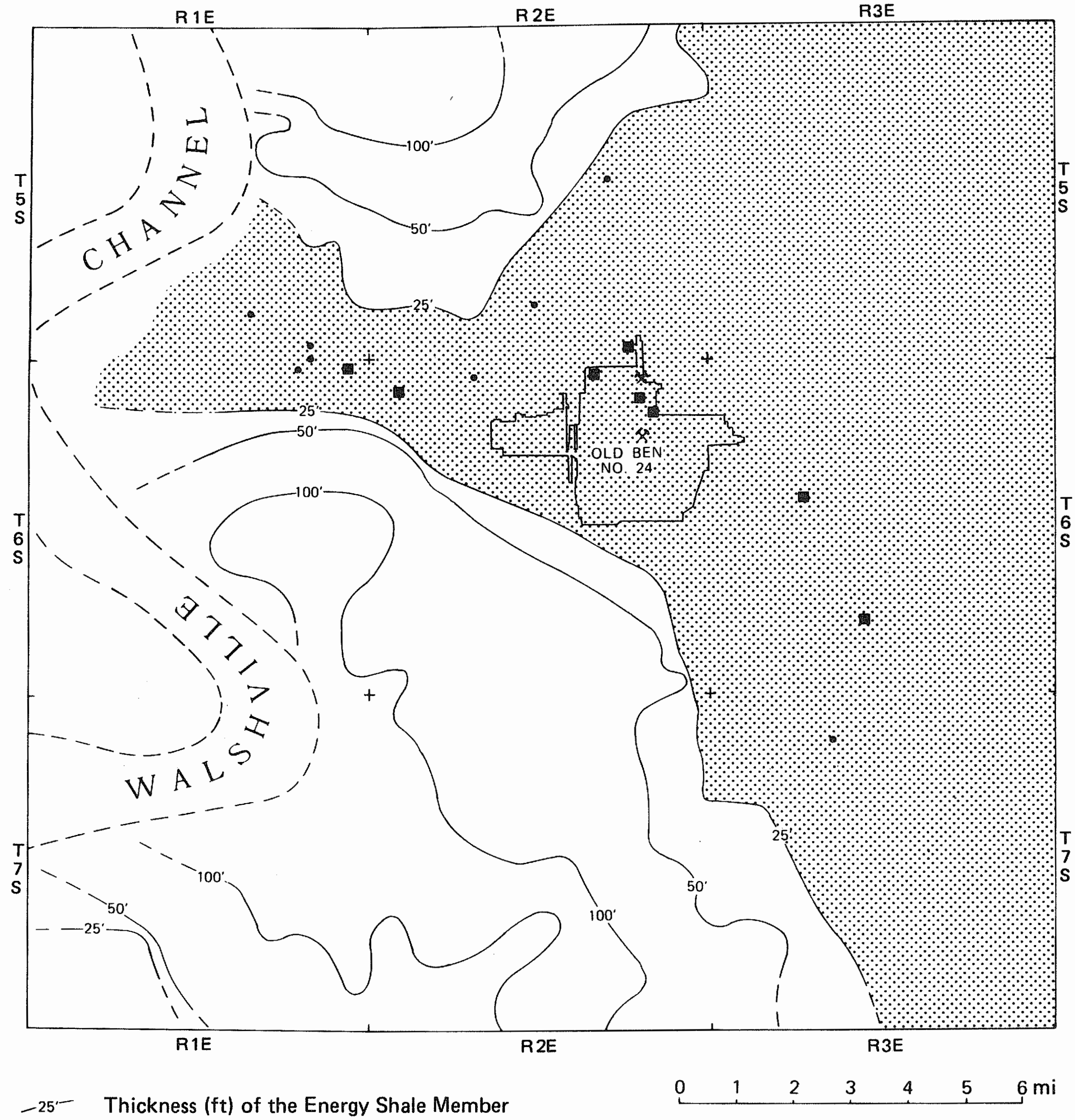
Based on drill-hole data we have extended the area of transitional roof within part of Franklin County (fig. 5) using the 25-foot thickness line as the break point between thick Energy Shale and the area of rapidly varying thickness. A corridor of this roof type separates two lobes of thick Energy Shale and appears to extend to, or very near to the Walshville channel. The north-facing slope of the southern lobe is much steeper than the opposite slope of the northern lobe, suggesting that erosion has accentuated the slope. The erosion may have been caused by temporary diversion of the south-flowing river waters toward the east-southeast, forming the corridor. The genesis of the transitional roof on the east side of figure 5 is uncertain because no active mines exist there.

GEOLOGIC CHARACTERISTICS OF OLD BEN NO. 24 MINE AREA

Setting

The mine is situated beneath the bottomlands of a small river. The Pennsylvanian bedrock over the longwall panels is covered by 50 to 60 feet of Pleistocene material, which is largely composed of silts and clays deposited on a lake bottom.

The longwall demonstration panels, located in mapped area A (fig. 6), are about 620 feet below the surface, with bedrock representing 565 feet



25' Thickness (ft) of the Energy Shale Member

Energy Shale slightly over 25 ft (point not honored by 25 ft thickness line)

Transitional roof (Energy Shale thickness from 0 ft to < 30 ft)

Coal-ball sites

Entrance shafts

Figure 5

Distribution and thickness of the Energy Shale Member in a portion of Franklin County, IL. Areas of transitional roof and all known coal-ball sites are also plotted. Townships and ranges are indicated along the map border.

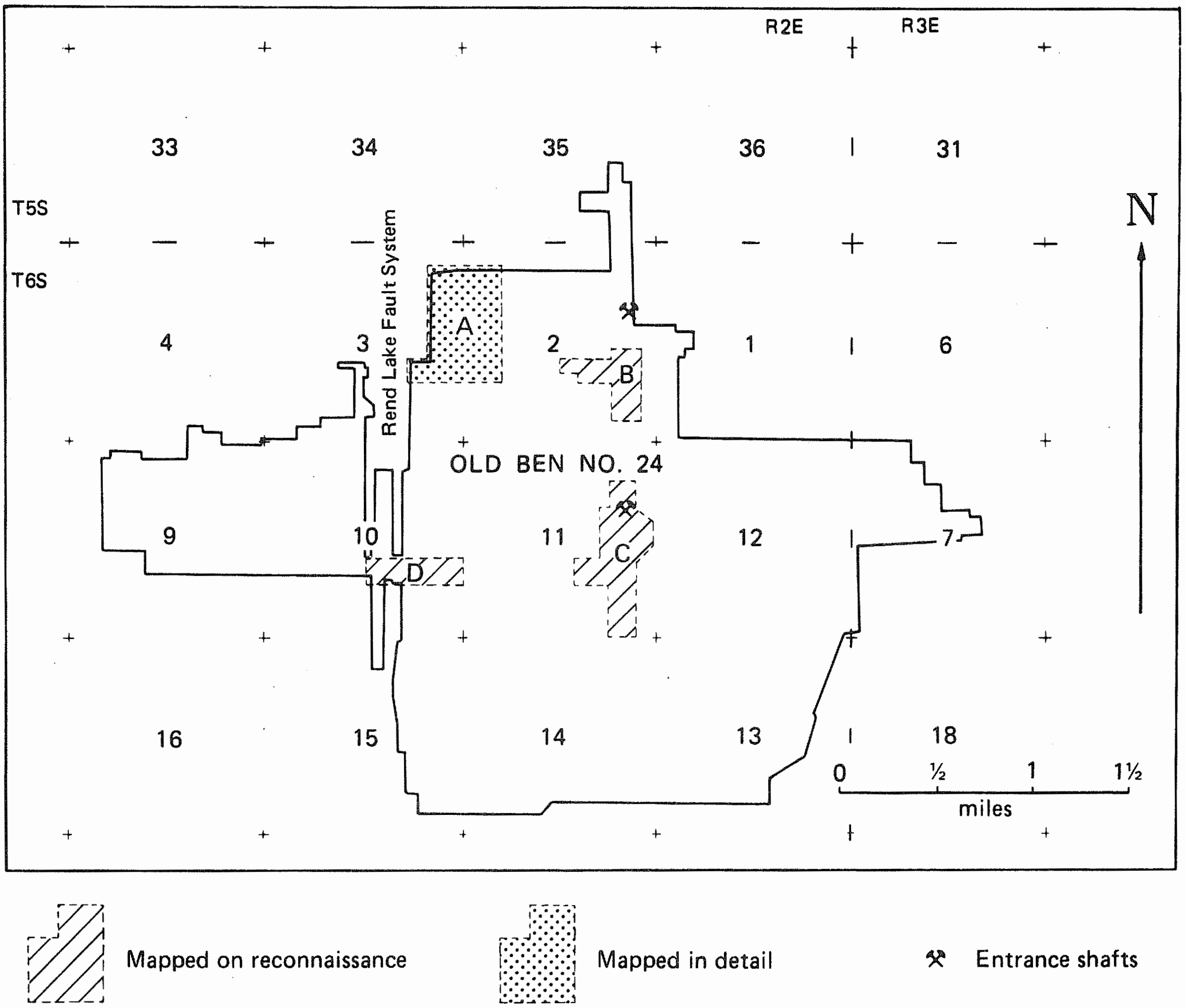


Figure 6

Index to mapped areas in the Old Ben Coal Company Mine No. 24. (Numbers on the map are section numbers, defining 1 square mile areas.)

of that distance. The overburden consists of about 5 percent limestone, 80 percent shale, claystone, and siltstone, 1.3 percent coal, 3.5 percent sandstone, and 10 percent Pleistocene cover.

Roof

The immediate roof of the longwall demonstration panels is the transitional type described in the preceding section; about 65 percent of the roof is Energy Shale (fig. 7). The Energy Shale is a fine-grained, medium-gray shale that is usually poorly bedded and has some thin ironstone bands and ironstone nodules roughly an inch in diameter scattered throughout. The gray shale rests conformably on the coal; in many areas the top of the coal and the bottom of the Energy Shale interfinger slightly. Clay mineral analysis of samples of Energy Shale from the longwall panel area show that it is homogeneous both laterally and vertically (fig. 11a). The contact between the top of the gray Energy Shale and the black Anna Shale is unconformable, dipping 10° to 14°. The angle decreases as the top of the Energy Shale is approached (fig. 8). This unconformity is the result of erosion that removed the gray shale and exposed the top of the coal seam, forming long sinuous areas from which gray shale is absent (fig. 9).

Two different facies of the Energy Shale are found as immediate roof; a lower, carbonaceous shale facies of limited distribution, and an upper, widespread, light- to medium-gray shale facies. The carbonaceous facies ranges from medium- to dark-gray in color, is rarely more than 0.4 feet thick and locally contains a lycopod-dominated compression flora. This carbonaceous facies is generally similar to the dark-gray unit described from a nearby mine (Edwards et al., 1979). The light- to medium-gray facies locally reaches over a hundred feet in thickness, but only rarely contains recognizable plant material. This facies is sometimes silty, varies from finely laminated to weakly laminated and often contains sideritic bands or bands of small pyritic nodules near the base.

The next younger unit, the Anna Shale, overlies the eroded top of the Energy Shale, or the coal where the Energy Shale is absent. The bedding of the Anna Shale parallels the surface on which it was deposited. The lower part of the Anna Shale is black, very carbonaceous, fissile, hard, and typically has a prominent set of joints that strike about N 80° E with occasional minor joint sets perpendicular to it. Large disc-shaped concretions up to 3 feet across occur in this lower portion of the unit. It grades upward into a massive, very dark-gray claystone. The Anna Shale reaches a maximum thickness of about 4 feet but locally thins to zero near the central axes of sinuous areas lacking Energy Shale (fig. 10). Clay mineral analysis of the Anna Shale shows that the characteristic

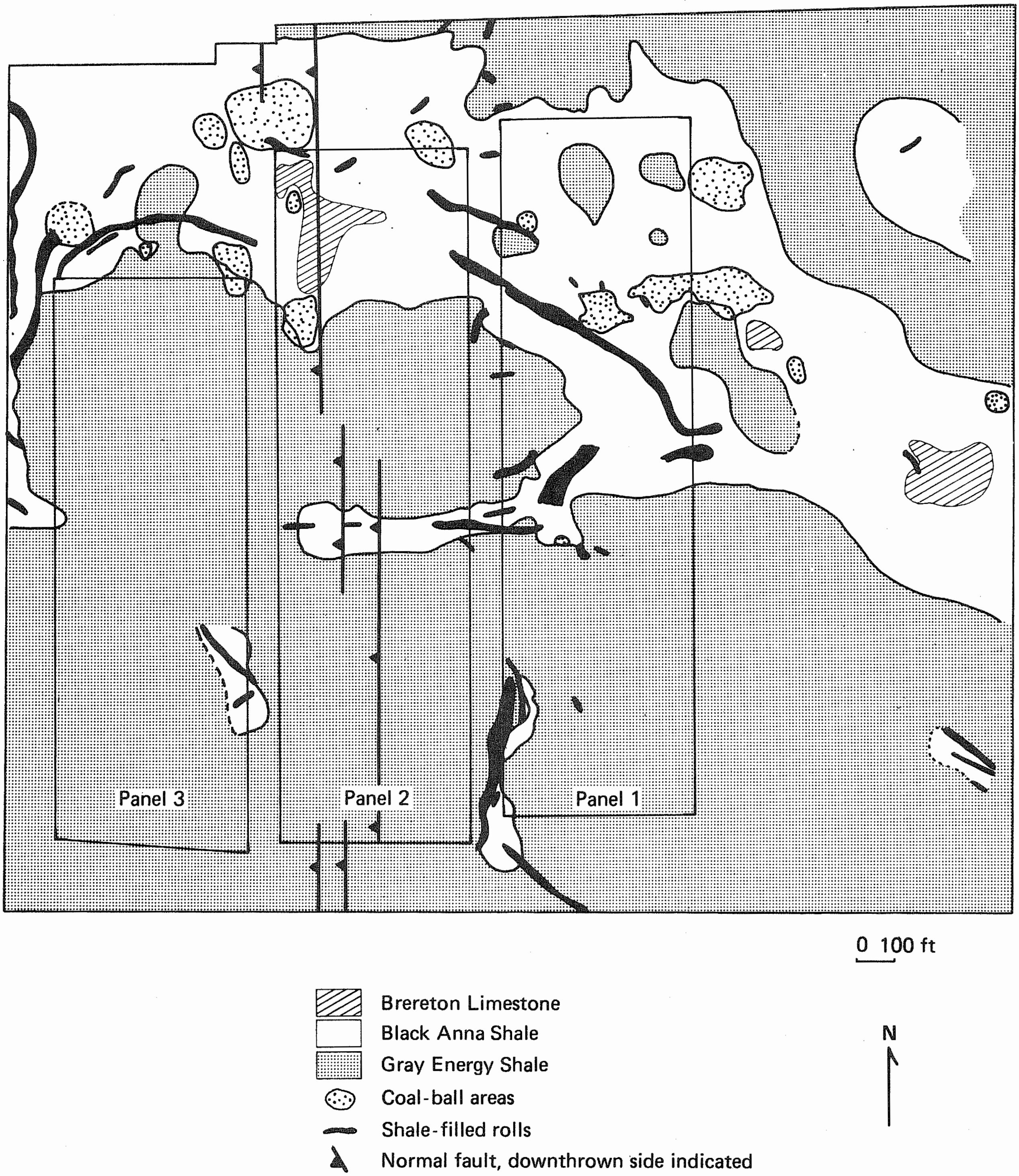


Figure 7

Plan view of roof geology at the longwall demonstration site in mapped area A.

