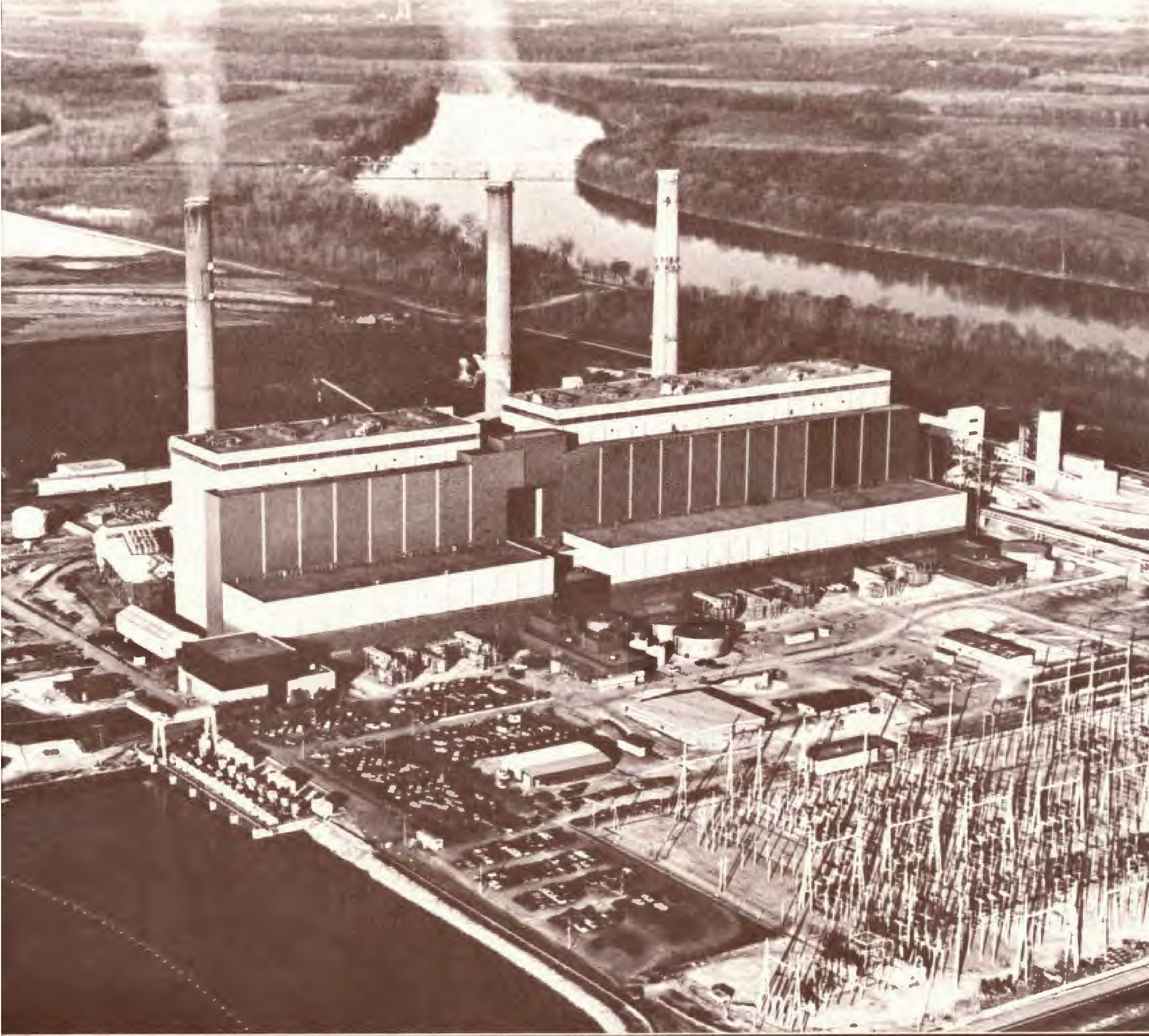
# COAL RESOURCES OF GIBSON COUNTY, INDIANA

## Special Report 50



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# Coal Resources of Gibson County, Indiana

*By* Donald L. Eggert

INDIANA UNIVERSITY
INDIANA GEOLOGICAL SURVEY SPECIAL REPORT 50

Bloomington, Indiana: 1994

## AUTHOR OF THIS REPORT

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**On the cover:**
Public Service Indiana's Gibson Station generating plant is the third largest coal-fired electric power plant in the United States.

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## PLATE (in pocket)

Plate 1 Cross section showing representative geophysical logs from Gibson County, Indiana

# COAL RESOURCES OF GIBSON COUNTY, INDIANA

*By* Donald L. Eggert

## INTRODUCTION

Gibson County, the third largest of Indiana's coal producing counties, covers about 500 square miles (1,300 sq km) of flat and rolling land occupied by farms, forests, and small towns. About 80,000 people live and work in the county, earning their living from agriculture, construction, service industries, manufacturing, mining, and petroleum production. The two main line class I railroads, U.S. Highway 41, and several state highways are essential transportation corridors for the economic development of this county (fig. 1).

Gibson County residents have prospered for almost two centuries because of their rich natural resources. These resources include gravel, sand, fertile soil, water, petroleum, and coal. During the past hundred years this county has been one of the major petroleum-producing counties in Indiana. Coal mining once employed almost a thousand county residents in underground and surface mines that produced a total of more than 48 million tons, but in recent years underground mining has declined because of competition with other energy sources. As petroleum and surface-mineable coals in the United States are depleted, meeting some of our energy needs by the deep mining of coal in Gibson County may again be profitable. Today coal is being mined by several small surface mines in the eastern part of the county and at a major underground mine in the western part. This report is intended to provide information on the distribution, quality, and amount of coal resources in Gibson County.

## PREVIOUS STUDIES

Because there are few natural outcrops in Gibson County, subsurface data are essential in understanding the geology of the coal seams. The increasing accuracy and greater detail of the reports on the coal deposits of Gibson County through the years reflect the increase in the amount and quality of drilling data resulting from coal and petroleum exploration.

The early coal resource studies of Gibson County were based on scant data. Significant coal deposits in Gibson County were first reported by Collett (1874) on the basis of a few surface exposures, small mines, and drilling records. Collett noted (p. 418) that, "Workable seams . . . will occasionally be found, but the search will be attended with much cost and many disappointments." Information from a few additional small mines

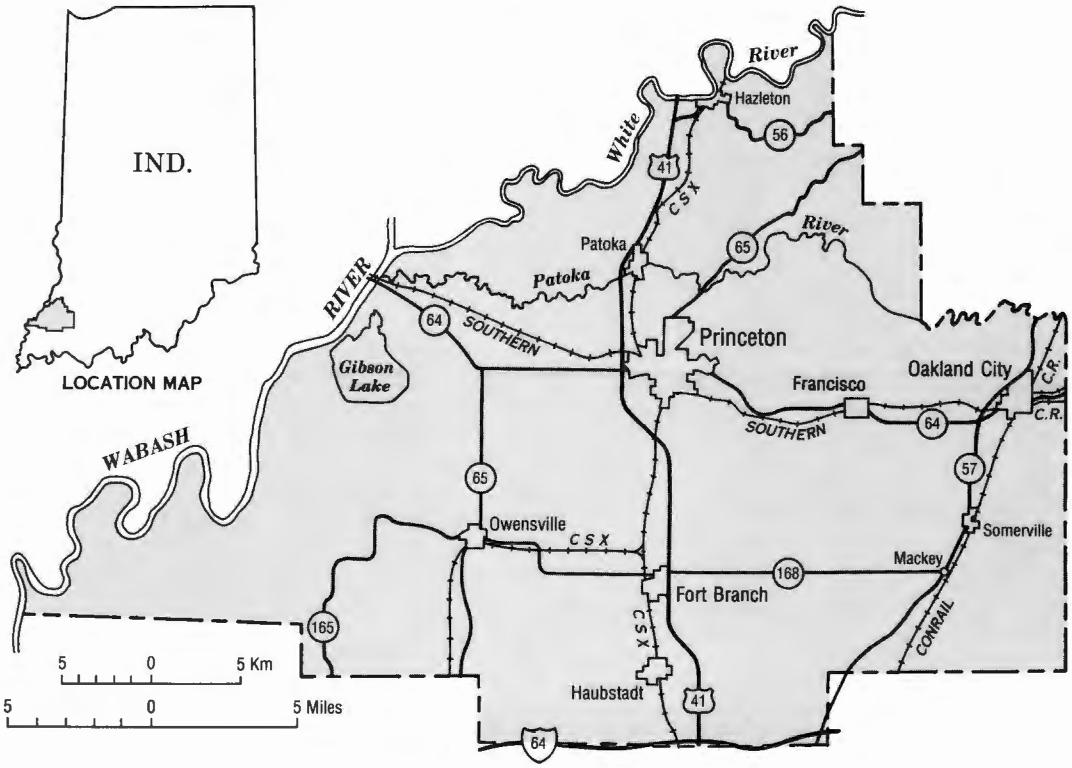

Figure 1. Map of Gibson County, showing main railroads and highways.

and from the search for oil and gas provided Ashley and his staff with a few more drilling records. Ashley's report (1898) indicated that there were major coal deposits in Gibson County and that the coal now called the Springfield Coal Member was being mined (fig. 2). Ashley recognized that this coal was the same seam present in other counties. He estimated that there was more than 900 million tons of Springfield coal in this county. He also reported several mines and exposures of the coal he referred to as Coal VII, and he estimated that the reserves were more than 775 million tons. This coal may have included coals now assigned to the Danville and Hymera Coal Members. Ashley estimated that at least 4 billion tons of mineable coals were below the Springfield.

More than half a century passed after publication of Ashley's report before Spencer (1953) reported on the coal reserves of Indiana. He followed the formal system of classifying coal reserves that the U.S. Geologic Survey used at that time. He calculated that the original coal resources of Gibson County were 4.5 billion short tons and that 2.3 billion tons was recoverable. Spencer did not indicate the coal reserves on a seam by seam basis, however.

Friedman (1954) used the raw data from Spencer's Gibson County report and calculated 752 million tons of original coal reserves for what is now believed to be the Danville Coal Member, 872 million tons of coal for what is now the Hymera Coal Member, and 2.9 billion tons of coal for the Springfield Coal Member. He mapped the structural elevation of the Springfield coal over for about four-fifths of the county. He also mapped a fault that he called the Maunie Fault, now called the New Harmony Fault, and he inferred the presence of the fault now called the Owensville Fault. Friedman showed on his map mined-out areas of what are now considered to be Springfield, Hymera, and Danville coals. He also included a table listing mine names, mining companies, location, thickness of the seam mined, depth to coal, years of operation, and production.

Since 1954, no new coal resource estimates have been published for Gibson County, but several publications have focused on the Springfield coal and the relationships between quality, thickness, and sedimentology. These reports include Eggert (1982a, 1982b, 1982c, 1983, 1984), Eggert and others (1983), and Eggert and Adams (1985).

This report differs from its predecessors in that it includes detailed studies of several coals in the Carbondale Group and the Seelyville coal in the Raccoon Creek Group. The amount of data now available allows for better correlation, more accurate reserve estimates, detailed maps of seams and associated strata, and better understanding of the origin of these coals and associated sediments.

## METHODS OF STUDY

Gibson County is an excellent area in which to study the nature of subsurface coal deposits. Since the 1930s more than 7,300 holes have been drilled for petroleum exploration. Most of these holes have geophysical logs on file in the Energy Resources Section of the Indiana Geological Survey. Open file records of the Indiana Geological Survey consisting of a few coal exploration driller's logs, Survey drill holes, and chemical analyses of coals sampled by the Survey staff have also been used. The most valuable and essential data used in this report are the petroleum geophysical logs, because of their well-documented locations and reliability in predicting thickness, rock types, and elevations.

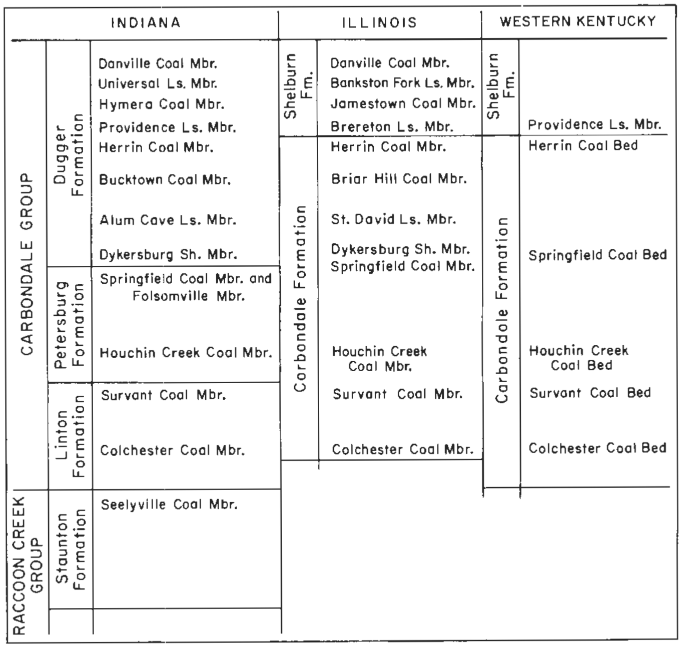

Figure 2. Correlation chart showing selected units of the Pennsylvanian System in Gibson County and states adjoining southwestern Indiana (Tri-State Committee on Correlation of the Pennsylvanian System in the Illinois Basin, in press).

Nearly all of the geophysical logs from the Energy Resources Section were examined. Coal and rock units were identified and the thickness and elevation of each unit were determined and recorded. Open file maps showing elevation and thickness of various units or the interval between units at a scale of 1 inch (2.5 cm) equals 1 mile (1.6 km) were then made. These maps are available from the Indiana Geological Survey for the cost of reproduction.

Coal resources for the Seelyville, Springfield, Herrin, and Danville Coal Members were calculated for this report. An isopach map showing the net thickness and omitting all splits was constructed for the Seelyville coal, a complicated multiple-split coal, and an isopach map was constructed for the coal showing the net thickness and omitting all splits. Coal resource values were then calculated by determining the area between thickness contours.

Most of the contoured areas were digitized with a Summagraphics Digitizer. A Pascal program was used to calculate the area in square miles within each contoured region. For a few contoured areas, the extent was determined by use of a

Bruning Planimeter. The thickness of coal resources within each area was assumed to equal the mean between the upper and lower value of the contoured area. The amount of coal per acre-foot was assumed to be 1,800 tons. The coal resources present in each area were determined by the equation: area expressed in square miles x 640 acres per square mile x 1,800 tons per acre foot x thickness = tons.

