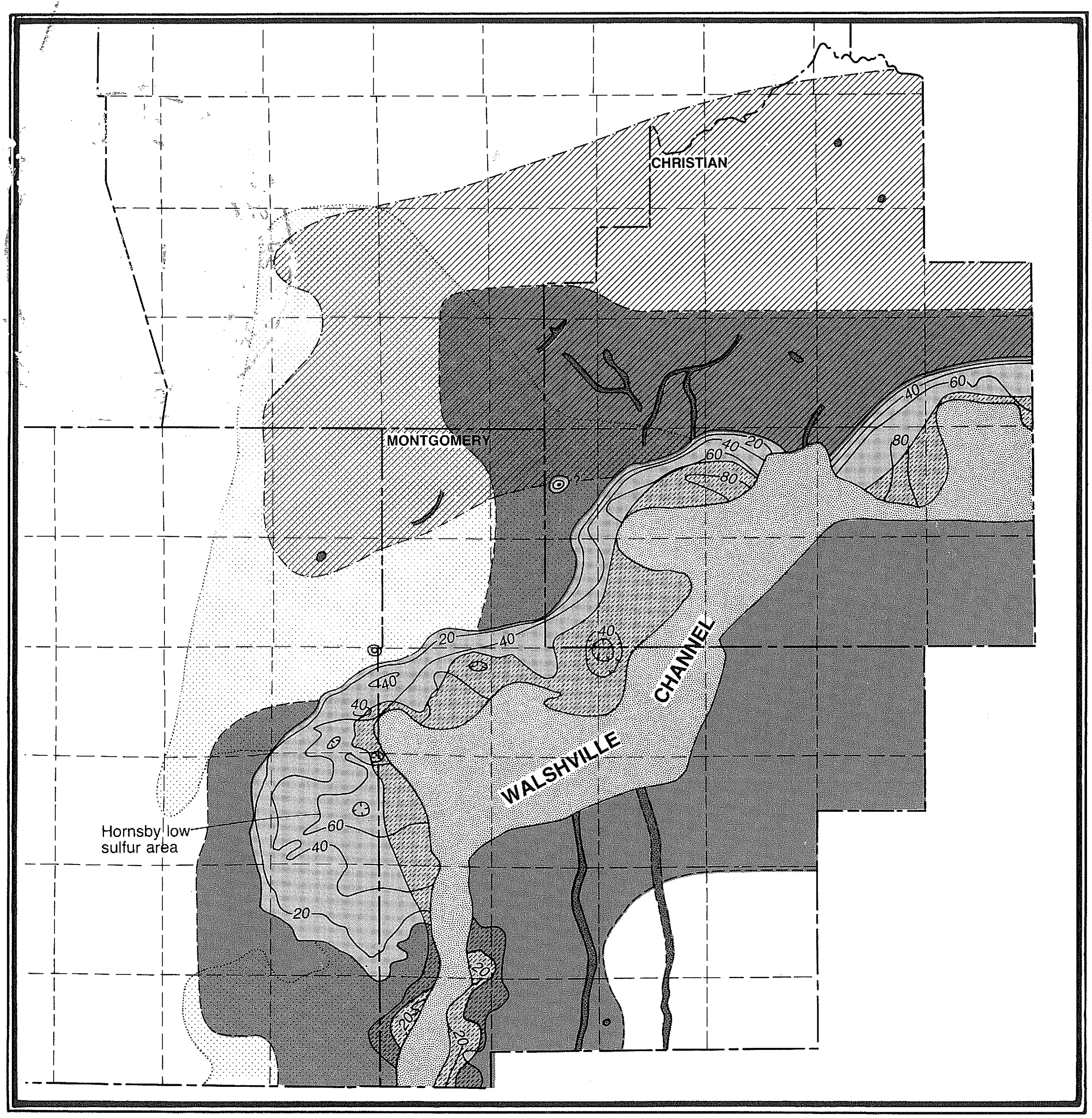
THE HORNSBY DISTRICT OF LOW-SULFUR HERRIN COAL IN CENTRAL ILLINOIS (CHRISTIAN, MACOUPIN, MONTGOMERY, AND SANGAMON COUNTIES)

by W. John Nelson
with contributions by Philip J. DeMaris and Robert A. Bauer



Department of Energy and Natural Resources
ILLINOIS STATE GEOLOGICAL SURVEY

CIRCULAR 540
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Morris W. Leighton, Chief

Natural Resources Building
615 East Peabody Drive
Champaign, Illinois 61820

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ABSTRACT

One of the largest deposits of low-sulfur coal in the Illinois Basin is in the so-called "Hornsby district" of Christian, Macoupin, and Montgomery Counties. An estimated resource of 1.17 billion tons of Herrin (No. 6) Coal, containing less than 2.5 percent sulfur, occurs here. Although the Hornsby deposit is thick, lies at moderate depth, and is close to market and labor supply, it has been barely touched by mining. The primary deterrent to mining this high quality product has been fear of unstable roof conditions.

The low-sulfur coal (average 1.86% sulfur) is overlain by 20 feet (6 m) or more of Energy Shale, a medium- to dark-gray shale that originated largely as crevasse-splay or overbank deposits from the Walshville channel, a river that existed during peat accumulation. The nonmarine Energy Shale covered the Herrin peat and shielded it from sulfur-bearing marine water and sediments. Outside the area of thick Energy Shale, the Herrin Coal is overlain by marine strata and contains more than 3.0 percent (average, 4.25%) sulfur.

Low-sulfur Hornsby coal contains about 1½ percent less ash and 2 percent more moisture than does adjacent high-sulfur coal. The lower ash content probably reflects scarcity of pyrite. The reason for the difference in moisture content is unknown. High- and low-sulfur coal are nearly identical in heating value.

The Herrin Coal is thickest in broad belts alongside or close to the Walshville channel. In places, the coal becomes thin and/or split next to the channel, reflecting excessive water depth and/or excessive clastic input to the peat-forming swamp. North and west of the channel near the original limit of the peat swamp, the coal becomes irregular in thickness and eventually too thin to mine.

Little direct information is available on mining conditions in the Hornsby district. Analysis of cores indicates that Energy Shale from the Hornsby area has lower physical strength and slake (moisture) durability than do similar roof shales of southern Illinois. These findings show that Hornsby shale probably will require more artificial support than is normal for roof strata in Illinois, and that efforts should be made to protect the shale from changes in humidity.

Roof stability under marine rocks is highly variable because most of the rock members are lenticular. The presence of thick Brereton Limestone leads to stable roof; where limestone is thin or absent, roof control may be difficult. Channels filled with Anvil Rock and younger water-bearing sandstones locally cut out the coal and produce wet mining conditions. Clay dikes and small faults hinder mining and weaken the roof and ribs in places. The floor generally is claystone that turns to mud when wet and is prone to heave or squeeze. There is evidence of in situ horizontal east-west or ENE-WSW compressive stress, which may produce moderate roof-control problems in deep mines and in mines with Energy Shale roof.

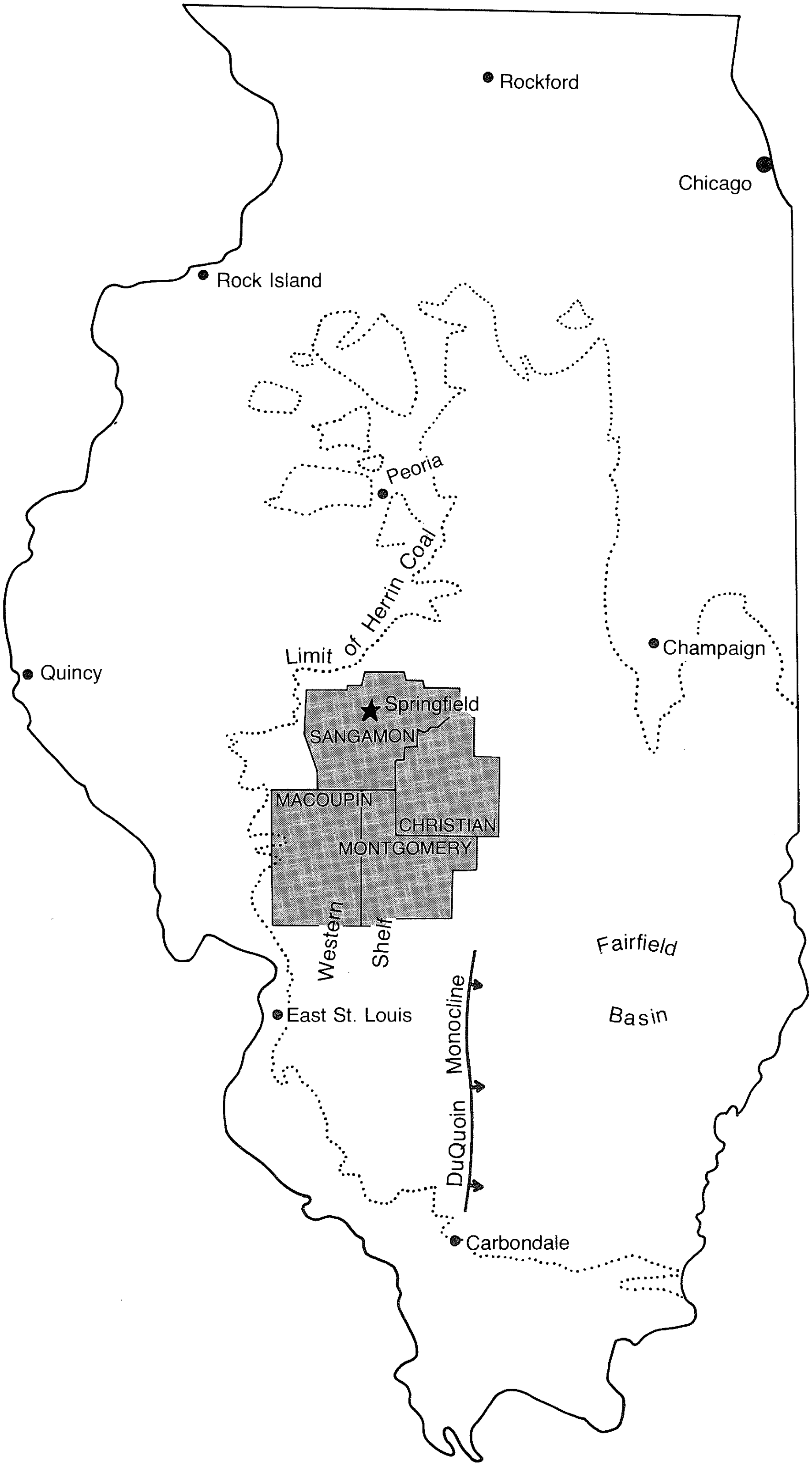


Figure 1 Location map of study area.

INTRODUCTION

The so-called "Hornsby district" of west-central Illinois contains an estimated resource of 1.17 billion tons of Herrin (No. 6) Coal at less than 2.5 percent sulfur. The coal, thick and laterally continuous, lies at moderate depth, and labor, transportation, and markets are readily available. Nearly a billion tons of high-sulfur coal has been mined adjacent to the Hornsby district in Christian, Macoupin, Montgomery, and Sangamon Counties. Yet despite unprecedented demand for low-sulfur coal, the Hornsby reserve has barely been touched by mining.

This report explores the geology and mining conditions of the "Hornsby district" and adjacent deposits of Herrin Coal in Christian, Macoupin, Montgomery, and Sangamon Counties. The distribution, thickness, and quality of the coal are considered in relation to its geologic origin. The strata overlying the coal are given special attention, because concern over roof stability appears to be the main deterrent to exploitation of the Hornsby deposit. All geologic factors that may influence mining, including faults and structure, channels, split coal, water, gas, floor stability, and in situ stress, are considered. In this report I have drawn on detailed studies at all active and recently active mines in the district, and examined hundreds of drill cores and extensive notes and reports of earlier geologists.

Geographic setting

The Hornsby district, as used in this report, comprises the deposit of low-sulfur (less than 2.5% S) Herrin (No. 6) Coal in Christian, Macoupin, and Montgomery Counties (figs. 1, 2). Gluskoter and Simon (1968), Gluskoter and Hopkins (1970), and Treworgy and Jacobson (1979) identified this deposit, but did not refer to it as "Hornsby." The name Hornsby, used by some of the mining companies working in the area, refers to a small town in eastern Macoupin County, site of one of the few mines to exploit this low-sulfur coal.

In order to place the Hornsby district in proper geologic perspective, I include in this report information on the Herrin Coal in all of Christian, Macoupin, Montgomery, and Sangamon Counties.

Geologic setting

The study area (fig. 1) lies near the western edge of the Illinois Basin, which covers roughly the southern three-fourths of Illinois, southwestern Indiana, and part of western Kentucky. Within the Illinois Basin minable coal is contained in rocks of Pennsylvanian (Desmoinesian) age. Desmoinesian strata in the Illinois Basin consist mainly of shale, siltstone, and sandstone deposited in stream channels, flood plains, and deltas. Coal beds and underclays are swamp deposits, whereas most limestones and dark gray to black shales were laid down in shallow seas.

The Herrin (No. 6) Coal is the principal commercial seam in Illinois. It accounts for about 75 percent of current production and 41 percent of mapped resources (Treworgy and Bargh, 1982). The Herrin Coal is 3½ to more than 13 feet (1.1 to 3.9 m) thick where it is mined, and thicker than 5 feet (1.5 m) over large areas (fig. 2). The Herrin is a high volatile bituminous coal, like other seams in the Illinois Basin. In most of the basin, where the Herrin Coal is overlain by marine black shale and limestone, it contains from 3 percent to more than 5 percent of sulfur. Locally, however, the coal is overlain by thick nonmarine gray shale, and contains less than 2.5 percent sulfur. These conditions occur along the Walshville channel (fig. 2), which was the site of a large river that flowed through the coastal swamps where the peat that became Herrin Coal accumulated. The gray nonmarine shale (Energy Shale), derived from the Walshville channel, shielded the peat from sulfur contained in marine water and sediments (Hopkins, 1968; Gluskoter and Simon, 1968). The Hornsby district is in this type of setting (fig. 2).

Brief history of mining

Although the date of the earliest coal mining in the study area is not known, several mines were operating in Macoupin and Sangamon counties before 1883, when the state began keeping systematic records. Expansion took place very rapidly after 1883, and by 1910 practically every city and town in the four counties hosted one or more mines. The first coal was dug at Pana in or before 1883, at Taylorville and Hillsboro in 1888, Virden in 1904, Nokomis in 1908, and Panama in 1906. The Staunton-Gillespie-Mt. Olive district was the first to assume major status, pushing Macoupin County to second place among all counties in Illinois for total production in the period 1883-1892. The other towns mentioned here also quickly became mining centers, as did Springfield, where the Springfield (No. 5) Coal was mined. By World War I, several mines in the study area were regularly topping 1 million tons of coal a year, making them among the largest in the United States at the time.

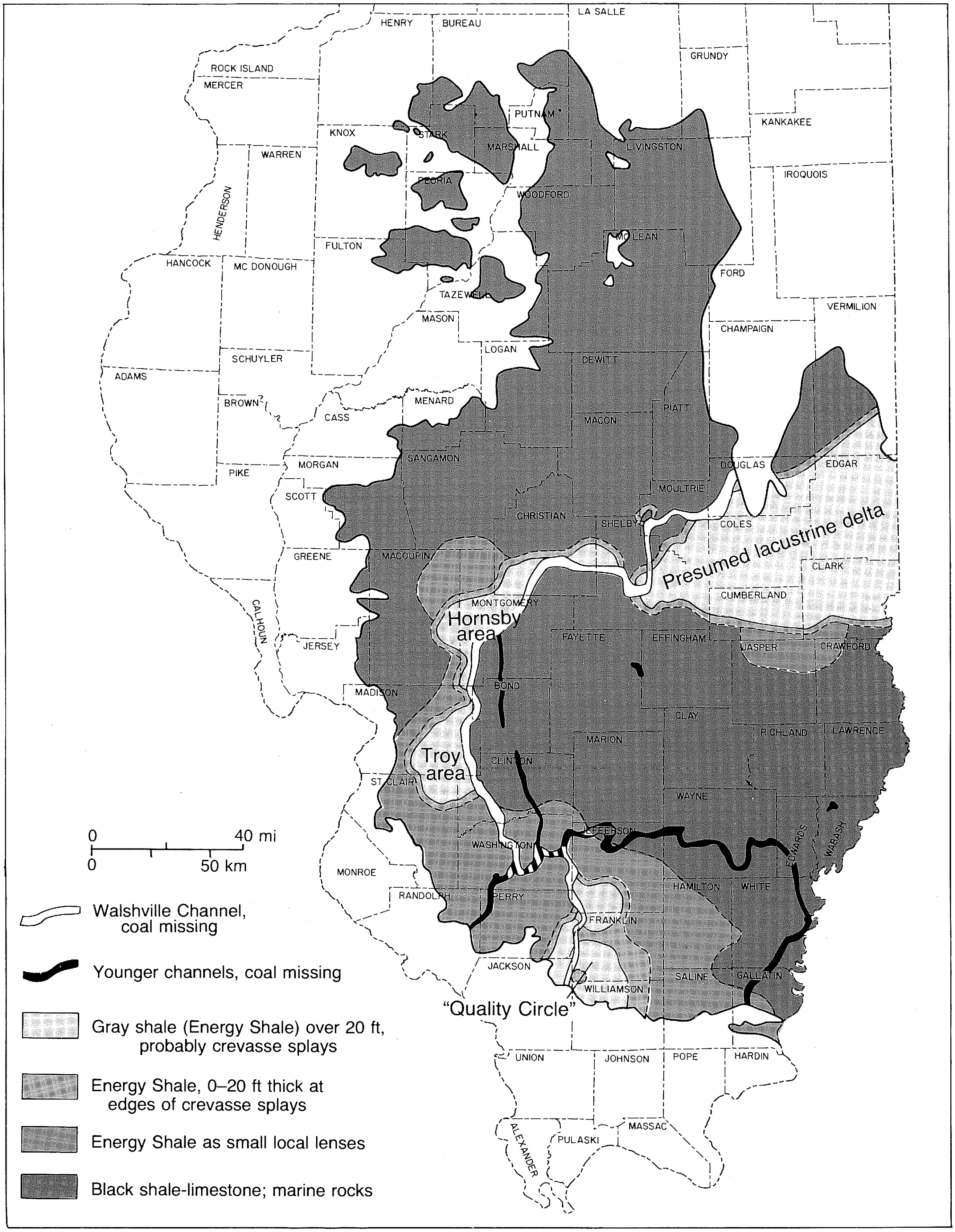


Figure 2 Generalized statewide distribution of Herrin Coal, channels, and roof types.

Because early mining companies depended upon railroads not only to ship their product but also to purchase large amounts of coal, it is not surprising that virtually all production shafts were located along railroads. A glance at a map of mined-out areas shows numerous mines strung out along the main lines, especially the Illinois Central-Gulf from Springfield to Carlinville, the Chicago and Illinois Midland from Taylorville to Pawnee, and the Penn-Central between Pana and Hillsboro.

Production in the region peaked during the 1920s and entered a serious decline in the 1930s, with the economic depression. According to the annual Coal Reports of the Illinois Department of Mines and Minerals, only seven new mines were opened in the study area between 1925 and 1949, and none of these achieved long life or large output. Many of the large shipping mines carried on through World War II, but by the early 1950s all but a handful of these had closed. They were victims of the nationwide slump in the coal market, brought on by the conversion of industries, home heating, and railroad locomotives from coal to oil or natural gas.

Today, only four mines are active in the counties of interest (plate 1) and their output is almost exclusively steam coal for electrical generation. Mine 10 of Peabody Coal Company at Pawnee serves the adjacent Commonwealth Edison power plant via overland belt. Monterey Coal Company's No. 1 near Carlinville, and Freeman United Coal Company's Crown II and Crown III Mines near Virden both supply power plants outside the district via railroad. Crown III Mine was opened in 1981 and lay idle from June 1982 through February 1985. All of these mines are designed to produce well over a million tons of coal per year.

Previous research

The earliest comprehensive reports on the Herrin Coal in Christian, Macoupin, Montgomery, and Sangamon Counties were by Andros (1914) and Kay (1915). Andros dealt with mining practice, and Kay evaluated coal resources. The resource evaluation was necessarily incomplete by modern standards, but information on the character of the coal, roof and floor strata, and other geologic conditions is highly detailed and still relevant.

Easton (1942), Payne (1941, 1942, and 1944), and Siever (1950) mapped the structure of the Herrin Coal in various portions of the study area and updated information on the thickness and distribution of the coal. Cady (1935) tabulated analytical data on coal statewide and in 1952 calculated county-by-county resources for all of Illinois. Important local studies include Ball (1952) on geology and mineral resources of the Carlinville Quadrangle, Macoupin County, and Clegg (1961) on subsurface geology and coal reserves of an area including Sangamon and part of Christian County. Smith (1961) mapped strippable coal in Macoupin County (the other counties lack strippable coal). Smith and Stall (1975) presented resource estimates and a map showing distribution and thickness of the Herrin Coal throughout Illinois. Treworgy and Jacobson (1979) included the Hornsby district in their discussion of origin and distribution of low-sulfur coal in Illinois.

The latest figures on statewide coal resources are found in Treworgy et al. (1978) and Treworgy and Bargh (1982). The former covers strippable coal—coal less than 150 feet (46 m) deep; the latter treats deep-minable seams. Both investigations are computer based, and in addition to presenting tonnages, they assess the relative minability, considering depth, thickness, continuity of deposits, and presence or absence of surface features and oil fields that may restrict development. Treworgy and Bargh also provide figures on resources of low-sulfur coal (less than 2.5% sulfur) for each county in Illinois.

Other reports of interest include those of Krausse et al. (1979) and Nelson (1981 and 1983). Krausse et al. describe geology and stability of roof strata of the Herrin Coal throughout Illinois, including detailed mapping of the recently abandoned Consolidation Coal Company Hillsboro Mine in Montgomery County (identified as "Mine A" in Krausse et al.). Nelson (1981) covers faults and their effect on mining in Illinois, and Nelson (1983) assesses geologic features other than faults that interfere with coal extraction.

Method of study

The conclusions of this report are based mainly on examination of the logs of approximately 2500 drill holes, mostly coal-test borings, in Christian, Macoupin, Montgomery, and Sangamon Counties. Most of these logs include core descriptions made by geologists; in addition, some contain chemical analyses of the Herrin (No. 6) Coal. Geophysical logs and detailed driller's logs of coal-test holes also are valuable sources of data. Logs of water wells and of oil and gas test holes are less reliable, but are useful for determining depth and approximate thickness of coal beds and general nature of enclosing strata.

Information from active and abandoned coal mines also is tremendously valuable. Geologists from the ISGS have regularly visited coal mines through the years, recording geologic observations and collecting channel samples of coal for chemical analysis. In addition, I have visited all active mines in the region and carried out, with Survey colleagues, detailed geologic mapping at several of these mines.