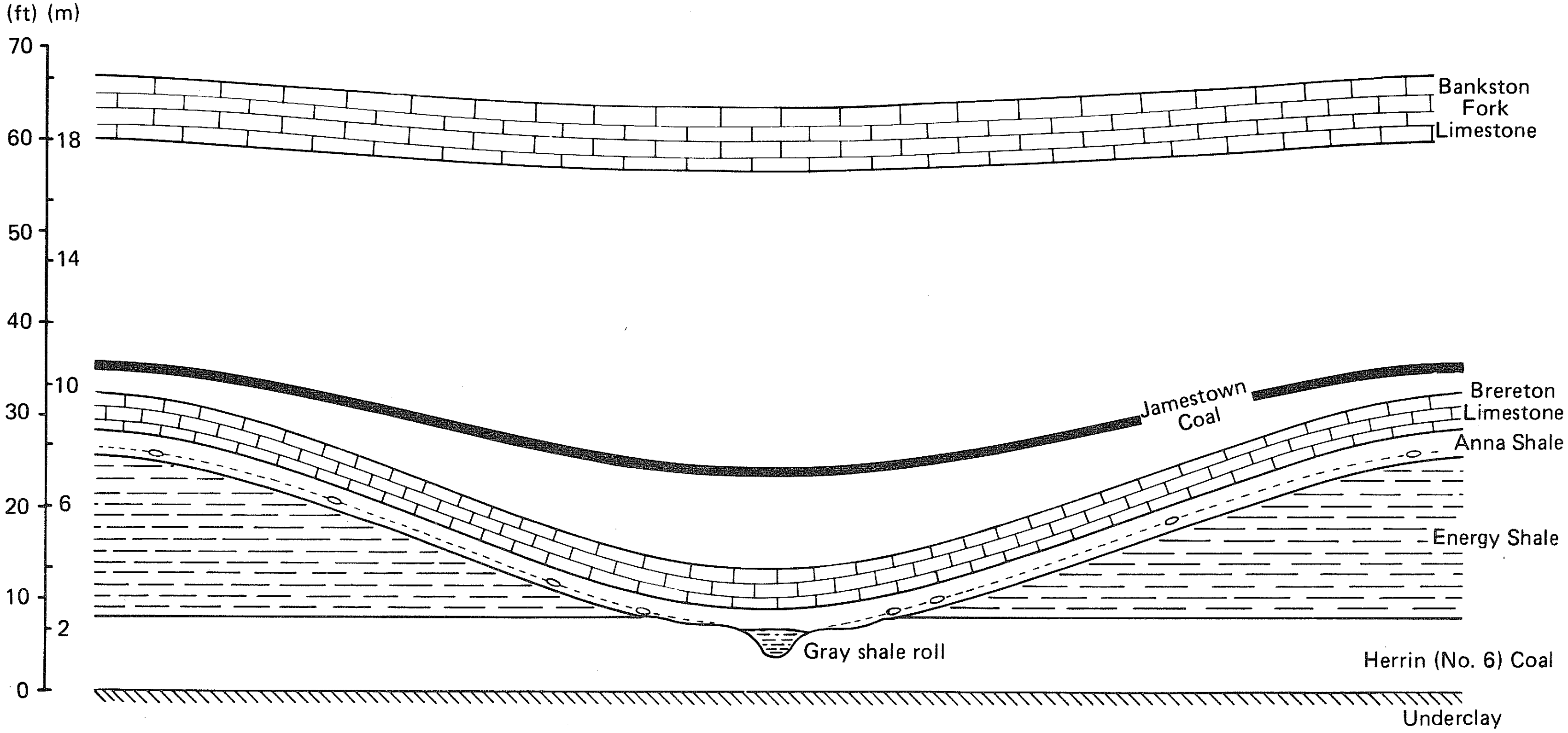


Figure 8
Schematic cross section showing interrelationships of Herrin Coal, rolls, and immediate roof members.

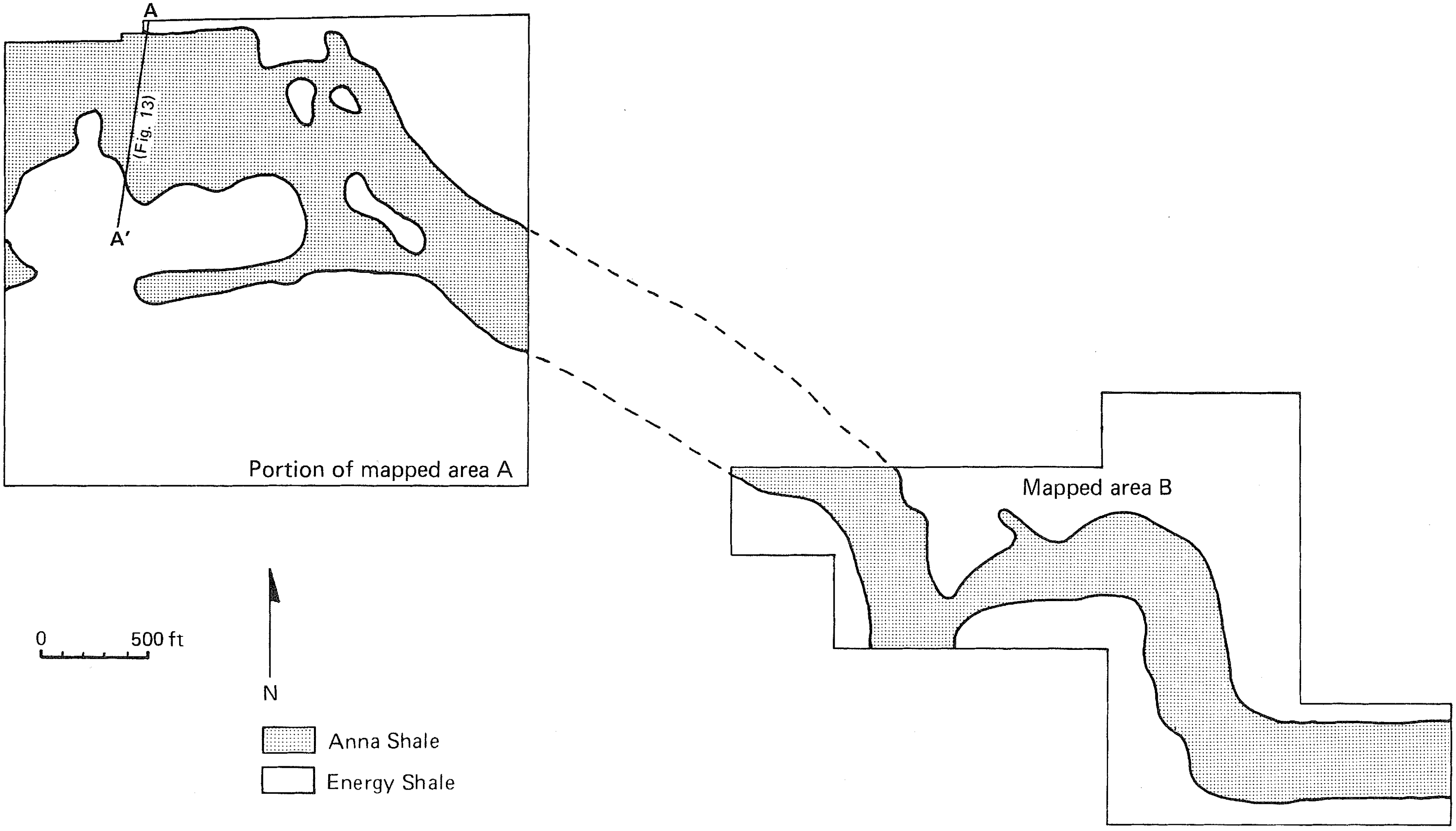


Figure 9

Spatial relationship of mapped areas A and B and the sinuous exposure of Anna Shale roof.

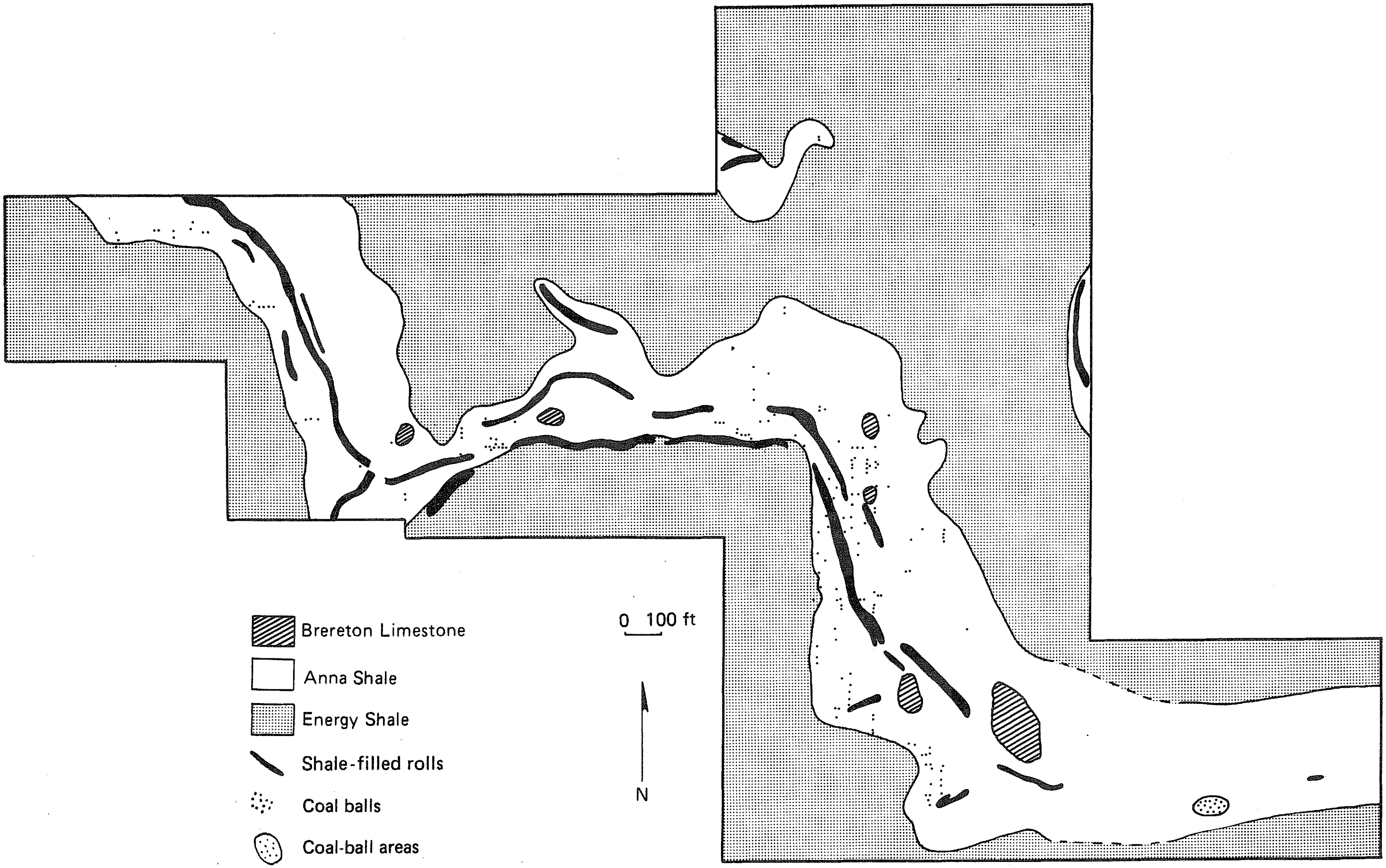


Figure 10

Map of the roof geology for mapped area B, which is centered about 5,000 feet east of mapped area A.

upper and lower portions differ slightly (fig. 11b). Field exposures and preliminary chemical analyses suggest that the lower portion of the Anna Shale is missing locally due to nondeposition. In some small areas no Anna was deposited and Brereton Limestone, the next higher unit, became the immediate roof of the coal. The Brereton Limestone overlies the Anna Shale and the coal where the Anna Shale thins to zero. It is a gray, argillaceous, fossiliferous, fine-grained limestone, ranging in thickness from about 4 to 6 feet.

Coal

The Herrin (No. 6) Coal in the demonstration area is of high volatile B bituminous rank. Based on six face-channel samples from this mine, the coal averages 7.8 percent moisture, 36.2 percent volatile matter, 46.2 percent fixed carbon, 9.9 percent ash, 2.6 percent total sulfur, and about 11,900 Btu/lb on an as-received basis. The seam dips at only 17 feet per mile to the northeast. The cleat in the coal is poorly developed with a face cleat that strikes N 35° W, while the butt cleat varies between N 35° E and N 58° E. Both cleat surfaces have some localized calcite coatings.

The coal seam ranges from 7.2 to 8.7 feet thick. Measurements of the coal seam thickness show a bimodal distribution (fig. 12) with two populations corresponding to the two major roof types. The thicker coal occurs under the gray shale roof whereas the thinner coal is under the black shale roof. On the average, coal below the black shale roof is nearly three-fourths foot thinner, with the thinnest part located near the center of the channel-like black shale roof exposures.