## STRATIGRAPHY

Coal-bearing rocks are restricted in Gibson County to Chesterian (youngest Mississippian) and Pennsylvanian rocks (Plate 1; figs. 2 and 3). Chesterian coals are thin and deep, and are not economically important. They are found in clastic units, such as the Bethel Formation, the Tar Springs Formation, and

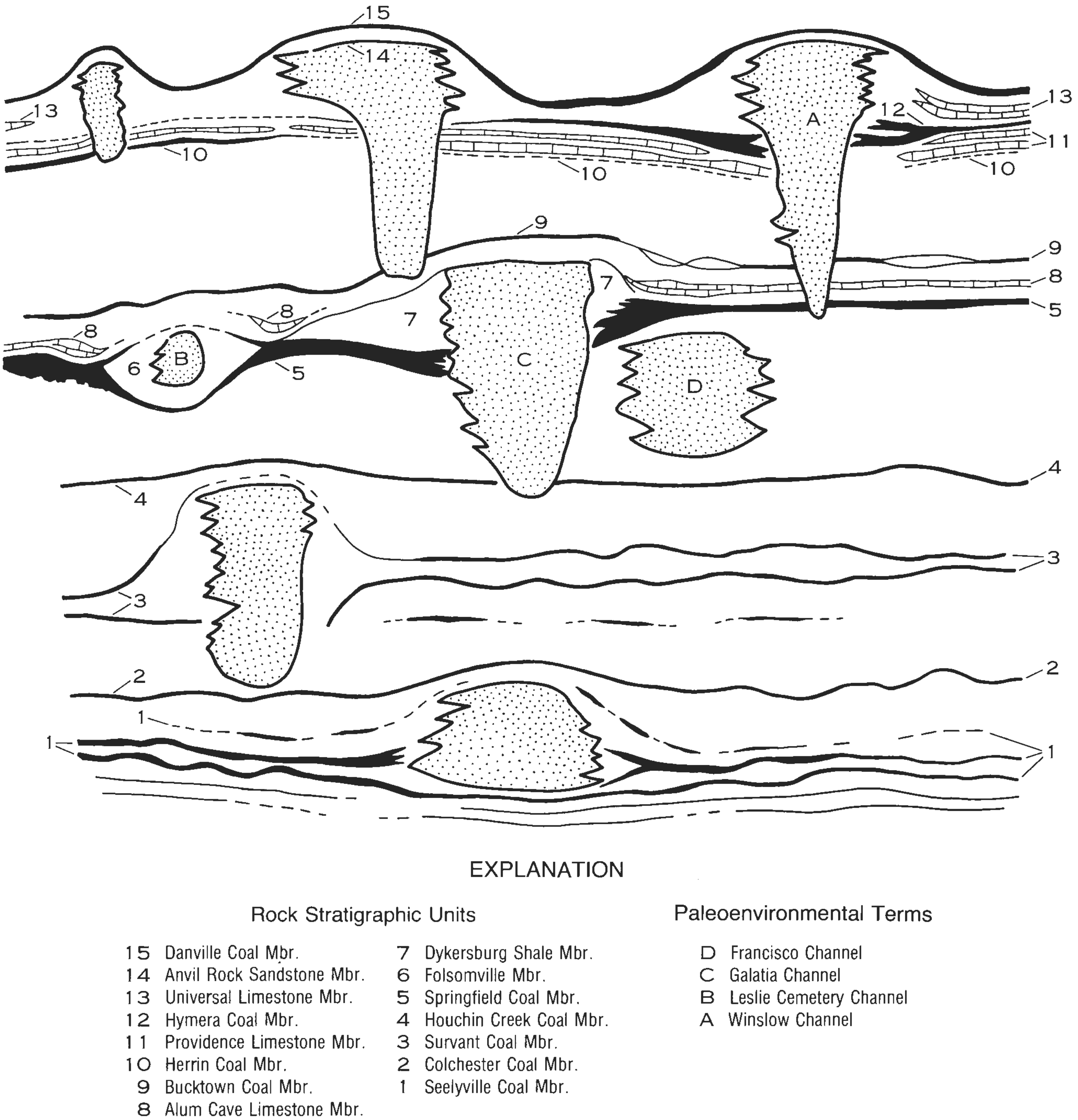

Figure 3. Diagrammatic sectional view of interval from the upper part of the Staunton Formation through the Danville Coal Member of the Dugger Formation in Gibson County.

the Waltersburg Sandstone. Pennsylvanian sediments in Gibson County consist of shales, sandstones, siltstones, and thinner coals and limestones. It is within this sequence of rocks that the economic coals occur. Pennsylvanian rocks are assigned in Indiana to the Raccoon Creek, Carbondale, and McLeansboro Groups. All three groups are present in Gibson County.

The oldest Pennsylvanian rocks in Gibson County are those assigned to the Raccoon Creek Group, which consists of the Mansfield, Brazil, and Staunton Formations. These formations are difficult to define. They consist in many places of sandstone, shale, thin coal, and thin limestone beds that have not been correlated with other named stratigraphic units. Separating the top of the Brazil Formation from the base of the Staunton Formation is difficult, but marine limestones in the Staunton Formation help differentiate it from the Brazil and Mansfield Formations. Although most of the unnamed Staunton coals below the Seelyville Coal Member are thin, some are at least 3 to 5 feet (1 to 1.5 m) thick. The Seelyville coal is commonly split into two or three recognized seams. Wier and Gray (1961) placed the top of the Staunton Formation at the top of the Seelyville coal. In Gibson County, however, one or two of the Staunton coal splits are missing from some places, and their position is occupied by contemporaneous shale or sandstone. The Tri-State Committee on Correlation of the Pennsylvanian System in the Illinois Basin (in press) has placed the boundary of the Staunton Formation at the top of the Seelyville Coal Member. Therefore, these sandstones and shales are assigned to the Staunton Formation where overlain by a younger split of the Seelyville coal and to the Linton Formation where the upper coal is missing.

Burger (1970b) formalized the definition of the Linton Formation, so that the base of the Linton Formation is whatever rock type directly overlies the Seelyville coal. As noted, some rocks above the lower split of the Seelyville coal are assignable to either the Staunton Formation or the Linton Formation. The problems of recognizing the Linton Formation in Gibson County are not restricted to its base.

The contact of the Linton Formation is defined as the top of the Survant coal, which is also split. One bench or another is missing along a fluvial channel contemporaneous with the coal. Therefore, the upper and lower contacts of this formation are variable and limited in value as mappable formational boundaries.

Burger and Wier (1970) defined the overlying Petersburg Formation as the interval from the top of the Survant coal to the top of the Springfield coal. The Petersburg Formation in Gibson County shares with the underlying Linton Formation a confused contact that is based on the split Survant coal. The Petersburg in this county consists of the Houchin Creek Coal Member, the Springfield Coal Member, and the Folsomville Member. Ledvina and Shabria (1985) proposed that the sandstone fill of the Galatia Channel be assigned member rock-stratigraphic rank in Illinois.

Burger (1970) defined the Dugger Formation as the rocks above the Springfield coal to the top of the Danville coal. For the past several decades geologists have discussed the correlation of the Hymera Coal Member, the Universal Limestone Member, and the Danville Coal Member and their relationship to what have been called the Lower and Upper Millersburg Coals in Gibson, Pike, and Warrick Counties. On the basis of subsurface mapping completed for this report, I have correlated the Hymera coal of Knox County with the first coal above the Providence Limestone Member (Dugger Formation) in Gibson County. This coal is split along a fluvial channel that is contemporaneous with the deposition of the coal, and it is on the opposite site of the channel in Pike and Warrick Counties, where it has been referred to as the Lower Millersburg Coal. The Universal limestone is in far western Gibson County, and it may correlate with the limestone above the Hymera coal in Warrick County. The Danville coal is in Gibson County at variable intervals above the Hymera coal and is above the sandstones that have eroded or were contemporaneous with the Hymera coal.

## SEDIMENTATION AND COAL RESOURCES

Pennsylvanian coal seams were deposited as peat in swamps roughly 280 to 310 million years ago. There are more than 30 coal beds in the county, but only a few are thick or laterally extensive enough to be mined. The sequences of coal beds and associated strata in the county are somewhat repetitious, and some might call them cyclic. The coal seams vary in thickness; there are major changes in chemical characteristics both between beds and in their lateral extent within the county. These variations are the product of the depositional habitat of each coal seam.

Chemical analyses are included to demonstrate the variations in Gibson County coal (table 1), but the number of these analyses is small. Mean and average values are presented for reference only. The depositional setting determines the chemical character of these coal seams and controls their economic potential.

The depositional and geologic setting of each coal bed determines whether the coal bed can be mined and sold in the prevailing market place. The chemical properties are among those that are used to determine the value and use of a coal in the open market. Other geologic controls, such as depth and thickness, determine whether a coal bed will be surface- or deep-mineable. Deep-mineable coals require relatively strong and stable roof and floor rock. These are all products of the depositional environment.

## COALS BELOW THE SEELYVILLE COAL MEMBER

A number of coals are below the Seelyville in Gibson County. The coals in the oldest Pennsylvanian strata in the county are assigned to the Mansfield Formation and to the overlying Brazil Formation. These coals are generally less than 1.5 feet (0.5 m) thick and have not been traced geographically in the subsurface. Limestones or other marine beds have not been

Table 1. Chemical analysis of Indiana Geological Survey coal samples from Gibson County, Indiana

| Coal | Sample number | Location | | | Thickness (ft) | Ash (%) | S (%) | Btu |
|---|---|---|---|---|---|---|---|---|
| | | Sec. | T. | R. | | | | |
| Unnamed coal in Shelburn Fm. | 83 X 10 | 18 | 1 S. | 9 W. | 0.8 | 18.5 | 5.1 | 1,306 |
| Danville Coal Member | 73 X 11 | 11 | 3 S. | 9 W. | 3.0 | 9.1 | 3.8 | 13,090 |
| | 76 X 30 | 25 | 2 S. | 9 W. | 3.7 | 10.1 | 3.6 | 12,840 |
| | 76 X 48 | 25 | 2 S. | 9 W. | 3.75 | 13.9 | 4.8 | 12,120 |
| | 82 X 05 | 29 | 2 S. | 9 W. | 2.6 | 23.0 | 5.9 | 10,620 |
| | 83 X 02 | 18 | 1 S. | 9 W. | 2.45 | 14.0 | 4.1 | 11,820 |
| Hymera Coal Member | 76 X 31 + 32 | 25 | 2 S. | 9 W. | 3.1 | 22.1 | 3.8 | 10,400 |
| | 76 X 46 + 47 | 25 | 2 S. | 9 W. | 3.65 | 24.5 | 3.2 | 10,270 |
| | 76 X 36, 37 + 38 | 34 | 3 S. | 9 W. | 9.8 | 32.0 | 3.3 | 8,920 |
| | 78 X 33 | 33 | 3 S. | 9 W. | 1.0 | 31.5 | 1.9 | 9,390 |
| | 82 X 06 | 29 | 2 S | 9 W. | 4.5 | 24.0 | 2.5 | 10,114 |
| | 83 X 03 | 18 | 1 S. | 9 W. | 0.45 | 11.4 | 2.6 | 12,073 |
| Springfield Coal Member | 57 X 34 | 21 | 2 S. | 11 W. | 6.1 | 8.1 | 1.7 | 13,120 |
| | 57 X 35 | 31 | 2 S. | 10 W. | 6.2 | 9.6 | 3.4 | 13,030 |
| | 63 X 01 | 32 | 2 S. | 8 W. | 2.5 | 8.7 | 6.0 | 12,860 |
| | 67 X 05 | 29 | 2 S. | 8 W. | 3.9 | 7.1 | 3.1 | 13,290 |
| | 70 X 20 + 21 | 24 | 2 S. | 11 W. | 7.7 | 23.1 | 1.3 | 10,500 |
| | 70 X 22 | 24 | 2 S. | 11 W. | 7.7 | 13.7 | 2.3 | 11,960 |
| | 73 X 13 | 5 | 3 S. | 8 W. | 5.1 | 9.3 | 4.1 | 12,970 |
| | 78 X 34 + 35 | 33 | 3 S. | 9 W. | 6.7 | 16.5 | 3.2 | 9,950 |
| | 79 X 06 + 07 | 34 | 3 S. | 9 W. | 7.7 | 18.8 | 4.5 | 11,160 |
| | 79 X 09 + 10 | 34 | 3 S. | 9 W. | 7.0 | 24.7 | 3.5 | 8,927 |
| | 82 X 07 | 29 | 2 S. | 9 W. | 5.7 | 12.9 | 4.6 | 9,506 |
| Houchin Creek Coal Member | 82 X 08 | 29 | 2 S. | 9 W. | 1.6 | 19.0 | 6.1 | 10,843 |
| Survant Coal Member | 82 X 09 | 29 | 2 S. | 9 W. | 0.45 | 17.6 | 11.0 | 10,959 |
| | 83 X 05 | 18 | 1 S. | 9 W. | 0.2 | 19.5 | 4.2 | 11,384 |
| Colchester Coal Member | 82 X 10 | 29 | 2 S. | 9 W. | 0.3 | 10.3 | 4.3 | 12,763 |
| | 83 X 06 | 18 | 1 S. | 9 W. | 0.6 | 6.2 | 2.8 | 13,482 |
| Seelyville Coal Member | 82 X 11 + 12 | 29 | 2 S. | 9 W. | 8.4 | 11.3 | 3.5 | 12,170 |
| | 83 X 07 + 08 | 18 | 1 S. | 9 W. | 3.3 | 23.4 | 10.5 | 10,060 |
| Unnamed coal in Staunton Fm. | 83 X 09 | 18 | 1 S. | 9 W. | 0.9 | 22.7 | 3.2 | 10,504 |
| | 83 X 10 | 18 | 1 S. | 9 W. | 3.8 | 14.6 | 6.1 | 12,090 |

recognized in proximity to these coals. Some of these coals may be low-sulfur coals because they are associated with fluvial and upper-delta deposits, but they are likely too thin and deep for recovery.