Records of water wells, oil and gas tests, and some coal tests, as well as geologic notes, maps, and analytical data from abandoned coal mines, all are available for public inspection at the offices of the ISGS. However, most of the core descriptions of coal-test holes and nearly all the analytical data from coal cores I used in preparing this report are proprietary information loaned to the Survey by coal companies. In order not to compromise these sources, I have refrained from plotting datum points except in cases where all data used are in the public domain. Similarly, chemical data are employed only in a statistical manner; no maps showing actual variations in sulfur, ash, or other factors in coal quality are presented. I believe that the resulting loss of detail is insignificant, because the aim of this report is to uncover principles and relationships rather than to show data, which may be atypical, from specific drilling sites.

STRATIGRAPHY

All the minable coal in the Illinois Basin lies in rocks of the Pennsylvanian System. Pennsylvanian rocks in Illinois have been classified into seven formations, of which six are known to exist in the study area within the four counties

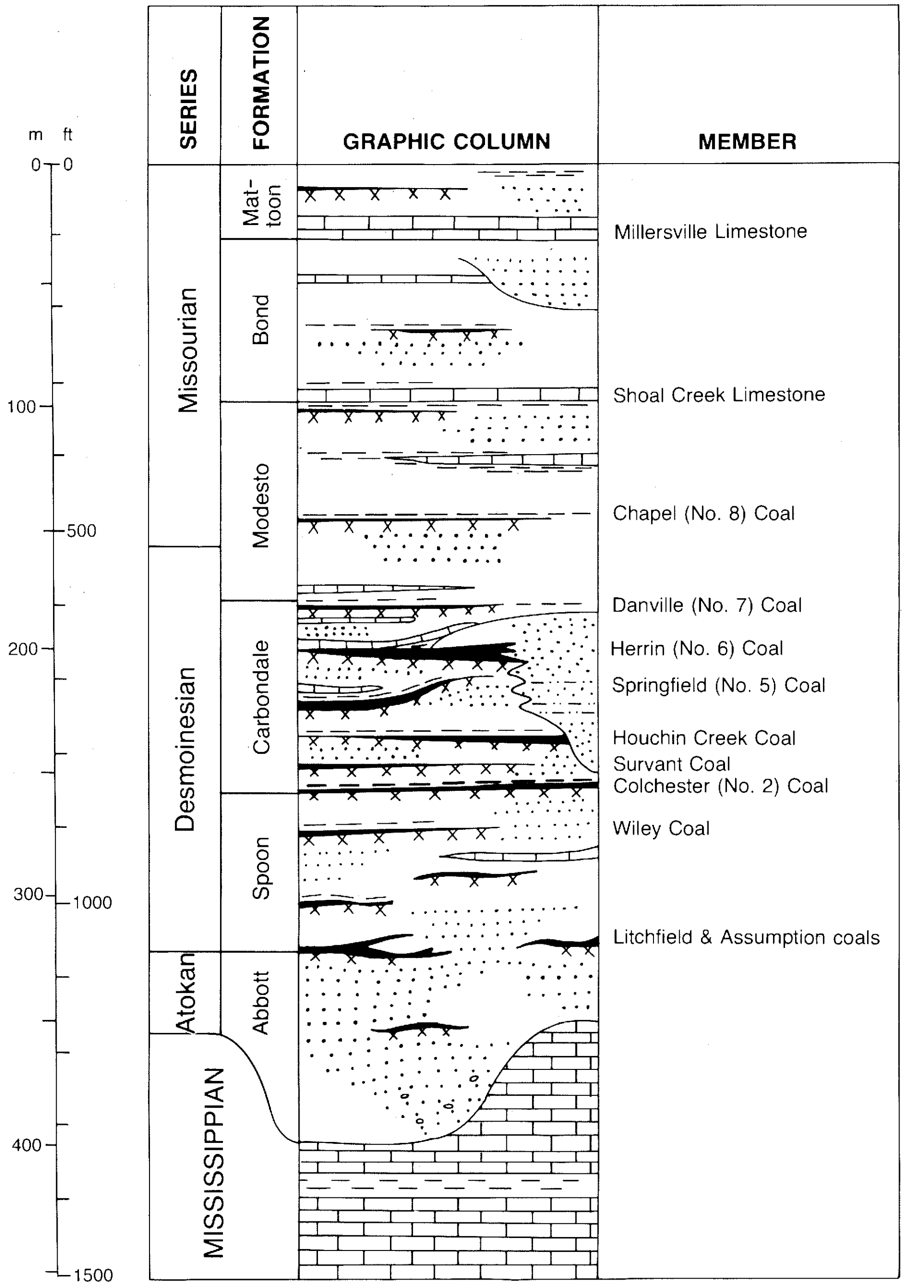


Figure 3 Generalized stratigraphic column of Pennsylvanian rocks in the study area.

of interest (fig. 3). The Herrin Coal Member is included in the Carbondale Formation.

The Carbondale Formation is present throughout the study area. It is defined as those beds lying between the base of the Colchester (No. 2) and the top of the Danville (No. 7) Coal Member (fig. 3). Because both of these coals occur practically throughout the four counties, the Carbondale Formation is well defined. Its thickness ranges from about 125 feet (38 m) on the north and northwest to about 275 feet (84 m) on the southeast, with considerable local variation.

The Carbondale Formation consists of shale, siltstone, and sandstone, along with widely continuous beds of limestone and coal. Most of the shale is medium to dark gray, well laminated, carbonaceous, micaceous, and commonly silty. Laminae and lenses of siltstone or fine-grained sandstone are common, as are nodules of siderite. Black, fissile, very thinly laminated shales overlie most coal seams in the Carbondale Formation. Shale grades laterally and vertically into siltstone, which varies from light to dark gray and from thinly laminated to massive. Sandstone is typically light gray to buff and ranges from very fine to coarse

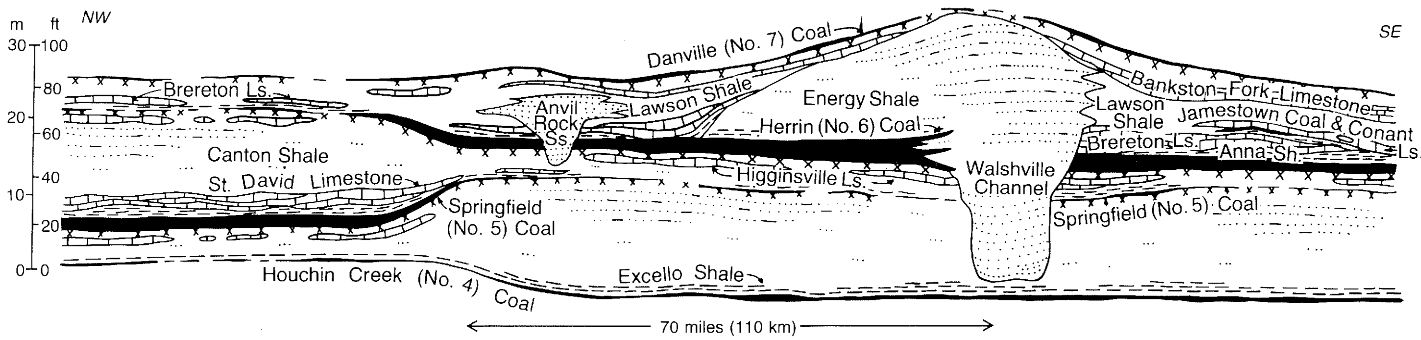


Figure 4 Generalized stratigraphic cross section of the interval from the Houchin Creek to the Danville Coal from northwestern Sangamon (left) to southeastern Montgomery County.

grained. It is normally poorly sorted, argillaceous, feldspathic, and micaceous, and commonly contains much carbonaceous debris. Sandstone, like siltstone, varies from thinly laminated to massive. Much sandstone in the Carbondale Formation occurs in channel-fill deposits that are linear or sinuous in map view and lenticular in cross section.

Most of the persistent limestones in the Carbondale Formation directly overlie the black fissile shales, which in turn overlie coal seams. These limestones, which range in thickness from a few inches to locally more than 10 feet (3.0 m), are typically fine grained and dense, and contain abundant marine fossils. Limestones occurring below coal beds commonly are nodular; they have been interpreted as freshwater deposits. Coal seams in the Carbondale Formation vary in thickness from less than an inch (2.5 cm) to more than 10 feet (3.0 m). Most coal belongs to named members that can be mapped and have been mined far beyond the boundaries of the study area; however, in some places where there was no peat accumulation, or where erosion occurred, the seams may be absent. Coal seams generally are underlain by underclays, which are soft claystones containing fossil roots of coal-forming trees.

Springfield (No. 5) Coal Member

The Springfield Coal, below the Herrin Coal (figs. 3, 4), is a major resource in northern Sangamon and Christian Counties. The coal is named for the capital city of Illinois, where it was mined on a large scale from the 1880s through the 1940s. In quantity of overall statewide resources, the Springfield is second only to the Herrin Coal. Treworgy and Bargh (1982) list 1,236 million tons in Christian County and 2,540 million tons in Sangamon County. The coal is extremely thin or absent in Macoupin and Montgomery Counties; no resources are mapped there.

The thickness of Springfield Coal is inversely related to the thickness of the Herrin Coal in the study area (fig. 4). In Macoupin, Montgomery, and southern Christian and Sangamon Counties, the Springfield Coal is extremely thin or absent, and where present, it occurs only a short distance below the Herrin Coal. The Springfield Coal is difficult to recognize in this region except in drill cores and in mine exposures, where it typically appears as thin streaks of coal or carbonaceous shale about 10 to 17 feet (3 to 5 m) below the base of the Herrin Coal. The interval between the two coals consists of soft shale, claystone, and nodular limestone. No evidence of erosion is present; all indications are that the Springfield peat failed to accumulate in this region. The Herrin Coal is thick in most of this area, except where contemporaneous and later streams eroded it or prevented its deposition.

North of a line that closely follows the boundary between T14 and 15N in Sangamon and Christian Counties, the Springfield Coal abruptly thickens to 5 to 6 feet (1.5 to 1.8 m). Along the same line the Herrin Coal pinches down from 6 or 7 feet (1.8 to 2.1 m) to 2 feet (0.6 m) or less, and north of the line (plate 1), it is widely absent. Furthermore, the interval between the two coals thickens northward to 35 to 50 feet (11 to 15 m). This interval consists of marine black shale and limestone at the base, overlain by dark gray, sideritic shale grading upward to siltstone or fine-grained sandstone, and topped by the underclay of the Herrin Coal (fig. 5).

Floor strata of Herrin Coal

In the area where the Herrin Coal is minable the immediate floor almost invariably consists of soft, mottled, greenish gray to olive gray claystone (underclay). Near the contact with the coal the claystone is highly carbonaceous and commonly contains inclined stringers of coal, along with the carbonized impressions or casts of *Stigmaria,* the fossilized roots and rootlets of coal-forming lycopod trees. These features indicate that the underclay was the soil or substrate in the swamps where the Herrin Coal accumulated as peat in situ. The underclay contains small nodules of calcite and siderite, and is penetrated by numerous small slickensided fractures. The usual range of thickness of the underclay is 2 to 5 feet (0.6-1.5 m), but in some boreholes and exposures in mines, more than 10 feet (3.0 m) of claystone is present below the coal.

Beneath the underclay a limestone that can be correlated with the Higginsville Limestone of Missouri is commonly found (fig. 4). This limestone is generally light gray to olive gray, fine grained, and highly argillaceous or silty. It is massive in places but more typically is nodular, with thick layers and partings of soft greenish to olive gray claystone or shale. In some boreholes and exposures the Higginsville consists of scattered, irregularly shaped lumps of limestone in a matrix of claystone.

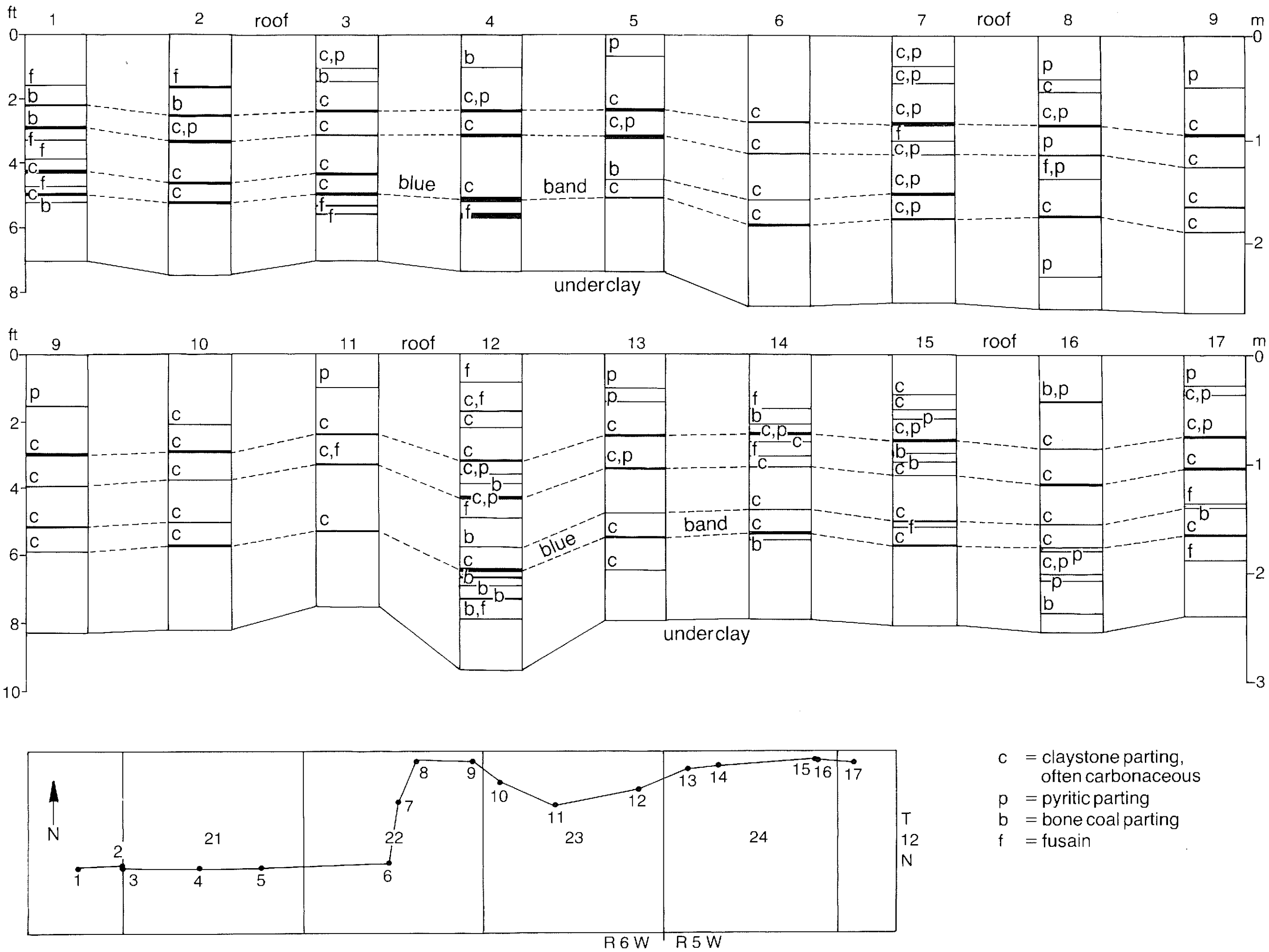


Figure 5 Measured sections of Herrin Coal at Crown II Mine, illustrating continuity of shale partings; length of traverse is about 5 miles (8 km). By Philip J. DeMaris.

Silty shale, siltstone, or shaly, fine-grained sandstone is usually found below the Higginsville Limestone, or below the underclay where the limestone is absent. The silty and sandy beds generally grade into the limestone or underclay; argillaceous content increases upward, and the upper layers tend to be heavily burrowed and/or rooted.

Herrin (No. 6) Coal Member

The Herrin, like nearly all coal in the Illinois Basin, normally is a bright-banded coal: it is composed of alternating laminae of lustrous vitrain and dull attrital coal (durain and clarain), with the attrital coal dominant. Individual laminae rarely are thicker than a fraction of an inch (a few millimeters). Fusain (dull, soft, charcoal-like material) occurs as thin partings and in places as lenses or discontinuous layers up to several inches thick. In the larger layers and lenses the fusain commonly is mineralized by pyrite or other minerals. Mineralized fusain is extremely hard and tough, even though the minerals may be so finely disseminated that they are not identifiable in hand specimen.

The Herrin Coal has a blocky structure, produced by the cleat (intersecting sets of vertical fractures). At least two and often three or more directions of cleat can be observed. Measurements of cleat orientations in the four counties indicate that trends are not consistent from one mine to another, and often vary within a single mine.

Pyrite is the most common visible mineral impurity and is, of course, the source of much of the sulfur in the coal. Brassy or golden pyrite is conspicuous on cleat facings and also appears as thin lenses or laminae, partially mineralizing shale or fusain. Lenses of solid pyrite up to several pounds (kilograms) also are fairly common. They may be found at any position in the seam but most frequently occur near the top. Some of these "sulfur balls" may have originated as fusain lenses or as calcareous concretions (coal balls). Pyrite also occurs as fracture fillings and small nodules adjacent to clay dikes and along other structural disturbances in the seam.

Other common mineral impurities include calcite and kaolinite, both of which line cleat faces and other fractures in the coal.

Only scattered occurrences of coal balls have been reported. These coal balls are lens shaped or irregular masses of peat that was impregnated with calcite, dolomite or other minerals before being coalified. Coal balls in the study area generally are less than a foot (0.3 m) in diameter, and most of them are found within a foot of the top of the seam. They are of scientific interest, for they contain excellently preserved fossil plants; they do not significantly hinder mining in the four counties of interest.

The Herrin Coal is notable for distinctive bands of claystone that display remarkable regional continuity. The best-known of these is the "blue band," which has been traced through most of the Illinois Basin. Studies within the four counties indicate that at least two other claystone layers in the coal are widely traceable, and still others may be followed through part or all of individual mines.

The "blue band" is a specific layer of claystone that occurs about 1½ to 2½ feet (0.4 to 0.8 m) above the base of the coal. It is generally less than 2 inches (5 cm) thick, and its color varies from olive gray to dark brown or gray. Carbonaceous debris and coal stringers are common, but well-preserved plant fossils rare. Pyrite is found as laminae and as small lenses or nodules, or is disseminated through the "blue band."

The "blue band" can be recognized in practically every mine and detailed core description in the four counties. The band can be traced throughout most mines with little difficulty, although it may pinch out locally. As a general rule, the distance from the "blue band" to the floor increases as the total thickness of the coal increases. This is definitely the case at the Crown II Mine, where Philip J. DeMaris identified the "blue band" in 17 out of 17 carefully measured sections of the coal throughout the mine (fig. 5).

In the same study at Crown II, DeMaris recognized three additional clay-rich partings that are essentially continuous. The highest, consisting of claystone or bone coal 2.1 to 3.2 feet (65 to 97 cm) from the top of the coal, was found in all 17 sections. A second band of pyritic clay stone was found 0.6 to 1.0 feet (19 to 30 cm) below the first in all the 17 sections. The third band, of carbonaceous or pyritic claystone, is 0.5 to 0.7 feet (15 to 22 cm) above the "blue band"; it was identified in all but three of the sections. Examination of 20 coal seam descriptions made by various geologists at the Peabody No. 10 Mine reveals that two shale partings, probably corresponding to the upper two at Crown II, are present at that mine, along with the "blue band." The Crown II and Peabody No. 10 Mines are more than 10 miles (16 km) apart. In mines located about 20 miles (32 km) south of Crown II, the "blue band" was identified in 11 out of 11 sections of the coal seam described by various geologists. Most of these sections also indicated three claystone bands above the "blue band," approximately corresponding with the bands at Crown II. Continuity of these higher bands southward, however, is not as well established as at the Peabody and Crown Mines.

The blue band and similar partings probably originated as overbank deposits from the Walshville channel. Johnson (1972) found that the "blue band" thickens toward the channel in a region including the present study area and several counties to the south. Similar thickening near the channel is recorded in southern Illinois (DeMaris et al., 1983; Nelson, 1983). Hughes et al. (1987) found the mineral composition of the blue band to indicate detrital sediments, somewhat altered chemically by exposure to swamp waters.

Walshville channel

The Walshville channel (figs. 2, 4; plate 1) is the course of a large river that flowed through the swamps during accumulation of the Herrin peat. The existence of "barren areas" was noted by Kay (1915); subsequent workers identified these as a paleochannel. The feature, however, was generally attributed to erosion after deposition of the peat and associated with channels of the Anvil Rock Sandstone until Johnson (1972) recognized the true nature of the Walshville channel and named it.

The Walshville channel has been traced approximately 230 miles (370 km) from the northern subcrop of the Herrin Coal in Douglas County to the southern subcrop in Jackson County (Treworgy and Bargh, 1982). It enters the study area in T12N, RIE, Christian County, trends southwestward to western Montgomery County, and then turns due south (plate 1). Within the area mapped as "channel," the Herrin Coal is missing and replaced by clastic sediments, although a few boreholes show thin coal near the expected horizon of the Herrin.

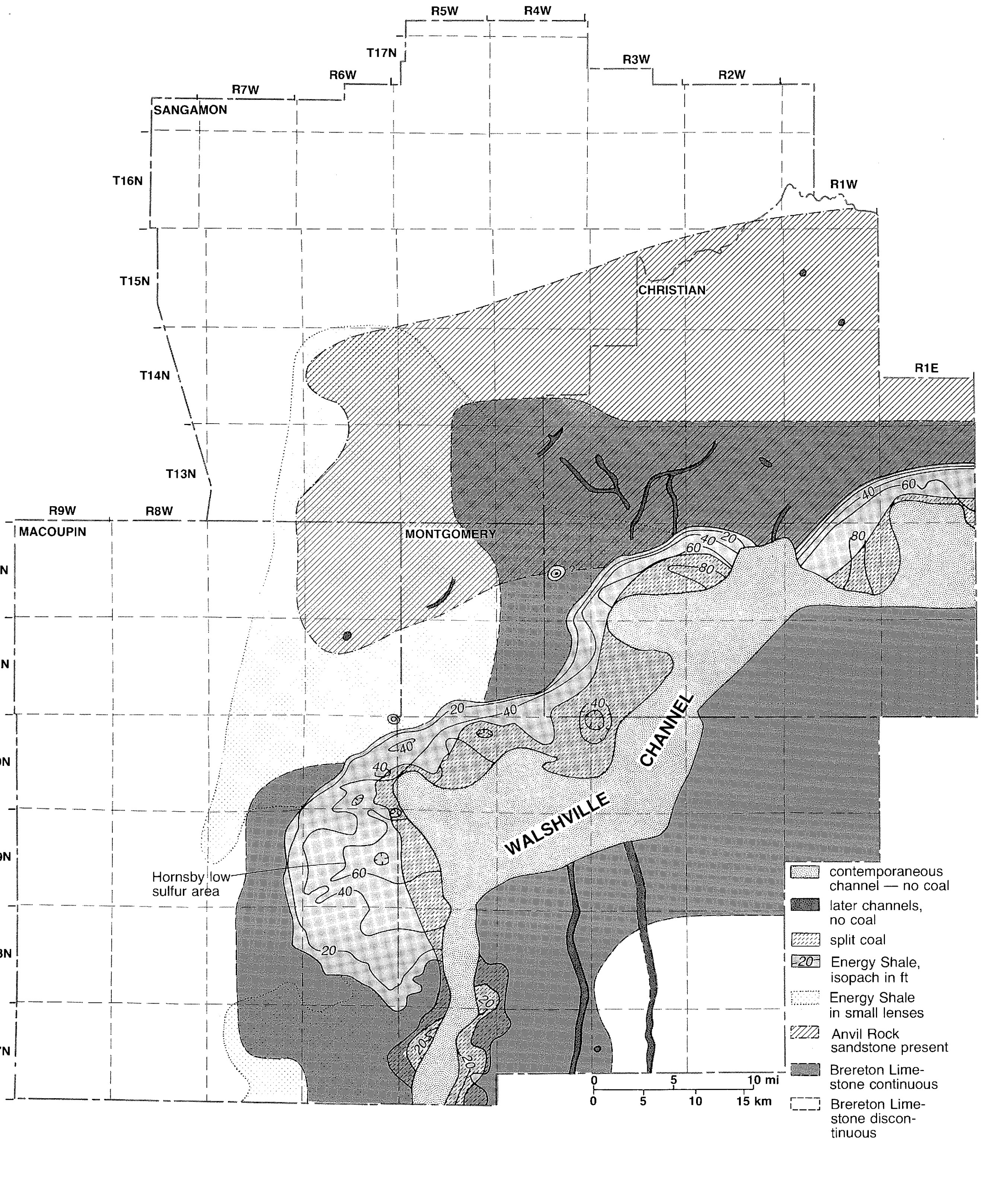
Several features indicate that the river (the Walshville channel) was contemporaneous with peat deposition:

- *The presence of split Herrin Coal along the margins of the channel (plate 1).* The number and thickness of splits increase toward the channel. These splits apparently represent clastic sediments washed out of the channel into surrounding swamps during floods.
- *Thickening of the coal toward the channel (plate 1).* The river followed the lowest area through the peat-forming swamp; areas adjacent to the river were almost continually submerged, and subsided most rapidly, allowing thickest accumulation of peat.
- *The presence of thick deposits of gray nonmarine shale (Energy Shale) above the coal along the channel (figs. 4; plate 2).* This shale was derived from the channel. Marine rock members that normally lie directly on the Herrin Coal overlap both Energy Shale and deposits of the Walshville channel itself.