The thinning of the coal is related to the erosional cutout of the Energy Shale (fig. 8). This was confirmed by petrographic study of a series of full-seam columns traversing the linear Anna Shale/Brereton Limestone roof exposure in study area A (fig. 9). Johnson (1979), in a detailed petrographic study, recognized four distinct petrographic units within the seam along a 1,000-foot traverse (fig. 13). Significantly, the petrographic units are continuous except where the top unit is truncated or missing under Anna Shale roof. This loss of coal is attributed to erosion, and/or degradation due to oxidation of the peat (Johnson, 1979).

Floor

The floor immediately below the coal seam consists of an underclay varying in thickness from 1 to 3 feet. The underclay usually contains many

Figure 11a
Clay mineral compositions of the Energy Shale and roll material.

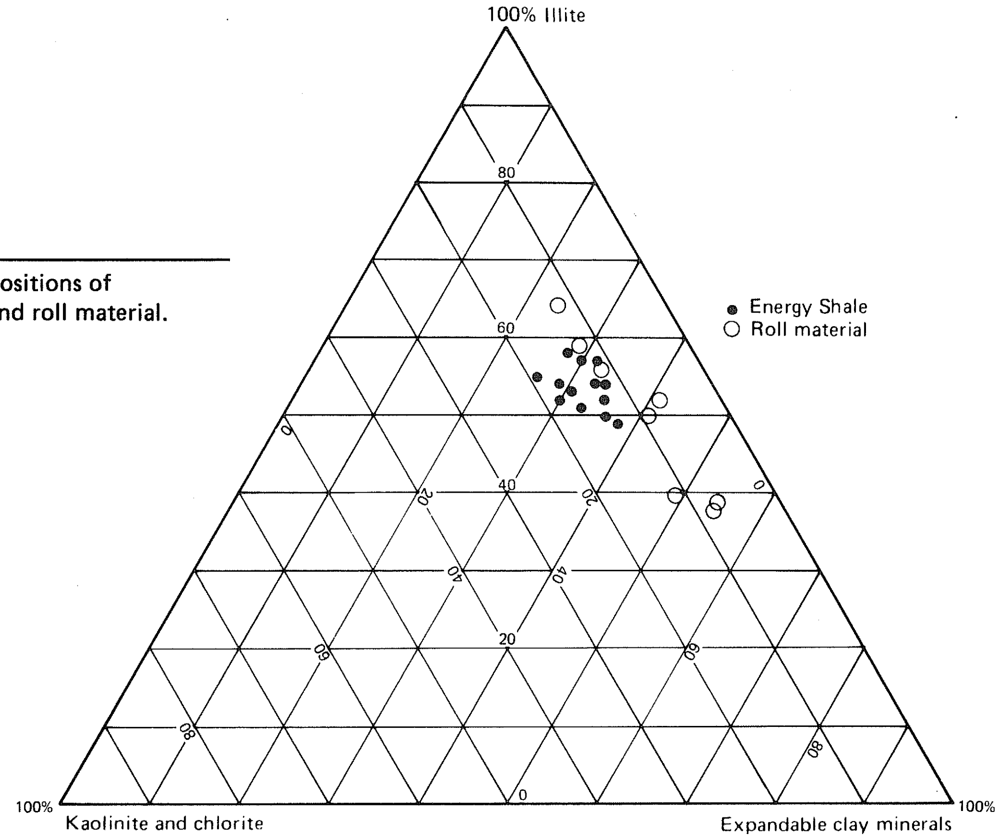
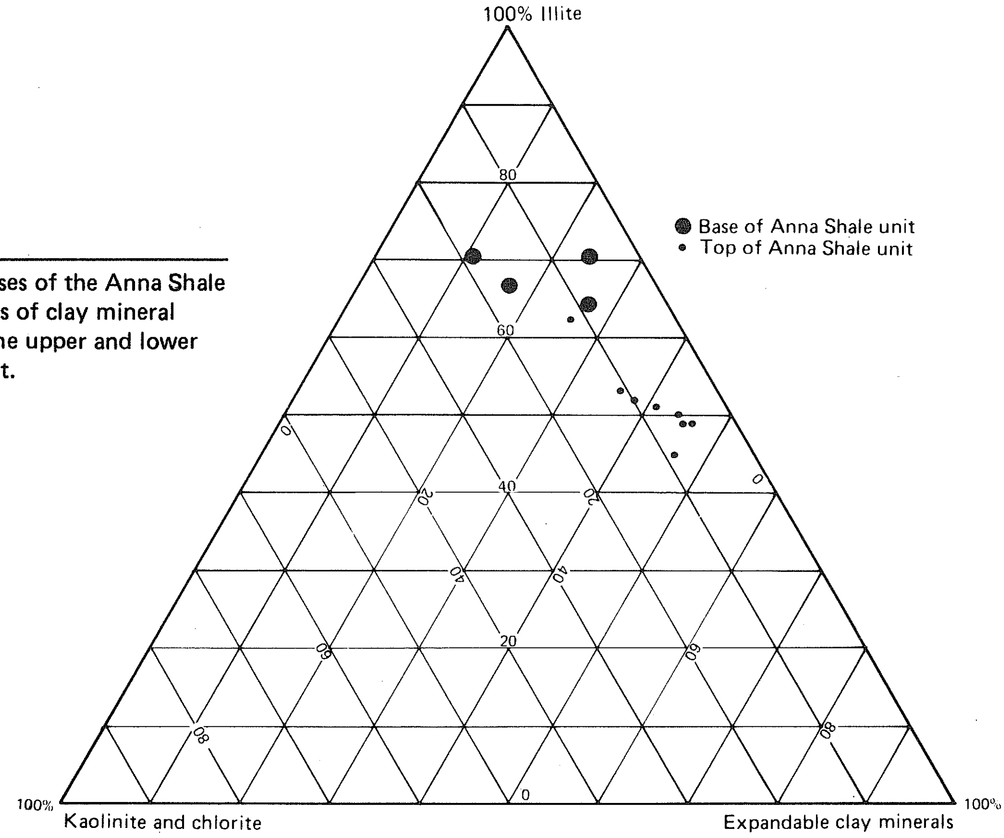


Figure 11b
Clay mineral analyses of the Anna Shale showing differences of clay mineral content between the upper and lower portions of the unit.



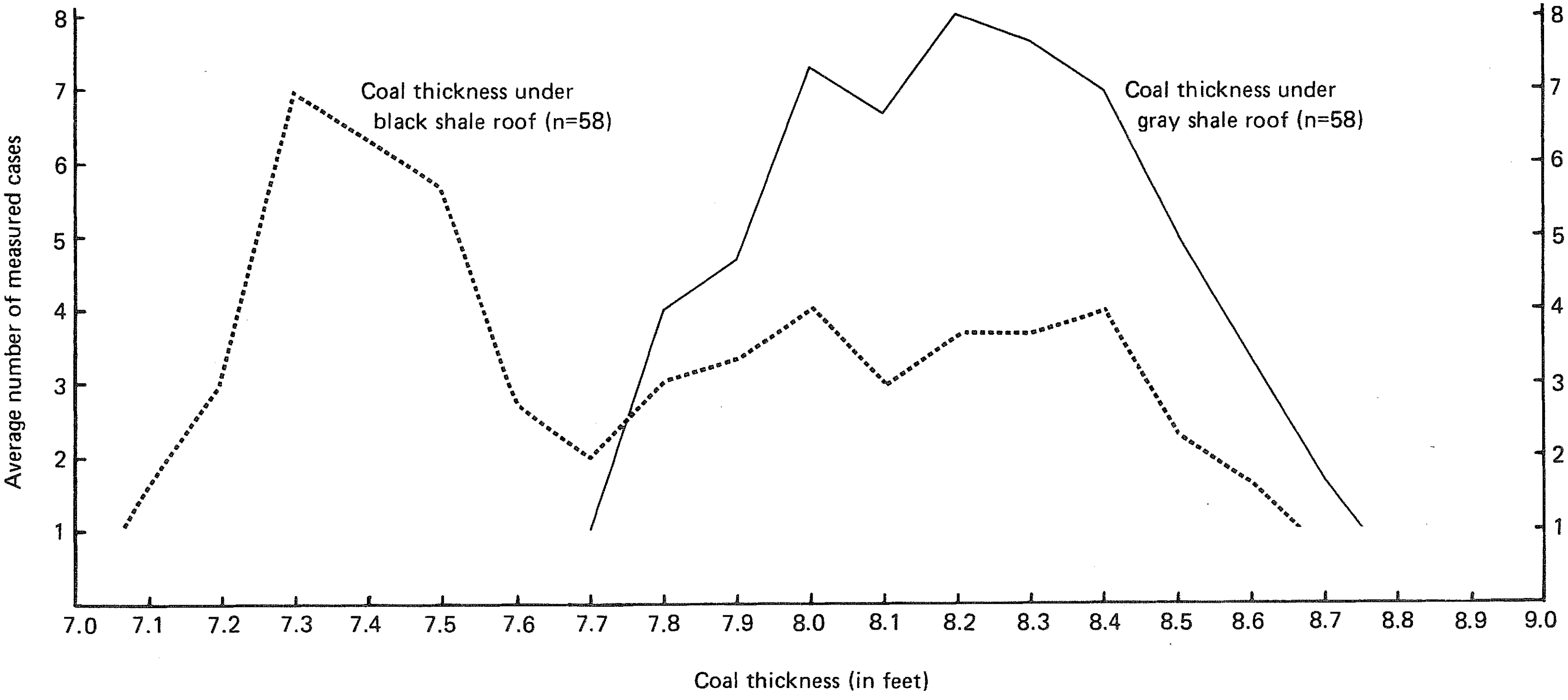


Figure 12

Coal thickness variation by roof lithology. Data from areas with coal balls as well as areas under rolls have been excluded. Values on Y axis are moving averages for 3 adjacent intervals. Thickness interval is ±0.05 feet; actual data range is 7.2 to 8.6 feet.

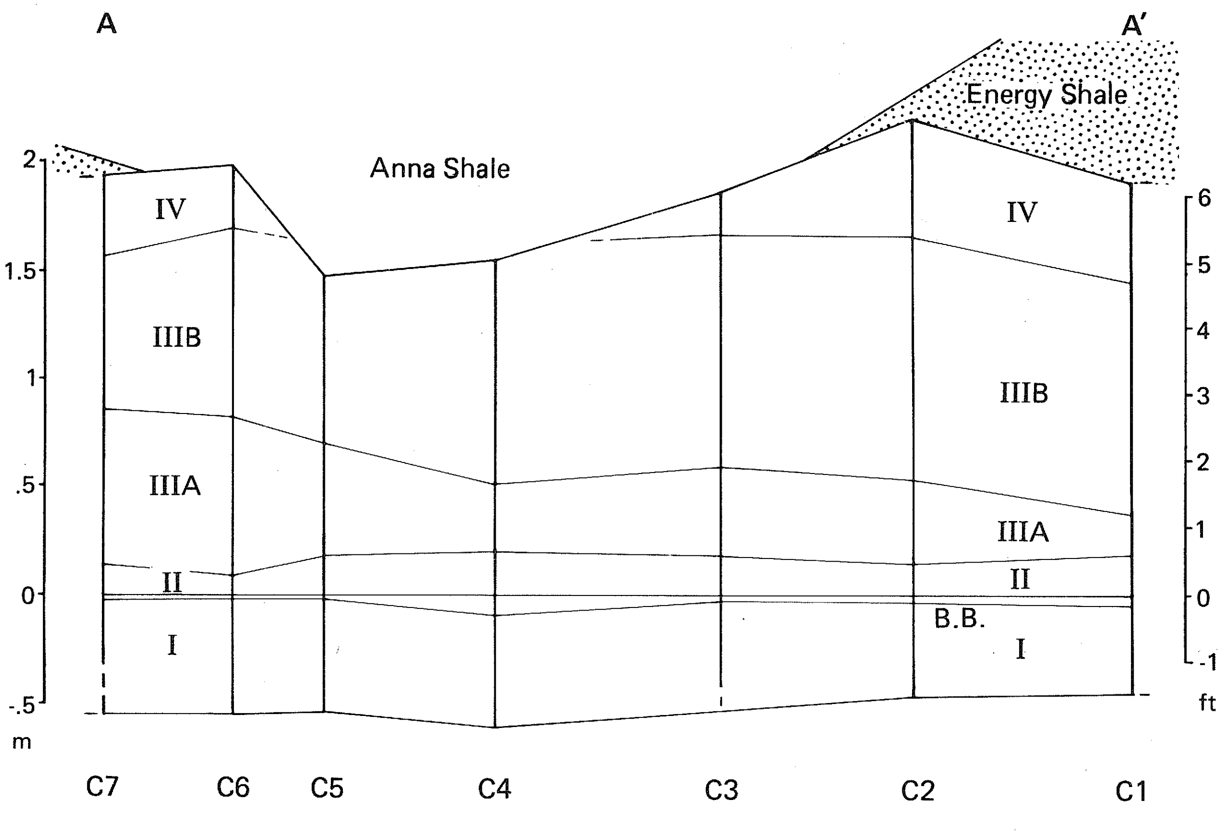


Figure 13

Correlation of macropetrographic units within the Herrin (No. 6) Coal along a 1,000-foot traverse. The units are I, B.B. (blue band), II, IIIA, IIIB, and IV. Vertical exaggeration within the seam is 68:1. (Modified from P. R. Johnson, 1979.)