Also below the Seelyville in Gibson County are strata assigned to the Staunton Formation. In several areas coal beds that are between 4 and 5 feet (1.2 and 1.5 m) thick and that persist laterally can be recognized on geophysical logs for some distance. Beds of black fissile shale and limestone are commonly directly above these coals. These coals are likely high-sulfur coals because of their probable exposure to brackish to marine water. They are much too deep for surface mining. Roof conditions might be favorable for deep mining because the limestones and black fissile shales above the coals are usually quite stable roof rocks.

## SEELYVILLE COAL MEMBER

Although the Seelyville coal has been mined extensively in Clay, Greene, Sullivan, and Vigo Counties and one mine has been opened in northeastern Vanderburgh County, this coal has never been mined in Gibson County. In recent years there has been renewed interest in this coal interval in Gibson, Posey, Vanderburgh, and Warrick Counties, which compose the southwestern region of the Indiana coal field. A major objective of this report is to better explain the nature of this coal in Gibson County.

In Gibson County the Seelyville coal is a complex group of coal layers (benches) or closely related beds (seams) split by clastic sediments. Geophysical logs used in this report indicate that the Seelyville may be absent beneath the fluvial channels contemporaneous with the coal. Most geophysical logs or coal-drilling records indicate that the Seelyville consists of two coal beds separated by 1 to several feet (.3 to 1.0 m) of shale and that each bed can be as much as 5 feet (1.5 m) thick. These two coal beds seem to be split near the contemporaneous channels. A third, but very thin, layer or bed less than 16 inches (0.3 m) thick is commonly present below the Colchester Coal Member and above the two persistent beds. Correlation of these coal beds is difficult; therefore, this report maps coal thickness and calculates resources on the sum of the Seelyville coal (fig. 4; table 2). Again, because of the complexity of this coal interval, the base of the lowest coal in the interval is the reference elevation for the structure map of this coal.

The geologic data indicate that the Seelyville coal formed within a deltaic environment. This coal rests on a mudstone substrate that coarsens upward and that may represent a prodelta deposit. Multiple coal seams in the Seelyville interval may represent the establishment and abandonment of several deltaic lobes. Several sandstone-filled fluvial channels in Gibson County provide further evidence for this theory of multiple delta lobes (fig. 5). The fluvial nature of these sandstones is demonstrated by their fining-upward particle size and their geometry. These channels seem to be mostly younger than or contemporaneous with the middle seam of the Seelyville coal. These streams may have eroded the peat of the middle seam, or the peat may not have been deposited in active channel areas. Therefore, the upper and middle coals are commonly missing in areas where these fluvial-channel deposits are present.

Chemical analysis of this coal was restricted to four samples representing two benches of Seelyville coal from two Indiana Geologic Survey drill holes. The net coal thickness of these samples ranges from 3.3 feet (1 m) to 8.4 feet (2.5 m). The ash content varies from 10.0 to 24.2 percent, sulfur content deviates from 1.7 to 11.3 percent, and thermal values range from 10,024 to 12,529 Btu/lb. The high sulfur content of the Seelyville coal may delay large-scale mining until the coal can be used without polluting the air. Although the changes in the chemical characteristics of this coal are significant, not enough information is available to predict variation in chemical content throughout the county.

More than 2.6 billion short tons of Seelyville coal is present in Gibson County in one to five benches. Most of this resource is in the lower two benches, which are thick enough to be mined over large areas of this county by present mining technology. But mining both benches at the same time may pose technical, environmental, and safety problems that cannot be overcome, and therefore only one bench may be mineable in a given area. Finally, because there has been only one deep mine in this interval within 25 miles of Gibson County and because there are no published reports on conditions at this mine, there is a general lack of information about mining conditions, such as roof falls, rolls, or water problems, that may be encountered. The geology of this coal indicates, however, that conditions would be similar to other coals that have been successfully deep mined.

## COLCHESTER COAL MEMBER

The depositional setting of the Colchester coal is an enigma. Coal thickness variations of many coal seams offer clues to the formation of a particular coal, but the Colchester coal does not show measurable variation. It is not contemporaneous with any fluvial channels within Gibson County. This coal generally overlies a coarsening-upward sequence of mudstone, siltstone, and fine-grained sandstone, and it underlies black fissile shales. This evidence indicates that it may have formed on a delta or coastal plain that was abandoned after peat deposition stopped. Baird and others (1985) reported on the origin of the strata associated with this coal in northeastern Illinois, and they presented sedimentological evidence showing fluvial deltaic processes similar to those found in Gibson County in the Springfield and Hymera coals. The Colchester is overlain by a black fissile shale that represents the establishment of a shallow brackish to marine environment after peat deposition stopped. This may have allowed for a further sulfide mineralization of the peat and the ensurance of a high-sulfur coal.

Figure 4. Map of Gibson County showing the distribution and thickness of the Seelyville Coal Member.

Table 2. Coal resources of the Danville, Hymera, Herrin, Springfield, and Seelyville Coal Members

| Coal | Thickness | Original resources* | Mined out or lost in mining* | Remaining resources* |
|---|---|---|---|---|
| Danville Coal Member | 2.5-3.5 | 384,000 | | 384,000 |
| | 3.5-4.5 | 36,600 | | 36,600 |
| Total Danville Coal Member | | 420,600 | | 420,600 |
| Hymera Coal Member | 2.5-3.5 | 174,400 | | 174,400 |
| | 3.5-4.5 | 225,800 | | 225,800 |
| | 4.5-5.5 | 62,200 | | 62,200 |
| | 5.5-6.5 | 13,800 | | 13,800 |
| Total Hymera Coal Member | | 476,200 | | 476,200 |
| Herrin Coal Member | 2.5-3.5 | 122,000 | | 122,000 |
| | 3.5-4.5 | 55,800 | | 55,800 |
| Total Herrin Coal Member | | 177,800 | | 177,800 |
| Springfield Coal Member | | | | |
| High sulfur** | 2.5-3.5 | 130,300 | | 130,300 |
| | 3.5-4.5 | 948,500 | 7,500 | 941,000 |
| | 4.5-5.5 | 490,300 | 14,300 | 476,000 |
| | 5.5-6.5 | 234,700 | 18,700 | 216,000 |
| | 6.5-7.5 | 143,600 | 10,400 | 133,200 |
| | 7.5-8.5 | 50,000 | 300 | 49,700 |
| | 8.5-9.5 | 30,700 | | 30,700 |
| | > 9.5 | 9,800 | | 9,800 |
| Total high sulfur | | 2,037,900 | 51,200 | 1,986,700 |
| Probable low sulfur*** | 2.5-3.5 | 3,400 | | 3,400 |
| | 3.5-4.5 | 72,300 | | 72,300 |
| | 4.5-5.5 | 150,500 | 1,500 | 149,000 |
| | 5.5-6.5 | 187,900 | 30,500 | 157,400 |
| | 6.5-7.5 | 110,600 | 12,800 | 97,800 |
| | 7.5-8.5 | 25,800 | 5,200 | 20,600 |
| Total low sulfur | | 550,500 | 50,000 | 500,500 |
| Total Springfield Coal Member | | 2,588,400 | 101,200 | 2,487,200 |
| Seelyville Coal Member | < 3.5 | 400,300 | | 400,300 |
| | 3.5-4.5 | 381,400 | | 381,400 |
| | 4.5-6.5 | 1,381,500 | | 1,381,500 |
| | 6.5-7.5 | 359,900 | | 359,900 |
| | 7.5-8.5 | 99,900 | | 99,900 |
| | > 8.5 | 24,200 | | 24,200 |
| Total Seelyville Coal Member | | 2,647,200 | | 2,647,200 |

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*In thousands of tons.

**Springfield coal resources having sulfur content greater than 2.5 percent.

***Springfield coal resources overlain by more than 20 feet (7 m) of nonmarine Dykersburg Shale Member and having a sulfur content probably less than 2.5 percent.

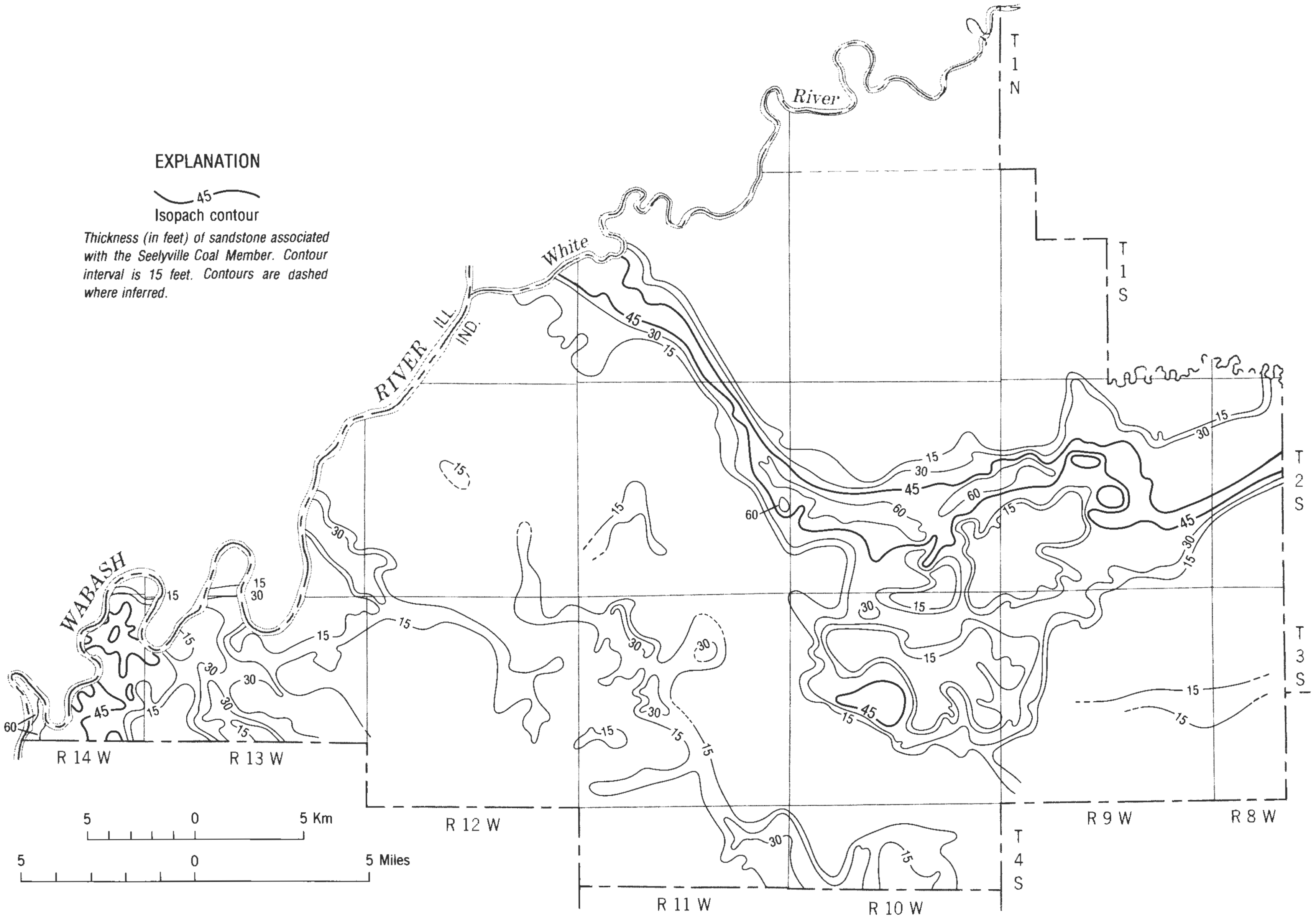


Figure 5. Map of Gibson County showing the distribution of fluvial sandstone-filled channels associated with the Seelyville Coal Member.

The Colchester coal underlies nearly all of Gibson County. This seam is generally less than 16 inches (0.4 m) thick and only rarely exceeds this thickness. The thin nature and depth of burial prevent this coal from being mined by present technology. There are chemical analyses for only two samples from Gibson County. These samples have the following ranges: 6.2 to 10.3 percent ash, 2.8 to 4.3 percent sulfur, and 12,763 to 13,482 Btu/lb (table 1). A fair assumption is that any development of this seam will be by highly theoretical in situ combustion.

The Colchester is one of the easiest coals within the Carbondale Group to identify on conventional resistivity and spontaneous potential electric logs.

## SURVANT COAL MEMBER

The Survant coal in Gibson County is split into two seams rarely thicker than 2.5 feet (0.6 m). In some places both seams are absent. In Greene, Sullivan, and Vigo Counties this coal is at least 4 feet (1.2 m) or more thick and has low ash, low to moderate sulfur, and high thermal values.

The Survant coal is clearly a deltaic coal. A major fluvial channel is contemporaneous with the upper bench of the coal, and both benches in many places rest above coarsening-upward bay-fill or barrier-mouth bar deposits (fig. 6). The origin of the two benches probably is the result of the abandonment of the original delta lobe followed by renewed fluvial deltaic deposition and the formation of the second delta plain with its upper coal.

Only two samples of the Survant coal from Gibson County have been analyzed by the Indiana Geological Survey. The analyses show 17.6 to 19.5 percent ash, 4.9 to 11.0 percent sulfur, and 10,959 to 11,385 Btu/lb moisture ash free (see table 1).

It is unlikely that this coal could ever be economically mined by conventional methods. Only in a small area north of Princeton is this coal as much as 4 feet (1.2 m) thick. Electric log signatures indicate that this coal is at least 2 feet (0.6 m) thick over a much of the county. The Survant coal might be recovered by in situ methods.

## HOUCHIN CREEK COAL MEMBER

The Houchin Creek coal ranges from less than 16 inches (0.4 m) to 4 feet (1.2 m) thick and is absent in places where it has been eroded later by the Galatia fluvial channel. Because it is generally too thin for conventional mining, this coal might also be recovered by in situ methods. Like the Colchester coal, the Houchin Creek coal can be recognized easily on most conventional electric logs because of its "bird's-beak signature." This unusual dual shift is caused by the high resistivity of the upper part of the black fissile shale that overlies the coal. The Houchin Creek coal is such a good marker bed that it could be used in making detailed structure maps for petroleum exploration.

The exact depositional environment of the Houchin Creek coal cannot be positively determined from the limited evidence found in Gibson County. It generally is above a coarsening-upward sequence, but there are no fluvial channels contemporaneous with the coal in this county. It is most likely a deltaic coal.

Chemical analysis of the one sample analyzed was 19.0 percent ash, 8.1 percent sulphur, and 10,843 Btu/lb (table 1).