The detailed map (plate 1) shows that the width of the Walshville channel in the study area varies from less than 1 mile (1.6 km) to more than 9 miles (15 km). Many lobate extension or salients of the channel protrude from the sides, particularly on the northwest side. The pattern strongly suggests that the Walshville river meandered and changed course many times during its history. The channel-fill deposits, as mapped, reflect not the riverbed at one time, but the meander belt as the channel shifted during several hundreds or thousands of years. Peat generally did not accumulate, or was eroded, within the meander belt, but small islands may have developed locally, and their peat escaped destruction. An alternative explanation for some coal found within the Walshville channel may be that these deposits represent mats of peat ripped out of the adjoining swamps and incorporated in the bedload of the river.

The Walshville channel shows similar patterns outside the study area. Oxbows or abandoned meanders of the

PLATE 2
ROOF STRATA OF HERRIN (NO. 6) COAL



Walshville channel have been identified in southern Illinois (Bauer and DeMaris, 1982; Nelson, 1983, p. 20).

The depth of the channel, or thickness of contained sediments, is difficult to determine, because the interval is seldom cored and few detailed logs are available. Channel-fill sediments are difficult to distinguish from underlying and overlying shales and sandstones on most drillers' logs and geophysical logs. Coals below the Herrin Coal, such as the Houchin Creek and Survant Coals, are missing in some holes, but their absence is not necessarily due to scouring by the Walshville river. Also, in places the Walshville sediments may be superimposed on older paleochannels (Palmer, Jacobson, and Trask, 1979). Similarly, the Anvil Rock Sandstone and younger channel-fill sandstones may truncate the Walshville channel in places. Where good logs are available, the channel-fill sediments seem to range from roughly 100 to 200 feet (30 to 60 m) thick.

Energy Shale Member

As mentioned previously, the Energy Shale Member is a gray shale that overlies the Herrin Coal in the Hornsby district and elsewhere along the Walshville channel (fig. 4; plate 2). The Energy Shale intervenes between the coal and its usual roof units of black shale and limestone.

Plate 2 shows the thickness and distribution of Energy Shale in the study area. The largest body of Energy Shale (which defines the "Hornsby area") covers portions of southwestern Christian, northwestern Montgomery, and east-central Macoupin Counties northwest of the Walshville channel. A second large body lies north of the channel in eastern Christian and western Shelby Counties. Two small areas of gray shale are found on opposite sides of the channel in southern Montgomery County.

The thickness of Energy Shale increases rapidly from where it first appears at the outer edges of the large bodies to 40 feet (12 m) or more close to the channel. The greatest thickness measured in a borehole is 84 feet (25.6 m). The thickest shale borders the channel. At the outer margins the Energy Shale thins abruptly; this is illustrated by close proximity of the 0 and 20-foot (6.1 m) isolines on plate 2. In places the shale thins from 20 feet to 0 within less than 1,000 feet (305 m) laterally. Cores and exposures in mines commonly show an erosional contact between the Energy Shale and overlying marine rocks (fig. 7), indicating erosion of Energy Shale before deposition of marine sediments, and suggesting that the Energy Shale was originally more widespread than at present. Krausse et al. (1979) and Bauer and DeMaris (1982) observed similar relationships at mines in southern Illinois.

The lithologic sequence of the Energy Shale is quite consistent throughout the study area (fig. 6). At the base is dark gray to black, highly carbonaceous clay shale that becomes progressively siltier, lighter in color, and less carbonaceous upward. The basal zone, which normally varies from a few inches to a few feet thick, but locally reaches 20 feet (6 m) thick, is typically thinly laminated, smooth, platy, brittle, weak shale. Sideritic lenses are common, as are partings and stringers of coal and laminae of carbonaceous debris. In one mine where the outer edge of the crevasse-splay was exposed, large fossil tree trunks were abundant at the base of the Energy Shale. Most of these were flat-lying, but many upright stumps ("kettle-bottoms") were noted. Also seen in this mine, and occasionally encountered in drill cores, are calcareous or pyritic concretions. These range up to a foot (0.3 m) or more in diameter and generally are found right at the coal-shale contact.

The dark basal shale passes upward to medium or light gray silty mudstone or poorly laminated shale. The contact is normally gradational, rarely sharp. In many cores a transition zone consisting of several feet of alternating bands of dark and light shale is seen. The upper shale is considerably firmer and more competent in cores than the lower dark shale, probably reflecting its higher silt and lower clay content. Laminations of siltstone occur in a few cases but most of the rock has no visible bedding and does not split readily into layers. Nodules, concretions, coaly stringers, and other irregularities are rare in the upper part of the Energy Shale.

Krausse et al. (1979) and Bauer and DeMaris (1982) described similar sequences of Energy Shale, in which dark gray basal shale is overlain by lighter gray silty shale, at mines in southern Illinois.

Siltstone and sandstone occur in the upper part of the Energy Shale in Christian County, but are rare in Montgomery and Macoupin Counties. Sandstone is fine grained and generally interbedded with silty shale or siltstone. Few details of lithology and sedimentary structure are available, because the uppermost part of thick Energy Shale is known mainly from drillers' logs and geophysical logs. The siltstone and sandstone, however, probably will have little effect on mining, because they normally occur more than 20 feet (6 m) above the Herrin Coal. The proportion of sandstone appears to increase toward the Walshville channel, which was the source of sediment.

Beyond the main Hornsby wedge, Energy Shale is widely distributed as small isolated pods or lenses between the Herrin Coal and younger marine units. Mapping in underground mines has shown these lenses range from a few tens of feet to several hundred feet across and typically are 2 to 10 feet (0.6 to 3.0 m) thick at the center. They are roughly circular or irregular in outline, and their local distribution apparently is random. The largest region of Energy Shale lenses is in northeastern Macoupin, southeastern Sangamon, northern Montgomery, and southwestern Christian Counties (plate 2). Lenses here are found as far as 25 miles (40 km) from the Walshville channel. Pods of gray shale also were observed in several of the now-abandoned mines in southeasternmost Macoupin County, west of the channel (Spotti, 1941). In contrast, such lenses are virtually absent southeast of the Walshville. During very extensive mapping at Consolidation Coal Company's abandoned Hillsboro Mine (T7N, R2-3W), only two or three examples were noted. Energy Shale has not been reported in any other mine or borehole southeast of the channel, except in the small lobe in T7-8N, R5W.

The lenticular Energy Shale varies from medium gray to almost black. The darker shale (mudstone) typically is massive or nearly so (fig. 7). It is weak, sensitive to moisture slaking, and difficult to support in mine roof. Coal stringers and plant fossils are rare. Pyritized shells of pectenoid and other pelecypods in places are found at or near the base of the shale in Crown II Mine (T12N, R6W), the only active mine in the study area where lenticular Energy Shale is common.

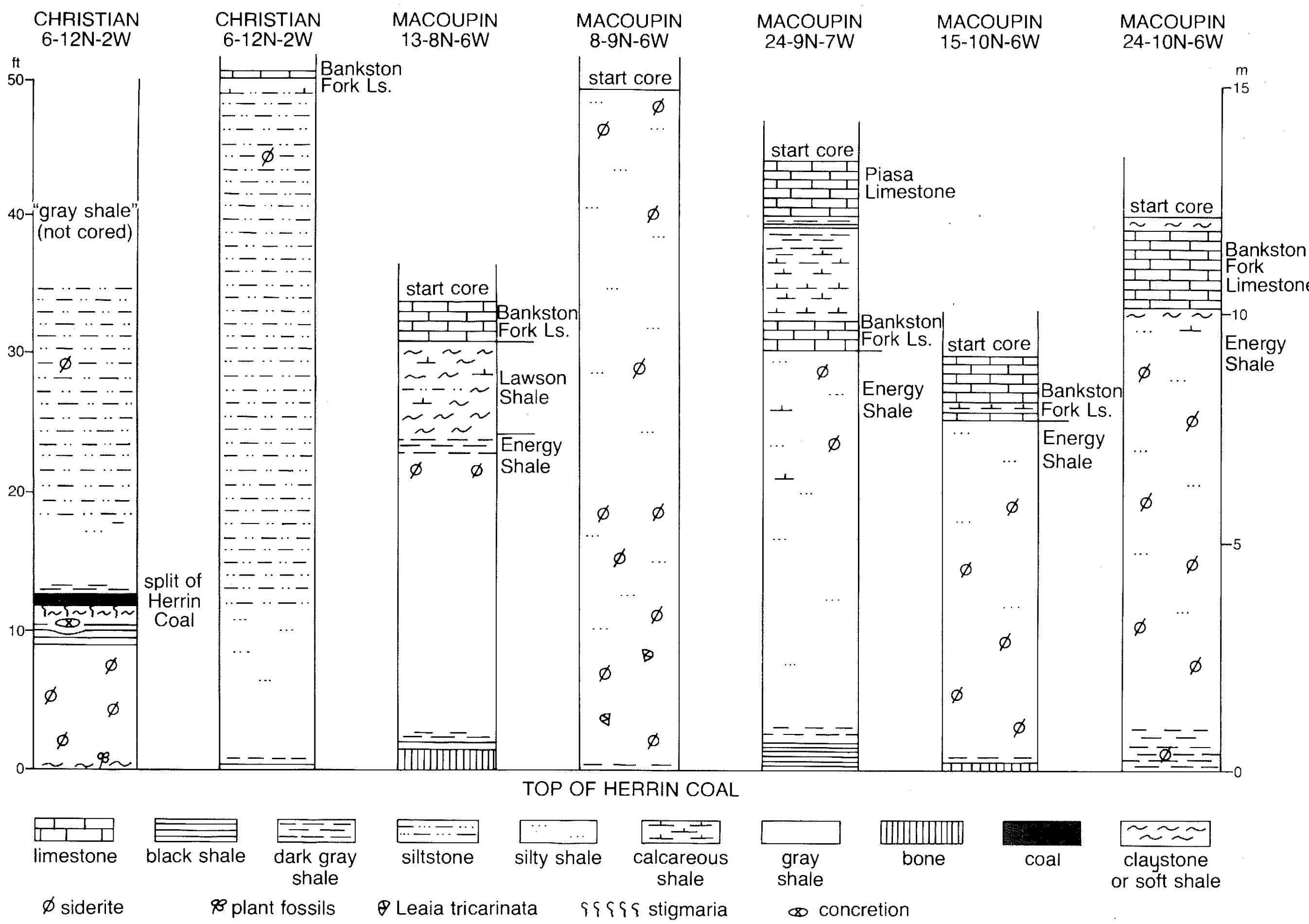


Figure 6 Selected columnar sections of Energy Shale, from core descriptions.

Energy Shale in lenses is overlain by the Anna Shale and younger marine units. The contact occasionally is gradational, but in most cases is sharp and definitely erosional, with layering in the Energy Shale truncated beneath overlying units (figs. 7, 8).

Geologists agree that most, if not all, of the Energy Shale was derived from the Walshville channel, but the exact mode of deposition in the Hornsby district requires more study. More than a decade ago Johnson (1972), Allgaier and Hopkins (1975), and others described Energy Shale as a series of crevasse-splay deposits. In this model, the Walshville River had raised banks, or natural levees, which confined the stream to its channel in normal stage. When the river reached flood stage it broke through (crevassed) its levees and flowed out into the adjacent swamps, depositing a sub-delta (crevasse splay) of sediment there. Modern crevasse splays of the Mississippi and other large rivers are well documented (Coleman, 1981) and are remarkably similar in geometry and distribution to the deposits of Energy Shale in Illinois. However, some pieces that would conclusively identify the Energy Shale as crevasse splay deposits are missing:

- No natural levees of the Walshville channel have been conclusively identified.
- The original depositional pattern of the Energy Shale was modified by erosion before deposition of the Anna Shale.
- Not enough details on sedimentary structures or fossils are available for the Hornsby district.

Because of this missing information, the general term "overbank deposit" seems more appropriate than the more precise "crevasse splay" to describe the Energy Shale in the Hornsby district.

Moreover, the basal dark gray, carbonaceous portion of the Energy Shale may not be an overbank deposit. A lower dark sub-unit of the Energy that is widespread in southern Illinois is interpreted as a bay-fill sediment deposited in fresh to "marginal marine" water (Deshowitz, 1979; Burk and Utgaard, 1983). Evidence for these interpretations includes the presence of undoubtedly marine or brackish-water fossils in some of the basal Energy Shale. Similar fossils also have been observed in some of the small pods and lenses of dark gray Energy Shale north and west of the

Figure 7 Edge of a lens of Energy Shale, overlain by Anna Shale (upper right). Numerous slip-fractures make Energy Shale difficult to support. Photo from Spotti (1941).

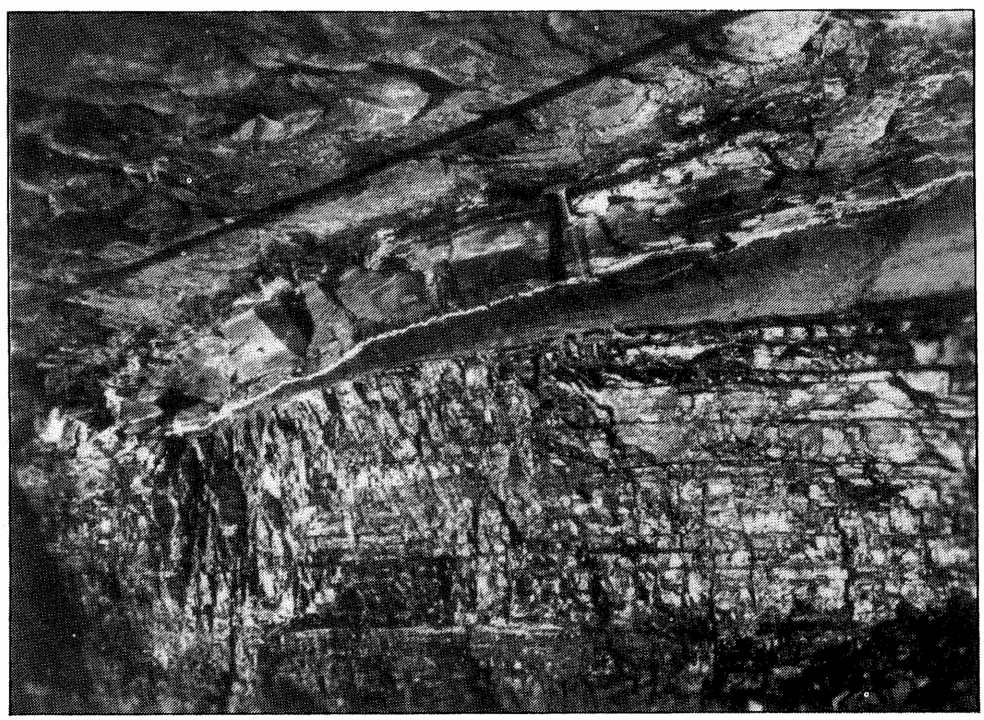


Figure 8 Tapering edge of a lens of Energy Shale, overlain by Anna Shale and Brereton Limestone.

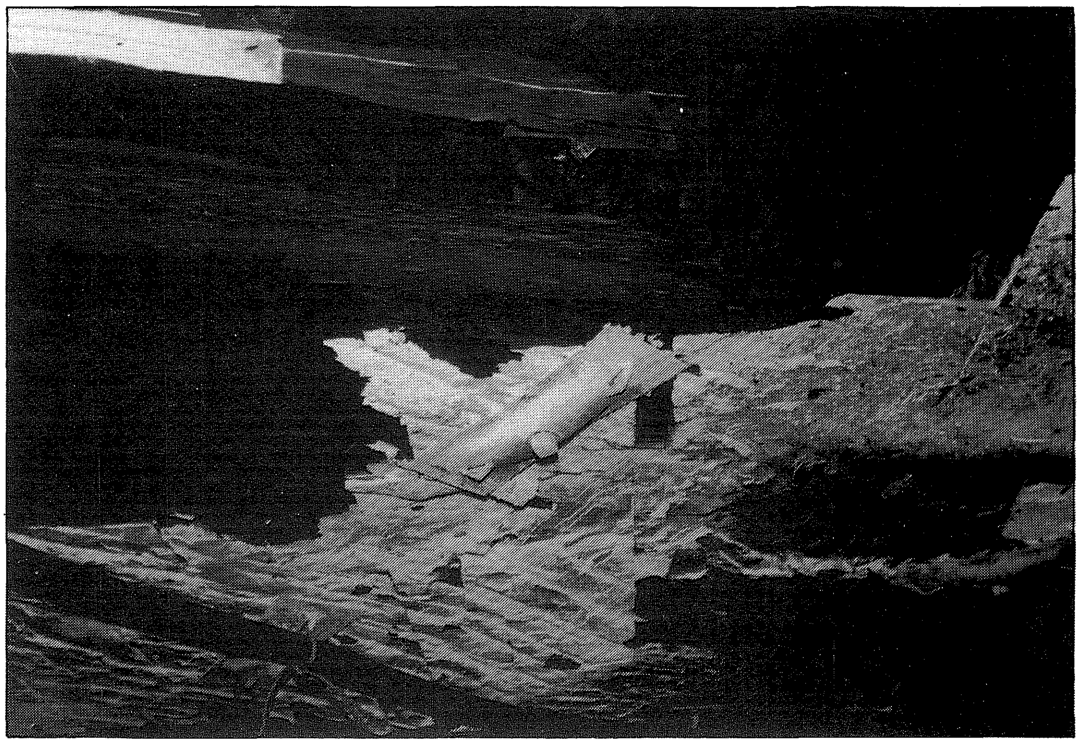


Figure 9 Anna Shale, showing well-developed jointing and thin, light-colored, calcareous lenses and laminae.

thick Hornsby deposit. No marine fossils have been found yet in the Energy Shale of the main Hornsby area, but their discovery would not be surprising. The presence of marine Energy Shale might explain some of the anomalously high sulfur values in coal overlain by thick gray shale. However, the fine, parallel, undisturbed laminations of the shale seen in cores and the presence of the fresh-water fossil *Leaia tricarinata* suggest that some dark gray Energy Shale is a lacustrine deposit.

We may envision the following general sequence of events. The rate of subsidence along the Walshville channel eventually exceeded the rate of Herrin peat accumulation, and the forest was drowned. Fine mud mixed with carbonaceous matter was deposited on top of the peat, either in a lake or in a bay. Sedimentation was rapid enough in places to bury standing tree trunks (kettle-bottoms) as well as fallen ones; more plant debris may have washed in from inland. Later, even more rapid influx of sediment from the Walshville channel occurred, with more silt and less organic matter than before. Continued subsidence and compaction of the Herrin peat allowed accumulation of 20 to 85 feet (6 to 25 m) or more of sediments before the Walshville river itself was drowned by marine invasion. A period of erosion preceded deposition of the first totally marine unit, the Anna Shale.

Anna Shale Member

The oldest marine rock member found above the Herrin Coal is the black Anna Shale (fig. 9). This unit commonly forms the immediate roof where the Energy Shale is absent. It is found throughout the study area, except in the Walshville channel and in areas where the Energy Shale is thick.

The Anna Shale is lithologically uniform and distinctive. Characteristically it is jet black, with a black streak; it is hard, brittle, fissile, and well jointed. The black color is due to finely disseminated carbonaceous matter. Small fragments and very thin stringers of coal are locally present. Concretions up to 4 feet (1.2 m) in diameter, composed of calcite, siderite, and pyrite, are common, as are small lenses and laminae of a light brown phosphatic substance. Where the Anna Shale is more than a foot or two thick, the upper portion tends to be weak and poorly laminated (fig. 10). The uppermost portion of the Anna is thoroughly burrowed in many places. Common fossils in the Anna include *Lingula*, *Orbiculoidea*, *Pecten*, and scales, teeth, and bone fragments of fishes.

In places, a zone of calcareous shale or impure limestone occurs at the base of the Anna Shale. This material, which Krausse et al. (1979) called "bastard limestone," contains large fragments of brachiopods and other marine fossils. The "bastard limestone" varies from a thin basal "shell hash" to a sporadic lenticular limestone up to about 2 feet (0.6 m) thick. "Bastard limestone" rarely covers areas larger than one or two adjacent rooms or cross-cuts in an underground mine.