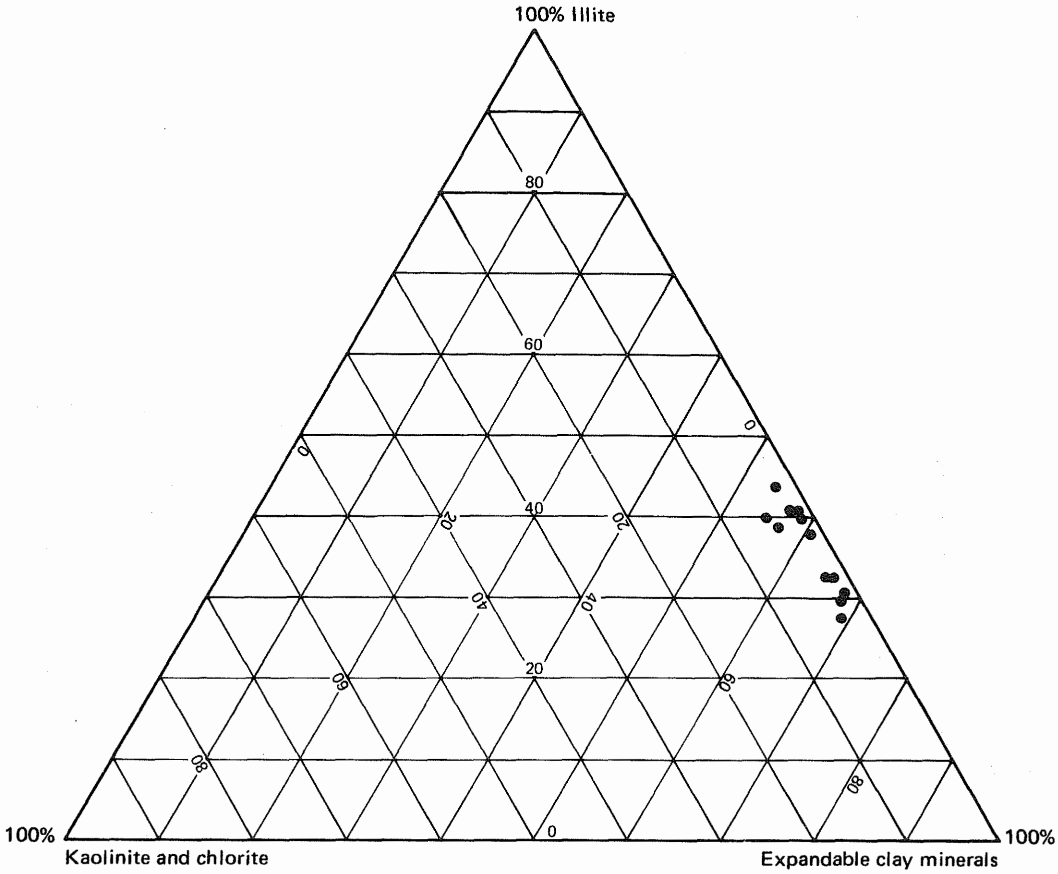


Figure 14

Clay mineral composition of underclay samples.

slickensided surfaces near the contact with the coal seam. The variation in the clay mineral composition of the top of the underclay throughout the longwall demonstration area is shown in figure 14. The underclay generally overlies a nodular underclay limestone, which is composed of small 1- to 2-inch diameter nodules of limestone in a claystone matrix. The nodular form of limestone may grade downward into a massive limestone. The thickness of the limestone ranges from 3 to 12 feet. No relationship was found between the variations in thickness of these floor units and the thickness and distribution of the roof shales.

Rolls

A "roll" is a general term for any linear protrusion of shale or other clastic material into the top of the coal seam. We interpret most rolls at this mine to be erosional channels in the peat which were subsequently filled with clastic materials. These rolls are usually 10 to 20 feet wide and 1 to 4 feet thick. They have many shapes; many are broad and shallow with only a weakly defined low point, while others are lens-shaped or V-shaped in cross section.

Despite some local erosion of the roll-fill materials, many rolls can be followed as far as exposures permit, and several rolls appear to be continuous for more than 1,000 feet. The rolls tend to parallel the edge of Energy Shale roof areas; they may occur in subparallel pairs, or more rarely in triples (fig. 10). Similar features have been noted by Williamson (1967) who found that elongate rolls tend to be developed in parallel swarms or riggs in the British coal fields. Williamson attributed the development of these features to erosion produced by a fairly constant current direction. Rabitz (1979) found similar features in the Ruhr district.

Erosional rolls are produced in two different environments and are filled with two distinct materials in varying combinations. The majority of the rolls were developed as a part of the initial erosion of the Energy Shale. The initial fill material is a medium-gray shale with interlaminated fine coal stringers. Its appearance and clay mineralogy (fig. 11a) are similar to those of the Energy Shale.

A small number of erosional rolls were developed by tidal action after the erosion of the Energy Shale. These tidal channels are filled with a more carbonaceous, fossiliferous shale grading locally to an argillaceous limestone. This fossiliferous material commonly contains small coal fragments and stringers, marine gastropods, and other size-sorted shells (Harold Rollins, University of Pittsburgh, personal communication, 1981). During this same period, many rolls that had been developed during the initial erosion were selectively reused in whole, or in part, as tidal channels.

The result is a variety of roll-fill materials as illustrated in figure 15: 15a represents the initial condition of many rolls, 15b the most typical roll with a sharp contact between fill materials, 15c the less common gradational contacts between materials, and 15d the fossiliferous tidal material only. When the material is calcite-cemented, the plant fragments may be permineralized. Coal balls (with a normal peat matrix) have also been found in rolls at several sites and are believed to have been eroded from the peat in which they were formed.

The shale body of the rolls usually contains many small normal faults, apparently produced through compaction of sediments while still in a soft state. The compaction produces normal faulting and indicates overall extension in the horizontal direction. The roll-fill materials often

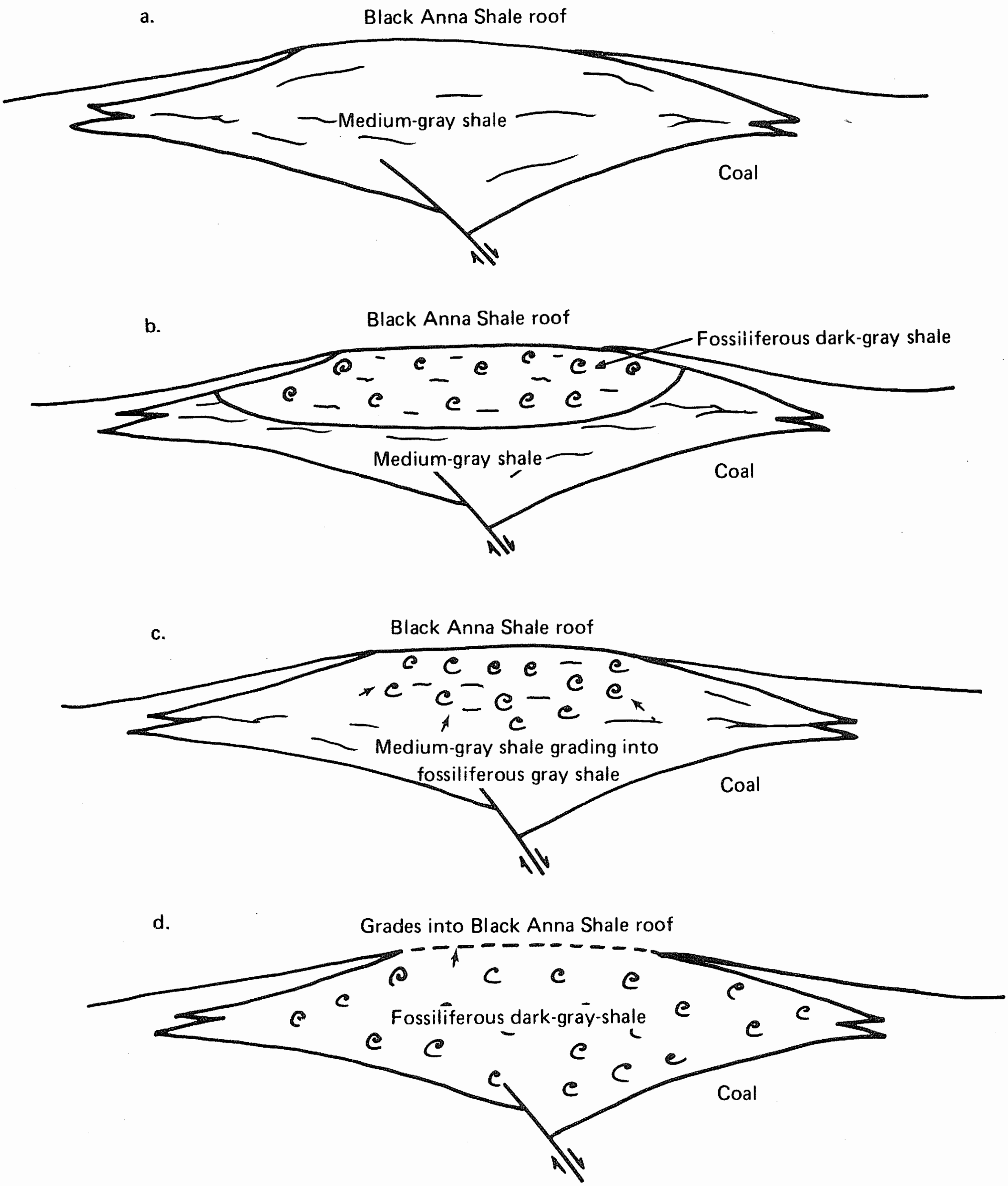


Figure 15
Idealized cross sections of rolls showing variation in fill materials. Horizontal scale varies from <5 feet to >60 feet.

slake and tend to fall out around roof bolts after mining. These falls usually end within the overlying Anna Shale and are fairly shallow.

Coal balls

Coal balls are masses of peat that have been permineralized in place during or soon after peat deposition. Carbonate minerals were introduced into the tissues of the peat before the peat deposit was coalified, thus preserving the original plant materials. Identification of the plant materials in the coal balls by T. L. Phillips of the University of Illinois (table 1) shows the typical peat composition for the Herrin (No. 6) Coal with strong dominance of lycopod trees (Phillips et al., 1977; Phillips, 1979).

Coal balls are locally a serious obstacle to mining. While we now have a short-range ability to successfully predict these deposits, general prediction of coal-ball locations must await a more thorough understanding of their origin.

A fresh, broken surface of these coal balls has a light brown color which darkens only slightly with oxidation. Size and shape of coal balls vary considerably. In general, coal balls are less than 1 inch to more than 3 feet wide and are often elongated horizontally. Smaller coal balls (fist-sized and smaller) are usually spherical or slightly ellipsoidal in shape. Medium-sized coal balls (up to 1.5 ft long) typically have height-width ratios from 1:3 to 1:6. Where coal ball material exceeds 60 to 70 percent of the seam, the coal balls have varied shapes and range from 1 to 4 feet thick.

Clarification of the spatial distribution of the coal balls was accomplished by mapping coal balls both on pillar ribs and in the roof. When

Table 1. Identified plant material by plant group from coal ball vertical section 3 in Area L (T. L. Phillips, personal communication)

	%
Lycopods	76.8
Ferns (primarily tree ferns)	12.6
Pteridosperms	7.6
Sphenopsids	2.9
Cordaites	.1
	100.0

coal balls were encountered, special attention was paid to both their association with roof lithology and their density of occurrence. Coal balls occurred individually, in clusters, and in concentrated groups defined as "coal-ball areas," ranging from about 20 feet to more than 150 feet across. The distinction between a cluster and a coal-ball area was made both on the size of the accumulation and the concentration of coal balls. In the absence of a natural boundary, coal balls more than 5 feet apart were considered to be outside of a coal-ball area. The large coal-ball areas with a dense accumulation of coal balls often show an increase in both size and number of coal balls toward a central point (fig. 16), where a core of highly concentrated coal balls may exist (fig. 17). At one point in area L (fig. 18), only 0.25 feet of coal remained in a 10-foot vertical section of coal balls.

There is a strong association between the areas of black shale/limestone roof and the distribution of coal balls (figs. 18 and 10). Coal-ball areas B, H, I, and N partially span the boundary between Anna Shale and Energy Shale roof.

A stratigraphic approach to coal-ball distribution shows two distinct patterns in the longwall demonstration area. Coal balls near the top of the seam are by far more widespread than those in lower positions in the seam. The mid- and low-seam coal balls are almost exclusively found within coal-ball areas. Where these two patterns of distribution coincide, it is not yet clear whether they are independent distribution or are simply preferred areas of permineralization.

The origins of these coal balls are not fully resolved. Stratigraphic evidence based on the close association of coal balls with black shale/limestone roof suggests that mineralization began after the initial erosion of the Energy Shale. Mineralization was also probably complete when coal balls with a normal peat matrix were redeposited within the fossiliferous gray shale found in rolls. Preliminary carbon isotope data from these coal balls (T. F. Anderson, University of Illinois, personal communication, 1981) suggest the dominance of freshwater carbonates in their formation. The study of other coal-ball sites in the Herrin (No. 6) Coal should help resolve some of the questions raised at Old Ben No. 24. Within Franklin County there are several other coal-ball sites following the pattern of coal balls under the black Anna Shale roof (fig. 7). These sites are known only from Illinois State Geological Survey mine notes and cannot be mapped or sampled to check their similarity to conditions at Old Ben No. 24.

The thickness of the coal seam in the coal-ball areas is greatly increased because the permineralization preserved the volume of the peat from later compaction. Therefore, coal balls provide evidence on the original

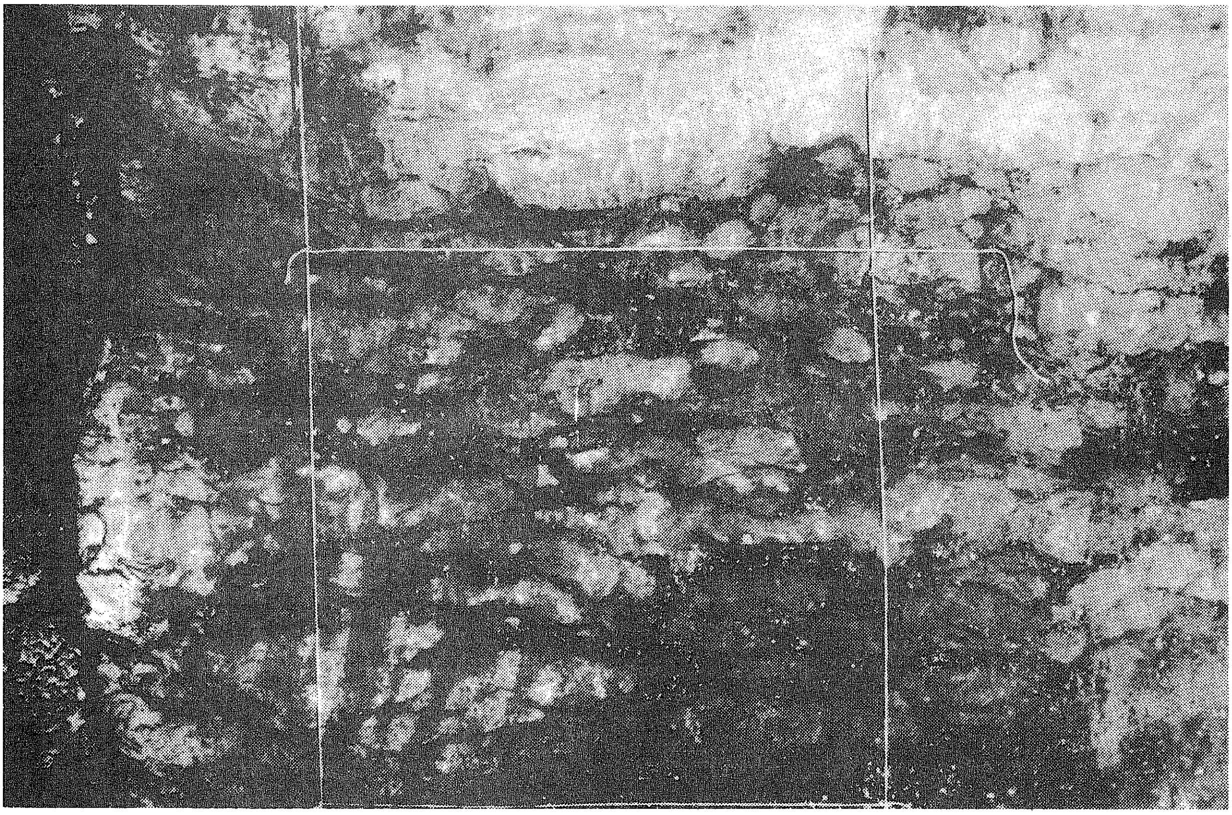


Figure 16. Concentrated coal balls near the center of coal-ball area L. Strings form a box 0.5 meters on a side.