## SPRINGFIELD COAL MEMBER

The most important coal in Gibson County is the Springfield coal. The original resources of this seam were about 2.6 billion short tons (table 2). This is the oldest and deepest coal mined in the county. The Springfield coal has had more mines in operation and has yielded more tons of coal than any other seam mined in this county. About 2.5 billion short tons is still mineable. Unlike the coal resources of the Seelyville, which are in split seams, those of the Springfield are in primarily one seam and are more likely to be mined. Because other coals in Gibson County have much less recoverable coal, the Springfield will be the most important coal bed in the economic development of this area.

The Springfield has been the subject of a number of reports (Eggert 1982a, 1982b, 1982c, 1983, 1984, 1994a, 1994b; Eggert and Adams, 1979, 1985; Eggert and others, 1983). These reports detail the depositional setting of the Springfield coal and identify fluvial channels, bay-fill sediments, backswamp, crevasse splay, and lacustrine sediments associated with the coal. The geographic distribution of these depositional features determines the presence or absence of the coal, its thickness, ash content, thermal value, sulfur content, and the lithology of the roof and floor.

The thickness of the Springfield coal is the most important economic factor. Because of its sedimentologic history, this coal may be absent or may be more than 12 feet (3 m) thick (fig. 7). The depositional history of the Springfield coal consists of three stages: deposition of earlier fluvial and deltaic sediments, deposition of peat, and later sedimentation and erosion.

Pennsylvanian deposits beneath the Springfield coal in Gibson County consist of shales, sandstones, siltstones, coals, and thin limestones. Differential compaction of these sediments and tectonic subsidence determined the surface topography that controlled the location of the deltaic fluvial channels and interdistributary bays of the delta on which the Springfield was deposited.

Fluvial channels in and bay environments of the Springfield coal were determined by using geophysical logs in mapping the distribution of fluvial sandstones and bay-fill sediments (fig. 8). Two major channel systems were identified: the earlier Francisco Channel and the later Galatia Channel. Hopkins and

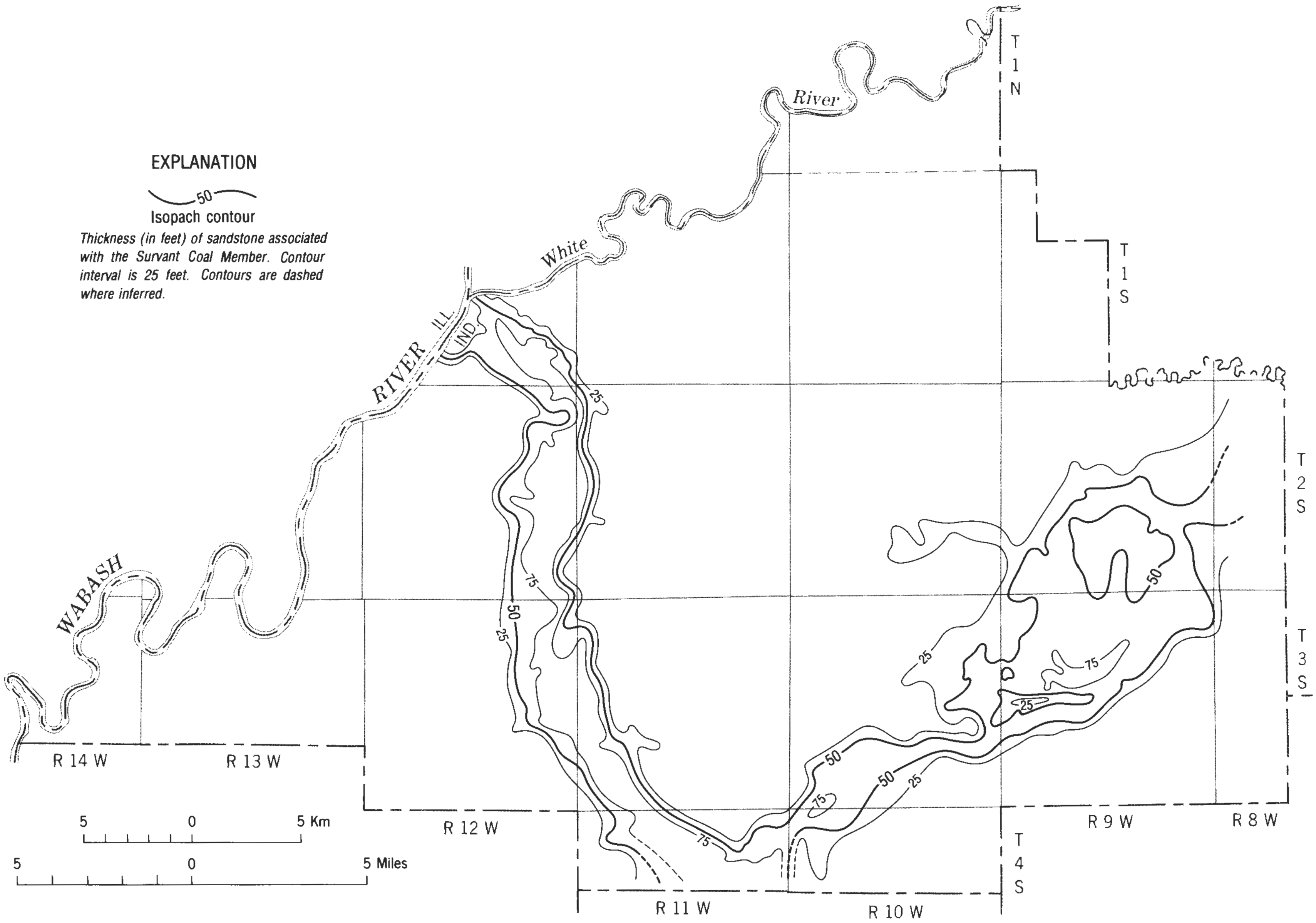


Figure 6. Map of Gibson County showing the distribution of fluvial sandstone-filled channels associated with the Survant Coal Member. Isopach interval 25 feet.

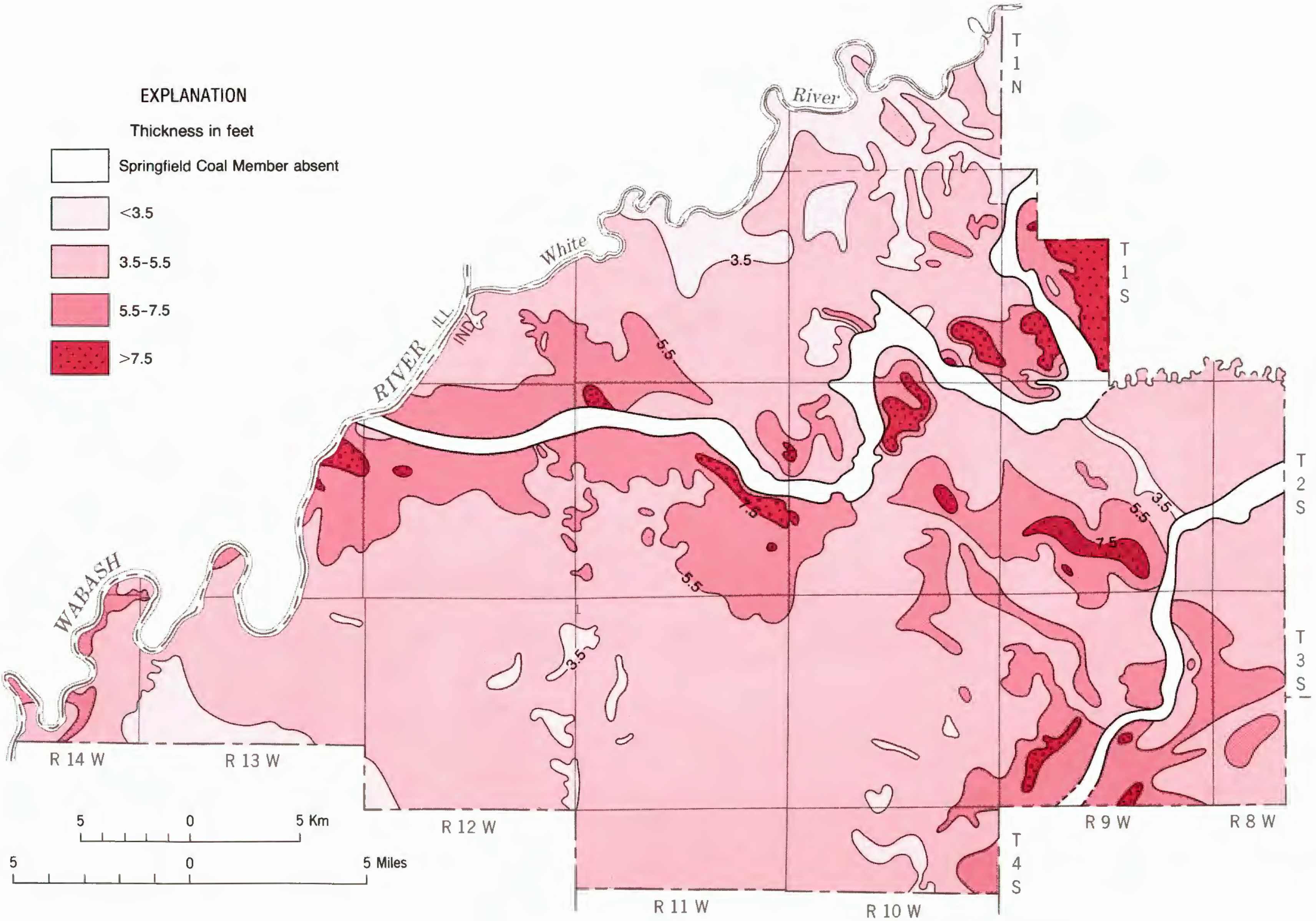


Figure 7. Map of Gibson County showing the distribution, thickness, and extent of the Springfield Coal Member.

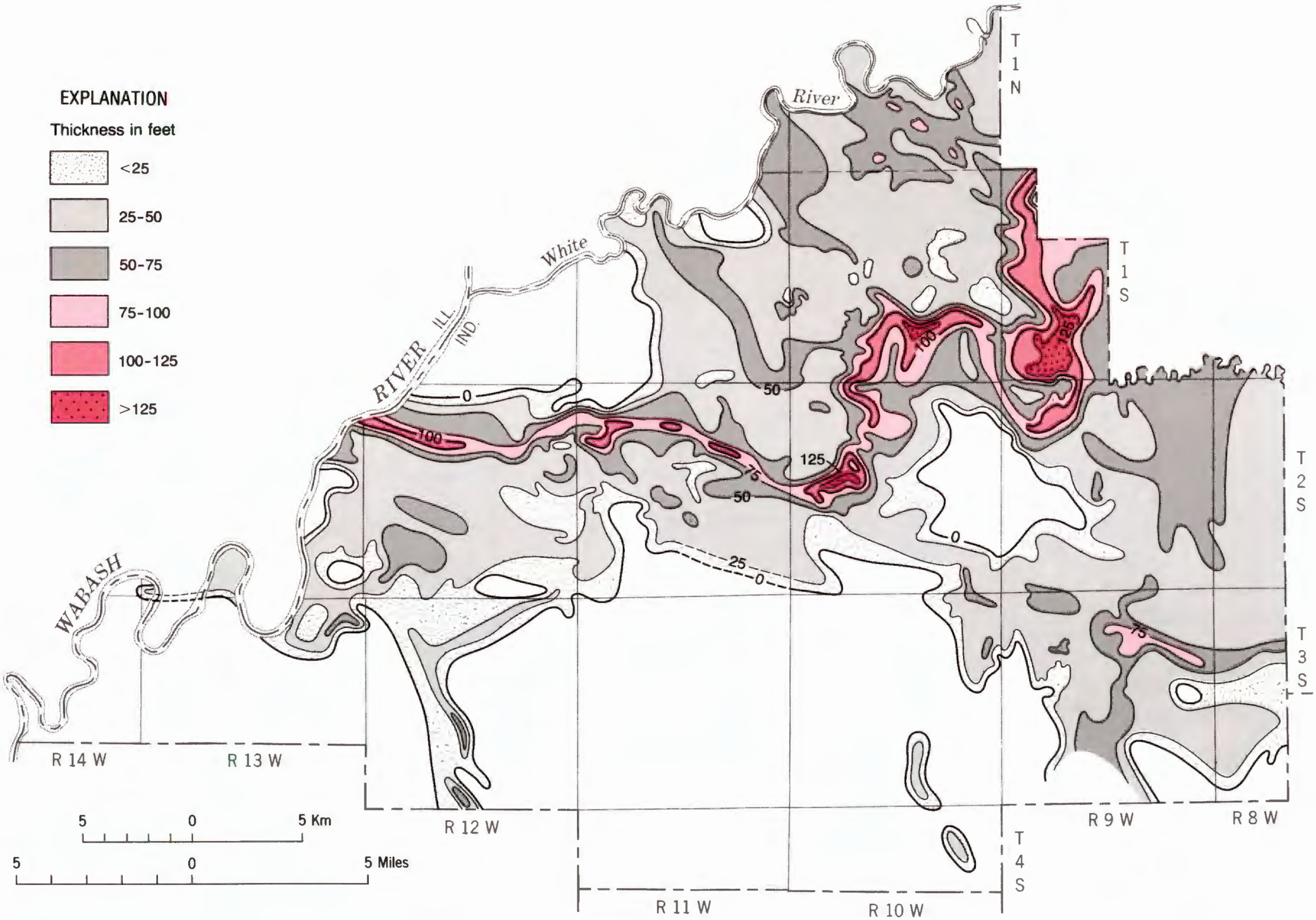


Figure 8. Map of Gibson County showing the distribution and thickness of sandstone-filled channels associated with the Springfield Coal Member.

others (1979) proposed the term "Galatia Channel" for a channel-fill sandstone contemporaneous with the Springfield Coal Member in southeastern Illinois. The Francisco Channel was first described and reported by Eggert (1982a, 1982b, 1984) for a wide sandstone-filled channel complex in southeastern Gibson County that consisted of a parallel-trending series of meandering channels generally less than 75 feet (22 m) thick. Eggert (1983, 1987) also found this complex in northeastern Gibson County. The Galatia Channel is narrower, and its sandstone fill exceeds 125 feet (38 m) in thickness. These two sand-filled channels represents the framework of the delta platform upon which the Springfield coal was deposited, and the space between these channels represent former interdistributary bays. The bays were infilled with mud, silt, and fine-grained sand in coarsening-upward sequences that can be less than 40 feet (12 m) to more than 120 feet (37 m) thick. Deltaic clastic sediments and earlier deposits underlie the surface upon which the Springfield peat formed. These deposits compacted differentially during the peat deposition.