The Anna Shale is regionally very extensive but locally patchy or lenticular. The member is found throughout the Illinois Basin and in Missouri and Kansas, but in most of

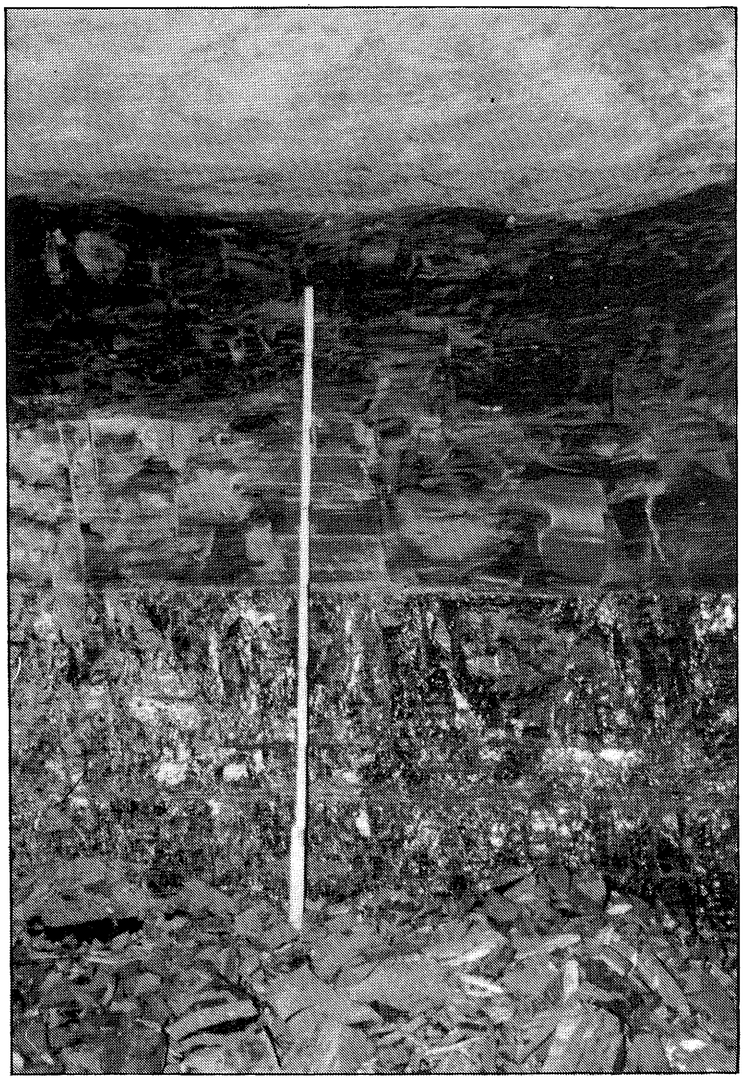


Figure 10 Anna Shale overlain by smooth-bottomed Brereton Limestone. Lower half of Anna is hard, fissile, and well jointed; upper half is less competent and more massive. Ruler measures 4 feet (1.2 m).

its range it is thin and discontinuous. The maximum thickness in the study area is about 8 feet (2.4 m), and the usual range is 0 to 4 feet (1.2 m). Mapping in underground mines reveals intricate patterns of distribution. Therefore, accurately mapping the Anna Shale on the basis of normal coal-test drill holes is impossible. The only regional change noted in the study area is that the Anna Shale is generally thinner to the north and west where the Herrin Coal is mostly too thin to mine.

The Anna Shale barely overlaps the edges of the thick wedge-shaped deposits of Energy Shale. As the Anna rides up over the gray shale, the Anna thins, becomes weak and mottled, and loses its fissility. Generally, the Anna Shale pinches out before the Energy reaches 10 feet (3 m) thick, although in a few drill records black shale is found above as much as 30 feet (9 m) of Energy Shale. The Anna-Energy contact, as noted above, is erosional in most places.

The contact of the Anna with the overlying Brereton Limestone is widely irregular; commonly the lower surface of the limestone is lumpy and nodular, although in places it is flat and smooth (fig. 10). Truncation of bedding in the Anna, however, has never been observed, and the mottled, burrowed upper layers of the shale generally grade into the soft, flaky calcareous shale or "clod" that underlies the limestone.

The Anna Shale clearly is a marine or marginal-marine sediment laid down in stagnant, anoxic, extremely quiet waters. Conditions during deposition were strongly reducing, and few organisms could tolerate life in the sediment or water. Opinion is divided as to whether this and other Pennsylvanian black shales represent the deepest phase of marine transgression, below wave base (Heckel, 1977), or very shallow lagoonal conditions, perhaps with floating mats of vegetation on the surface of the water to restrict

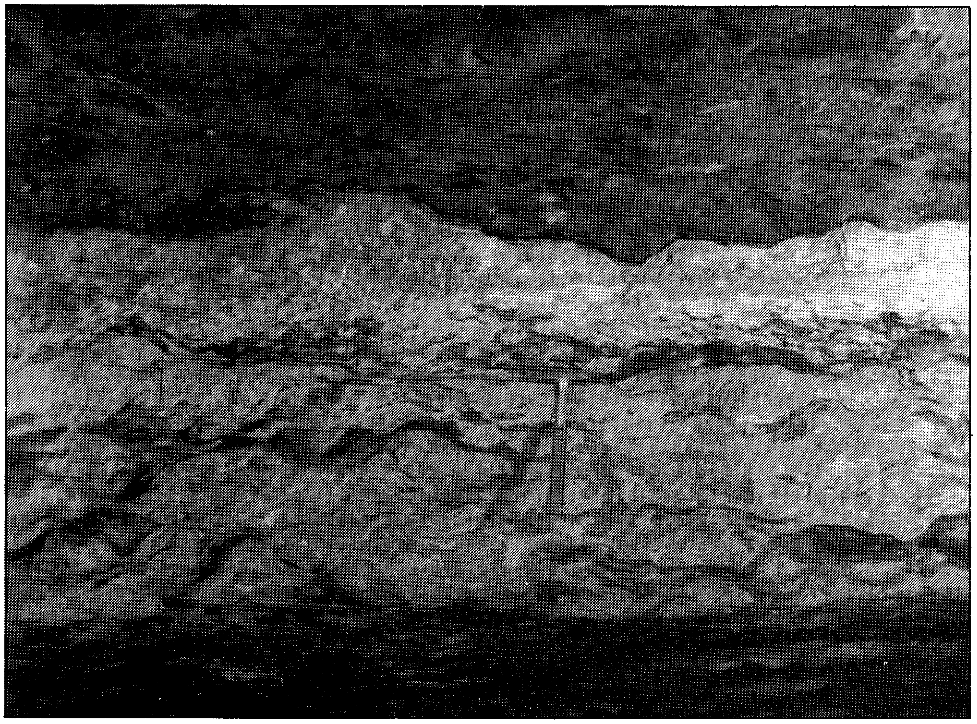


Figure 11 Brereton Limestone, showing typical knobby or nodular bedding. Slabs of limestone occasionally separate along the dark, wavy shale partings.

circulation and wave action (Zangerl and Richardson, 1963). The latter theory appears better able to account for local patchy distribution of the Anna, without requiring pre-Brereton erosion; the former theory, however, better explains the wide regional extent of the black shale.

Brereton Limestone Member

The Brereton Limestone overlies the Anna Shale or, where the shale is absent, lies directly on the Herrin Coal. The Brereton typically is an olive to dark gray fine-grained limestone. It is massive in places but more commonly layered in nodular beds that vary from a few inches to about a foot (0.1 to 0.3 m) thick and are separated by dark, wavy argillaceous partings (fig. 11). The latter are especially prominent near the base. The Brereton also contains a high percentage of disseminated clay and silt. A diverse fauna, including brachiopods, pelecypods, gastropods, cephalopods, crinoids, and fusulinids, indicate an open-marine environment of deposition.

As previously mentioned, a thin zone of calcareous, carbonaceous shale, called "clod" by miners, occurs at the base of the Brereton. It ranges from less than an inch to about half a foot (0.15 m) thick; occasionally it is thicker.

The Brereton is thickest and nearly continuous in belts on both sides of the Walshville channel (fig. 5; plate 2). Here it is typically 3 to 10 feet (1 to 3 m) thick, but in places it is 20 feet (6 m) or even more. Farther from the channel the limestone is thinner—not more than 10 feet (3 m) and normally half that or less—and lenticular. Mapping in mines shows that local variations in the Brereton are as intricate as those of the Anna Shale and cannot be mapped reliably from subsurface data. The Brereton tends to be thick where the Anna is thin, and vice versa; but in some places both are absent and younger rocks rest directly on the Herrin Coal (Krausse et al., 1979).

Like the Anna Shale, the Brereton only slightly overlaps the Energy Shale, and is absent where the shale is 30 feet (9 m) or thicker, as well as in the Walshville channel. Data from boreholes suggest that the limestone grades laterally into calcareous shale or siltstone as it approaches the channel.

The thickness and distribution of the Brereton Limestone reflect depositional conditions. The presence of thick, continuous Brereton alongside the Walshville channel indicates that this region continued to subside more rapidly than adjoining areas even after marine inundation. In shallower water away from this trough the limestone was not deposited continuously. Local variations in Brereton thickness probably relate to uneven sedimentation on an irregular ocean floor. Utgaard and Cleaveland (1983) and Guzan and Utgaard (1983) found that thick Brereton in southern Illinois represents mounds where algae and other organisms trapped sediments. Areas between mounds were swept by currents, so limestone did not accumulate as thickly. No reliable model for predicting local variations in thickness of Brereton Limestone has been developed.

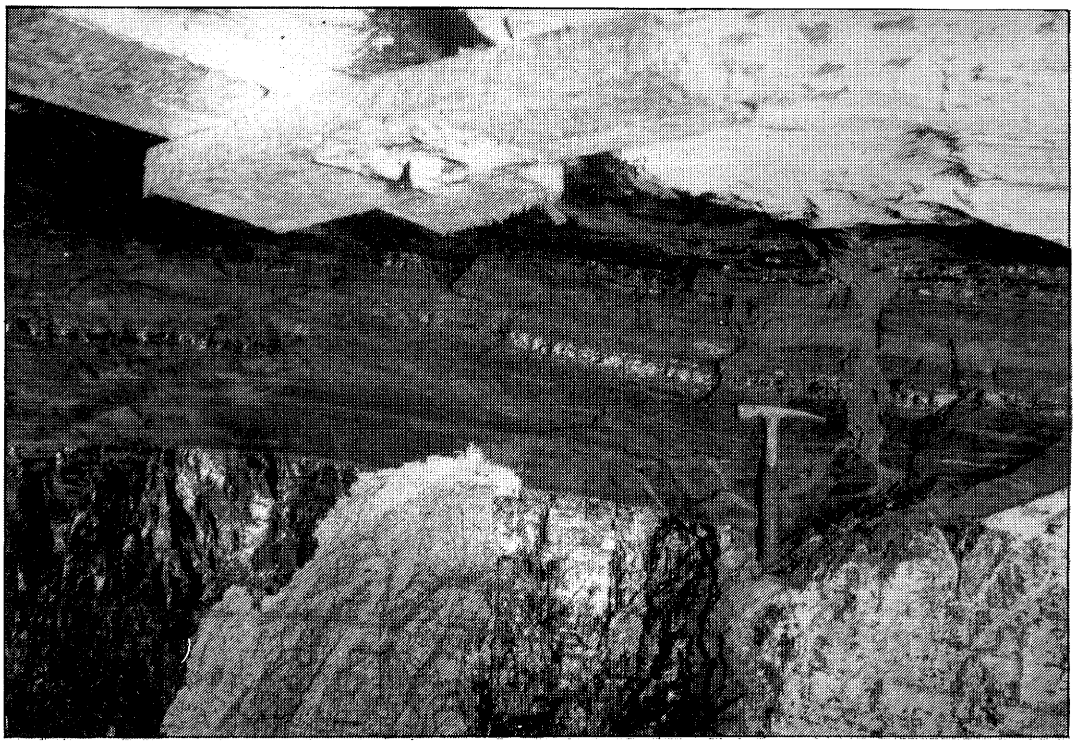


Figure 12 Jamestown Coal, consisting of two thin bands of coal separated by dark shale and nodular limestone, overlying thin Anna Shale. Conant Limestone forms mine roof. Note clay dike to right of hammer.

Jamestown Coal and Conant Limestone Members

The Jamestown Coal and Conant Limestone Members are widespread in the Illinois Basin, but within the study area they are very thin and appear to be confined to the east side of the Walshville channel.

The Jamestown Coal, as found in eastern Montgomery County, consists of less than a foot (0.3 m) of very shaly, impure coal (figs. 12, 13). Commonly it is reduced to a few streaks of coal, interbedded with dark gray carbonaceous shale and gray, highly argillaceous lenticular limestone that rests directly on top of the Brereton Limestone or is separated from the limestone by a few inches of shale or claystone. In a few areas, the intervening members are absent and the Jamestown Coal directly overlies the Herrin (fig. 13).

The Conant Limestone is coextensive with and immediately overlies the Jamestown Coal. The Conant is typically brownish, coarse grained, argillaceous, and highly fossiliferous. Dolomitic septarian concretions are common (fig. 13). The Conant Limestone rarely is thicker than about one foot (0.3 m) in the study area.

The Jamestown Coal is an in situ swamp deposit, as shown by the occurrence of *Stigmaria* (fossil tree roots) in the thin underlying shales; thus, it records a brief withdrawal of the sea, followed by return of the sea that deposited the Conant Limestone.

Anvil Rock Sandstone and Lawson Shale Members

The names "Anvil Rock Sandstone" and "Lawson Shale" have been applied to the interval of strata between the Brereton or Conant Limestones and the Bankston Fork Limestone within the four counties of interest. Unfortunately, these names, which were derived from other regions, do not do justice to the great variety of rock types found between the Brereton/Conant and Bankston Fork Members in the study area.

The Anvil Rock Sandstone was named in 1856 by the pioneer geologist David Dale Owen from exposures in western Kentucky. The sandstone is widespread in southern Illinois and is considerably thicker than equivalent rocks in the study area. Anvil Rock Sandstone occurs as a "sheet facies," conformable with underlying rocks, and as a "channel facies," filling ancient stream beds eroded into and through the Herrin Coal and adjacent strata (Hopkins, 1958). Anvil Rock Sandstone correlates with the Copperas Creek Sandstone, named in western Illinois. Both are equivalent to the Lawson Shale, a fine-grained deposit whose type area is in Bureau County, north-central Illinois (Willman et al., 1975).

In the study area sandstone, conglomerate, and siltstone; silty, mottled, carbonaceous and calcareous shale; and coal, underclay, and lenticular limestone all are found within the Anvil Rock/Lawson interval. These rock types interfinger laterally and grade vertically into one another within short distances. Both "sheet" and "channel" facies can be recognized and mapped. Although more appropriate names could be devised, "Lawson" and "Anvil Rock" are

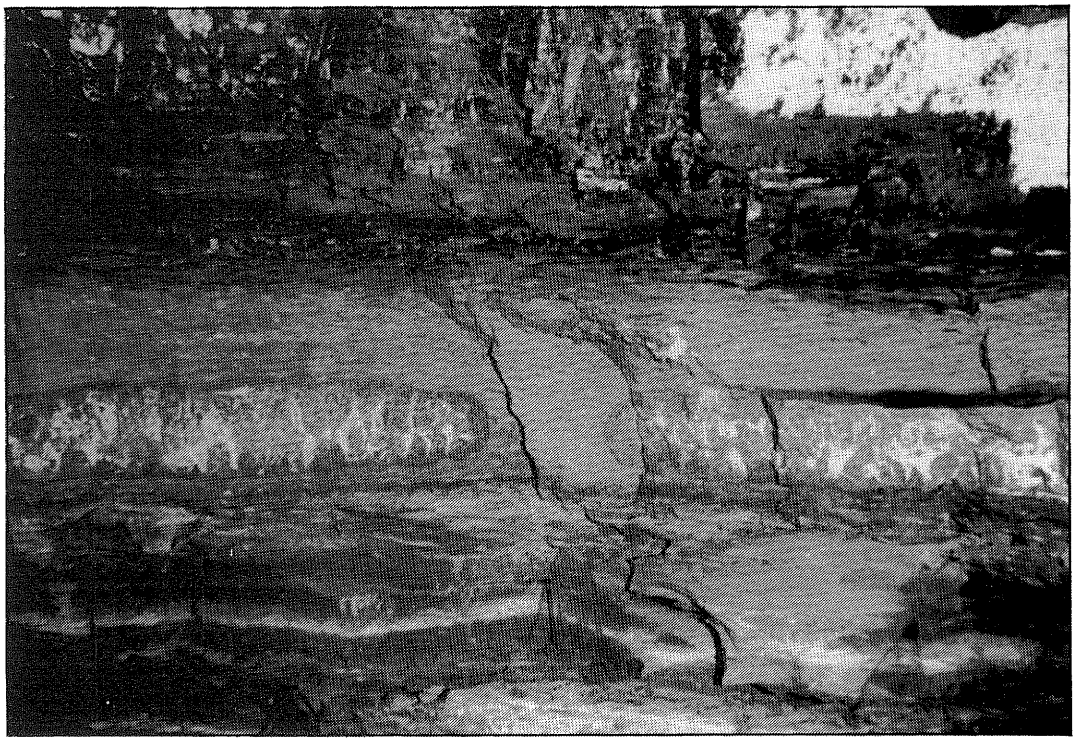


Figure 13 Jamestown Coal and Conant Limestone. Thin, shaly Jamestown Coal here lies directly on Herrin Coal. Conant Limestone is shaly and contains large dolomitic septarian concretions.

well established by long usage, and retaining the old names thus appears justified. In this report, "Lawson Shale" refers to fine-grained rocks (shale, mudstone, claystone) occurring in "sheet facies." Coarse clastic rocks (siltstone, sandstone, and conglomerate) of sheet facies will be called "Anvil Rock Sandstone," and channels will be referred to as "Anvil Rock channels," even though sandstone often is a minor constituent.

Plate 2 indicates the generalized distributions of Lawson Shale and Anvil Rock Sandstone and channels. Sandstone is present north of the Walshville channel in Christian, southeastern Sangamon, northeastern Macoupin, and northern Montgomery Counties. Elsewhere, only Lawson Shale appears to be present. Anvil Rock channels are widespread in the area of sandstone; larger channels are shown on plate 2.

Lawson Shale southeast of the Walshville channel generally is 2 to 15 feet (0.6 to 4.5 m) thick. Two types of shale are common (fig. 14). One type is medium-dark gray to nearly black, moderately competent, and faintly laminated. In some areas this shale is calcareous, and it may contain marine fossils and nodules or lenses of limestone. The other type of Lawson Shale is a soft, incompetent, distinctly mottled greenish to olive gray mudstone. This rock frequently is crisscrossed by cracks or veinlets that have been attributed to syneresis (chemical de-watering of the sediment during compaction). These intersecting light-colored cracks give a patchwork appearance to the rock. Mottled Lawson Shale commonly overlies dark Lawson Shale, with the former fingering into the latter (fig. 14). Field relationships suggest that the mottled shale originally was uniformly dark gray, but has been altered to its present condition.

In Macoupin and Sangamon Counties the mottled variety of Lawson Shale dominates; generally it is less than 10 feet (3 m) thick. In places, this shale rests directly on the Herrin Coal, but there is no evidence of erosion. Apparently, the underlying units were not deposited.

Mottled Lawson Shale also occurs within the area where Anvil Rock Sandstone is present. Mottled shale may underlie, overlie, or grade laterally into sandstone. All varieties of gradation between silt-free shale and sandstone are present within this region.

Sheet-facies sandstone within the study area typically is 5 to 10 feet (1.5 to 3.0 m) thick. This rock generally is light gray, very fine to fine grained, micaceous, argillaceous, and well laminated. The bedding planes are coated with coarse mica and carbonaceous flakes, so the rock splits easily into layers (fig. 15). Planar laminations and ripple marks are common. The sandstone grades laterally and vertically to siltstone and shale.

Many Anvil Rock channels have been encountered in mines and boreholes in southern Christian County and nearby parts of the other three counties. Within these channels, rock units underlying the Anvil Rock/Lawson have

PLATE 3
STRUCTURE OF HERRIN (NO. 6) COAL MEMBER

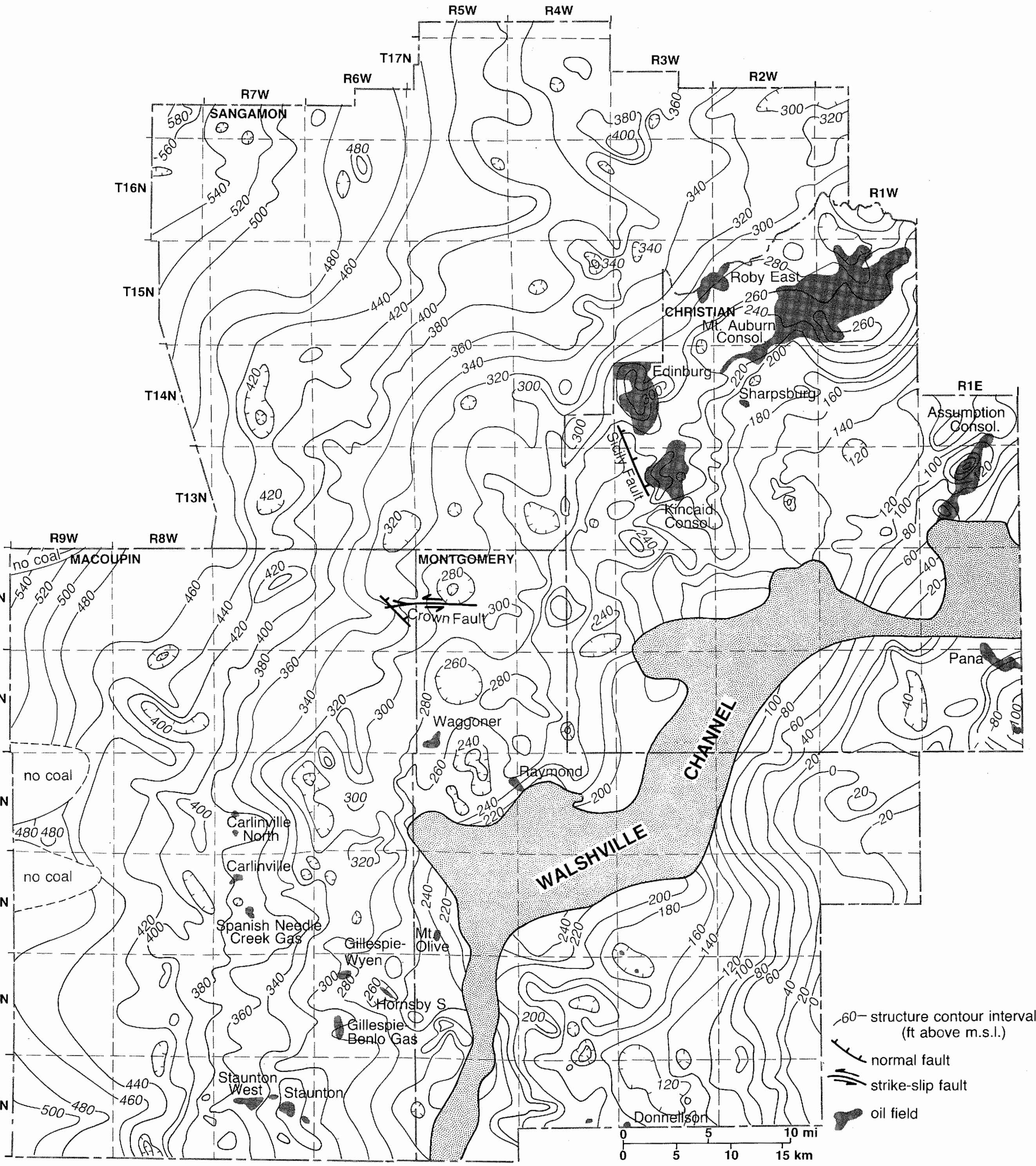


Figure 14 Lawson Shale here is immediate roof. Lower part is dark and massive; upper part is mottled and penetrated by light-colored syneresis cracks. This shale is difficult to support in mine roof.