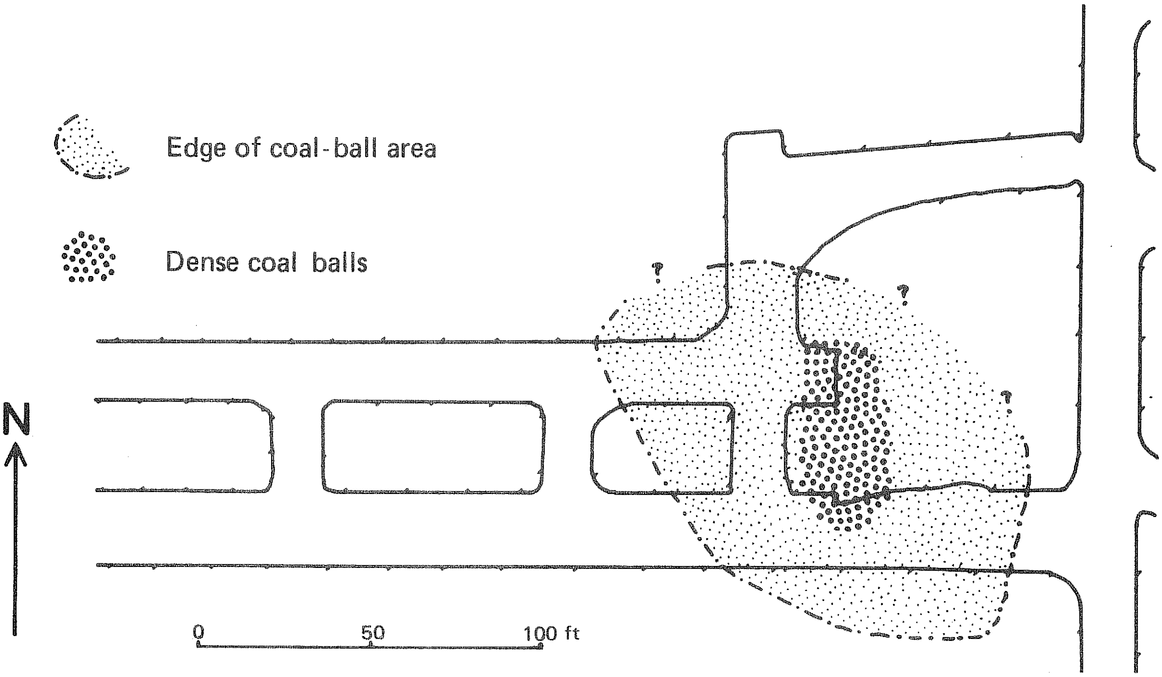


Figure 17

Map of area M showing limits of the "core" of concentrated coal balls, and a minor alteration of mine plan due to concentrated coal balls.

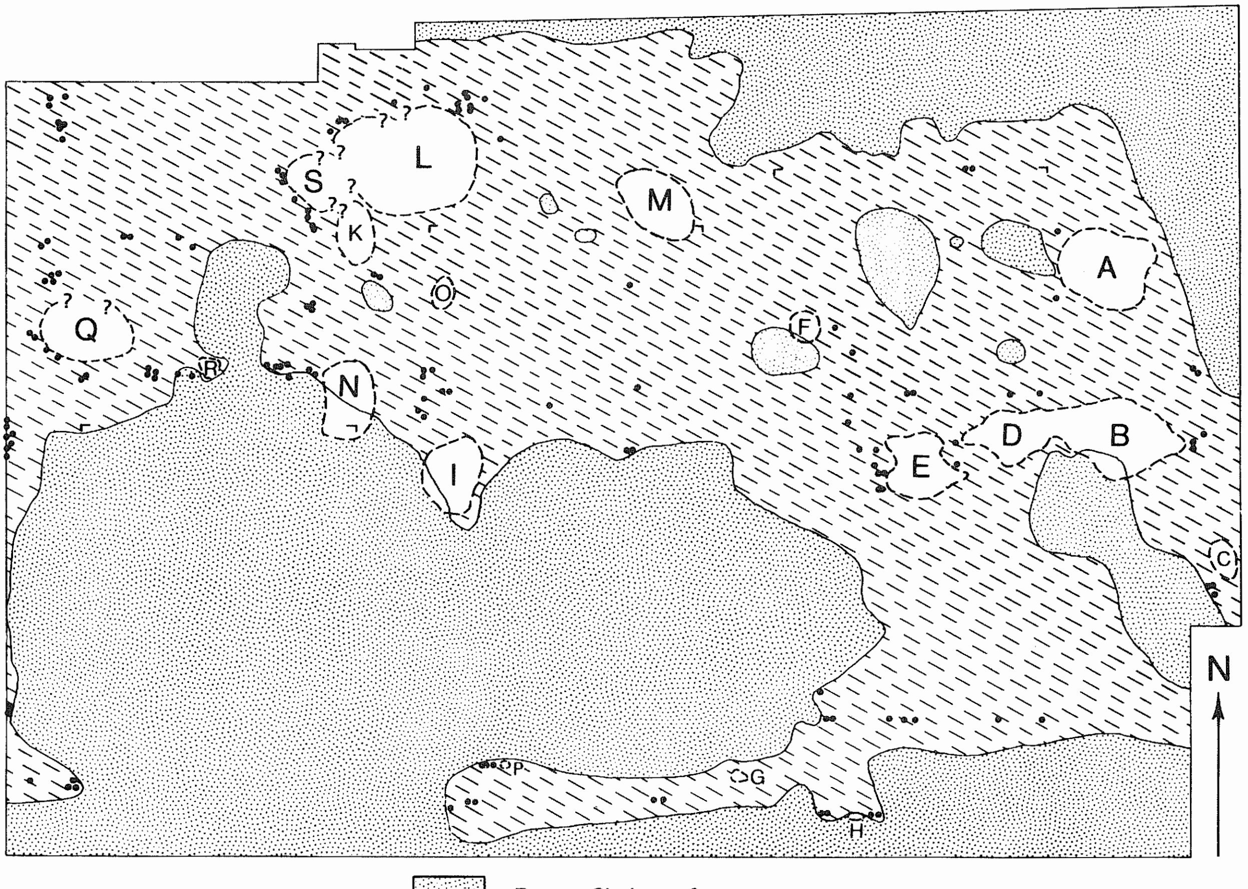


Figure 18
Coal balls, coal-ball areas, and roof lithologies identified during mapping of the 3 longwall panels.

thickness of peat at the time of mineralization. Peat-to-coal compaction ratios were derived by comparing the thickness of coal next to individual coal balls with the corresponding thickness of permineralized peat in the coal ball (Teichmüller, 1955; Zaritsky, 1975). The coal balls of Old Ben No. 24 Mine show an average value of 5:1, which is similar to values found by Zaritsky for coal balls of similar age in the Donets Basin (USSR). Another set of measurements between stratigraphic markers in the seam gave a value of about 2.0:1 (fig. 19a). The coal immediately above and below each coal ball often shows extra compaction, and some slippage of coal (shown by slickensides) has also occurred (fig. 19b); these factors produce the lower compaction ratios in measured sections through multiple coal balls.

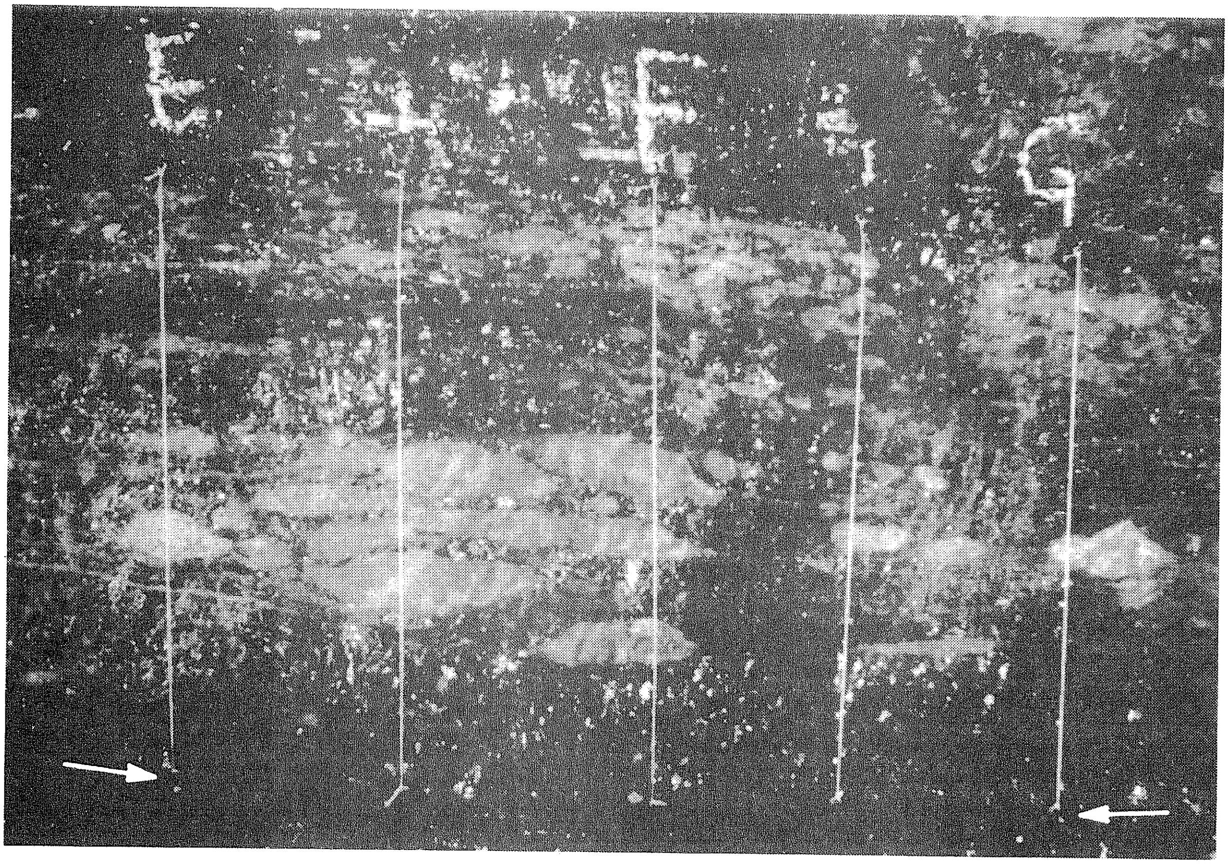
MINING PROBLEMS

Prediction of coal balls

Problems with concentrations of coal balls occurred early in the development of the first longwall panel. In mining these areas, the continuous miners had to repeatedly receive new cutting bits due to excessive wear. The belt entry east of the first panel had to be offset to the east at coal-ball area B (fig. 18); and a smaller problem with coal-ball area F was encountered low in the seam on the west side of the first panel. As the first longwall panel was being mined, two large areas of coal-ball concentrations were encountered, areas D and E. The longwall shearer suffered damage as well as excessive wear, and advanced at the low rate of only 155 feet during 105 eight-hour shifts—1.5 feet per shift compared to a normal 10 feet per shift. Explosives had to be used to break up the masses of coal balls in the core of each area.

When mine development reached the west side of the second panel, coal-ball area L (fig. 18) was encountered. Because of these coal balls, this panel was shortened by 80 feet (fig. 7). Similar obstacles in area Q also required the third panel to be shortened by nearly 300 feet (fig. 7). Subsequently, the second and third panels had no serious mining problems due to coal balls, but because of their occurrence, approximately 50,000 tons of coal were lost within the two panels.

Initial mapping showed that the coal balls were closely associated with black shale/limestone roof, and this predictive link between coal balls and roof type has proven reliable. Because of the many areas of black shale/limestone roof in the mine, the distinctiveness of the exposure crossing the longwall panels was not initially apparent. With the discovery in late 1979 of another area of concentrated coal balls more than a mile east of the longwall area associated with the same roof exposure

a. 

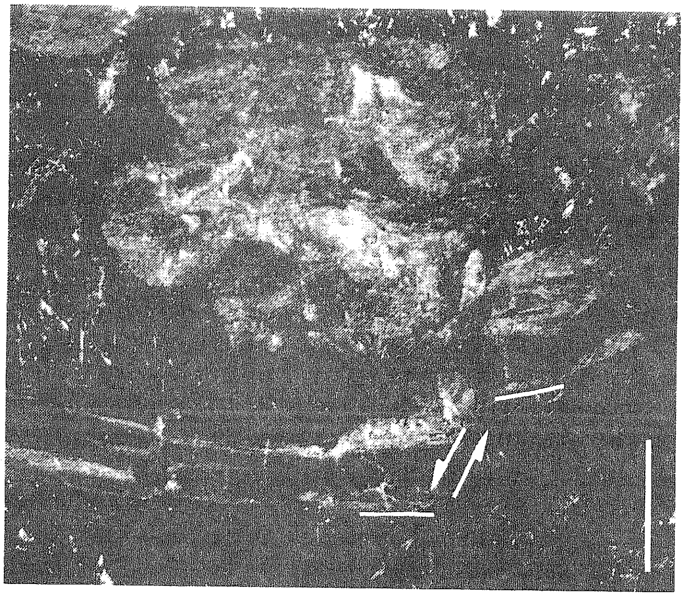
b. 