The Galatia Channel was a prograding fluvial channel during deposition of the peat that became the Springfield coal. The earliest Springfield peat swamps formed near the margins of the Galatia Channel but were absent within the channel areas. As the Galatia Channel advanced seaward, the peat swamp gradually colonized the interdistributary bays distal to the channels. Eggert and Adams (1985) referred to this coal as time-transgressive and noted that the interval between the Springfield and the next older coal, the Houchin Creek, thickened from the Galatia Channel margins toward the former interdistributary bays (fig. 9). Brown (1975) noted the importance of differential compaction in deltaic deposits. Differential compaction of the delta platform and earlier deposits combined with the more uniform basinal tectonic subsidence resulted in a variable sinking and variable water depth within the Springfield peat swamp. These factors determined the thickness, roof, and sulfur content of the Springfield coal. During peat accumulation, compaction and subsidence continued more rapidly along the margins of the Galatia Channel than in more distal areas. More peat could accumulate in the area proximal to the channel than in areas having a lower rate of subsidence and less available space, so that thicker coal would be near the channel. Moderately thick coal accumulated in areas distal to the Galatia Channel above areas underlain by thick bay-fill mud, silt, and fine-grained sand. Some of the thinnest Springfield coal is in northeastern Gibson County where thick sand-filled anastomosing channels of the Francisco system are beneath the coal. Because sand does not compact much, this area did not subside quickly to provide the needed space for thick peat formation. Where the Galatia Channel crossed the older channels of the Francisco system, there must have been enough compaction of earlier deposits to produce the needed subsidence for thick coal to have been deposited.

Similar compaction took place along part of the peat-buried Francisco Channel in southeastern Gibson County. This subsidence occurred along a linear trend at a rate such that peat deposition could not keep pace with the local subsidence. In this area organic shale and rash were deposited, and shortly afterwards a splay from the Galatia Channel initiated the Leslie Cemetery Channel. This channel is somewhat similar to the Terre Haute Channel mapped by Friedman (1956,1960). These sediments can be traced from near Princeton in Gibson County to northeast of Boonville in Warrick County, 30 miles away. The Leslie Cemetery Channel and earlier rash deposits are more than 40 to 50 feet (12 to 15 m) thick. Adjacent to this channel and the split coal is a parallel zone of thick coal, in many places greater than 6.0 feet (3 m) thick, which was deposited because differential compaction of earlier sediments induced greater subsidence in this area. The present distribution of the Springfield coal in Gibson County reflects geologic events and processes that took place before, during, and after its deposition.

The last modification in the distribution of this coal was the erosion of later fluvial channels. The Winslow Channel is a Pennsylvanian fluvial channel that was eroded into the Springfield coal in southeastern Gibson County. This channel is believed to be contemporaneous with the Hymera coal (Eggert, 1982b, 1984). Modern and postglacial rivers may have eroded the Springfield in the far northeastern part of the county.

Some of these processes and the geologic history of this coal determined the high- or low-sulfur content of the Springfield coal in Gibson County. Personnel of the Indiana Geological Survey have collected 11 coal samples from areas of mostly high-sulfur coal within Gibson County. These samples range from 1.3 to 6.0 percent total sulfur with an average of 3.2 percent. Sampling of the coal is too sparse to determine sulfur distribution, but knowledge of the sedimentologic history of this coal can help predict areas of low-sulfur and high-sulfur coal.

The term "Dykersburg Shale Member" was introduced by Hopkins (1968) for a gray silty shale that is the immediate roof rock of what is now called the Springfield Coal Member. He described the stratigraphic relationships with other named units. The Dykersburg shale is linear in its distribution in southeastern Illinois. It thins and pinches out away from a sandstone-filled channel that occupies the position of the Springfield coal and that is now called the Galatia Channel. The Dykersburg shale is generally above the Springfield, but it can split the Springfield into two or more beds and render the coal unmineable. It is below the St. David Limestone Member, equivalent to the Alum Cave Limestone Member of Indiana and the hard black sheety marine shale. Hopkins noted that these two marine beds thinned and pinched out generally in areas where the Dykersburg shale exceeded 30 feet (9.2 m). In these areas the Dykersburg shale is overlain by the unnamed gray-shale units above the St. David limestone or by sandstones assigned to the Briar Hill Cyclothem. Hopkins presented several examples of electric logs that showed

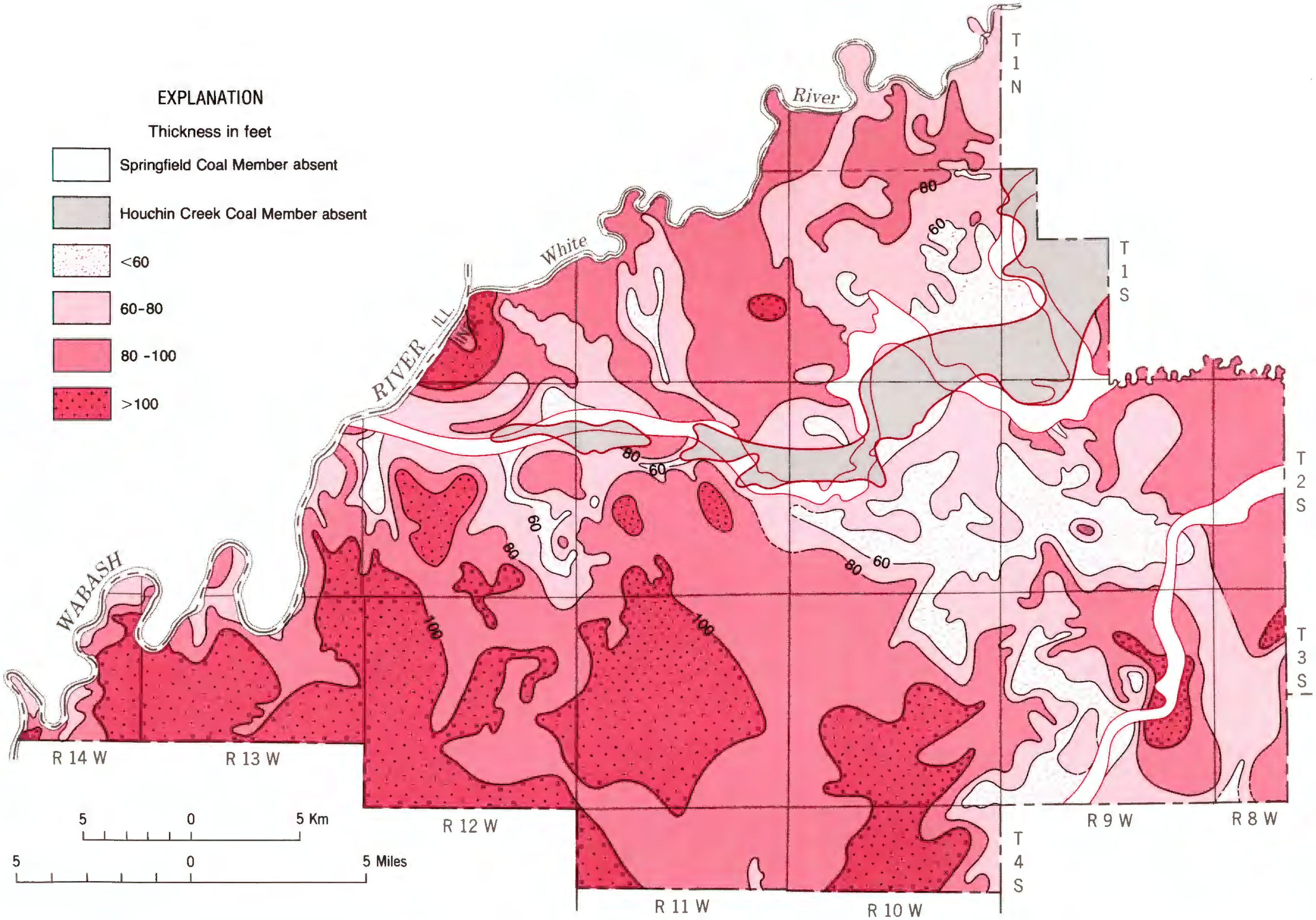


Figure 9. Map of Gibson County showing the thickness of the interval between the Houchin Creek and Seelyville Coal Members.

the Springfield Coal, Dykersburg Shale, St. David Limestone, and the Briar Hill Coal Members. These illustrations suggest that the Dykersburg can be recognized from other gray shales in that it has a higher resistivity than the marine shale below and above the St. David limestone.

In Gibson County the Dykersburg shale can be recognized on geophysical logs. This unit has a resistivity intermediate between the other shales and fine-grained sandstones. It pinches out distal to the Galatia Channel but thickens toward the channel axis (fig. 10). This unit distal to the channel is found below the Alum Cave limestone and its unnamed black slaty shale. The interval between the Springfield and Alum Cave thickens toward the Galatia Channel because of the thickening wedge of Dykersburg shale until the Dykersburg shale is 30 feet (9.2 m) thick. At that point, as found by Hopkins, the marine marker beds pinch out on the thicker wedge of shale (fig. 11). The interval between the Springfield coal and the Bucktown coal also increases toward the channel axis (fig. 12). Near the channel axis, in western Gibson County, the Bucktown coal generally rests on a thin fine-grained sandstone that rests on the top of the Dykersburg shale. Near the Galatia Channel the Dykersburg shale may be more than 80 feet (24 m) thick. The mapped extent of the Dykersburg shale correlates well with the extent mapped by Hopkins in southeastern Illinois (fig. 13).

It has been a custom in Indiana to use coals as the tops of Pennsylvanian formations. In keeping with this convention the Dykersburg is assigned to the Dugger Formation, which overlies the Petersburg Formation and Springfield Coal Member. Therefore, where the Springfield coal is split by Dykersburg-like sediments, these shales are assigned to the Springfield coal.

The Dykersburg Shale Member and the Folsomville Member are areally distinct. They are both associated with paleochannels contemporaneous with the Springfield coal: the Galatia Channel with the Dykersburg, and the Leslie Cemetery Channel with the Folsomville. There are other lithologic and stratigraphic differences that justify the use of these two names. First, the Folsomville in many places contains significant volumes of sandstone. Second, the Folsomville is generally overlain and underlain by Springfield coal. Third, the Folsomville is generally thinner and narrower than the Dykersburg. Fourth, the two units have not been shown to connect, although the Folsomville does terminate against the Galatia Channel. In summary, both unit names are used because they are lithologically and areally distinct and because their use provides a stratigraphic identity to depositional and sedimentological understanding of these sediments.

Previous studies reported that thick nonmarine gray-shale roof rocks, such as the Dykersburg shale or the shales within the Folsomville Member, prevented postdepositional sulfide mineralization of the peat directly beneath. Ashley (1920) reported the association of lower sulfur coals with gray-shale roof deposits. Hopkins (1968) identified areas of low-sulfur Springfield coal in southeastern Illinois by mapping areas of Springfield coal overlain by 20 feet (6 m) or more of the gray nonmarine Dykersburg Shale Member found along the channel now considered the Galatia Channel. Eggert (1984) found that the thickness of the Dykersburg shale could be inferred from geophysical logs by measuring and mapping the thickness of the intervals between the Springfield coal and the overlying Alum Cave Limestone and Bucktown Coal Members. In western Gibson County the interval between these units increases toward the Galatia Channel, which suggests that over 86 square miles (223 sq km) of Springfield coal is overlain by Dykersburg shale thicker than 20 feet (6 m) and that this coal may be a low- to moderate-sulfur coal (fig. 6). Because only small areas of Dykersburg shale extend from the Galatia Channel in eastern Gibson County, only limited areas of low-sulfur Springfield coal are adjacent to the channel. Eggert (1983, 1984) attributed the absence of this unit in the east and its thick development in the west to differential compaction of the delta platform. The delta platform on which the Springfield coal was deposited in the eastern part of the county is largely composed of thick Francisco Channel deposits, which did not compact as much as the mud, silt, and clay sediments that make up the platform in the western part of the county. The compaction of the delta platform permitted space needed for the deposition of the lacustrine and overbank muds that the Dykersburg shale represents. Also in the southeastern half of the county is the Leslie Cemetery Channel. Eggert (1978, 1982a) and Eggert and others (1983) have identified low-sulfur coal beneath thick deposits of the Folsomville Member in Warrick County. Although no samples of this coal have been collected in Gibson County beneath thick Folsomville sediments, conditions are favorable for as much as 5 square miles (13 sq km) of low-sulfur Springfield coal.

The location of fluvial channels and coal areas having variable sulfur content has an impact on the ash and thermal character of the coal. Analysis by the Geological Survey of the Springfield coal samples shows an ash content from 7.1 to 27.6 percent with an average of 14.1 percent. Thermal values range from 8,927 to 13,290 Btu/lb with an average of 11,500 Btu/lb (table 1). High-ash coal is adjacent to the contemporaneous channels where the coal is split by clastic sediments. These high-ash areas are zones of coal having low thermal-value as well. The coal having the highest value as a fuel is the low-sulfur unsplit coal near but not directly adjacent to the Galatia Channel. Eggert (1982a) found the lowest ash coal beneath thick Folsomville deposits. He postulated that the higher-sulfur coals had high ash content partly because of their sulfide-mineral content and this contributed to the high-temperature ash content of the coal.

Along the Galatia and Leslie Cemetery Channels beside zones of thin clastic partings that result in high-ash coal are partings that are easily visible in a mine, in cores, and on geophysical logs. These partings are composed of mudstone, siltstone, and fine-grained sandstone. Such a parting may be variable in thickness, may be uniform in thickness, or thicken toward the channel. These splits may reduce the market value of the coal if they reduce the thermal value of the product, and they may increase the cost of mining if they require special handling underground or require washing of the coal to remove rock from the raw product. Severe splitting may prevent mining outright because of poor roof conditions or reduction in the thickness of mineable coal.