Figure 15 Light-colored Anvil Rock Sandstone in erosional contact with Anna Shale. Slabby sandstone easily separates along bedding planes.

been eroded and replaced by other sediments. Because these channels adversely affect mining, they have been studied extensively by Survey geologists.

Most channels removed only the Brereton Limestone and Anna Shale, and perhaps part of the Herrin Coal. Complete erosion of the coal is rare. Indeed, it is common to find sandstone or other channel-fill deposits lying directly on the coal over broad areas without visible erosion of coal. Where coal is missing, the coal/channel contact generally is abrupt and may be nearly vertical, and in some cases the coal interfingers with the sandstone or shale. Large stringers or layers of coal with layering intact but gently deformed are found in places within the channels deposits. These observations suggest that at the time of stream-cutting the peat was tough, fibrous and matted, and resistant to erosion.

A typical channel is illustrated in figure 16, a map compiled by Philip J. DeMaris, showing part of the northern workings of the Crown II Mine in Macoupin County. In roughly one-third the area of the map the channel-fill siltstone and sandstone rest directly on the Herrin Coal. Elsewhere siltstone and sandstone lie with angular contact on truncated layers of Energy Shale, Anna Shale, and Brereton Limestone. Little, if any, Herrin Coal is missing in this channel. In a few places the sandstone roof bulged sharply downward as much as several feet (1 m) into the coal over an area less than 10 feet (3 m) in diameter. Beneath these bulges the layering of the coal was bent and broken downward in a manner suggesting that slumping or uneven compaction, rather than scouring, was the cause.

Anvil Rock channels are filled with a variety of materials including sandstone, siltstone, shale, and coal. Figure 17 illustrates cross sections of two channels at the Peabody No. 10 Mine in Christian County. The upper drawing prepared from core data shows a cutout filled with sandstone, overlain by claystone, coal, and dark shale. All of these units wedge out abruptly at the channel margins and are replaced by calcareous Lawson Shale. The lower sketch, based on exposures in the mine, shows a stream bed filled mainly with siltstone and silty shale. A small lens of sandstone containing ripped-out fragments of coal and shale is found at the midpoint of the channel. This is the only place where the Herrin Coal shows significant erosion; evidently it represents the axis of the channel. Above the sandstone and siltstone is a body of shaly coal up to 8 feet (2.4 m) thick that rises, splits, and pinches out toward the channel margins.

Channels at Crown II Mine are filled mainly with dark gray siltstone and silty shale that commonly contain abundant, well-preserved fossil leaves, stems, and tree trunks. Sandstone is confined to small lenses at the base of the channel. Bony or impure coal is found above the siltstone in many places, and is closely overlain by the Bankston Fork Limestone.

The streams that cut these channels evidently were short-lived and not very powerful. The currents were not rapid enough to erode much of the leathery Herrin peat or to carry much coarse sediment. The channel-fill coals record abandonment of these waterways. Bypassed streams became sloughs or bayous, into which plant matter was washed and/or accumulated in place from swamp vegetation. The cycle ended with return of the sea and deposition of Bankston Fork Limestone.

Anvil Rock channels mapped in the study area range from a few hundred feet to more than 1,000 feet (c. 100 to 300 m) wide. Some that have been traced for many miles approach, intersect, or apparently cross other earlier channels. They are gently sinuous; they do not meander as the Walshville channel does. Their trends are not consistent and no master stream has been identified. These observations paint a picture of a poorly drained area, probably a coastal plain with insufficient gradient to permit establishment of an integrated river system.

The two north-trending channels in southern Montgomery County are considerably larger than Anvil Rock channels found farther north (plate 2). The Montgomery County cutouts, more than 1,000 feet (300 m) across, completely cut out the Herrin Coal and adjacent strata. Drilling records indicate as much as 100 feet (30 m) of shale, sandstone, and conglomerate in these cutouts. Boreholes also reveal that the Bankston Fork Limestone and younger marker beds are missing in the channels, and that no Anvil Rock Sandstone, only fine-grained Lawson Shale, occurs nearby. These facts show that the Montgomery County channels were cut after Bankston Fork time and therefore are not Anvil Rock channels.

Bankston Fork Limestone Member

The youngest rock unit of direct interest to mine operators is the Bankston Fork Limestone (fig. 4), which overlies the Lawson Shale/Anvil Rock Sandstone. Its base is generally 5 to 15 feet (1.5 to 4.5 m) above the top of the Herrin Coal in the study area, except where the Energy Shale is thick. The Bankston Fork is generally light in color and fine grained, with scattered fossils indicating marine origin. It tends to be argillaceous and may be split into two or more benches, with layers of shale or claystone between. The usual thickness of the Bankston Fork is about 2 to 10 feet (0.6 to 3.0 m) thick. The limestone is nearly continuous throughout the study area and it persists even above thick Energy Shale and Walshville channel sediments.

Danville (No. 7) Coal Member

The Danville Coal, which marks the top of the Carbondale Formation, is present in most of the study area, but is too thin to mine in most places. Coal thicker than 28 inches (71 cm) occurs locally in eastern Montgomery County, in TllN, RlE and T13N, R2W of Christian County, and near Standard City, Macoupin County. No mining of the Danville is known to have occurred within the study area.

In western Macoupin and northern Christian and Sangamon Counties, where the Herrin Coal and Danville Coal are both discontinuous, the two seams are not easily distinguished on many logs.

THICKNESS AND DISTRIBUTION OF HERRIN COAL

Plate 1 illustrates the distribution and generalized thickness of Herrin Coal in the four counties. Although the pattern is complex in detail, several features are readily apparent: (1) the Walshville channel, where no coal is present; (2) areas of split coal discontinuously flanking the channel; (3)

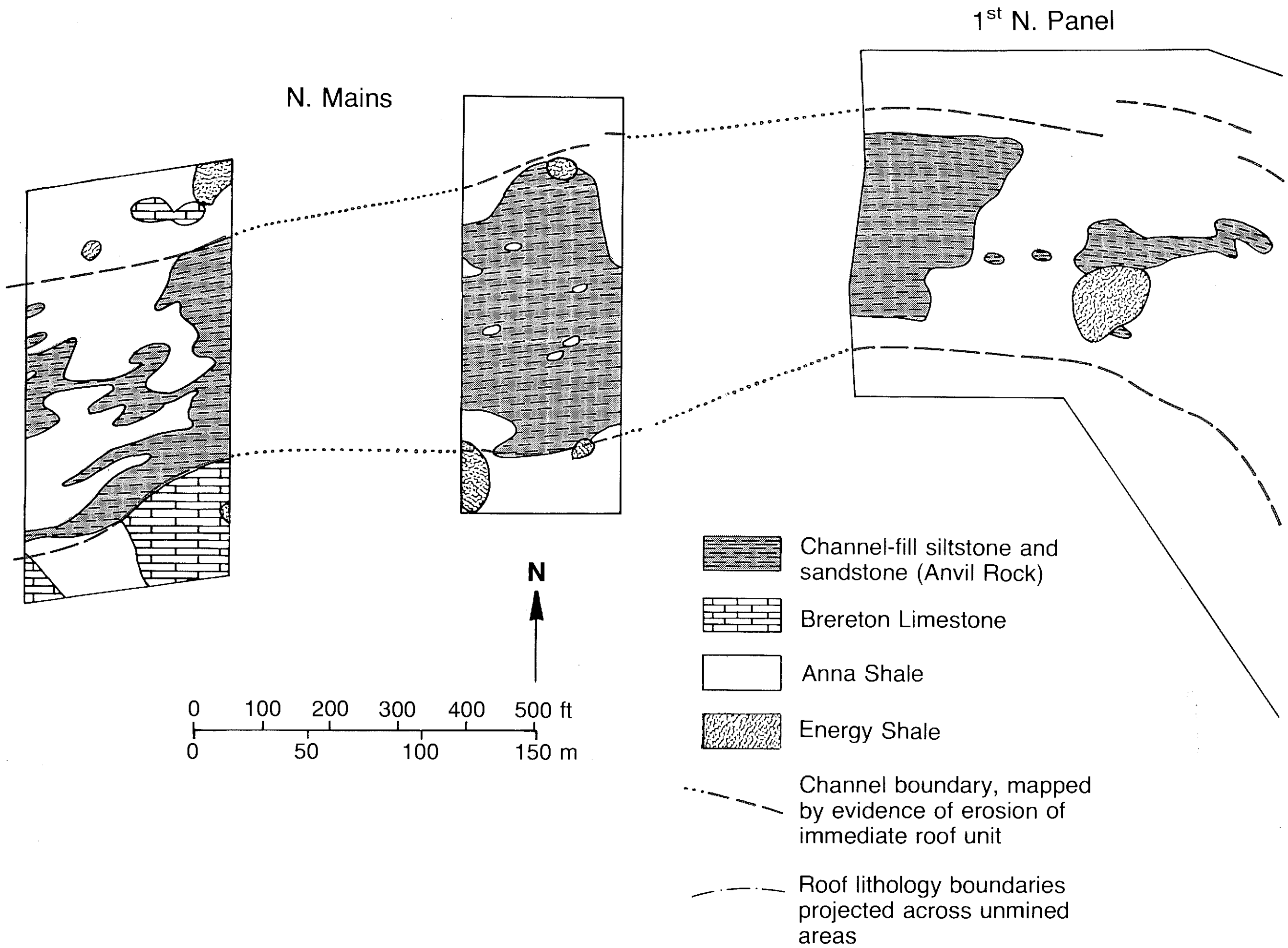


Figure 16 Roof lithology of the Herrin Coal under an Anvil Rock channel in the Crown II mine, Macoupin County. (Map

small areas of thin coal, also flanking the channel; (4) large regions of thick coal on both sides of the channel, bordering (2) and (3); and (5) thin coal in the northern and western portions of the study area.

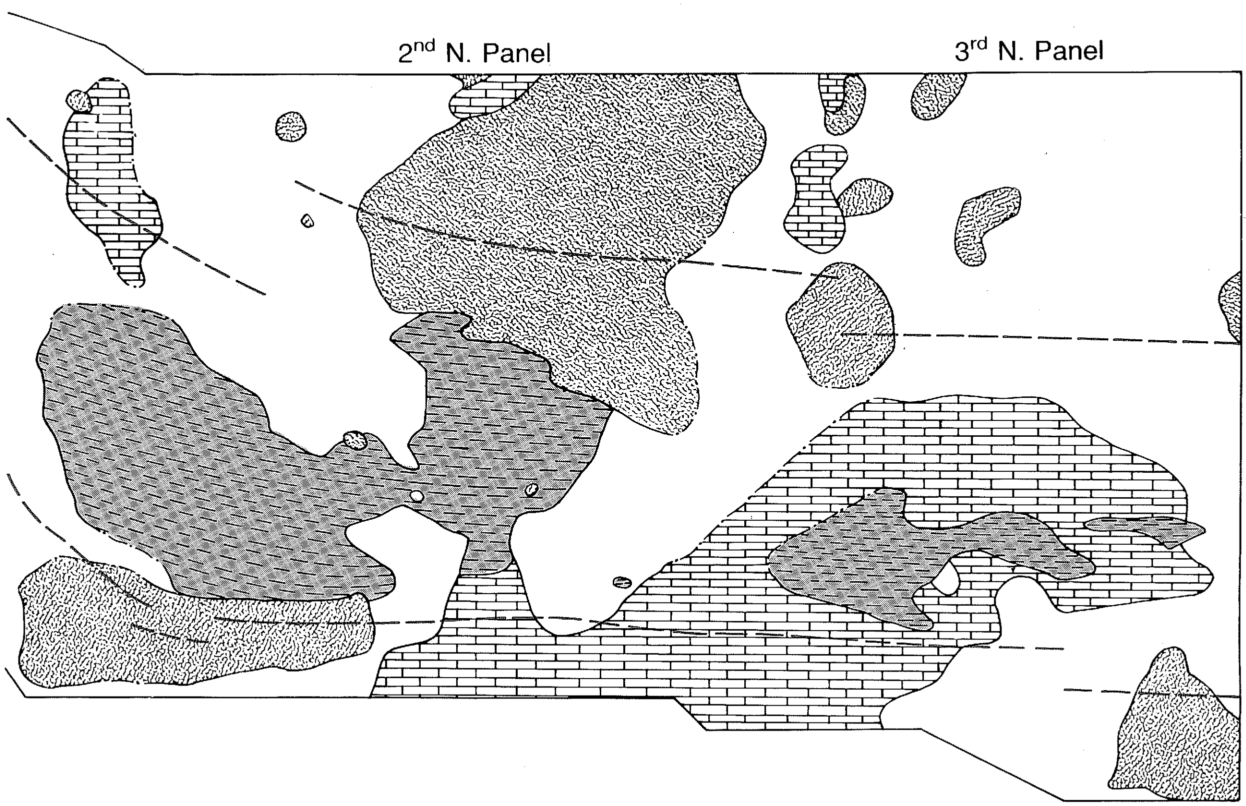
The Walshville channel was the master stream of the region. Obviously, it occupied the lowest area, topographically, where subsidence was most rapid. No peat accumulated in the channel; any vegetation that fell or was swept into the river was carried out to sea, or perhaps deposited on a sand bar to become a stringer of coal.

As previously discussed, some coal next to the channel is split by layers of clastic sediment that were derived from the channel.

The localized areas of thin Herrin Coal adjacent to the channel probably were areas where the water was too deep and/or deposition of mud and silt too rapid for optimum growth of plants. For at least part of the time, some of these areas may have been open water with no trees. Only vegetation that floated out into these lakes drifted to the bottom to form peat. Around the edges, plants could grow, but not as densely as where water was shallower.

Although erosion may be partly responsible for thinning of the coal alongside the channel, I believe that the main reason is that peat did not accumulate here. Direct evidence is not available, because no mines are working into the thin coal; but drill cores do not support the idea of erosion. In the large areas of thin coal on the southeast side of the Walshville channel in southeastern Christian County (plate 1), the coal is directly overlain by the normal marine sequence of Anna Shale and Brereton Limestone. No channel deposits such as would be expected if peat had been eroded overlie this coal. Most of the thin coal bordering the northwest side of the Walshville channel is overlain by Energy Shale, but this shale appears to be a quiet-water deposit. The shale in contact with the coal typically is very fine grained and often finely laminated; it contains large unbroken plant fossils. Had peat been eroded, we should expect to find sandstone (if not conglomerate) with fragments of coal and other eroded materials, along with sedimentary structures indicating deposition from rapidly moving water—as in Anvil Rock channels.

It is possible, however, that some of the split coal close to the channel has been eroded. Some of the split coal may include mats of peat or masses of driftwood that were carried with the current and buried in silt, mud, and sand. Most drill logs from the area of split coal are not sufficiently de-



compiled by P. DeMaris; field work by DeMaris and Nelson, with contributions by H.-F. Krausse and R. Nance.)

tailed to enable one to distinguish drifted peat deposits from in situ swamp deposits. The latter would have a rooted underclay; the former would not.

The thickest coal is slightly farther from the channel than are the split coal and discontinuously thin coal. Over large areas the coal consistently is more than 7 feet (2.1 m) thick and locally it is more than 10 feet (3.0 m) thick. This apparently was the region where subsidence matched peat accumulation for the longest period of time. The water was deep enough to cover the peat continuously and prevent its oxidation, but not too deep to inhibit growth of rooted plants. The forests grew vigorously, and most plants, once they died and fell, were submerged and converted to peat. Local areas of thinner coal in this region presumably reflect less optimal conditions.

Farther from the channel, in northern Christian and Sangamon, western Macoupin, and southeasternmost Montgomery Counties, subsidence probably was too slow for maximum peat accumulation. Either plant material never became peat, or the swamps were periodically drained, allowing oxidation of peat. A number of core descriptions from western Macoupin County indicate that thin coal, especially in its upper layers, is dull, poorly banded, and "bony." Such descriptions suggest partial oxidation of peat. In many boreholes of northern Sangamon County the Herrin Coal is completely absent. The position of the coal, however, is well indicated by underclay, which is overlain by dark gray to black shale and/or Brereton Limestone. These findings strongly imply that nondeposition, rather than erosion, accounts for the absence of the coal. A marsh developed, producing soil (underclay) and supporting vegetation, but there was no permanent standing water to preserve peat; therefore, no sediments accumulated until general subsidence brought in the sea, with dark mud or lime.

The northward pinching of the coal in Christian and Sangamon Counties is quite abrupt and easily mapped. This thinning occurs in the northern part of T14N and the southernmost part of T15N. In most places the coal thins from 7 feet (2.1 m) to less than 3½ feet (1.1 m) within a distance of 3 to 5 miles (5 to 8 km). A few small areas of thin coal occur south of the zone, and isolated pods of thicker coal are found in T15N; however, for the most part, the decrease in thickness is steady to the north.

As previously noted, where the Herrin Coal thins to the north, the Springfield Coal abruptly thickens (fig. 4). So does the interval between the two coals. Evidently the

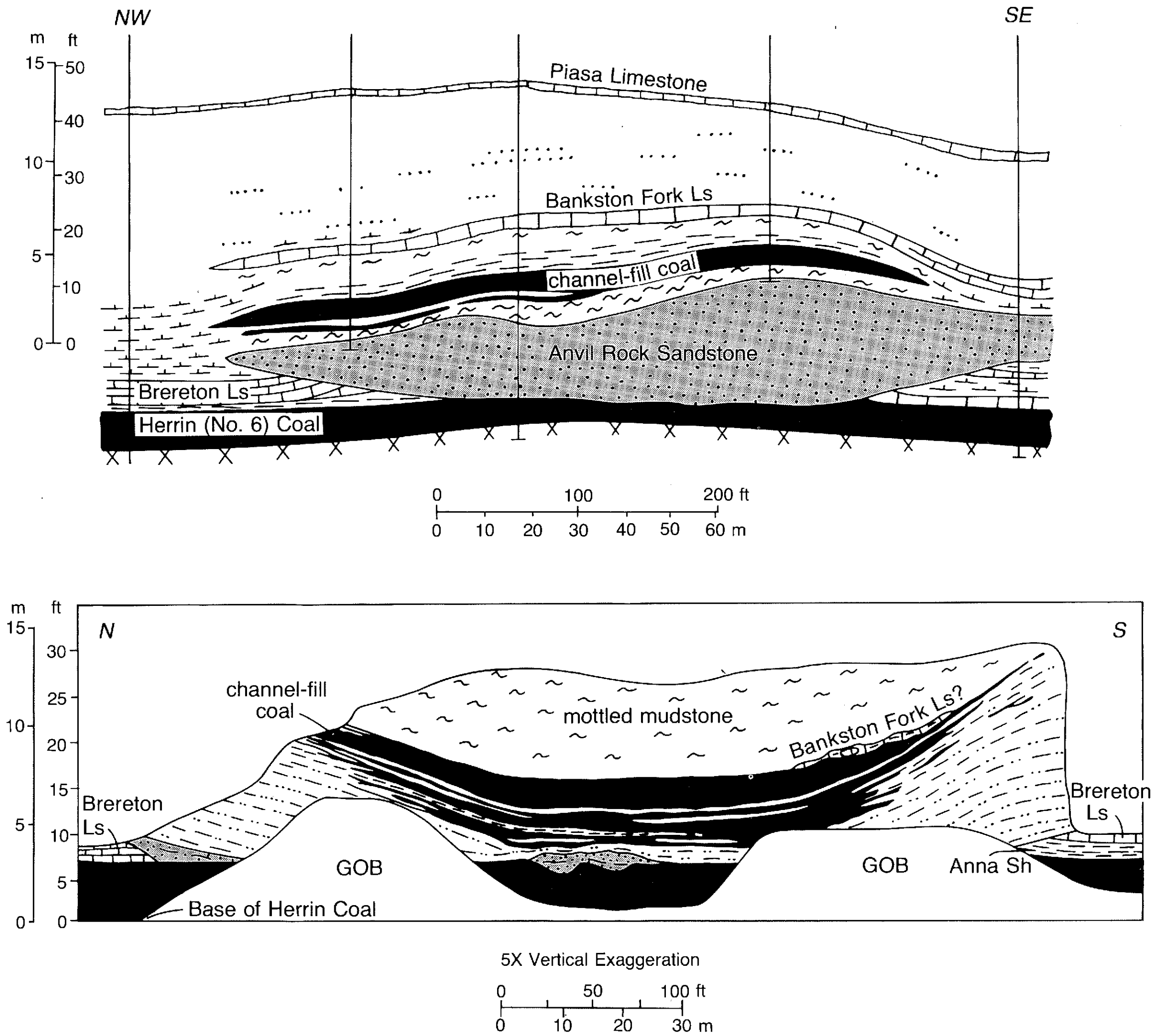


Figure 17 Cross sections of two Anvil Rock channels in the Peabody No. 10 Mine. Upper section was prepared from drill-hole data and lower from exposures in the mine.

area to the north subsided rapidly from Springfield Coal through Canton Shale time, but the pattern was reversed in Herrin Coal time.

On the west side of the study area the decrease in thickness of the Herrin Coal is not as sharply defined as it is to the north (plate 1). In western Macoupin County is a belt 3 to 12 miles (5 to 19 km) wide where the thickness of the coal varies greatly. Here the coal ranges from less than 3 to more than 10 feet (0.9 to 3.0 m) within short distances. The variability is especially extreme in west-central Macoupin County T 10–11N, R 8 W), where two adjacent drill holes seldom indicate similar thickness. The actual pattern probably is far more complex than that shown on plate 1, and would require densely spaced drilling for accurate mapping of coal-bed thickness and reserves.

Still farther west the Herrin Coal appears to be generally less than 3½ feet (1.1 m) thick, although the spacing and quality of control points leave much to be desired. A salient of thick coal extends westward into Greene County in T lO N, R 9-10 W, where much of the thicker coal is at or near subcrop. Numerous small mines were formerly operated in Sections 29, 30, and 31, T lO N, R 9 W, and in these the Herrin Coal was reported to range from 4 feet (1.2 m) to more than 7 feet (2.1 m). Treworgy et al. (1978) mapped 72 million tons of strippable reserves, at a depth of 100 feet (30.5 m) or less, in Macoupin County, and another 52 million tons of strippable Herrin Coal in adjacent areas of Greene County.

The westward thinning of the Herrin Coal accompanies the general westward thinning of the entire Pennsylvanian succession from the basin to the shelf. The Abbott Formation (basal Pennsylvanian) pinches out westward, and the Spoon and Carbondale Formations, together with most of their individual members, become compressed. The Springfield Coal is extremely thin or absent, as are lower coals, except for the Colchester (No. 2) Coal; the Colchester is consistently 2 to 3 feet (0.6 to 0.9 m) thick in western Macoupin County.

Western Macoupin County, therefore, probably was the scene of gentle flexure down to the east for most of Pennsylvanian time. There is no evidence of faulting; rather, a broad basin-shelf marginal hinge is postulated.

COAL RESOURCES

Readers interested in resource calculation and evaluation can consult Treworgy and Bargh (1982). Their estimates of remaining deep-minable resources are listed in table 1. These figures represent all coal 28 inches (71 cm) or thicker at a depth of 150 feet (45 m) or greater. Treworgy et al.'s (1978) assessment of strippable coal in Macoupin County included only coal at 100 feet (30 m) or shallower. Coal at depths of 100 to 150 feet was not considered by either Treworgy et al. (1978) or Treworgy and Bargh (1982). But Smith (1961), considering all coal at 150 feet or less as strippable, calculated 251 million tons of strippable Herrin Coal in Macoupin County. No Herrin Coal thicker than 18 inches (46 cm) and shallower than 150 feet exists in the other three counties. Thus, adding Smith's 251 million tons to Treworgy and Bargh's 12,362 million gives 12,613 million (12½ billion tons in round figures) as the grand total of Herrin Coal remaining in the four counties.