Figure 19

a. Five of the 13 positions where coal and coal balls were measured separately. Lower stratigraphic marker is the "blue band," which is indicated by the arrows. Measured positions are at .5 m intervals.

b. Small compaction fault under round coal ball has displaced thin coal ball about 1 cm. (Bar scale is 1 cm.)

(fig. 10), general prediction of coal-ball occurrences can now be made with some assurance. In general, concentrated coal-ball areas are associated with a continuous sublinear area of Anna Shale/Brereton Limestone roof trending N 60° W.

Roof stability

The variable conditions encountered at the face were a good test of the longwall mining procedure. The face advanced through a number of geologically difficult areas: (1) a massive 130-foot diameter coal-ball deposit; (2) one of the largest rolls documented in Old Ben No. 24 Mine, which was 600 feet long and cut to a maximum of 4 feet into the coal; (3) an unstable, slipped, and fractured roof area 2 to 3 feet high covering an area about 150 by 50 feet over a large roll in the first panel; and (4) a fault zone which ran the entire length of the second panel (perpendicular to the advancing face) with vertical displacement as great as 7.5 feet. Nowhere was roof stability serious enough to stop the advance of the longwall face.

Roof control at the longwall face is good, especially if the shield supports are promptly advanced as soon as a cut is made by the shearer. The stability of the face can be a problem when faults, low angle slips, or roof lithology boundaries parallel the face. Several areas of slips associated with roof lithology boundaries paralleled the longwall face. During cutting of the coal at these areas, pieces of roof would fall before the shields could be advanced. After advance of the shields many small pieces would fall from the gaps in front of and between the shields near the face. Neither amount was great enough to hinder any operation of the longwall. Only the roof area just in front of the shields in the tailgate entry posed a continuing problem. Here pieces of the roof shale would pile up on the floor and have to be removed in order to advance the shield and pan assembly. A possible solution to this problem would be to bolt wire mesh to the roof to retain the small pieces.

The greatest roof-control problem for the longwall operation exists in the support entries (for men, materials, ventilation, and belts). In the Anna Shale, minor problems in entry ways are associated with rolls, coal balls, and roof concretions. The top surface of a roll body of shale is often slickensided and may also have a thin layer of coal between the body of the roll and the roof shale. In both cases a plane of weakness is created from which the body of the roll can pull away from the roof. Coal balls in top coal left as roof as well as concretions in the Anna Shale are hazards due to slickensides that have developed around these concretions, allowing them to fall.

Within the Energy Shale, thin stringers of coal commonly extend from the top of the coal into the shale and form planes of weakness in the roof. Slips and slickensided surfaces associated with the steeply dipping truncated upper surface of the Energy Shale often cause serious problems in roof control.

The contact between the top of the gray Energy Shale and the overlying black Anna Shale is sharp and occasionally slickensided, particularly where the contact dips (fig. 20). Also, slips in the Energy Shale are common within 150 to 200 feet from the boundary of the black shale roof; generally they parallel the gray shale/black shale boundary (fig. 21). Intersections with such slips become particularly vulnerable to failure (fig. 22). Two factors possibly contributing to the falls in figures 20 and 22 include (1) the belt entry that was cut wider than the rest of the entries, and (2) that they were within 150 feet of the north-south fault system in the second longwall panel.

The north-south fault system in the second longwall panel (fig. 7) with a range in vertical throw from 3.0 to 7.5 feet was only a minor problem for the longwall process. The face was graded across the fault, and only small parts of the roof fell out from the footwall side of the fault. This fault system had some large horizontal east-west compressive stresses in the downthrown block, which locally produced bad roof conditions (fig. 23) and slowed development of the entries for the second longwall panel. These entries parallel the fault system. The closest entry, only 30 feet west of the fault system, had the most roof-control problems with large blocks falling out during entry development (fig. 23). In one short section, concentrated horizontal stress was relieved in the form of sizable mine bumps. The roof in the area of the bumps had a vertical, thin, crushed zone of roof shale produced by failure of the shale in east-west compression. Other mines in the area have also experienced roof problems caused by east-west compression. One mine in the general area has experimented with cutting slots in the roof of some north-south entries. The slots have been observed to close halfway in about a week. Additional data from hydrofracting in the Mississippian strata below the Pennsylvanian shows that southern Illinois is under horizontal compression in an east-west direction (Lindner and Halpern, 1978; Zoback and Zoback, 1980).

For mapped area B shown in figure 10, the number of fallen intersections has been tabulated as a function of lithology and the presence of structures that may influence falls of the immediate roof (table 2). Only roof falls where more than one foot of rock had come down were included. Tables 2 and 3 show that mine entries with an Energy Shale roof have roof-control problems. This same study area displays the north-south roof fall problem (fig. 24) associated with other mines in the region; similar roof-control problems in the region have been documented over the past 60 years in the Illinois State Geological Survey mine notes.

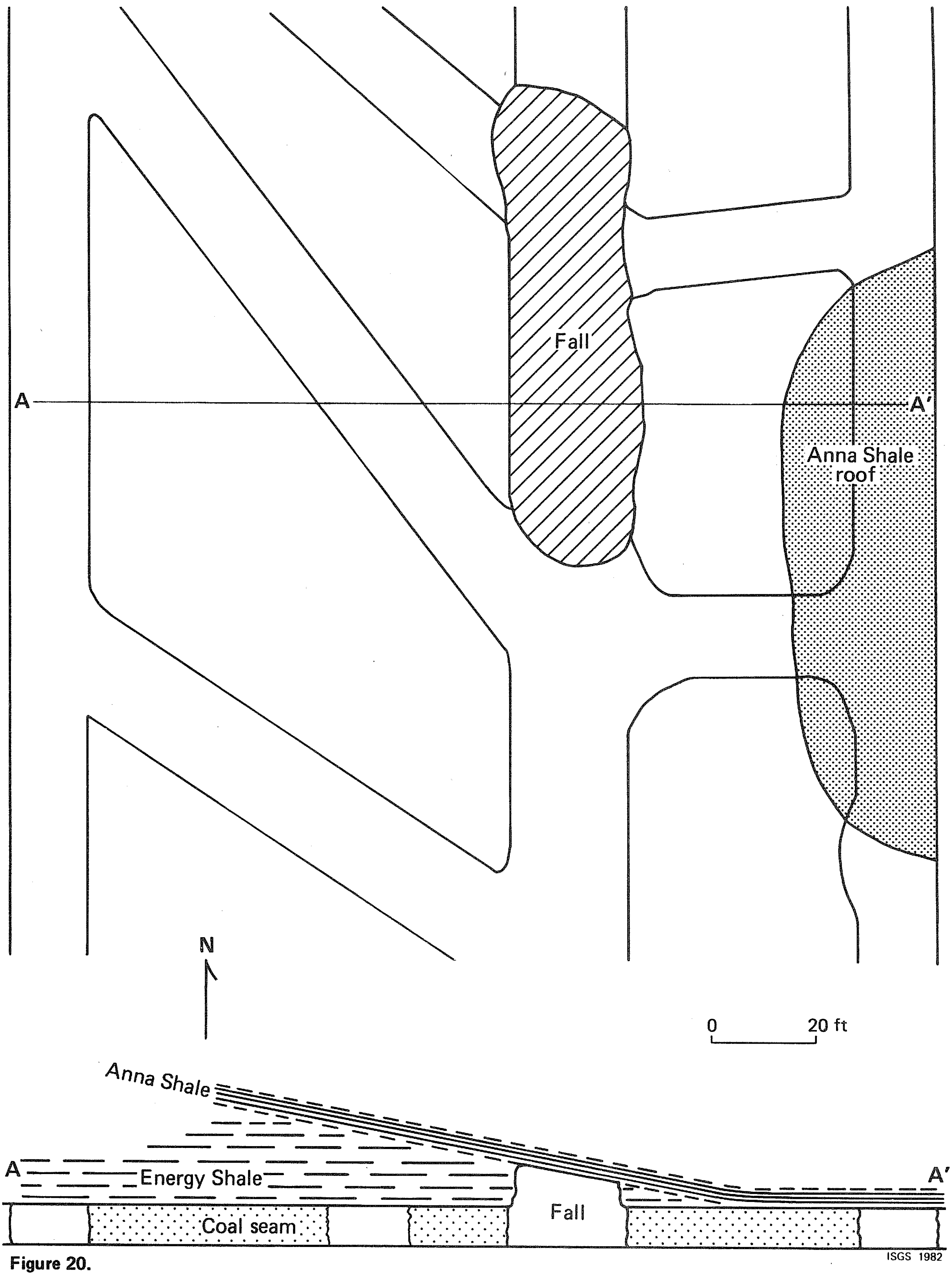


Figure 20.
Plan view (above) and cross section of roof fall in relation to mine and geologic setting.

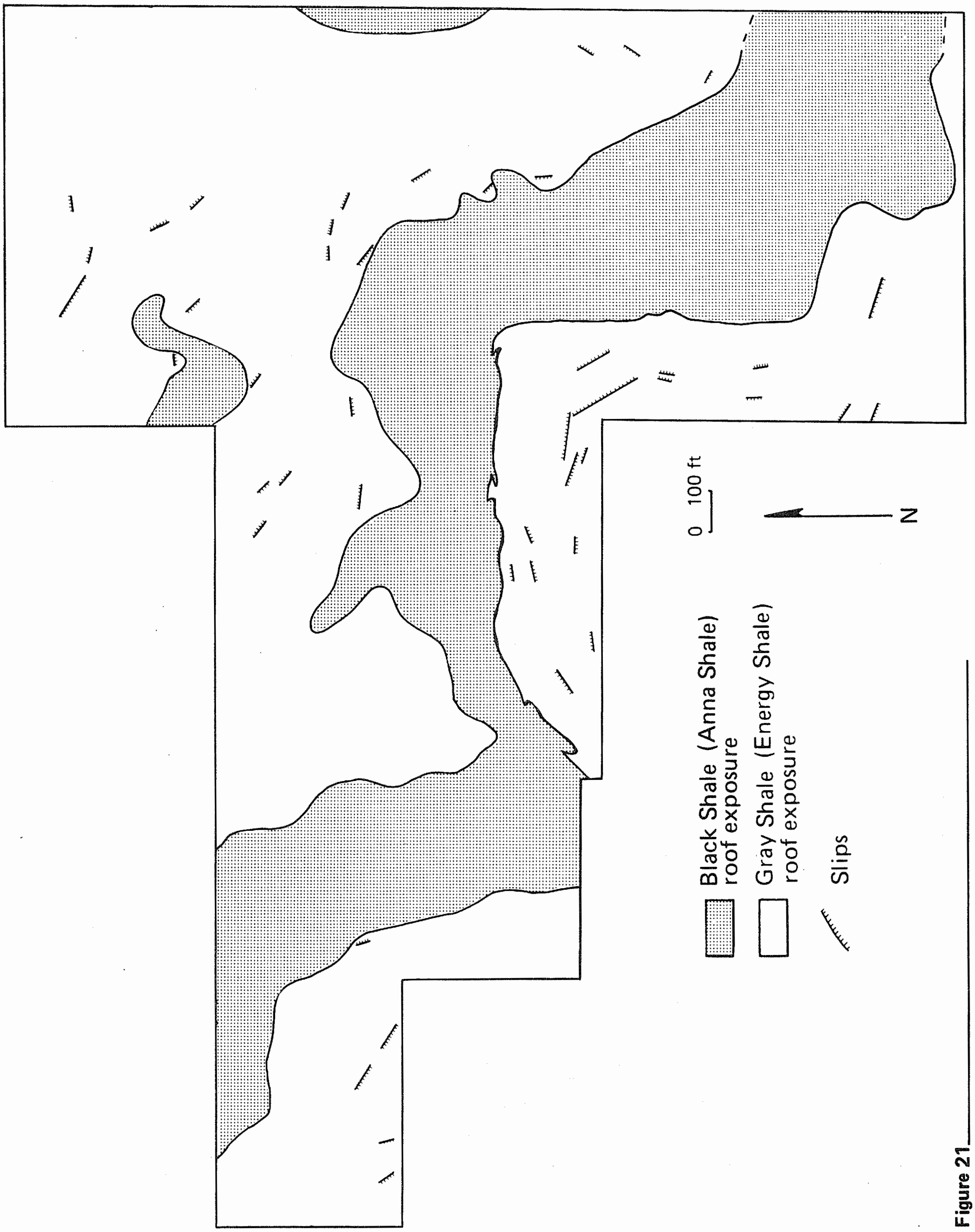


Figure 21
Slips in roof shown paralleling black shale roof exposure (area B).