Mining conditions of the Springfield coal are partly dependent on the depositional history of the coal and structural depth, faulting, and erosion. This coal has been both surface and deep mined (Weber, 1984; Irwin and Weber, 1986). Surface mining has been restricted to the far eastern edge of the county because of the regional dip and the decreasing ratio between coal thickness and overburden thickness westward. This coal has been mined in one large mine, the Kings Station Mine, and in 11 small underground mines since 1892. Trade journal reports and personal communication with retired miners and engineers indicate general good roof and floor conditions in these mines. Some roof failures have been associated with roof concretions in mines having black fissile shale roofs. Differential compaction of the underlying strata has produced irregular coal elevations that may have increased roof failures in areas where the coal is domed upwards. Eggert (1982a) has found that the lower bench of Springfield coal beneath the Leslie Cemetery Channel can be overlain by rash—highly organic shale that is weak and slakes easily. Therefore, mining beneath this deposit will be difficult. Cady (1919) discussed mining conditions in underground mines near the Galatia Channel in Saline and Gallatin Counties, Illinois. Meier (1985) described in detail conditions at the Wabash Mine of the Amax Coal Company, which is south of the Galatia Channel in Wabash County, Illinois, and western Gibson County. He discussed problems associated with the Dykersburg shale, splits, roof rolls, and floor rolls and listed ways to minimize adverse mining conditions.

Roof problems may also be encountered in areas where the Dykersburg shale thins. Mining experience in other areas indicates that zones having transitional roof rock are more prone to failure because of multiple bedding planes that can be planes of weakness. Greater caution may therefore be needed when mining near the edge of the gray-shale Dykersburg roof.

The deep mines in Springfield coal were considered gassy, and several explosions resulted in deaths and injuries. One in situ gas sample has been collected from this seam, and its gas content indicates that modern mine ventilation and rock dusting practices reduce the risk of an explosion.

There will be future deep mining and limited surface mining of the Springfield coal. Significant coal resources thicker than 4.5 feet (1.4 m) occur in several areas (table 1).

## HERRIN COAL MEMBER

The Herrin coal in Gibson County thins abruptly to the east and in places grades into marine shales both above and below. The thickest Herrin coal is in the westernmost part of the county, where 3 to 4 feet (1 to 1.2 m) of coal is common. The Herrin and Springfield coals are the most important economic coal seams in the Illinois Basin, but economic Herrin coal in Indiana is limited because it is generally thin. This is true in Gibson County, where there is only about 177,800 million short tons of Herrin thicker than 2.5 feet in the western part of the county (fig. 14; table 2).

No samples of this coal from Gibson County have been analyzed by the Indiana Geological Survey, but on the basis of its sedimentology and stratigraphy the coal is probably a high-sulfur coal. It is almost everywhere overlain by a black fissile shale and above the shale by the Providence Limestone Member. The relationship between this coal and the overlying marine beds indicates exposure of the peat to brackish and marine water. Therefore, the coal likely has a sulfur content of more than 3 percent. The overlying Providence limestone will provide a strong and stable roof in underground mines.

## HYMERA COAL MEMBER

The Hymera coal may be one of those most likely to be mined in the future of Gibson County because of its thickness, its possible low-sulfur resources, and its shallow depth. More than 476 million short tons of original coal resources are present in the county (table 2). This resource figure may be conservative because of the lack of available drilling data in the easternmost part of the county. Underground and surface mines have produced large tonnages of Hymera coal in Sullivan, Knox, and western Greene County. In Pike, Gibson, and Warrick Counties this coal sometimes has been referred to as the Lower Millersburg Coal, and has been mostly surface mined, although there have been several small and one modest-sized underground mine. The surface mines in Gibson County have been restricted to the eastern part of the county from just west of Oakland City southward. Ashley (1898) mentioned several small active underground mines in Gibson County, and some of these mines may have been in the Hymera coal.

Six sample locations provide a limited insight into the quality of the Hymera coal in Gibson County. Three of these are composite samples because the coal was split by shale partings. The coal thickness at the six sites ranges from 0.45 to 9.8 feet (0.14 to 3.0 m) and averages 3.75 feet (1.1 m) (table 1). The ash content of 11.4 to 32.0 percent (an average of 24.0 percent) is higher than that of most Indiana coals. The sulfur content ranges from 1.9 to 3.8 percent and averages 2.9 percent. The high ash content of the sampled Hymera coal depresses the thermal values. The sampled Hymera in Gibson County varied from 8,920 to 12,073 Btu/lb and averages 10,300 Btu/lb.

The sedimentologic interpretation of this coal provides a better overview of its economic nature than can be made from the limited coal drilling and mine samples. Mapping the thickness distribution of this coal in Gibson County revealed that the Hymera thickens toward a sandstone-filled channel in the eastern third of the county (fig. 15). This channel is

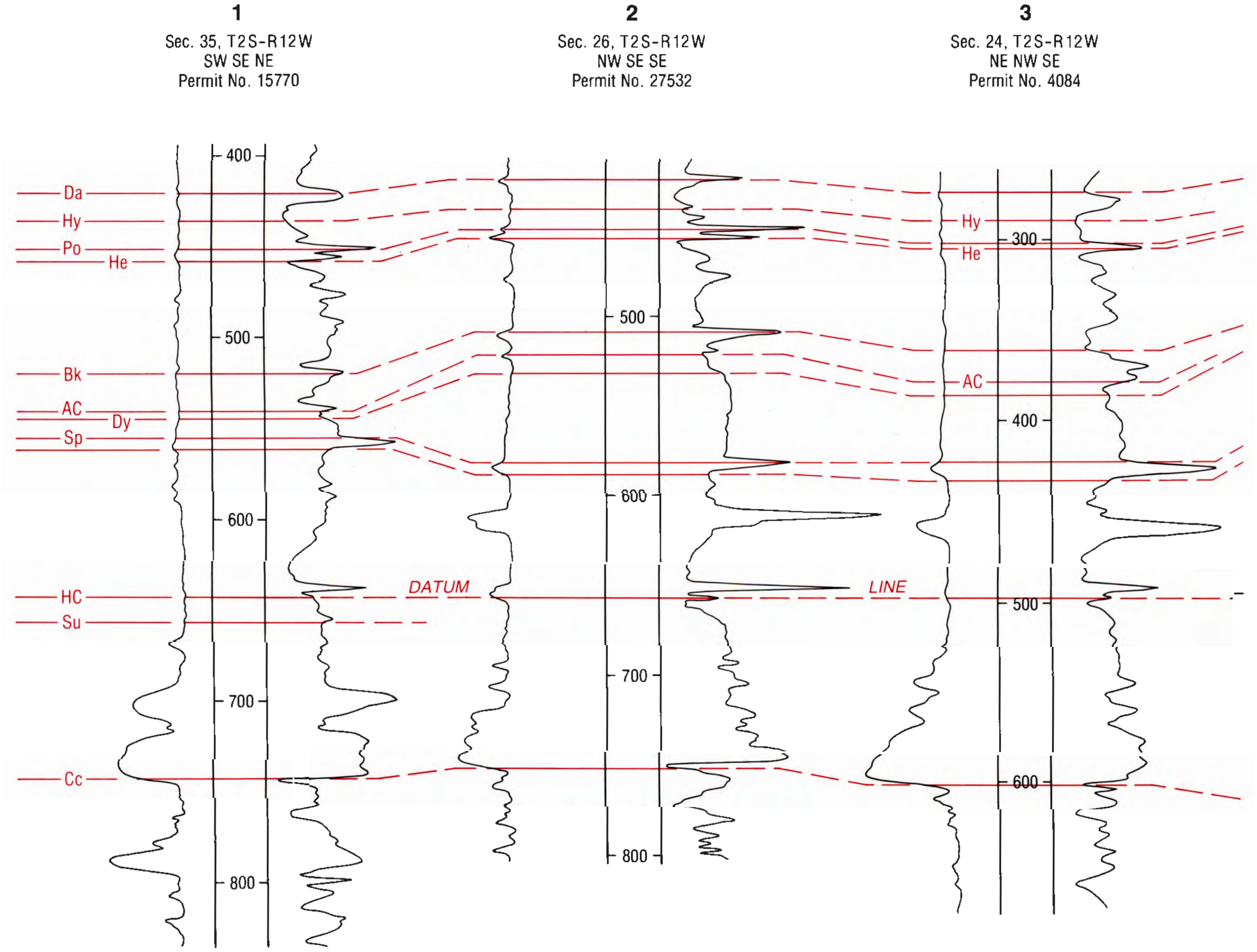
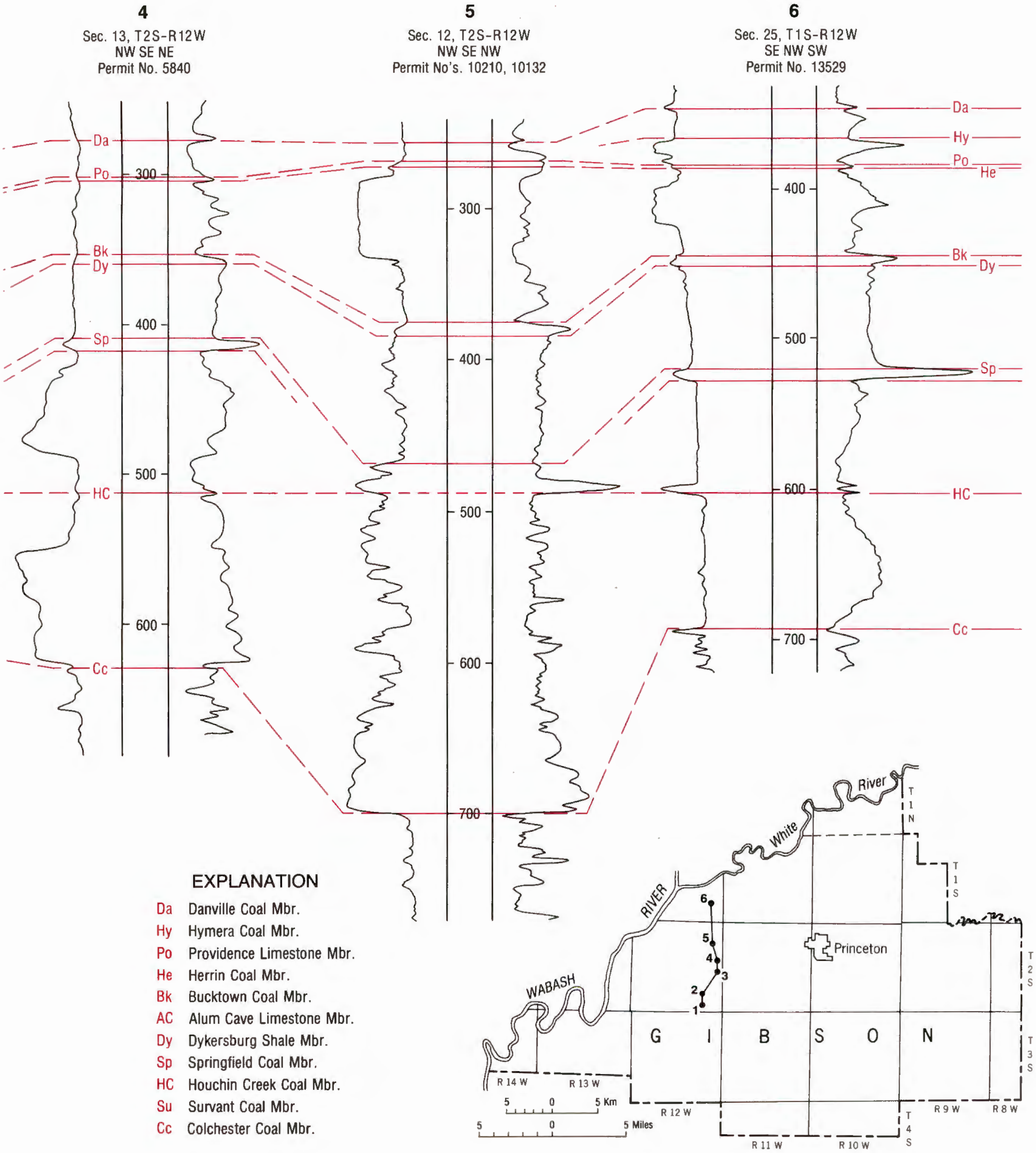


Figure 10. A line of geophysical logs showing the stratigraphic relationships of the Dykersburg Shale Member in western Gibson County, Indiana.



## EXPLANATION

| | |
|---|---|
| Da | Danville Coal Mbr. |
| Hy | Hymera Coal Mbr. |
| Po | Providence Limestone Mbr. |
| He | Herrin Coal Mbr. |
| Bk | Bucktown Coal Mbr. |
| AC | Alum Cave Limestone Mbr. |
| Dy | Dykersburg Shale Mbr. |
| Sp | Springfield Coal Mbr. |
| HC | Houchin Creek Coal Mbr. |
| Su | Survant Coal Mbr. |
| Cc | Colchester Coal Mbr. |