Treworgy and Bargh (1982) list resources of low-sulfur Herrin Coal (less than 2.5% sulfur). They defined low-sulfur coal as any coal overlain by 20 feet (6.1 m) or more of Energy Shale. The present study confirms the validity of this relationship. Treworgy and Bargh's figures are given in table 1.

Precise figures are not available on the amount of Herrin Coal already mined out in the four counties of interest. The annual coal reports of the Illinois Department of Mines and Minerals provide cumulative production by county, but not by coal seam. Nearly all coal mined in Christian, Macoupin, and Montgomery Counties came from the Herrin seam, but in Sangamon County both the Herrin and Springfield Coals were mined extensively. Taking 50 million tons as a rough estimate of Herrin Coal removed from Sangamon County, we obtain a total output of about 830 million tons from the four counties since mining began. Approximately an equal amount of coal was left as pillars of room-and-pillar mines and thus rendered unminable. Therefore, a total of about 1,660 million tons of mined-out and unminable coal can be added to the remaining resources of 12,613 million tons, to yield about 14,273 million tons of original resources.

The amount of low-sulfur coal mined out is unknown, but probably amounts to less than 10 million tons, which is smaller than the margin of error for the total resource calculations.

QUALITY OF COAL

Sulfur

The strong correlation between low-sulfur coal in Illinois and the thick nonmarine gray shale overlying the coal was noted by Cady and others (1952, p. 35) and discussed at length by Gluskoter and Simon (1968), Hopkins (1968), Gluskoter and Hopkins (1970), Johnson (1972), and Allgaier and Hopkins (1975). These workers found that coal overlain by 20 feet (6 m) or more of gray shale tends to have low sulfur content, while coal overlain by less than 20 feet of gray shale or directly topped by marine strata almost invariably contains more than 3 percent sulfur. The same relationships were found to hold for the Murphysboro (Jacobson, 1983), Colchester (No. 2) (Gluskoter and Hopkins, 1970), and Springfield (No. 5) Coals (Hopkins, 1968), as for the Herrin (No. 6) Coal.

My results confirm these earlier studies. Low-sulfur Herrin Coal in Christian, Macoupin, Montgomery, and Sangamon Counties occurs only where the coal is overlain by 20 feet or more of Energy Shale.

Table 2 gives sulfur content of the coal versus thickness of the Energy Shale for 331 boreholes in the study area. Values given are sulfur content of the coal (by weight) on the samples as received at the laboratory. The cores were drilled by a number of coal companies and the samples analyzed by various commercial laboratories.

The average sulfur content of coal overlain by marine strata (Anna Shale or Brereton Limestone) is a little more than 4 percent. Of 283 samples available, only two contained less than 3.0 percent sulfur; many contained more than 5 percent sulfur, some up to as high as 7.2 percent.

The average sulfur content of 48 samples of coal overlain by 20 feet or more of Energy Shale was 1.86 percent. Only two of these samples contained more than 3 percent sulfur, and both were from cores where the gray shale was less than 30 feet (9 m) thick.

Among seven samples of coal overlain by 1 to 20 feet of Energy Shale, the average sulfur content was 3.84 percent and the range from 2.89 to 5.15 percent. The average sulfur content is slightly lower than that of coal topped directly by black shale or limestone, but does not constitute "low-sulfur coal."

TABLE 1 Resources of Herrin Coal in study area (millions of tons)

	Deep-minable Treworgy and Bargh, 1982)	Strippable (Smith, 1961)	Total	Low-sulfur (Treworgy and Bargh, 1982)
Christian	3,362	0	3,362	439
Macoupin	3,365	251	3,616	453
Montgomery	3,673	0	3,673	277
Sangamon	1,962	0	1,962	0
TOTAL	12,362	251	12,613	1,169

TABLE 2 Sulfur content of coal and thickness of Energy Shale in Hornsby district

Thickness of Energy Shale (ft)	(m)	No. of samples	Average (%)	Maximum (%)	Minimum (%)
None	West of Channel	221	4.31	7.20	2.56*
None	East of Channel	62	4.04	5.54	3.03
None	East and West	283	4.25	7.20	2.56
1 to 10	0.3 to 3.0	5	3.94	5.15	2.89
11 to 20	3.1 to 6.1	2	3.63	3.73	3.49
21 to 30	6.2 to 9.1	11	2.51	4.65**	1.26
31 to 40	9.2 to 12.2	14	1.86	2.93	0.95
41 to 50	12.3 to 15.2	11	1.51	2.66	0.74
51 to 60	15.3 to 18.3	8	1.48	2.61	0.24
61 or more	18.4 or more	4	1.76	2.15	1.16
All 21 or thicker	6.2	48	1.86	4.65	0.24

* Only 2 samples of 283 under marine roof contained less than 3.0% sulfur
**Only 2 samples of 48 under 20 ft (6.1 m) or more of the Energy Shale contained more than 3.0% sulfur

TABLE 3 Ash, moisture, and heating value for 38 samples of Hornsby low-sulfur coal vs. 38 samples of high-sulfur coal directly adjacent to Hornsby district

	Low-sulfur	High-sulfur	All samples
Ash (%)	11.9	13.3	12.6
Moisture (%)	15.6	13.7	14.7
Heating value (Btu/lb as received	10,116	10,111	10,113

Also available are analytical results of 136 face-channel samples of coal collected by ISGS geologists at mines through the years and analyzed at the laboratories of the ISGS. All of these, so far as is known and recorded, represent coal overlain directly by marine rock. The average sulfur content is 4.06 percent, and not a single sample contains less than 3 percent sulfur. No face-channel samples of coal overlain by Energy Shale in the study area have been analyzed by the Survey.

These data show that although 20 feet of Energy Shale is not a "magical" figure, the 20-foot isoline represents an excellent approximation of the boundary between high-sulfur and low-sulfur coal, and thus the edge of the Hornsby district. Coal overlain by thick Energy Shale has, on the average, a little under 2 percent sulfur, while coal with marine roof averages slightly above 4 percent sulfur. The narrow intermediate zone, with 1 to 20 feet of gray shale, represents a small area in the three counties (plate 2). Rarely is it more than a mile wide (1.6 km) and in many places it is only a few hundred feet (about 50 to 200 m) wide.

The high-sulfur coal from the four counties typically contains 1.5 to 2.2 percent organic sulfur, about 0.1 percent sulfate sulfur, and 1.5 to 4 percent pyritic sulfur. The sulfur in low-sulfur coal is largely organic; it has only a few tenths of a percent pyritic and sulfate sulfur. Since organic sulfur cannot be removed by current commercial techniques of coal washing, high-sulfur coal can be improved more by cleaning than can low-sulfur coal. However, little, if any, high-sulfur coal from Illinois can be washed to less than 2 percent sulfur.

The inferred origin of low-sulfur coal in Illinois has been well explained in the publications cited at the beginning of this section. Pyritic sulfur in coal is believed to be derived from a combination of iron and sulphate ions in a reducing environment. Marine water and sediments contain abundant sulfate ions; fresh water and sediments contain very little. Therefore, peat buried by thick fresh-water sediments is shielded from sulphate ions that may be brought into the area during later marine invasions.

Ash

Ash is not ordinarily a matter of special concern in coal from Illinois, and the ash content of most coal from the study area does not differ greatly from the statewide average. Most samples analyzed contained between 9 and 16 percent ash (by weight) as received. Quite a bit of this ash represents claystone partings, pyritic nodules, and other large impurities, which can be removed by cleaning the coal.

A comparison was made of ash, moisture, and heating value in high-sulfur vs. low-sulfur coal from the Hornsby district. Analytical values from all of the available boreholes (38) representing coal overlain by 20 feet (6.1 m) or more of Energy Shale, were tabulated along with values from 38 boreholes representing coal overlain by marine strata immediately adjacent to the gray shale area (table 3). The table shows that high-sulfur coal contains slightly more ash than does low-sulfur coal. The difference can be attributed mainly to the greater amount of pyrite in the high-sulfur coal.

A small number of borehole analyses from around the four counties revealed abnormally high ash, from 20 percent to more than 50 percent. In some cases the log of the core provided no clue as to the reason for high ash; analytical or sampling error may be to blame. More often than not the cores contained visible impurities that account for the high ash values. Most such cores fall into two categories. The first category is split coal near the Walshville channel. Here the ash value depends highly on sampling technique. In some cases, thick shale partings were included in the analyzed sample, and very high ash content resulted; in other cases, such partings were excluded, and ash is no higher than normal. The second category of high-ash coal is visibly dull or bony coal, found mostly in western Macoupin County. I speculate that here the high ash content and bony character reflect partial degradation of the peat due to subaerial exposure. This process would remove organic matter and enrich the sample in inorganic material.

Moisture

The moisture content of coal from the study area is relatively high, and this factor tends to hurt its market position relative to coal from southern Illinois. Among 76 samples in the study area, the average moisture of coal as received was 14.7 percent. This compares with county-wide averages of 11.3 percent for St. Clair, 10.0 percent for Perry, 8.0 percent for Williamson, and 4 to 5 percent for Gallatin County (Cady, 1935). The lower moisture of southern coal reflects its higher rank, which is a product of greater original depth of burial, and possibly higher geothermal gradient adjacent to igneous activity of the Illinois-Kentucky fluorspar region (Damberger, 1971).

A geologist working for one of the coal companies that has conducted exploratory drilling in the study area told me (1984) his company's analyses indicated that moisture was about 2 percent higher in coal overlain by thick Energy Shale than in coal having marine roof. To check this claim, I compared moisture values (table 3) for 38 (all available) core samples of coal overlain by 20 feet (6.1 m) or more of Energy Shale with values from 38 samples of coal overlain by marine rock adjacent to the Hornsby area of thick Energy Shale. The results verify the coal company geologist's statement. The average moisture of coal with marine roof was 13.7 percent (standard deviation 1.4%); the average moisture of coal with thick Energy Shale roof was 15.6 percent (s.d. 1.9%).

To my knowledge, such relationships have not been reported elsewhere, and are not easily explained. All of the coal should have been buried at the same depth at the same time and subjected to the same temperature and pressure. Differences in original moisture content of peat seem possible, but unlikely. Perhaps less moisture escaped from the peat through the Energy Shale than through marine rocks during coalification.

In any event, the matter deserves further study, especially by operators considering mining low-sulfur coal but concerned about high moisture.

Rank and heating value

Coal in west-central Illinois is classified as high-volatile bituminous "C". Within the study area, the heating value of the coal increases gradually toward the southeast. Damberger (1971) indicated an increase from about 11,800 Btu/lb (moisture and mineral-matter free) on the northwest to 12,600 Btu/lb on the southeast. This change probably reflects greater subsidence and depth of burial to the southeast, and conforms to the regional trend found in the Illinois Basin.

The average calorific value of low-sulfur coal is practically the same as that for high-sulfur coal (table 3). Apparently, the greater ash content of high-sulfur coal, which would lower its heating value, is offset by the lower moisture content of such coal. Local variations in ash appear to be the primary cause of local variations in heating value.

STRUCTURAL FEATURES OF STUDY AREA

General features

The most dominant structural feature of the study area is a regional dip southeastward toward the center of the Illinois Basin (plate 3). The rate of dip is extremely gentle. Across the region as a whole it is a little more than 10 feet per mile, or 1 in 500. The regional dip gradually increases toward the southeast, up to about 25 feet per mile, or 1 in 200. The latter is equivalent to a gradient of .5 percent or a dip of approximately .25 of a degree. Such an inclination is too slight to be perceptible in a mine unless the mine is accurately surveyed with instruments.

Superimposed upon the regional southeastward dip are numerous small irregular rises and depressions. These local irregularities seem to be found throughout the study area, although they are slightly less pronounced in eastern Christian County, where the regional dip is steepest. Fewer minor structures are mapped in northern Sangamon and western Macoupin Counties than in the central part of the study area, but the lower density of drilling to the north and west prohibits detailed structural mapping there. In areas where elevation surveys from mines are available, the actual structure is seen to have far more local irregularity than can be mapped from drill-hole data alone. Note the apparently random irregular structure of the coal in figure 18, a map of the abandoned Hillsboro Mine. Contouring in this figure is based on several hundred elevations, surveyed along mine entries, within an area of about 8 square miles (20 square km). Therefore, plate 3, which is based entirely on borehole data, presents only a crude approximation of the actual structure of the coal.

The minor basins, bulges, and noses in the study area (fig. 18; plate 3) have no apparent preferred orientation or trend. Many of them are roughly circular, or highly irregular, with many lobes or "fingers." Those that are elongate tend to be curved, not linear, and the long axes may trend in any direction. No hint of parallel or en echelon arrangement of folds can be seen. Indeed, the term "folds" seems inappropriate for these randomly arranged irregularities.

Despite such discrepancies, geologists working earlier in the study area glorified many of these subtle irregularities by naming them "anticlines" and "synclines." J. Treworgy's (1981) structural compendium lists 28 named structures in the study area, of which 19 are in Macoupin County. Easton (1942) was the most prolific namer of "folds" in the study area. Easton's report dealt with oil and gas prospects and, not suprisingly, most of his named structures are anticlines. He defined these features from subsurface mapping of the Herrin Coal, using far fewer control points than are currently available. Few of the "anticlines" and "synclines" named by Easton and other early workers show closure on the original structure maps, and several lose their identity completely when new data are added to the old.

It is interesting that the largest enclosed structural high in the study area has not been named formally; this is the dome located in northern T13N,RlE, Christian County. My data indicate at least 60 feet (18 m) of closure covering several square miles, and a large oil field (Assumption Consolidated) has been developed on the dome. Bell and Leighton (1949) and several later workers noted the dome, but refrained from naming it, as shall I.

Many other depressions and rises shown on plate 3 apparently have 10 to 40 feet (3 to 12 m) of closure. Precision

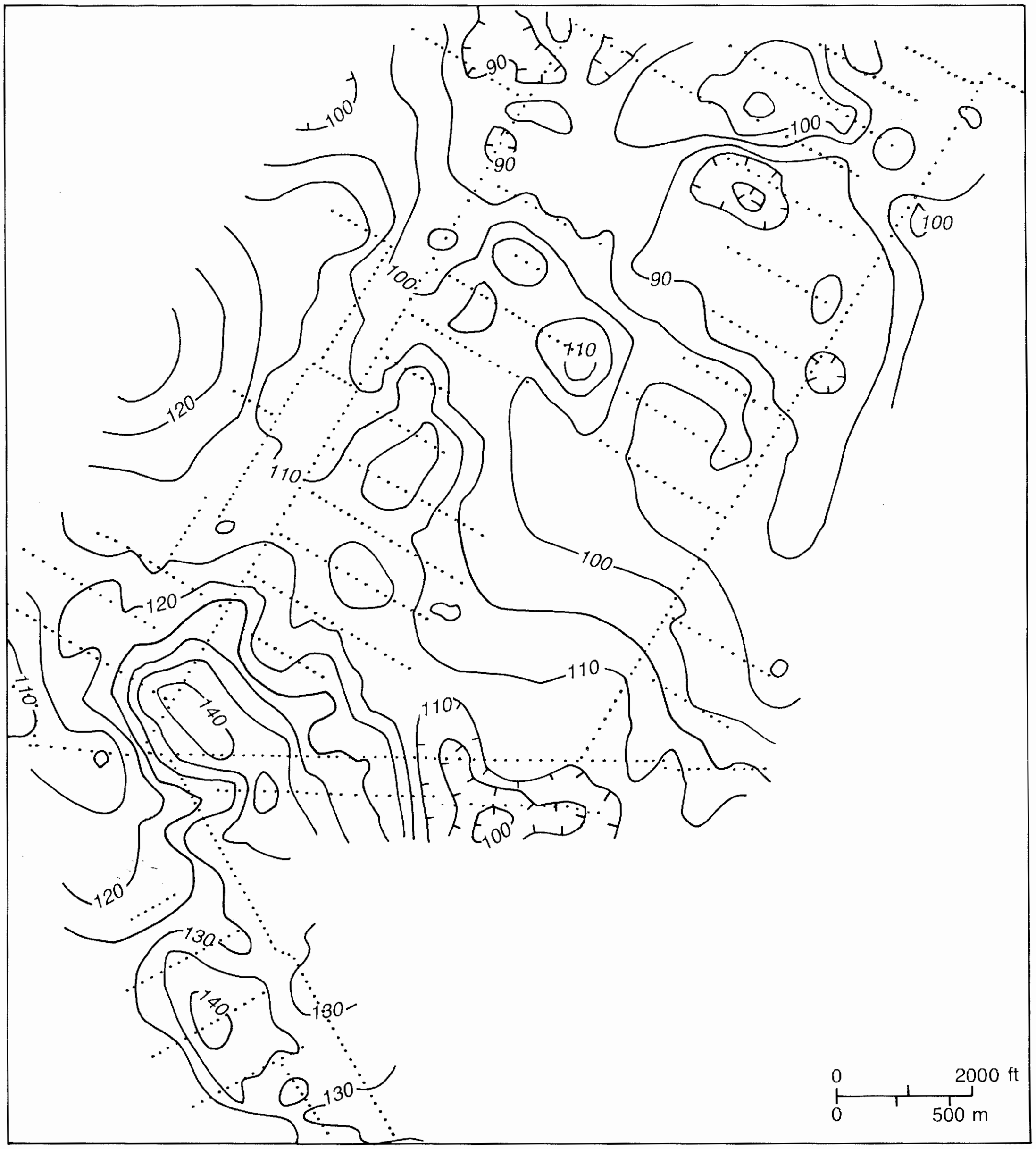


Figure 18 Structure of base of Herrin Coal in Hillsboro Mine, T7N, R3W, Montgomery County. Contour interval is 5 feet (1.5 m). Tiny dots represent datum points from surveyed elevations along mine entries. Modified from Krausse et al. (1979).

is not possible, and in many cases the feature can equally well be mapped as a "nose" rather than a closure. The lack of apparent structural grain deprives the geologist of clues or even intuition on how to contour from borehole data. The addition of information from mine surveys or other sources is apt to force complete revision of contouring.

Local structural irregularities are expressed in coal mines as gentle hills and valleys in the coal. In this regard the study area does not differ significantly from other mining districts in Illinois. Dips are slight, generally less than 5°, and rarely persist over large areas. Although grades steep enough to interfere with mining are rare, an elongate valley or syncline in the coal, with flanking dips as steep as 25°, occurs in Peabody Mine No. 10 (Nelson, 1983).

The origin of most of the local structures probably is related to differential compaction of the sediments rather than to tectonic forces. This conclusion is based on the random arrangement of structures. Sandstones below the Herrin Coal are known to be lenticular; sandstone is less compactable than shale. Many structural highs in the coal may overlie sandstone, and lows may overlie shale or mudstone. Other structures may reflect more deeply buried features. For instance, some coal "highs" in Illinois have been found to overlie Silurian reefs as deep as 2,000 feet (600 m) below the coalbed (Lowenstam, 1948).

Faults in coal mines

No large faults occur in the study area, but many smaller ones that interfere with coal mining have been encountered.

Normal faults, trending NW-SE, have been reported in all four counties. The largest known is in southwestern Christian County (plate 3). This fault has been traced nearly four miles (6 km) through workings of two mines, and another 2 miles (3 km) by means of drilling and high-resolution seismic surveys. The fault strikes N 20° W and the northeast side is downthrown as much as 15 feet (4.6 m) in places.

A fault in the Crown II Mine in Macoupin County (fig. 19) strikes N 40° W, and its northeast side is downthrown 4 to 7 feet (1.2 to 2.1 m). Ledvina et al. (1987) described this fault further and named it the Girard Fault. ISGS geologists have traced Girard Fault 3,200 feet (970 m) through the mine without finding either end. Several other faults having the same trend but less than a foot (0.3 m) of throw occur in the same mine. Similar faults were met in the Crown I Mine, about 5 miles (8 km) to the east. In the Farrant Coal Company mine, which exploited the Springfield (No. 5) Coal on the east side of the city of Springfield, a fault with its southwest side downthrown 14 feet (4.3 m) was reported (Simon and Harrison, unpublished field notes, ISGS).

Young (1892) described a fault in the mine on the north side of Girard, Sections 35 and 36, T12N, R6W, Macoupin County. The coal reportedly was cut off by a plane trending N 45° W and dipping about 45° to the southwest. An entry was driven horizontally 80 feet (25 m) across the interruption, exposing "flinty limestone, very much twisted and contorted." About 60 feet (18 m) into the tunnel there were "coal pipes or leaders near the top." Boreholes were drilled 15 feet (4.6 m) above and below the tunnel without finding the Herrin Coal. At this point the effort to cross the fault was abandoned.

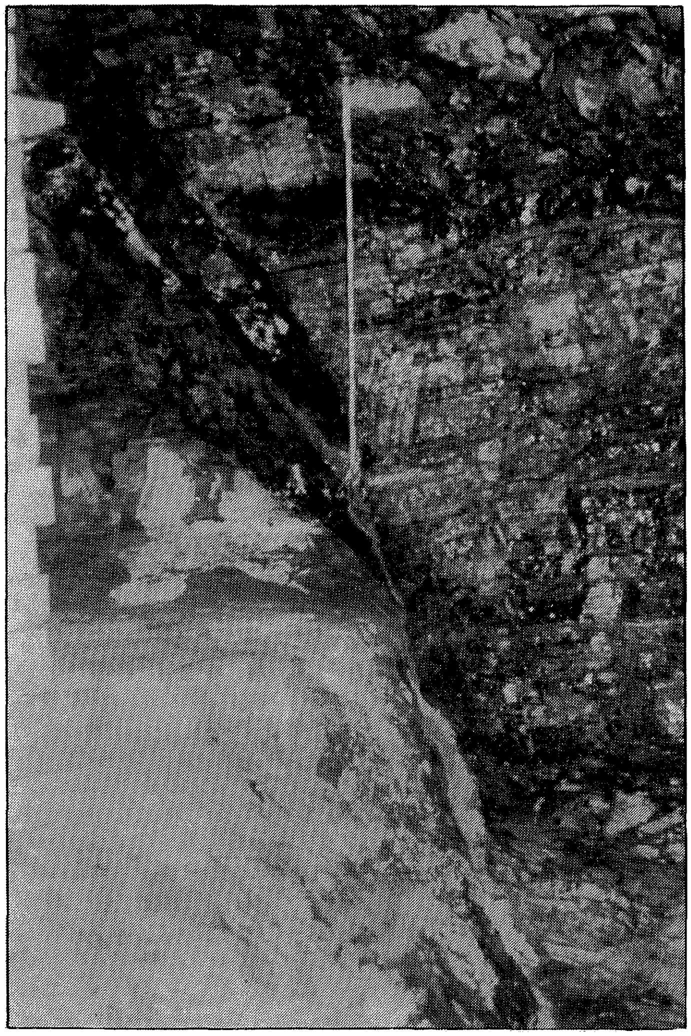


Figure 19 Normal fault in Crown II Mine. Coal and roof strata are displaced about 4 feet down to northeast (right). Fault has been mapped 3200 feet (970 m) across mine workings, and neither end has been found.