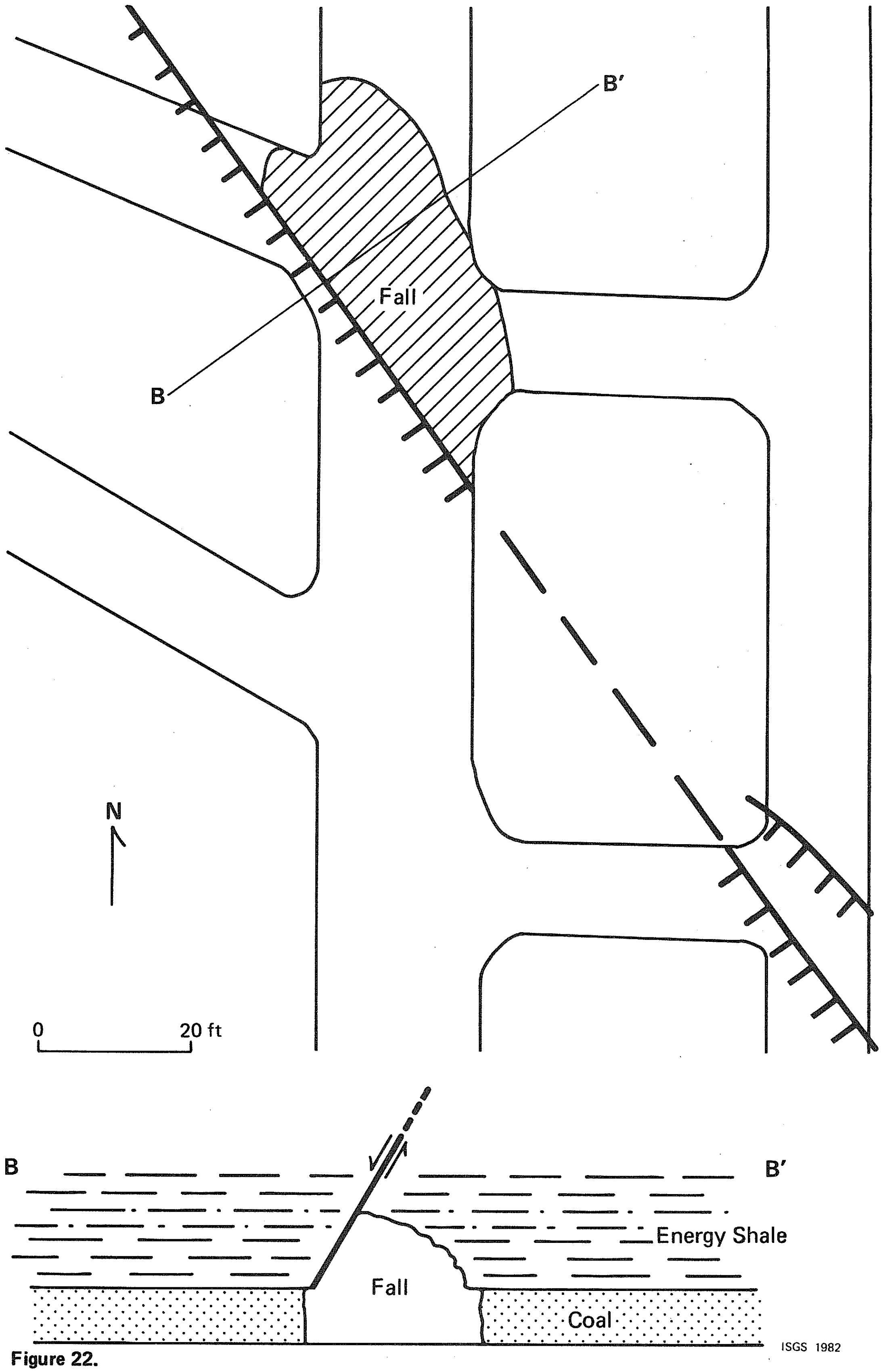


Figure 22.
Roof fall in relation to mine plan and geologic setting (plan view above and cross section below).

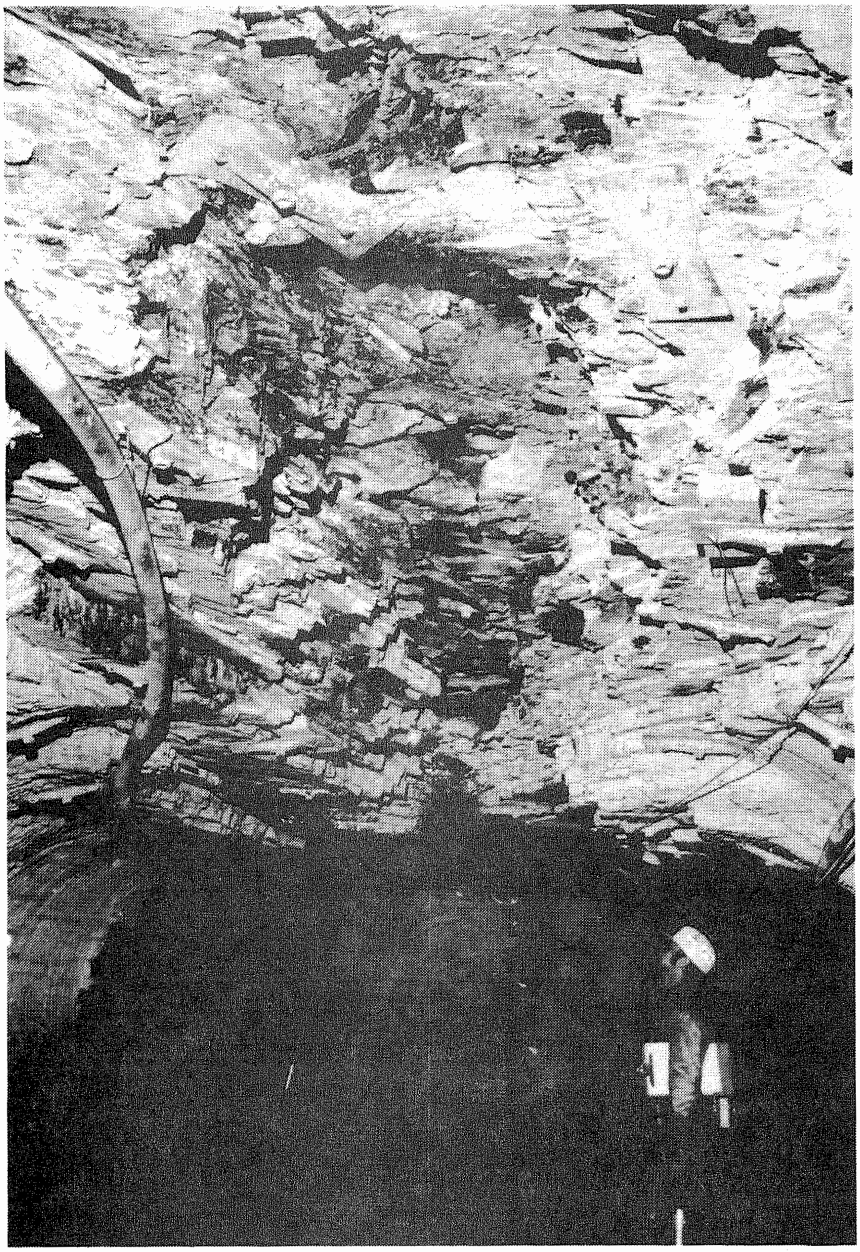


Figure 23.
North-south fractured zone in roof caused by large horizontal compressive forces.

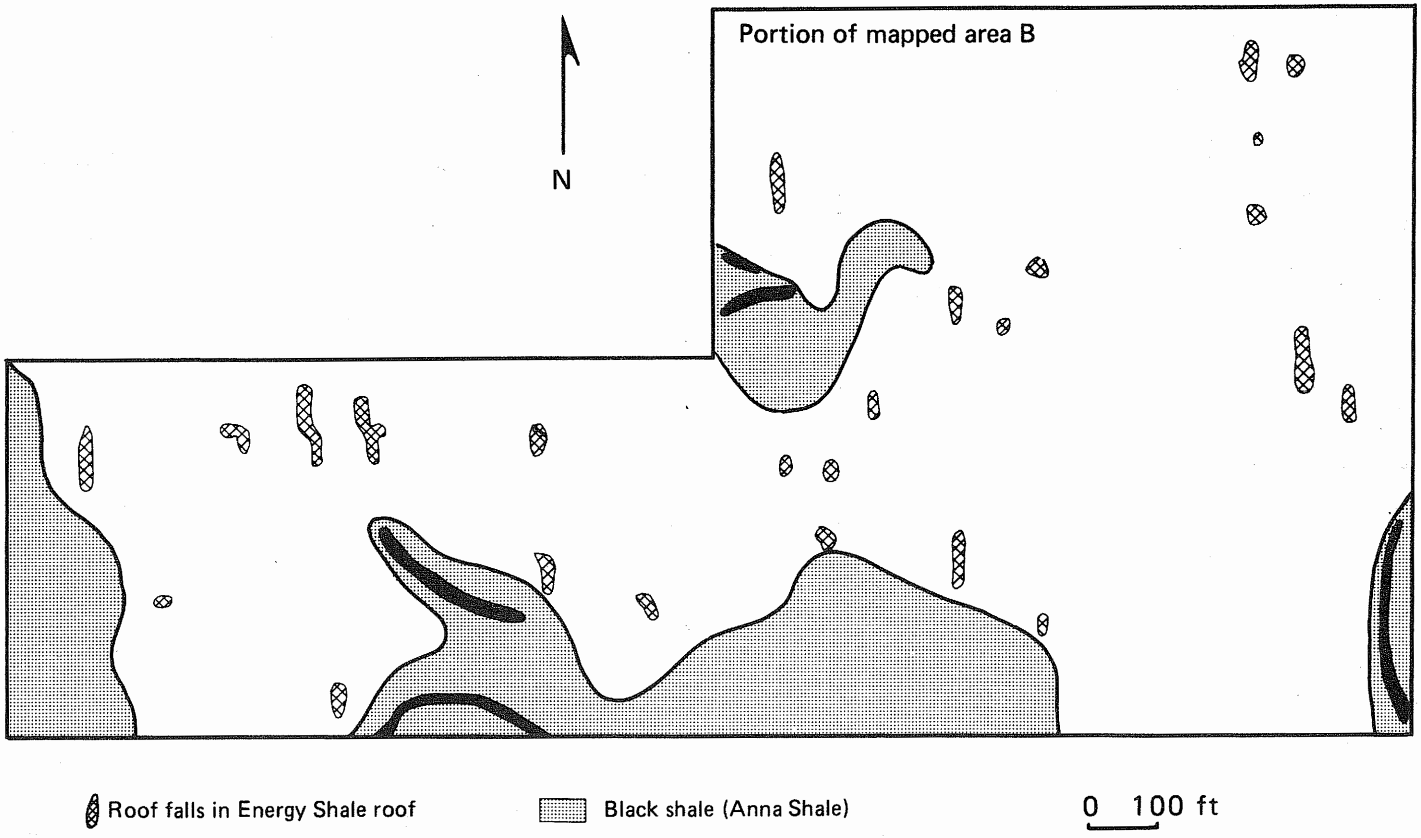


Figure 24
Roof falls in the Energy Shale showing a preferential north-south orientation. Direction of mining is not a significant factor in this orientation. Although the east side of the map area was mined moving north, the west side was mined moving west.

Table 2. Occurrence of fallen intersections for mapped area B by categories of roof lithology and structure

	Energy Sh. roof			Anna Sh./Brereton Ls. roof			Total no. of samples
	Sample size	Falls No.	Falls %	Sample size	Falls No.	Falls %	
Intersections with slips*	15	7	47	6	0	0	21
Intersections without slips*	293	41	14	191	0	0	484
Total intersections	308			197			505

* Slips are small faults, most of which are of nontectonic origin.

Table 3. Number of mapped falls by location for mapped area B

	No.	%
Falls at intersections	41	85
Falls in entries between intersections	7	15
Total falls	48	100

Subsidence

Subsidence of the surface over the first two longwall panels was periodically monitored by Old Ben Coal Company personnel. Conroy (1978), Curth and Cavinder (1977), and Wade and Conroy (1977) assumed a uniform mined-out void height of 7 feet to calculate the percentage of surface subsidence/mining height over the panels. However, the actual mined-out void heights measured during many traverses of the operating second longwall face vary between 7.2 and 8.25 feet. This introduces a 3 to 17 percent error in calculating the ratio of subsidence/mining height if a 7-foot mining height is used. Even though the coal thickness ranges from 7.2 to 8.6 feet, the variability in mined-out void heights can also be related to the roof rock being brought down by the longwall mining operation. The average mined-out void height in the area (not affected by the end constraints of the panel) is about 7.5 feet. These void measurements were made on the gob side of the face conveyor pan from the floor to the roof exposed between the shields. Using the maximum surface subsidence of 5.2 feet over the second longwall panel and dividing it by the 7.7-foot mining height found below the monument gives a ratio of .67 instead of .74 when using 7 feet as the mining height.

Figure 25a represents the subsidence profile from the second longwall panel and the mined-out void height measurements below the profile. It shows that the profile is controlled by small variations in the mining height. In figure 25b, the subsidence profile for the first longwall panel shows that the greater amount of subsidence has taken place over the area with thicker coal in the panel. Maximum surface subsidence over the first panel was 4.72 feet, and over the second panel, 5.21 feet (survey, December 4, 1978). It was found that the second panel had a 13 percent increase in maximum surface subsidence as compared to the first panel. The comparison was made when the faces had advanced equally from the surface monuments, which show the maximum subsidence of each panel.

This difference may be attributable to the presence of a fault system that runs along the length of the second panel. Large differential movements can take place along faults (Lee, 1966) and may allow larger blocks of rock to cave, reducing bulking. The amount of subsidence usually increases when a longwall panel is mined next to another longwall panel, as compared to the smaller amount of subsidence produced over a single longwall panel in a virgin coal mining area.

Physical strength test results

The cores for these tests were obtained from the roof of the mine by drilling from the mine level. A total of 50 feet of core was recovered and tested for its physical strength. Testing procedures, the raw data, and core descriptions are in appendixes A and B.