MAP SHOWING LINE OF CROSS SECTION

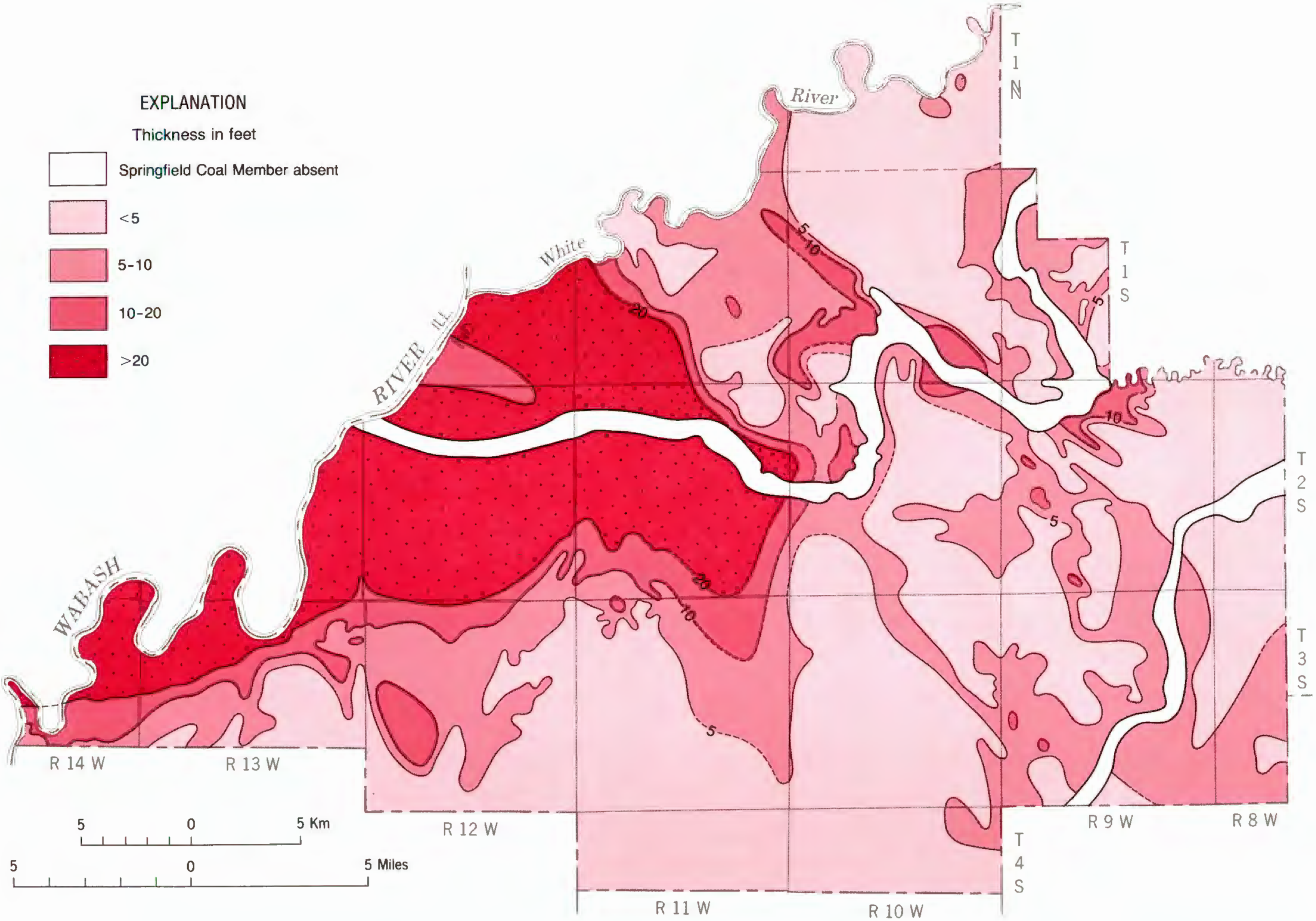


Figure 11. Map showing the interval thickness between the Alum Cave Limestone Member and the Springfield Coal Member. Isopach interval 10 feet.

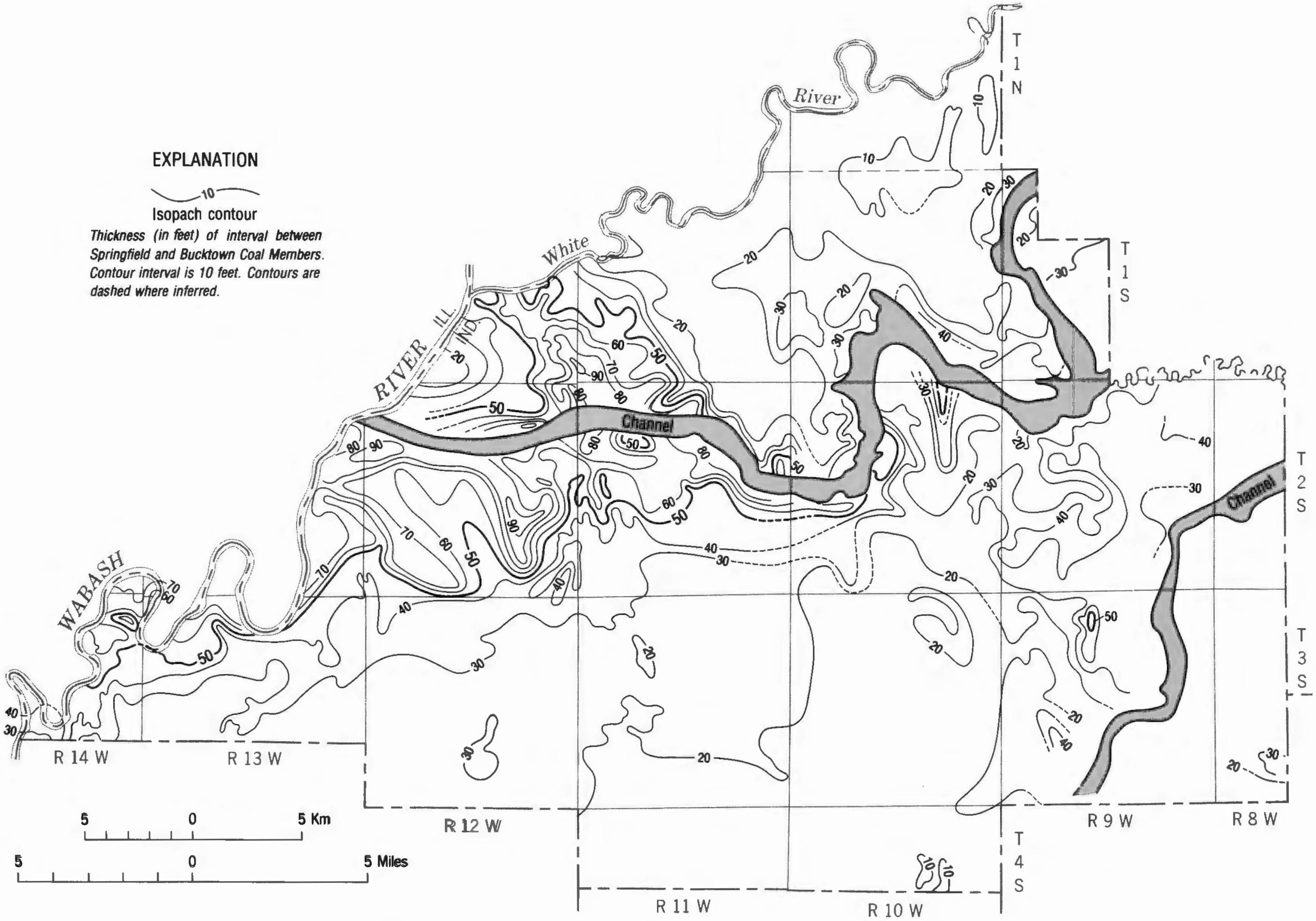


Figure 12. Map showing the interval thickness between the Springfield and Bucktown Coal Members. Isopach interval 5 feet.

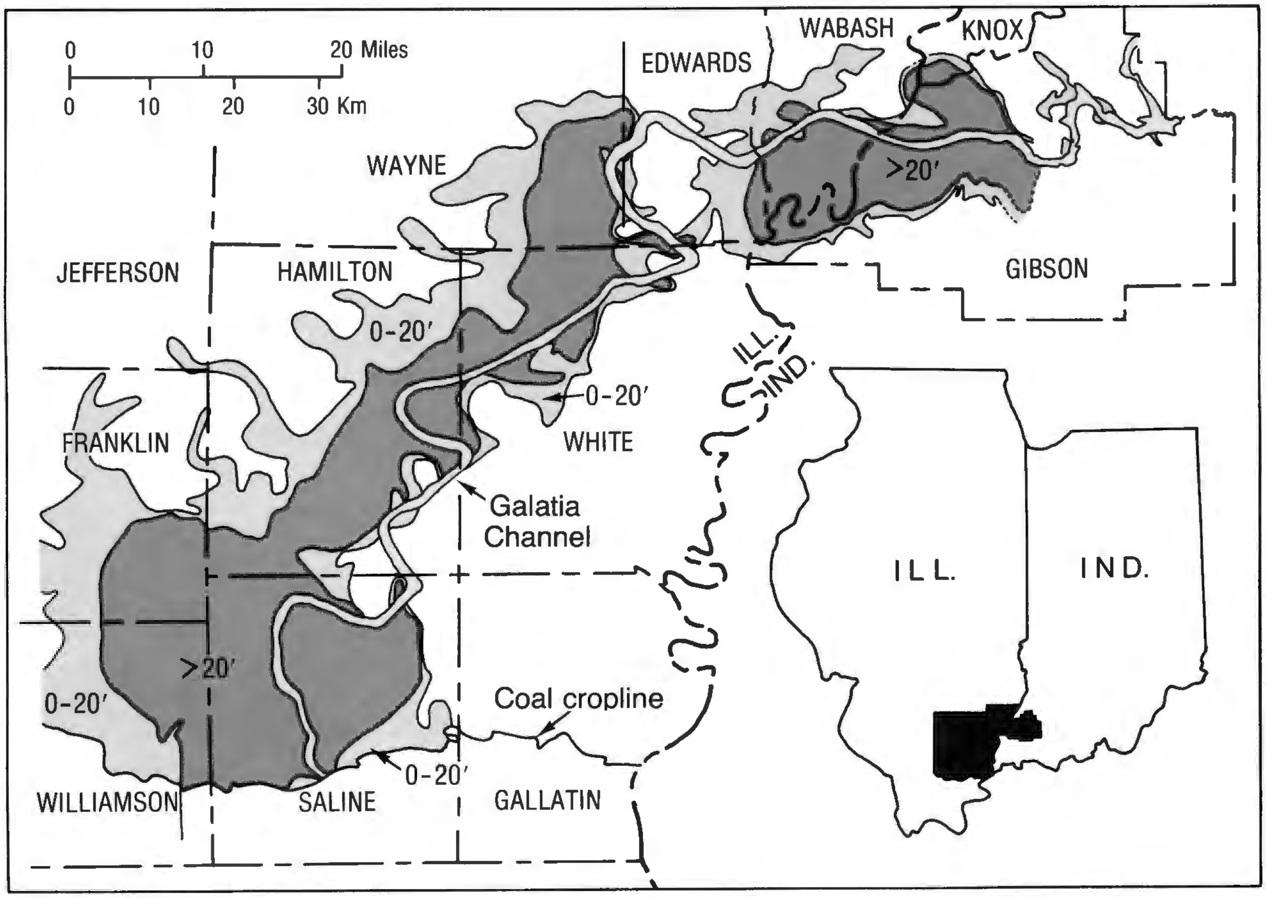


Figure 13. Map showing the approximate 20 foot (6.1 m) isopach of the Dykersburg Shale Member in southeastern Illinois and in Gibson County, Indiana (modified after Hopkins, 1968).

contemporaneous with the coal, because the Hymera splits and interfingers with sediments of the Winslow Channel and because this channel is probably a northern extension of the channel that is called the Henderson Channel in Kentucky (Eggert, 1982b, 1984) (fig. 16). Local subsidence during deposition determined the position of the channel, and this subsidence provided space needed for the accumulation of thick peat that is now a thick coal. On the eastern side of this channel in Pike County, the Hymera coal is commonly low in sulfur. There is a strong probability that similar deposits lie along this channel in Gibson County. This coal is absent along the track of this channel and two other sandstone-filled channels in the western part of the county.

The depositional habitat of the Hymera coal in eastern Gibson County resulted in areas of thicker and potentially commercial deposits of lower sulfur coal adjacent to the Winslow Channel. Because this coal is geologically younger and near the surface in the eastern quarter of the county, the coal is mineable where it is generally less than 100 feet (30 m) from the surface. Because accurate drilling records are sparse, the surface mineable resources of this coal have not been estimated.

Mining conditions in areas where the Hymera coal may be mined underground are also mostly determined by the depositional environment. First, the coal must be at least 3 feet (0.9 m) thick, and second, the coal must have stable floor and roof rocks. Ditney Hill Mine had problems with roof falls that were due to organic shale or weak shale and coal splits. The similarities between deposition of the Hymera coal and that of the Springfield coal along similar contemporaneous channels may have given rise to similar roof and floor strata. Therefore, mining under the gray silty shale above the Hymera coal may be similar to mining under the Dykersburg shale. In some areas there are sandstone-filled channels within the interval between the Hymera coal and Danville coal. These channels may result in local variations in roof stability.

Where the Hymera coal is thick enough to be surface or deep mined, partings may reduce the quality and productivity of the mine. Thick variable partings, such as those in the Springfield coal described by Meier (1985), may be more extensive in the Hymera coal in the eastern Gibson County. An operator may prevent the inclusion of noncombustible rock by carefully mining the coal benches.

## DANVILLE COAL MEMBER

An examination of the geophysical logs indicates that the Danville Coal Member ranges from less than 16 inches (0.4 m) to about 4 feet (1.2 m) in thickness (fig. 17). This coal has been mostly surface mined but has also been underground mined in Vermillion, Vigo, Sullivan, Greene, and Knox Counties. It is surface mined almost exclusively in Pike, Warrick, and Gibson Counties in places where it is usually of modest thickness, about 2 to 3 feet (0.6 to 0.9 m). In these counties it has been called the Upper Millersburg Coal. Ashley (1898) reported several small mines in this coal, but his correlation is difficult to verify.

Samples of the Danville coal provide a limited measure of its quality and economic potential. Five samples were taken from surface mines or cores. The coal represented by these samples was 2.45 to 3.75 feet (0.75 to 1.1 m) thick and averaged 3.1 feet (0.94 m). The ash content varied from 9.1 to 23.0 percent, had a mean of 17.0 percent, and averaged 14.0 percent (table 1). The sulfur content suggested that this was high-sulfur coal because all the samples exceeded 3 percent total sulfur. The total sulfur content ranged from 3.6 to 5.9 percent and averaged 4.6 percent. Samples of the Danville coal in Gibson County indicate that the Danville coal is thin, high-sulfur, and most likely marginal in its economic potential using conventional mining techniques.

The deposition of the Danville did not seem to be contemporaneous with any of the sand-filled channels in Gibson County. The sedimentology of this coal is difficult to interpret from the available data, but the coal likely formed from a peat that was deposited in the bay region of a delta. The high sulfur content indicates that the peat was exposed to brackish to marine water during or after deposition.

The Danville coal is thicker than 3.5 feet (1.1 m) in a limited area, but over a larger area this coal is between 2.5 and 3.5 feet (0.8 and 1.1 m) thick. In the area west of R. 9 W. about 410 million short tons of coal is thicker than 2.5 feet (0.8 m) (fig. 17; table 2).

The physical, sedimentological, and chemical analyses suggest that this coal is unlikely to be mined at extreme depths, for it is too thin. It is likely to be surface mined only where it is near the surface or where it can be mined with the Hymera coal. Where the thin coal is deep, it could be recovered in the future by in situ mining.

## COALS ABOVE THE DANVILLE COAL MEMBER

Several coals generally less than 2 feet (0.6 m) thick are present above the Danville coal, but their extent and correlation have not been established. The recovery of these coals may only be feasible from small surface mines or some form of in situ mining. No active or abandoned mines in these younger coal beds are known.