My examination of the mine map and borehole records, plus Young's description of the rock in the exploratory entry, suggest that the feature in the Girard Mine may not have been a fault, but rather a channel, or possibly a mass of coal balls. In any event, it robbed the mining company of reserves and interrupted production.

A strike-slip fault at the Crown II Mine was described in Nelson and Nance (1980) and Nelson (1981). Ledvina et al. (1987) named this fault the Crown Fault in honor of the Crown Mine. Since those reports were published, the Crown Fault has been traced out to 17,000 feet (5.2 km) along strike, but neither end has been found. The main fault strikes approximately east-west and has several subparallel branches. Vertical offset is about 4 feet (1.2 m) at most, but horizontal offset may reach 45 feet (14 m). The displacement is left-lateral; that is, the rocks north of the fault have been shifted westward. Associated with the Crown Fault are thousands of northeast-trending open extensional fractures (figs. 20, 21). These let water into the mine and weaken the roof. The company has altered mining plans to avoid the fault zone as much as possible.

The Crown Fault almost certainly is a tectonic structure. No known nontectonic process produces horizontal shearing of this magnitude. The Girard Fault and other northwest-trending normal faults also are evidently tectonic features, having, as they do, consistent and linear trends. The two types of faults cannot have developed in the same stress fields. The normal faults signify NE-SW tension; in the strike-slip fault, maximum tension was NW-SE. The Crown Fault offsets the Girard Fault at Crown II Mine, indicating that the Girard Fault is older than the Crown Fault.

Many other faults found in mines of the study area probably are nontectonic features. Most such faults are curving normal faults of low to moderate dip, offsetting the coal and adjacent strata by a few inches to a few feet. Many such faults are visibly related to irregularities in the coal or immediate roof strata, and can be attributed to differential compaction, loading, or slumping of unlithified sediment. Other small faults contain clay or pass laterally into clay dikes. These "clay-dike faults" and their effect on mining will be discussed in a later section of this report.

MINING CONDITIONS

Conditions for mining the Herrin Coal in the study area generally have been very favorable where the coal has been mined so far. The coal seam is uniformly thick over large areas, relatively shallow, and free of serious grades or large faults. Although water and gas are locally encountered, they are much less troublesome than in many American mining regions. The most serious problems have been with roof stability and, in some mines, with floor stability. Neither of these factors is known to have caused abandonment of a mine, although actual or anticipated poor roof conditions have deterred mining the low-sulfur coal. In general, the region has been free of surprises, and thus has fostered orderly development of some of the largest underground mines in the United States.

For the future, however, mine operators will have to probe areas of thinner coal of less certain quality and contend with geologic conditions with which there has been little or no experience to date. This is especially true for the low-sulfur coal. In this section I will attempt to evaluate geologic conditions that will affect future mining in the four-county district.

Consistency of coal thickness

In modern mining, it is highly desirable to have a coal seam of relatively constant thickness, especially where continuous miners are used. Seams of uncertain and highly variable thickness cannot be mined on orderly projections unless considerable loss of reserves and/or mining of rock is accepted.

As related earlier, the Herrin Coal is admirably thick

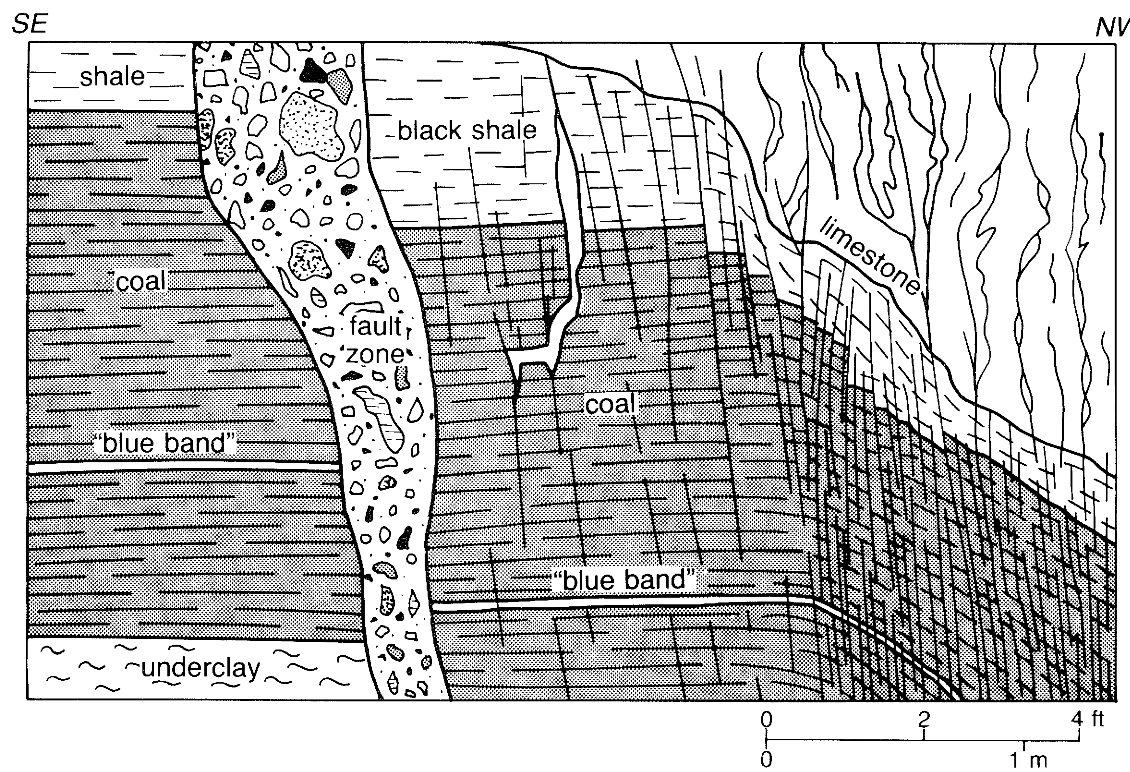


Figure 20 Field sketch of part of strike-slip fault zone in Crown II Mine. The wide vertical fissure (left of center) contains a loosely packed jumble of coal, shale, limestone, and sandstone fragments. To the right, coal and roof are shattered by hundreds of vertical fractures, many of them open. Fissures and open fractures yield large amounts of water.

and consistent in thick broad belts on both sides of the Walshville channel, away from the immediate environs of the channel. This is the region where virtually all the commercial mining to date has taken place. Future mining will have to reach beyond this comfortable region, particularly if low-sulfur coal is desired.

The low-sulfur coal appears to become steadily and consistently thinner towards the Walshville channel. The thickness decreases from 8 feet (2.4 m) or more at the outer edges to less than 5 feet (1.5 m) beside the channel. Several local exceptions to this pattern are evident, as shown in plate 1. There is no evidence, however, of sudden local variations in thickness that will impede orderly development of low-sulfur coal.

Any difficulties likely to be encountered in mining the zone of split coal bordering the channel remain largely unknown. Many drill holes within this belt show thick benches of apparently clean coal, but whether such benches persist over large areas is not known. Drilling data are not adequate to show whether shale splits are widely continuous, or local and lenticular. So far as is known, no mines in the study area have yet encountered split coal. Mining along the Walshville channel in southern Illinois reveals that some splits are predictable ahead of the working face, but others are not.

The greatest local variability in thickness of the Herrin Coal should be expected in western Macoupin County, specifically in R8W and the western half of R7W. As shown on plate 1, thickness can vary, in extreme cases, by 5 or 6 feet (1.5 to 1.8 m) within a mile (1.6 km). Actual variability may be even greater than suggested by the plate, which is based on irregularly spaced drill holes. Furthermore, some coal in this region may contain so much ash that it would not be worth mining; this appears to be especially so in the upper portion of the coal where the seam is thin.

Depth of coal

Nowhere in the study area is excessive depth of coal a problem. The greatest depth in the study area is approximately 800 feet (245 m) near the southeastern corner of T11N, R1E, Christian County. Several large mines were operated successfully for many years at nearly this depth, a few miles away at Pana. The only likely problem associated with greater depth is in situ stress, which is discussed in a later section.

At the opposite extreme the coal comes to subcrop in western Macoupin County, and the bedrock overburden may be uncomfortably thin in part of R8-9W. As noted above, the coal also is highly variable in thickness there, so closely spaced drilling will be mandatory before opening a mine.

Roof stability

Energy Shale Only two mines in the region were operated entirely under gray shale. These were the Perry Coal Company and the Clyde or Hornsby Mine, both in northwestern T8N, R6W, Macoupin County. The Perry Coal Company closed about 1924; the Clyde Mine was operated from 1882 to 1906. No geologic data are available from the Perry Mine. The Coal Reports of the Illinois Department of Mines and Minerals for 1884 and 1885 stated that the roof of the Clyde Mine was very poor and required more timber than the mines at Staunton, which had limestone roofs. The detailed map of the Clyde Mine, however, shows very regular and orderly development of rooms and entries, and gives no indication of difficult working conditions. Some rooms apparently were driven up to 30 feet (9 m) wide, much wider than would be risked today. The only departure from the typical mining plan of the era at the Clyde Mine was in driving the main headings northeast and northwest rather than north-south and east-west. Whether geologic factors influenced choice of mining direction is unknown.

Several mines in southern Macoupin County probed into the edges of the Energy Shale. Field notes of Survey geologists state that roof falls were common and the top difficult to hold.

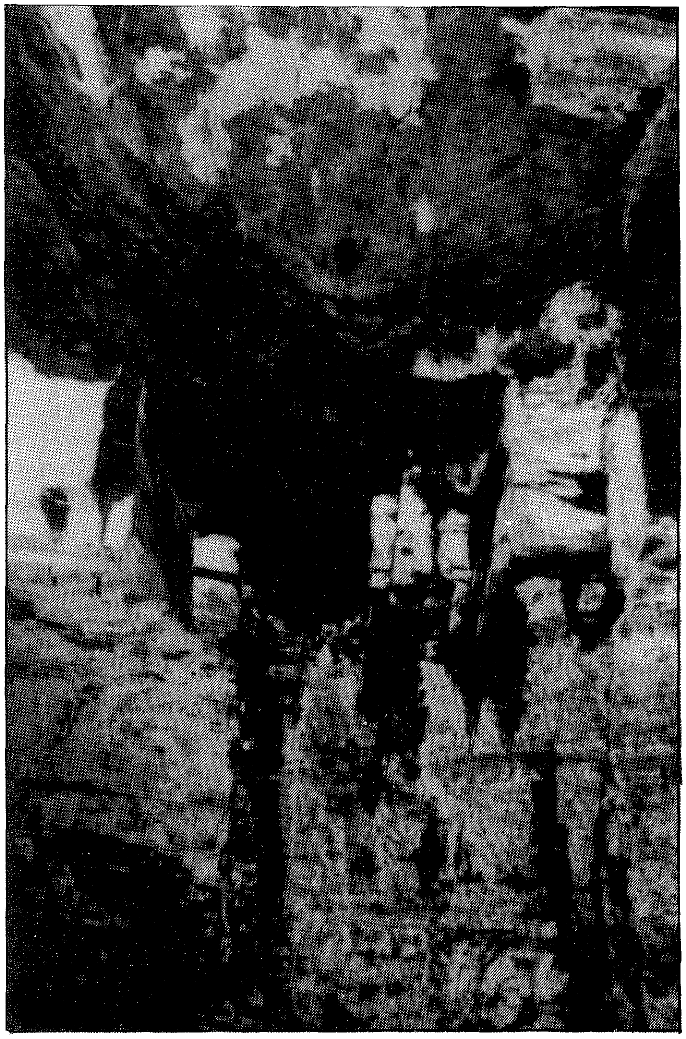


Figure 21 Intense northeast-trending fractures along the strike-slip fault in Crown II Mine. Petroleum seeping from fractures stained the rock dust.

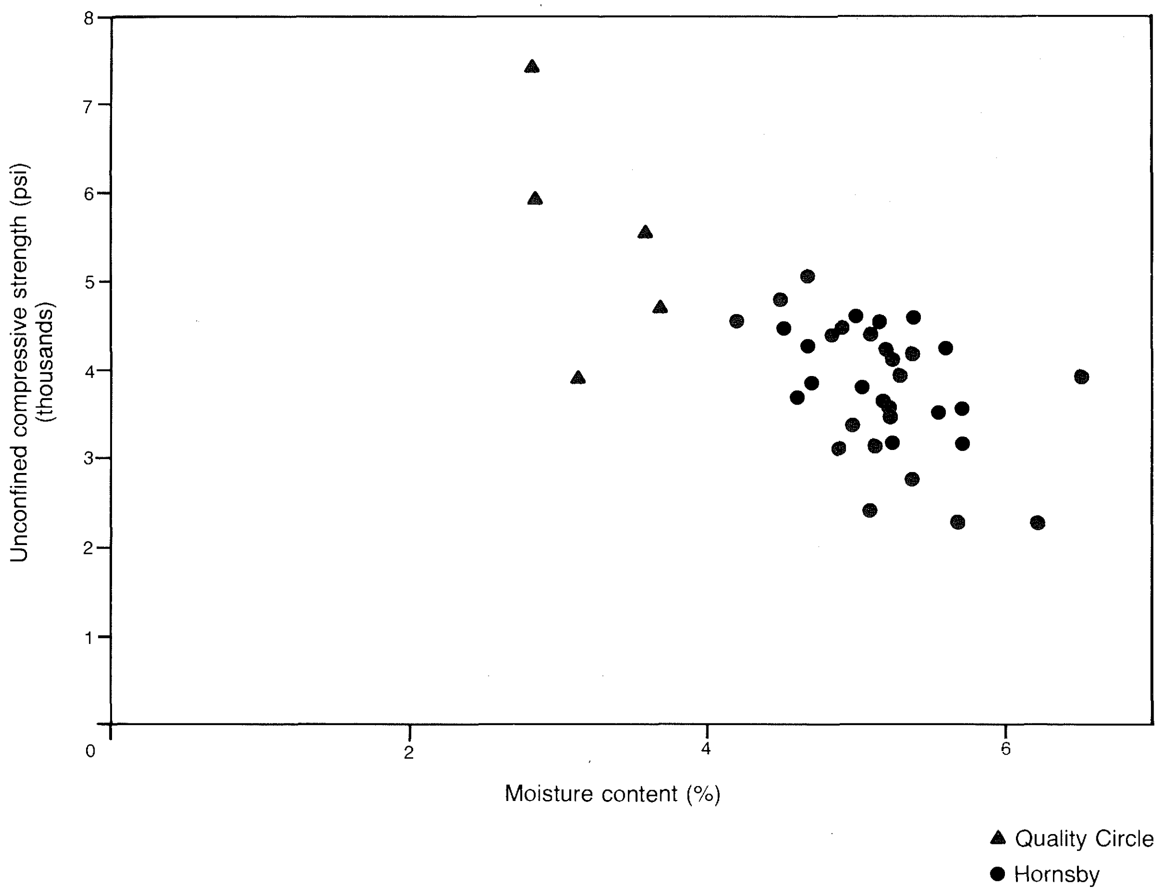


Figure 22 A comparison of compressive strength and water content of Energy Shale from the Hornsby district and from Quality Circle. From Robert A. Bauer.

The mining companies did not persist in mining beneath the gray shale when equally thick coal could be had under excellent roof and there was no special demand for low-sulfur fuel.

Data on the strength and durability of Energy Shale from core samples have been furnished by Robert A. Bauer of the ISGS. Bauer's data indicate that Energy Shale from the Hornsby area is significantly weaker and more susceptible to moisture slaking than Energy Shale from southern Illinois.

The average compressive strength of Hornsby roof shale is only 62 percent of that of shale from the "Quality Circle" region of southern Illinois (Franklin, Jefferson, and Williamson Counties). Tensile strength of Hornsby shale is about 80 percent of that of shale from the Quality Circle. As a general observation, cores of Hornsby shale fall apart along the bedding planes more easily than cores of Quality Circle shale.

Figure 22 compares compressive strength and water content of Energy Shale from the Hornsby district and from southern Illinois. The figure shows that Hornsby shale has consistently lower strength and higher water content than the southern shale. Water content may be one of several factors controlling the strength of the shale. Recall that coal, as well as shale, from the Hornsby area contains more moisture than coal from southern Illinois, and that Hornsby low-sulfur coal contains more moisture than adjacent high-sulfur coal.

Some roof shales in underground mines are very prone to deteriorate on contact with water or moist air. The slake-durability test is designed to assess the durability of rock samples subjected to a standardized cycle of drying and wetting. The sample is dried, weighed, and placed in a wire-mesh drum that rotates in a trough of water for a specified time. As the sample disintegrates, the small pieces fall through the mesh drum and the large durable pieces are retained, to be dried and weighed. The higher the percentage of material retained in the drum, the greater the slake durability of the sample.

Figure 23 provides slake-durability results for Energy Shale from the Hornsby district and the Quality Circle. All samples were taken from cores and were within 8 feet (2.4 m) of the top of the Herrin Coal, thus within normal roof-bolting range. The figure shows that most samples of Hornsby shale have lower slake durability than shale from the Quality Circle.

Fully grouted resin bolts or point-anchor bolts probably will work better than mechanical roof bolts in Energy Shale. Mechanical bolts work well where there is a competent stratum or "caprock" in which the expansion shells can be

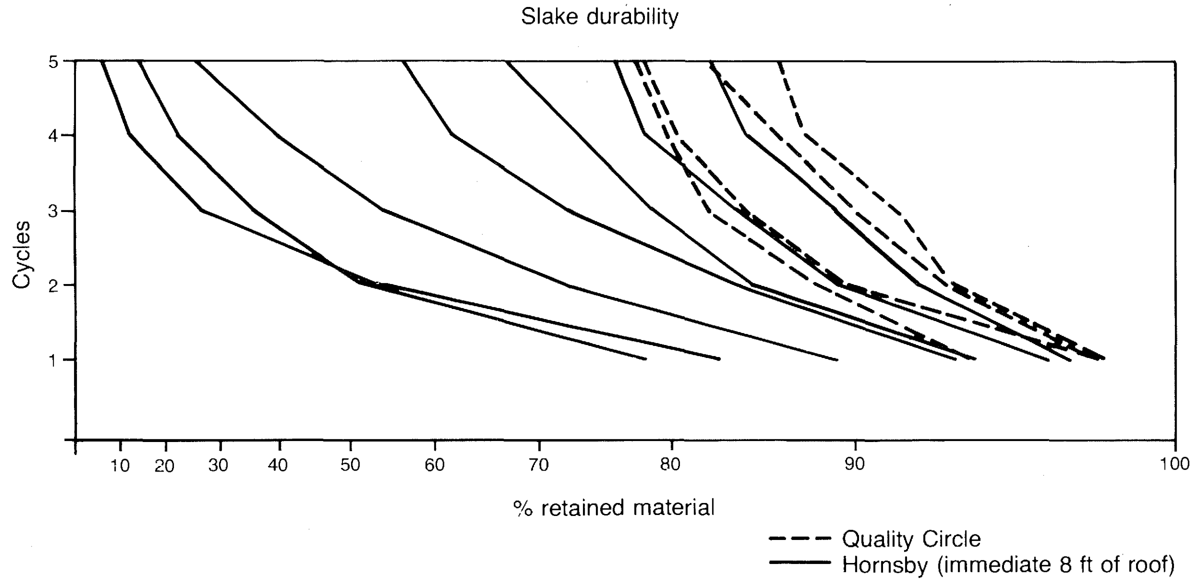


Figure 23 Slake durability results for Energy Shale from the Hornsby district and the Quality Circle. All samples within 8 ft (2.4 m) of the top of the Herrin Coal. From Robert A. Bauer.

firmly anchored. Energy Shale has low shear and compressive strength, so anchors are likely to pull out or slip. Resin or point-anchor bolts are cemented into the hole along its full length, and avoid this difficulty. Fully grouted bolts have the additional advantage of sealing the bolt holes from air and moisture, thus restricting deterioration of Energy Shale.

Moisture-slaking of Energy Shale is expected to be a serious problem in the Hornsby area (fig. 23). Changes in temperature and humidity of mine air, as found in intake-air entries, are especially destructive. The use of tempering chambers to condition air, as described by Lucas (1975), has proven effective in reducing deterioration of gray shale. Other approaches to consider are leaving top coal and applying artificial sealants to the roof in long-term entries.

The edges of bodies of gray shale are apt to be troublesome with respect to roof control. Small faults or slickensided "slips" are common and may lead to massive roof falls (fig. 7). These faults appear to have been formed by differential compaction of the sediments around the lenticular edges of the gray shale. They commonly trend parallel to the boundaries of the gray shale bodies (Krausse et al., 1979; Bauer and DeMaris, 1982). At mines in southern Illinois it is common for the entire thickness of gray shale to fall up to a height of 15 or 20 feet (4.5 to 6 m), exposing the base of the Anna Shale or Brereton Limestone. Away from the outer edges where the shale is uniformly thick, "slips" are rare and large falls less common.

In thick Energy Shale of southern Illinois "rolls" are common and are a major source of roof trouble (Krausse et al., 1979). These "rolls" are large lenticular bodies of gray shale that protrude downward into the coal. They contain many shear fractures and commonly have "riders" or stringers of coal splaying upward into the roof. Such features have rarely been observed in Energy Shale of the study area to date. Possibly, however, "rolls" will be encountered in areas yet unmined, particularly near the Walshville channel.

Minor irregularities include fossil trees, which occur in Energy Shale as fallen logs and as upright stumps or "kettlebottoms." The fallen logs with coalified bark seldom cause more than minor slabbing or flaking of the immediate roof. "Kettlebottoms," however, can be a serious hazard, as the central plug of rock, weighing several hundred pounds, may drop out of the roof without warning. Chase and Sames (1983) recommend that all kettlebottoms not dislodged during initial mining be specially supported. If the fossil stump is less than about 3 feet (1 m) in diameter, miners should bolt alongside and position the wooden or steel headers to overlap the base of the plug. Larger kettlebottoms should be held by steel straps or wooden planks secured by two or more bolts. Drilling directly into the kettlebottom is to be avoided because the vibration of the drill may dislodge the plug.

Black shale/limestone roof Black shale/limestone roof refers to Anna Shale, Brereton Limestone, and younger strata, and also to thin lenticular bodies of Energy Shale away from the thick Energy Shale along the Walshville Channel.

As Krausse et al. (1979) recognized, the key to roof stability in black shale/limestone is the thickness and position of the Brereton Limestone. Where the limestone is thicker than 2 or 3 feet (0.6 to 0.9 m) and lies directly on the coal, the roof is excellent. Where thick limestone overlies shale, the shale may fall but the main roof is stable; roof bolts generally should be anchored in the limestone. Where the Brereton is thin or missing, roof control is apt to be difficult.

Mapping in underground coal mines demonstrates that accurately mapping the thickness and distribution of Anna Shale and Brereton Limestone from drillhole data alone is impossible. Throughout the study area, and in most of the rest of Illinois, the Anna Shale occurs in lenses and interconnected bodies having highly irregular boundaries and ranging in thickness from less than an inch to more than 5 feet (1.5 m). Lateral dimensions of these bodies range from a few tens of feet to many hundreds of feet. Interspersed with areas of Anna Shale are regions where the Brereton Limestone or younger rocks form the immediate roof. Mapping to date has failed to reveal any depositional patterns or trends that might permit projecting roof types any long distance into unmined areas. At best, conditions may be projected perhaps a few crosscuts ahead of the working face.