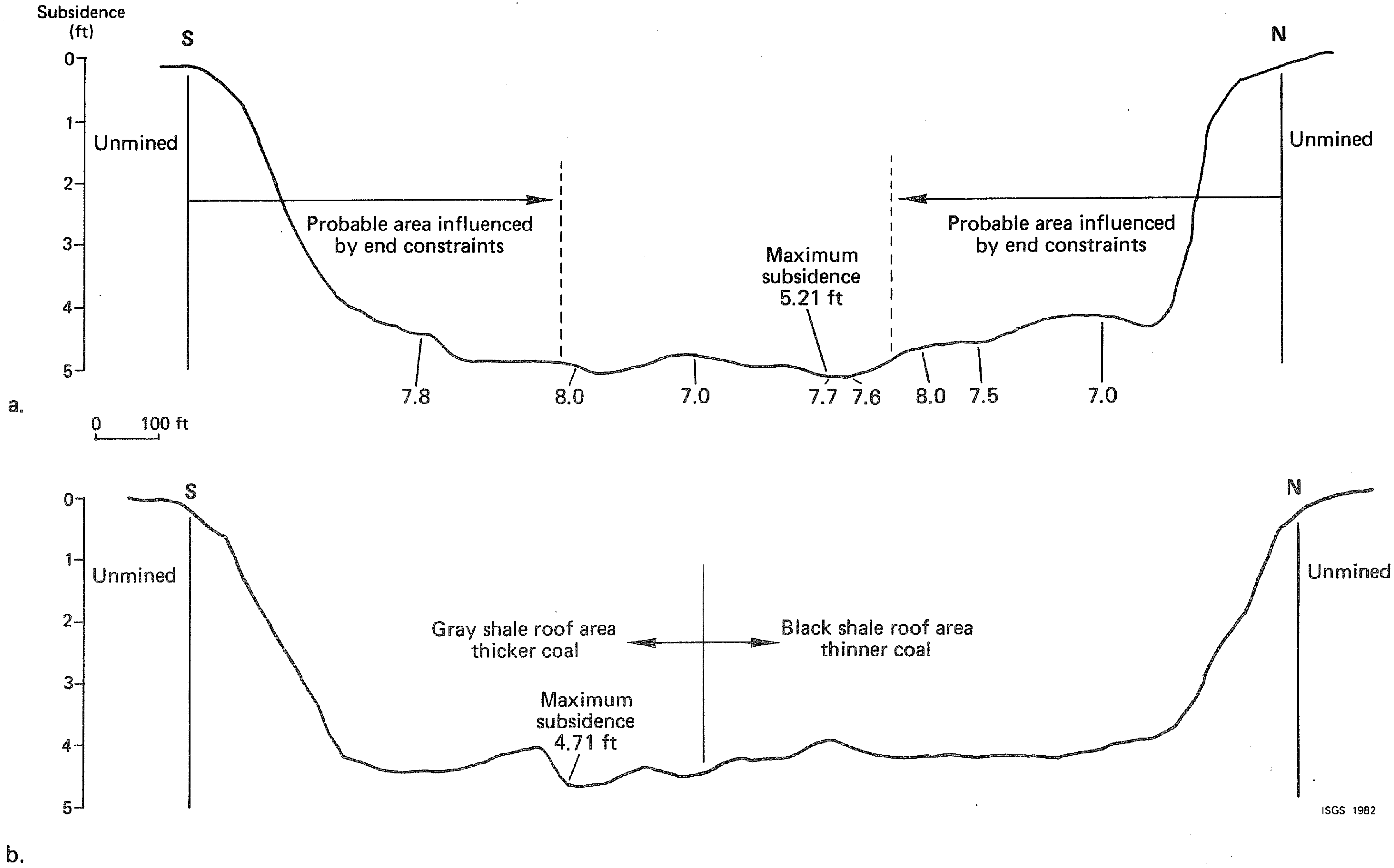


Figure 25

a. Subsidence profile (survey, 12-4-78) above the second longwall panel showing the corresponding mined-out void height measurements taken below the profile monument line. Void measurements are in feet.

b. Subsidence profile (survey, 12-4-78) above the first longwall panel showing a greater amount of subsidence over the areas where thicker coal was located and mined.

CONCLUSIONS AND RECOMMENDATIONS

The massive coal-ball permineralizations of the Herrin Coal, which interfered significantly with the orderly mining of three demonstration longwall panels, were found to occur exclusively in a well-defined geological setting: along channel-shaped erosions of a blanket of nonmarine shale that became filled with marine black shale or limestone. The windows of black shale-limestone roof in areas of dominantly gray shale can be easily recognized, traced, and used to evaluate chances for coal-ball occurrence in unmined areas.

Geological settings similar to that at the longwall demonstration site occur in other parts of the mine and in other mines along the perimeter of two adjacent large lobate deposits of nonmarine gray shale that originated as overbank deposits from the ancient Walshville river. Coal balls were found in several mines of these areas. Other areas of Herrin Coal under overbank deposits along the more than 200-mile long Walshville channel may have been similarly affected by the formation of coal balls. Their occurrence should be monitored, especially where longwall mining is planned.

Roof stability at the longwall face was good. In the support entries around the longwall panels, problems were the same as in other room-and-pillar developments: east-west compressive forces caused roof-control problems in the north-south entries. Roof stability would probably improve if the longwall panels were positioned in an east-west direction.

The subsidence profile showed surprising sensitivity to small variations in mining height. Where smooth, controlled subsidence is required, mining height must be kept uniform. Also, measurements of mining height are necessary to obtain accurate subsidence values.

FURTHER RESEARCH DIRECTIONS

Following the completion of the first three longwall panels, a decision was made to focus further research in three areas of interest. Our new objectives are

1. to develop a fuller understanding of the depositional environments of the Herrin (No. 6) Coal and its roof units;

2. to develop a model for permineralization of coal balls for prediction of their occurrence before mining;

3. to verify the presence and nature of transitional roof in other nearby mines.

The first two objectives are being pursued through stratigraphic, geochemical, and petrographic analysis, while the third objective is being approached through in-mine mapping. Conclusions for this research phase will be reported in part 2 of this report.

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APPENDIX A. TESTING PROCEDURES

Unconfined strength and elastic modulus

Immediately prior to testing, a section of core is removed from the plastic tubing and wrapped in tape to hold the specimen together and to protect it from the oil and kerosine used during sample preparation. Samples are cut to a right cyclinder with a saw, and the ends are lapped to obtain a length-to-width ratio of about 2.5 with a tolerance for non-parallelism of <0.0025 inch. The 2.5:1 ratio is not always maintained especially within a section of core where data are needed, so a short specimen is used. The compressive strength values of the short samples are in the raw state and are not normalized to any specific length-to-width ratios. Loading is under constant strain conditions at rates indicated on the raw data sheets. No caps of any type were used.

The modulus is obtained as a tangent modulus at 50 percent of the unconfined compressive strength. The ultimate compressive strength is found by dividing the ultimate axial force by the area of core perpendicular to its axis.

Indirect tensile strength

Discs with thicknesses one-half the diameter of the core are used in the indirect tensile testing. The discs are compressed diametrically between high modulus platens (steel).

The values of indirect tensile strength, σ_t, are calculated by the following equation (F = axial load, D = diameter of the disc, t = thickness of the disc):

$$\sigma_t = \frac{2F}{\pi Dt}$$

Water content

Samples are unwrapped, prepared, and tested the same day to minimize moisture loss. Portions of the tested samples are used for water-content determinations. Moisture content is calculated as a percentage of the dry weight of the sample. The water content of the tested samples is displayed in Appendix B.

Specific gravity

The specific gravity of all samples is determined by a procedure in accordance with ASTM D-1188-71. The samples are oven dried and coated with a plastic spray, and their specific gravity is obtained from the comparison of their submerged weight in water to their weight in air.

Shore hardness

A model D scleroscope, manufactured by Shore Instrument and Manufacturing Company, Jamaica, New York, was used for hardness determination on compression-strength specimens. Each of the values in the summary tables is an average of 20 individual readings taken on the lapped end of the compressive-strength test sample at natural moisture.

Slake durability

The slake-durability apparatus and testing procedure was developed at Imperial College by Franklin (1970) and Chandra (1970). A testing procedure was later suggested by the Commission on Standardization of Laboratory and Field Tests of the International Society for Rock Mechanics (1979).

The test is intended to assess the resistance offered by a rock sample to weakening and disintegration when subjected to changes in water content due to a standard drying and wetting cycle and slight abrasion by tumbling.

The only deviation from this procedure performed by the Illinois State Geological Survey Rock Mechanics Laboratory is that the samples used are discs or half discs of the core. Many of the shale samples are so friable that spheres cannot be constructed from them. Also, minimum handling of the samples insures that their natural characteristics are being tested. All samples are run in distilled water.

APPENDIX B. CORE DESCRIPTIONS AND TEST RESULTS

ISGS Drill Hole LW-1

Top of Hole	*Thickness (ft)*	*Elevation Top (ft)*	*Elevation Bottom (ft)*
Shale (Lawson, Carbondale Formation Member)— Fine grained, medium gray, noncalcareous with occasional hard, dark, iron bands. Sharp contact to	8.25	-199.33	-207.58
Limestone (Conant)— Gray fossiliferous with argillaceous matrix. Increasing shale and carbonaceous material downward. Grades into . .	1.41	-207.58	-208.90
Shale (part of Jamestown)— Dark gray, limy shale, with limestone nodules. Lighter colored upwards. Grades into	1.33	-208.98	-210.32
Coal (Jamestown)— Hard, very bony, with some thin vitrain bands. Interlayered with dark-gray to black carbonaceous shale. Sharp contact to	.5	-210.32	-210.82
Shale— Gray, hard, calcareous, with small fossil fragments. Sharp contact to	.16	-210.82	-210.98
Shale— Dark gray, carbonaceous, top part reworked; slickensided with horizontal calcite-filled cracks in top 1 ft. Grades downward into gray shale with laminae of fossil shells and shell fragments. Some shells 1 in. across. Grades into	5.83	-210.98	-216.81

	Thickness (ft)	Elevation Top (ft)	Elevation Bottom (ft)
Limestone (Brereton)— Gray, fine grained, argillaceous, darkening downward. More argillaceous downward. The entire length shows high angle 80° joints or fractures with calcite filling, 3 or 4 subparallel ¼ to 1 in. apart. Grades quickly into	4.58	-216.81	-221.39
Shale (Anna)— Black, hard, fissile, fine silt lenses at top. Several 45° slickensided planes and vertical joints with calcite filling .	2.91	-221.39	-224.3
Next 2 units, *not cored*— Gray shale roll and coal; cut out by entry in which we drilled.			
Shale— Medium gray, hard, smooth. Sharp contact.	1.2	-224.3	-225.5
Coal (Herrin)— Normally bright banded, blocky, prominent cleat with some calcite filling. Sharp contact to	7.5	-225.5	-233.0
Claystone— Dark gray, weak, slickensided, getting progressively calcareous towards bottom of core. Top not calcareous	2.16	-233.0	-235.16

Bottom of Hole

Total core: 24.97 ft

Location: 974 ft north on the 21st North Entry of the 1-11 West North Mains.

Date: Cored from within the mine on February 2-3, 1977. Elevation of the base of the coal is an estimate.

Core LW-1: Mechanical Properties of Longwall Roof Rock*

Ft above coal seam	Type of† rock (classifi-‡ cation)	Unconfined compressive strength (psi)	Unconfined modulus (psi x 10^6)	Indirect tensile strength (psi)	Moisture content (%)	Specific gravity	Shore hardness
0.3	Anna Sh. (CL)	8,773	1.0	765	2.64	1.99	36
4.5	Brereton Lm. (CM)	13,854	3.3	2,380 2,156	0.75	2.54	46
8.9	Calc. Sh. (CL)	9,980	1.5	1,048	2.04	2.53	26
14	Carb. Sh. (CL)	7,334	1.2	983	2.19	2.31	21
15.8	Conant Lm. (BL)	16,350	2.7	2,281	0.90	2.61	44
18.3	Lawson Sh. (DM)	5,862	1.5	—	1.29	2.62	25
25	Lawson Sh.	6,345	1.1	706	2.43	2.51	16

* Determined by Engineering Geology, Applied Rock Mechanics Laboratory, Department of Geology, University of Illinois.

† Based on Illinois State Geological Survey core description (p. 43-44).

‡ Deere and Miller classification (1966).

APPENDIX B—continued

ISGS Drill Hole LW-2

	Thick-ness (ft)	Ft above coal seam Top (ft)	Bottom (ft)
Top of Hole			
Limestone (Brereton Member)— Gray, fine-grained, argillaceous. Dark argillaceous bands near base. Grades quickly into	.5	11.71	11.21
Shale (Anna Shale Member)— Black, fissile, bedded. High angle fracture (joints) in lower foot of unit. Bedding inclined 14°, paralleling the contact with the Energy Shale. 1 cm thick calcite-apatite band 7 in. up from the base of the unit. Sharp inclined (14°) contact to	3.67	11.21	7.54
Shale (Energy Shale Member)— Medium gray, fine grained, hard, siderite bands and nodules throughout. No slips of joints noted	7.54	7.54	0
Bottom of Hole			

Location: 24th North Entry (at 1540 ft north), off the West North Mains (1-11 group).

Drill Hole LW-2: Mechanical Properties*

Ft above coal seam	Type of rock	Unconfined compressive strength (psi)	Unconfined modulus (psi x 10^6)	Indirect tensile strength (psi)	Moisture content (%)	Shore hardness
2.0	Energy Sh.			295	3.5	
2.5	Energy Sh.	4217	.63		3.68	16
3.2	Energy Sh.	4959	.6		3.58	14
3.6	Energy Sh.			261	3.5	
6.8	Energy Sh.			594	3.5	
7.8	Anna Sh.	5728	.5		2.66	35
10.3	Anna Sh.			311	5.29	

* Determined by the Illinois State Geological Survey Rock Mechanics Laboratory.

APPENDIX B—continued

ISGS Drill Hole LW-3

Top of Hole	*Thickness (ft)*	*Ft above coal seam* *Top (ft)*	*Bottom (ft)*
Limestone— Coring stopped in limestone.			
Shale— Dark gray, fine grained, scattered bands of white fossil fragments. Best fits description of shale unit below Conant limestone. Grades quickly into	.83	22.8	21.98
Limestone (Brereton? Member)— Medium gray, fine grained, massive. Grades quickly into	.46	21.98	21.52
Shale (Anna Shale Member)— Black, lower foot is fissile, jointed. Upper part massive. Beds inclined 5°. High angle fractures (joints) present in lower 2 ft. Concretion from 4.75 to 11.5 in. above base of unit. Sharp contact to	3.06	21.52	18.46
Shale (Energy Shale Member)— Medium gray, fine grained, siderite bands and nodules throughout. One slip encountered in core 15.5 ft above base of unit. Top 2 feet of core is darker gray.	18.46	18.46	0.0
Bottom of Hole			

Location: 1442 ft north on the 24th North Entry off the West North Mains (1-11 group).

Drill Hole LW-3: Mechanical Properties*

Ft above coal seam	Type of rock	Unconfined compressive strength (psi)	Unconfined modulus (psi x 10^6)	Indirect tensile strength (psi)	Moisture content (%)	Shore hardness
2.75	Gray Sh.	3,913	.62	597	3.12	17
11.2	Gray Sh.	6,570	.92	384	2.81	28
17.3	Gray Sh.	5,282	.77		2.84	26
21.3	Black Sh.	4,908	.85		4.13	25
Air-dried core—moisture not preserved						
6.6	Gray Sh.	10,887	.91	873	.87	30
14.2	Gray Sh.	10,649	.78	929	1.01	26
16.9	Gray Sh.	11,303	.92		.69	

* Determined by the Illinois State Geological Survey Rock Mechanics Laboratory.