Some important generalities can be posited, however. Near the Walshville channel (plate 2), the Brereton Limestone apparently is continuous except where Energy Shale is thick and where the limestone is cut out by channels. Here one may expect to find limestone either directly on the coal, or within boltable height above Anna and/or Energy Shale. The limestone near the Walshville commonly is 5 feet (1.5 m) or more, and in many places is thicker than 10 feet (3 m). In general, the best roof conditions in the study area are found near the Walshville channel where Energy Shale is absent.

Energy Shale occurs as isolated pods or lenses in a large area, mainly west of the Walshville channel (plate 2). Small bodies of Energy Shale may occur outside the region indicated on plate 2, but are rare. Lenticular gray shale makes poor roof, especially where the limestone is discontinuous over the top of the pod.

The distribution of Anvil Rock Sandstone is also indicated in plate 2. Wet working conditions may be encountered adjacent to channels and in places where the Brereton Limestone is thin, missing, fractured, or breached in mining. Outside this area the Lawson Shale occurs. This is of little concern if the Brereton is thick, but where the limestone is absent, roof control will be difficult.

Lenticular Energy Shale, like thick Energy Shale, is unstable because of its low mechanical strength, susceptibility to moisture slacking, and abundance of small compactional faults. The type of support required depends upon the thickness of the shale, and the presence or absence of Brereton Limestone above. If good limestone is present, mechanical bolts may suffice, but point-anchor bolts set into the limestone probably are better. Fully grouted bolts are advisable where limestone is thin or absent, for reasons already mentioned. For long-term entries, truss bolts, timbers, rail-bars, or cribs may be required to control lenticular gray shale. Sealants to keep moisture away from the shale, and/or wire netting to catch small pieces, also may be desirable.

Anna Shale generally makes better roof than Energy Shale, although its stability varies. The fissile basal portion of the Anna is strong, brittle and not much affected by moisture. It does tend to break into slabs along joint planes, and may contain large spherical concretions that should be supported the same way as kettlebottoms (p. 32). The upper portion of thick (3 ft, 1 m or more) Anna Shale tends to be weak and poorly laminated, and it deteriorates on exposure to air. The burrowed zone at the top of the Anna and the "clod" at the Anna/Brereton contact provide an easy plane of separation in the roof. Standard practice at mines in the study area (and elsewhere in Illinois) is to support Anna Shale with mechanical bolts anchored at least 1 foot (0.3 m) into the Brereton Limestone. If the Brereton Limestone is thin or missing, either extended mechanical bolts are set into the higher Bankston Fork Limestone, or resin bolts are used. Roof bolters should regularly drill test holes to determine thickness and postion of limestone. If no limestone is present, closer spacing of roof bolts and/or auxiliary support may be called for.

Brereton Limestone as immediate roof is the best top available. Many areas of limestone in older mines have stood for 20 years or longer with no artificial support. Today, mining law requires bolting all roof, including limestone, but short bolts are used in limestone. Falls of limestone are rare, but when they occur are sudden and massive. Such falls may be due to faults, clay dikes, or to shale partings in the limestone. Careful inspection of the roof sometimes, but not always, reveals such conditions that may call for extra support.

The basal "clod" or calcareous claystone is firm when first mined, but rapidly deteriorates in air and falls away between the header boards. It can fall in slabs large enough to cause injury. Mining the clod with the coal would eliminate the hazard, but is not always practical. If clod is left in the roof, miners should exercise caution and scale down loose pieces with a suitable pry bar.

Jamestown Coal and Conant Limestone generally are too thin to have much effect on overall roof stability. Where these units are seen in the immediate top, however, instability can be predicted. The Conant Limestone resembles the competent Brereton Limestone from below, but rarely is thick and strong enough to support the overlying Lawson Shale. Roof-control crews should proceed, therefore, as though the limestone were not present.

Lawson Shale varies from moderately competent to virtually unsupportable; when it is mottled it has very low strength, deteriorates on contact with moisture, and falls in irregular pieces of all sizes (fig. 14). This mottled shale locally forms the immediate roof, especially in western Macoupin County. Timbers, rail bars, and cribs may be required in addition to numerous roof bolts anchored into the Bankston Fork Limestone. In panel work, it has been common to leave rooms unmined rather than contend with mottled Lawson Shale as the roof. Such conditions, fortunately, have been unusual in most mines to date.

Anvil Rock Sandstone is highly variable as a roof material. Roof conditions may change from excellent to poor within the length of a crosscut in channel areas. Channels may be filled with materials ranging from massive, well-cemented sandstone to weak, thinly layered shale, claystone, and coal (fig. 17). Roof control needs should be evaluated after examining the roof and drilling test holes.

Away from channels Anvil Rock Sandstone commonly is thinly bedded or laminated. The bedding planes are apt to be coated with mica, clay, or carbonaceous debris, allowing the sandstone to cleave readily into layers (fig. 15). If the Bankston Fork Limestone is within convenient range, the bolts should be anchored into it in order to bind the layers of sandstone together. Setting mechanical bolts, all of the same length, within the sandstone, is not advisable. Such practice concentrates stress on one or a few bedding planes, and commonly produces a massive flat-topped fall just above the anchoring horizon.

Floor stability

The floor of the Herrin Coal in the study area, as in most of the Illinois Basin, generally is claystone that is prone to heave or squeeze. The effects of claystone floors on mining range from minor nuisance to forced abandonment of entire panels.

Mudding of the floor seriously hinders progress in areas of water influx, such as in Anvil Rock Sandstone channels and along fault zones at the Crown II Mine. At the latter, miners resorted to leaving bottom coal in some places to avoid burying mining equipment in mud. Even in dry mines the floor is soft and quickly becomes rutted along roadways. Frequent grading is necessary, and low areas may have to be filled with crushed rock, or planks may have to be laid to maintain the roads.

Floor heaving is common, and large-scale squeezes have been reported (fig. 24). One recent squeeze developed when the coal company attempted to increase recovery of coal by "punching" pillars in panels. Squeezes reportedly took place in five panels of the mine, and in some cases advanced so rapidly that mining equipment was lost. The coal company became resigned to taking no more than 50 percent of the coal. Another recent severe squeeze was investigated by geologists from the ISGS and mining engineers from the coal company and the University of Missouri at Rolla. In the affected panels, extraction was limited to about 50 percent, but the company drove some rooms wider than normal—up to 24 feet (7.3 m) wide instead of the usual 15.5 feet (4.7 m). Convergence of roof and floor was rapid and dramatic (fig. 24). In many places, the height of the entry was cut in half; some rooms squeezed completely shut. Movement of the floor induced roof failure and crushing of coal pillars, accelerating the squeeze. Mining equipment was lost, and portions of panels had to be abandoned. The investigative team (unpublished mine notes, ISGS, 1972) concluded that driving the rooms too wide was only part of the reason for the failure. Other factors cited included

- abnormally thick claystone sequence in floor, lacking competent beds
- presence of expandable clays in the floor
- presence of a structurally low area, to which water might have migrated, promoting expansion of clays
- possible stress concentrations induced by mining design and pattern and by the presence of a buried (preglacial) valley over the area that underwent squeeze.

These experiences indicate that in room-and-pillar mining within the study area, taking more than 50 percent of

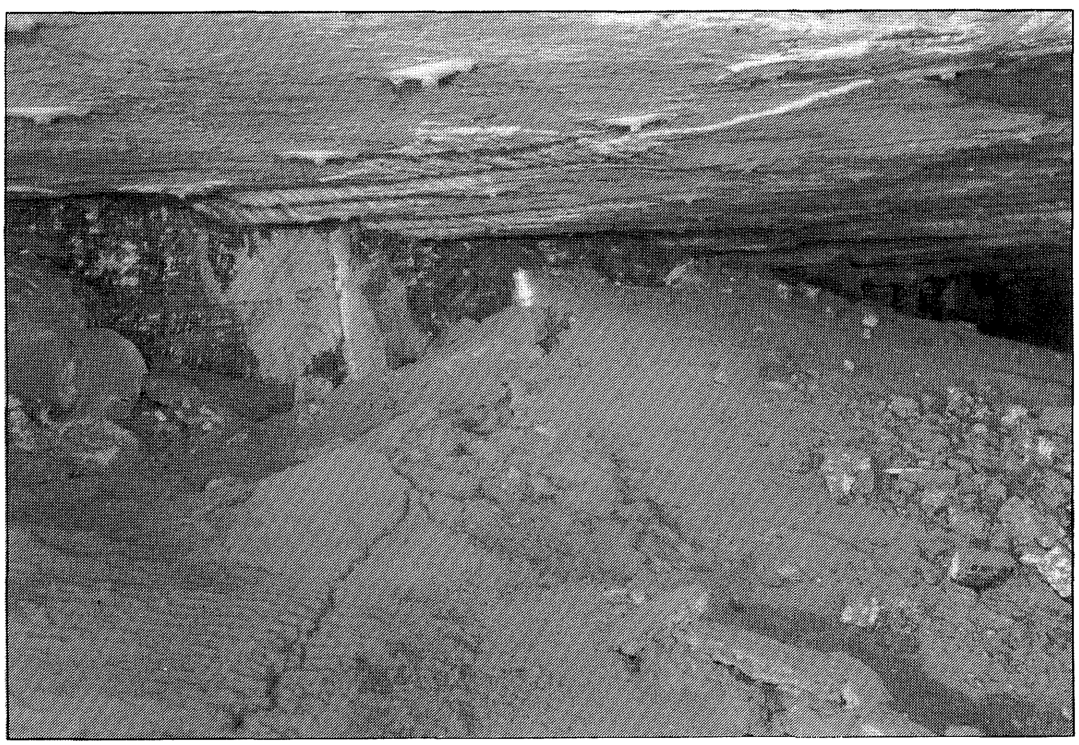


Figure 24 A severe floor heave or squeeze occurred here; pressure on pillars forced plastic underclay into mine openings. In this example the roof remains intact.

the coal or driving rooms wider than 20 to 22 feet (6 to 7 m) should be attempted, if at all, with extreme caution. Any such experiment should be preceded by thorough evaluation of the composition, mineralogy, and strength of floor materials, and convergence of roof and floor should be closely monitored as the experiment progresses.

No full-extraction mining (longwall or systematic removal of pillars) has been attempted in the study area because coal companies historically have not owned subsidence rights. Longwall mining and pillar-pulling have been practiced successfully in the Herrin Coal of southern Illinois for many years. The coal there has a claystone floor, but generally competent limestone, sandstone, or siltstone occur beneath. Evaluation of floor strength in southern Illinois versus the study area is beyond the scope of this report, but appears necessary for any operator contemplating full-extraction mining in the four counties of interest.

Water

Influx of groundwater to mine workings may be expected wherever permeable sandstone is found close to the coal seam. Within the study area, the Anvil Rock Sandstone is the primary offender, although younger sandstones filling the channels in southern Montgomery County may also yield water. Wet conditions also may be encountered as mining approaches the Walshville channel.

Anvil Rock channels very often produce water, which may hinder mining severely. Large channels should be avoided as far as possible, and crossed only where entries are required for haulage and ventilation. Any channels encountered should be mapped carefully. Their courses tend to be fairly linear and may be projected with fair confidence into yet-unmined areas.

Wet mining conditions may be expected anywhere the Anvil Rock Sandstone is present and the Brereton Limestone broken or discontinuous (plate 2). For example, the Crown II Mine in northeastern Macoupin County has been troubled by water from the sandstone throughout its workings (Nelson and Nance, 1980). Water enters directly where the sandstone is close to the coal, and also wherever the Brereton has been breached by roof falls, fractures, overcasts, and roof-bolt holes. The last two at least, being artificial, can be avoided. Instead of taking out limestone roof for an overcast, miners can excavate the floor for an undercast. Roof bolts ordinarily should not penetrate the Brereton. If they must, and water-bearing sandstone lies above, the holes should be grouted.

The volume of water and rate of flow are seldom large, except in places along the strike-slip fault where the roof strata are intensively fractured. Nevertheless, the steady, slow flow of water from many sources seriously hinders mining. At the Crown II Mine, the company considered dewatering the sandstone before mining or pumping grout into it, but studies showed that the permeability of the sandstone was so low that such efforts would have little effect. After dealing with obvious leaks (overcasts, bolt holes, and the fault zone) the company has learned to live with a certain amount of water influx. Fortunately, most areas dry out within a few weeks or months of mining. Such appears to be the case at most mines in the study area where groundwater has been a trouble.

Gas

The mines of the study area have never been known as gassy, and are notably less so than mines farther south. The record of disasters due to gas explosions is less severe in the study area than in southern Illinois, but is not spotless. The Illinois Department of Mines and Minerals lists three gas explosions resulting in the deaths of three or more miners in the study area. The worst was at the Mowequa Coal Company, on the Christian-Shelby county line, where 54 workers were killed in an explosion on December 24, 1932. The State inspection committee attributed this calamity to methane gas released from seals broken by a roof fall and ignited by the open flames of miners' cap lamps. The other two explosions occurred at the Shoal Creek Coal Company Mine at Panama, southwestern Montgomery County; six men died in 1910 and 11 in 1915 in these accidents.

Figures on average daily emissions of methane from coal mines in Illinois and elsewhere in the United States are given in Irani et al. (1972). Methane output measured 0.2 million cubic feet per day (MCFPD) from Consolidation Coal Company's Hillsboro Mine; 0.4 MCFPD from Monterey No. 1; 0.5 MCFPD from Peabody Coal Company Mine No. 10; and 1.0 MCFPD from the Crown I Mine. In comparison, methane emission from mines in southern Illinois ranges from 0.1 to 2.4 MCFPD.

The only recent problem with methane that has come to my attention was reported by company officials at the Crown II Mine, Macoupin County. According to their statements, pockets of gas were struck in open fissures or breccia zones at a few points along the strike-slip fault that crosses the mine. In at least one instance, an inrush of gas forced temporary evacuation of the face. I have observed small quantities of gas bubbling through water on the floor at several places along the fault in Crown II. A sample was collected and analyzed by Dennis Coleman of the ISGS. He reported its composition to be more characteristic of oil-field gas than of coal gas. This suggests that the gas is rising along fissures from lower Pennsylvanian sandstones. Several small gas fields in Macoupin County have produced from sandstones 200 to 300 feet (60 to 90 m) below the Herrin Coal.

The strike-slip fault apparently extends eastward into the Crown I Mine. Possibly the relatively high methane emissions of the Crown I Mine (Irani et al., 1972) are from the same source as in Crown II.

Clay dikes

Vertical or inclined fissures in the coal, filled with clay and other sedimentary materials, are common in some parts of the study area; they interfere with mining and lower roof stability (figs. 12, 25).

Krausse et al. (1979) described at length the clay dikes at the recently abandoned Consolidation Coal Company Hillsboro Mine (Mine "A" of Krausse et al.). Dikes were found in all parts of that mine. They ranged in width from less than an inch to several feet (about 1 m), and many could be mapped along strike for many hundreds of feet. They showed no apparent preferred regional orientation, but their curving trends tended to follow the lateral boundaries between Anna Shale and Brereton Limestone in the roof.

Figure 25 Clay dike and associated fault. Note offshoots or stringers of clay and characteristic "false drag" folding of coal near fault plane.

Similar clay dikes were described and illustrated by Spotti (1941) in his report on mining geology in southern Macoupin County. Dikes also have been mapped at the Crown II Mine but are generally small and much less numerous than at the Hillsboro Mine. Clay dikes are rare in northern Macoupin, Christian, and southern Sangamon Counties. They are, however, numerous in the Springfield (No. 5) Coal where it has been mined in northern Sangamon and in Logan County.

At the Hillsboro Mine and elsewhere, clay dikes commonly are accompanied by or change into small faults (figs. 12, 25). These are normal faults, generally having low to moderate dip, that offset the coal and adjacent strata. Most such faults have less than 3 feet (1 m) of throw, but at the Hillsboro Mine some had as much as 18 feet (5.4 m) of offset (Krausse et al., 1979). These larger faults required grading of entries. Smaller faults do not require grading; many do not reach the bottom of the coal. They do, however, penetrate the roof, and create problems in roof control.

Miners at the face should watch for clay dikes and faults, and be aware of the hazards they pose. The most dangerous situation is having a fault or dike parallel with the mine opening, especially near the rib. Such a dike or fault makes the roof span a cantilever, supported only at one end. If possible, miners should avoid driving rooms or crosscuts along a clay dike. Should this be unavoidable, extra roof support is mandatory. Extra support is also required if two or more dikes intersect or single dikes cross entries or intersections obliquely. The least hazardous case is having the feature cross the opening at a right angle, but even then large slabs of rock may fall along the dike or fault.

Oil and gas wells

Oil and gas wells and dry test holes are of course obstacles to coal mining, and must be considered in planning development of a mine. Several thousand such holes have been drilled within the four counties of interest. The approximate outlines of oil and gas fields are shown on plate 3. Locations of individual wells are plotted on the Oil and Gas Development maps sold by the ISGS; logs and other data on the wells themselves are open for public inspection at the Geologic Records office of the ISGS.

Oil and gas fields in Macoupin and Montgomery Counties are small, having from 2 to 27 wells each. These wells are completed in lower Pennsylvanian sandstones 200 to 300 feet (60 to 90 m) below the Herrin Coal. Production rates are low, and many wells have been capped. Carlinville Field was discovered in 1909 other fields were developed between 1915 and 1960, and a few more tests have been made recently. Especially in the older fields, coal mine planners should be prepared for holes that are inaccurately located or not noted in official records.

Fields in Christian County are much larger, and produce from deeper formations: Mt. Auburn Consolidated contains 437 wells, Assumption Consolidated has 189, Kincaid Consolidated 148, and Edinburg 130. Development began in 1940 and is continuing at present. Most wells produce from Devonian and Silurian strata 1300 to 1700 feet (390 to 520 m) below the Herrin Coal. Fortunately, large parts of these fields are situated in areas where the Herrin Coal is too thin to mine or is already mined out.

Mined-out areas

The boundaries of active and abandoned mines shown on plate 1 are generalized and intended for reference purposes only. The Mined-Out Area Maps sold by ISGS contain more complete and accurate information on regional mining. Detailed maps of underground workings are available at the ISGS for most mines in the study area. Original maps can be viewed in the Survey's map room, and paper copies prepared from microfilm can be obtained for a small fee. Other sources of maps and information on current and abandoned mines are the Illinois Department of Mines and Minerals in Springfield and the courthouses of counties within which the mines operate(d).

In situ stress

Recent evidence from several sources indicates that the Illinois Basin is undergoing active, in situ compressional stress. The major axis of compression is horizontal and oriented between ENE-WSW and E-W. This stress field apparently is the product of regional tectonic forces that affect much of the eastern United States (Nelson and Lumm, 1984; Nelson and Bauer, 1987).

In underground mines the stress field is manifested as increased incidence of roof failure in north-south headings. The effect typically is stronger with greater depth of mining and is most prominent where the roof strata are relatively uniform (thick gray shale or siltstone). Failure usually begins during or shortly after mining with the appearance of "kink zones" along the roof of north-south entries. Under lateral compression the rock layers snap downward, and the ends of broken layers are forced together, crushing them (fig. 26). The kink zone may develop into a major fall if extra supports are not installed. Several mines in southern Illinois have changed mining direction to minimize the problem.

Kink zones and preferential north-south failure have not been observed at most mines in the study area. Most active mines in the four counties are shallow, and local geologic features (such as lenticular rock bodies in roof and clay dikes) may overwhelm subtle effects of in situ stress. The deep mines at Pana, however, apparently felt the stresses. Netzeband (unpublished mine notes, ISGS) stated that at Pana 2 Mine "Lateral pressure is very great and posts set with a pitch of several degrees are soon pushed straight and eventually pitch in the opposite direction." Also, in one Macoupin County mine at the edge of the Hornsby gray shale area, all of the roof falls reportedly took place in the north-south headings. Minor north-trending kink zones also developed, but prompt roof support prevented serious falls.

In summary, stress problems should be anticipated at deeper mines in the study area, especially where the roof is Energy Shale. This shale is relatively homogeneous and its average compressive strength is lower than that of Anna Shale and limestone. In deep mines and under Energy Shale, consideration should be given to mining northeast and northwest rather than north-south and east-west; this was done at the old Clyde Mine, although the reasons for the choice of mining direction were not recorded. More data on magnitude and direction of in situ stress are needed, however, before definite recommendations can be made.

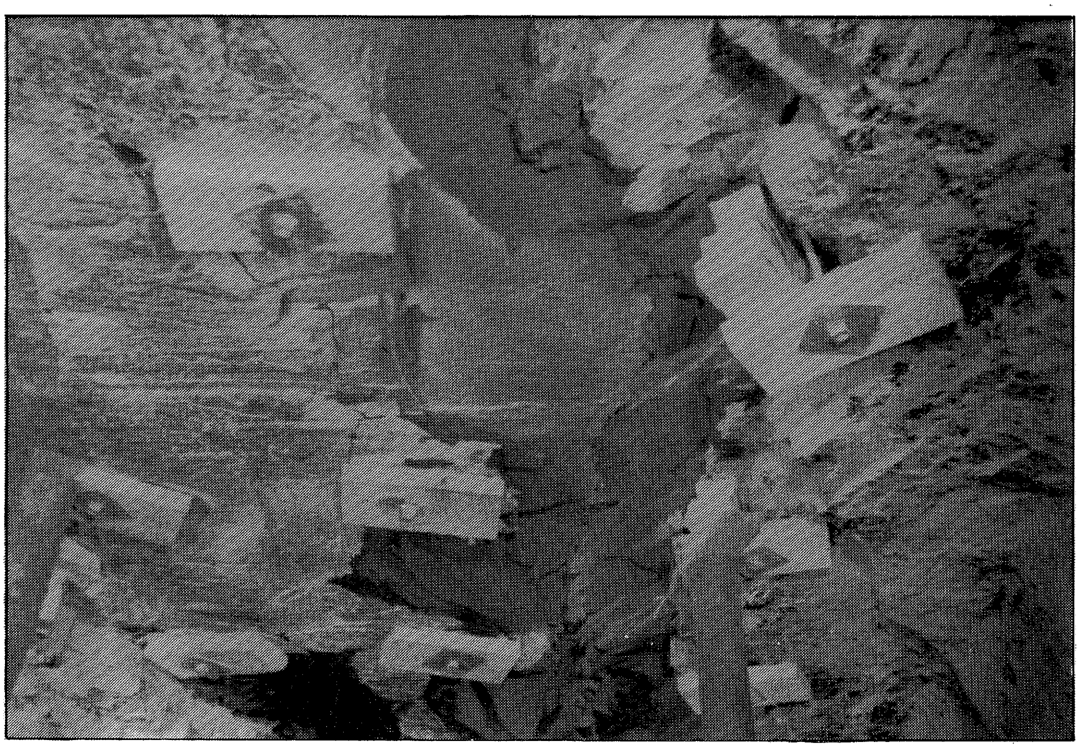


Figure 26 "Kink zone" caused by horizontal stress in mine roof.

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