## STRUCTURAL GEOLOGY OF GIBSON COUNTY

The structural setting of Gibson County is more complex than that of most of Indiana's coal field. Several structural features in Gibson County, including faults, folds, regional dip, jointing, and lineaments, are the product of crustal movements and stress. A knowledge of these features is essential for the development of coal and petroleum.

Southwestern Indiana is on the eastern edge of the Illinois Basin, a broad saucerlike depression of the earth's crust with rock strata dipping toward the center of the basin. This regional feature is evident on the structure maps prepared for this report (figs. 18, 19, 20, and 21), which show the mapped units dipping westward at 10 to 50 feet per mile (2 to 10 m per km). Additional evidence of the structural setting for Gibson County is provided by structure maps on the Colchester and Houchin Creek Coal Members (Eggert, 1994a, 1994b). The Illinois Basin has several direct effects on mineral development. First, economic coals or petroleum reservoir rocks will be several hundred feet deeper in the western part of the county than in the eastern part, and the cost of drilling to find these coals or reservoir rocks before development will be more costly in the west than in the east. Second, surface-mineable coals in the east will be too deep for surface mining in the west. Third, the cost of underground development will be greater in the west because shafts and slopes will be much deeper and more costly to construct. Fourth, in the western part of the county the Springfield and the lower coals are at depths where the pressure of overlying rocks and sediments increase the risk of roof and rib failures that may reduce the efficiency and safety of mining and increase the cost of production.

Other structural and nonstructural features that cause changes in the elevation of specific rock strata include domes, folds, faults, and differential compaction and are identified by abrupt changes in the elevation expected for particular strata. Of these features, faults represent the greatest release of energy within the earth's crust. Faults are fractures along which the rocks on either side have been displaced. They can interfere with coal mining by increasing production costs and the risk of roof falls. Two steeply dipping faults, the Owensville and New Harmony Faults, are present in the southwestern part of the county (fig. 20). Rocks along the New Harmony Fault have moved farther apart than those along the Owensville Fault. Rocks along the New Harmony Fault have been displaced vertically almost 300 feet (92 m) in contrast to the 40 feet (12 m) of vertical movement of the Owensville Fault. These faults were recognized or inferred by Friedman (1954), Ault and others (1980), and Tanner and others (1980, 1981). The Wabash Mine of the Amax Coal Co. is split by the New Harmony Fault into two reserve areas. The Amax Coal Co. decided that sinking a slope from the higher east side of the fault to the lower west side of the fault was less expensive than constructing a new shaft or slope from the surface (Koehl and Meier, 1983). As the Amax workers

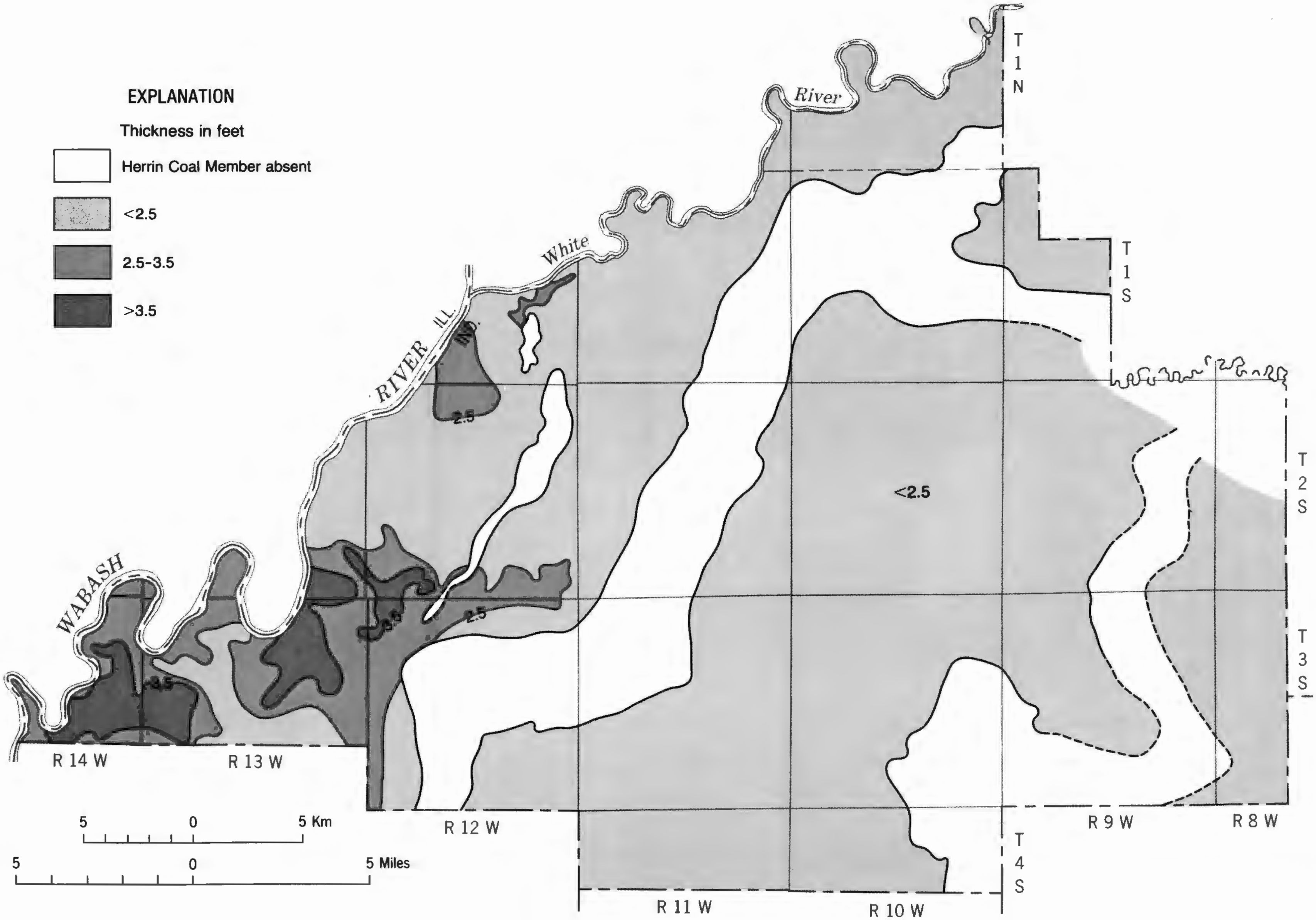


Figure 14. Map of Gibson County showing the distribution and thickness of the Herrin Coal Member. Contour interval 1 foot.

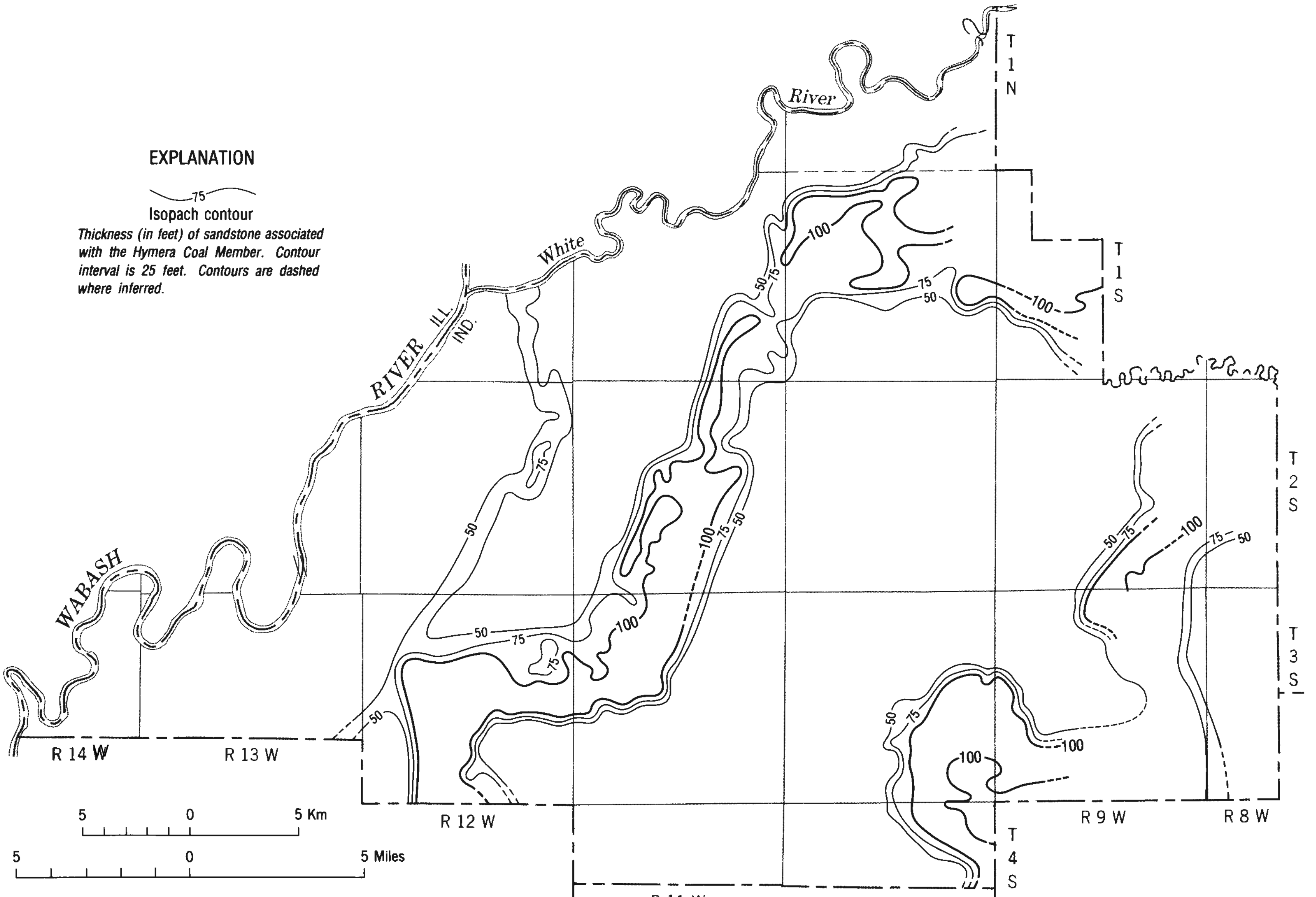


Figure 15. Map of Gibson County showing the distribution and thickness of sandstone-filled channels associated with the Hymera Coal Member. Contour interval 25 feet.

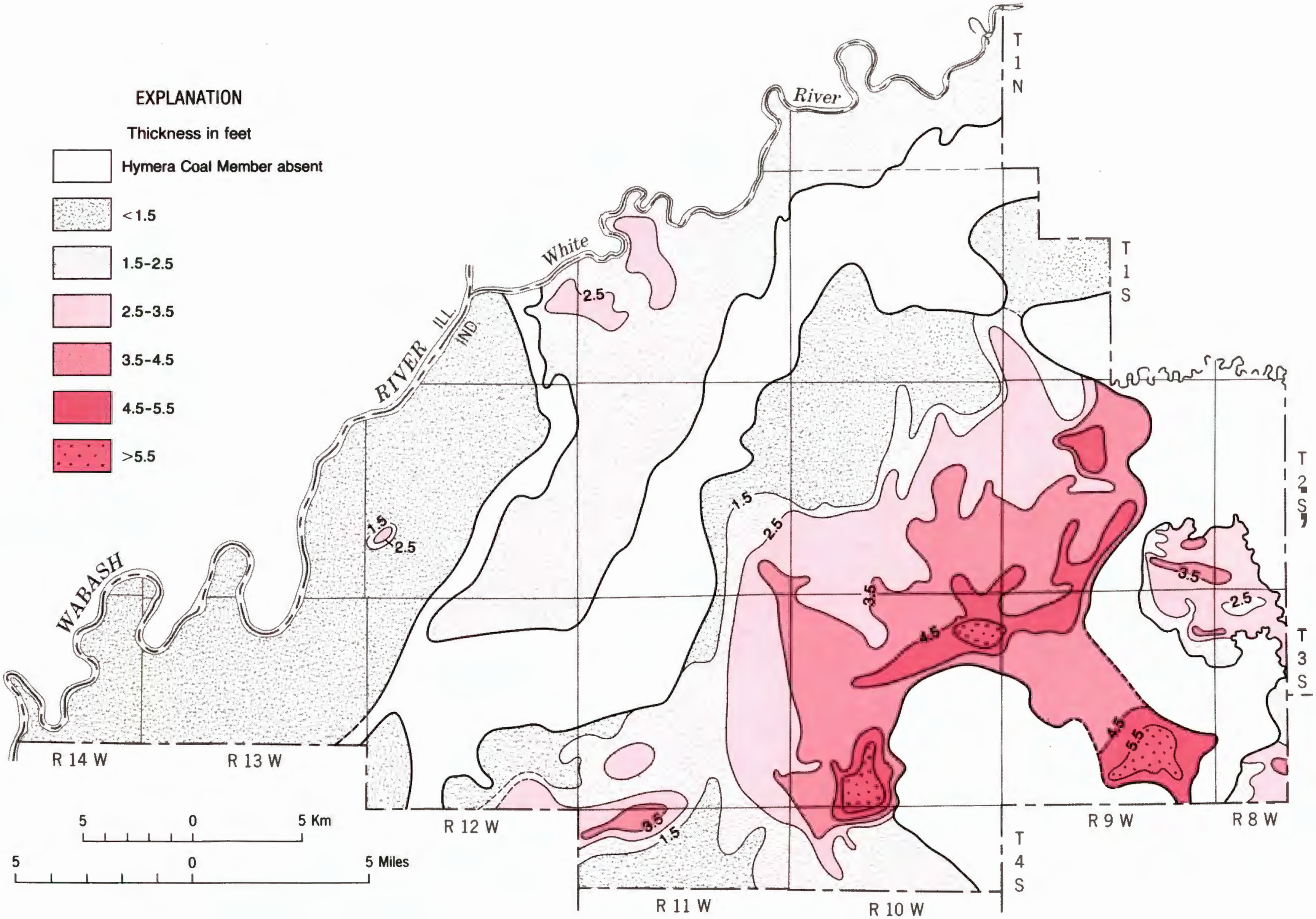


Figure 16. Map of Gibson County showing the distribution and thickness of the Hymera Coal Member.

neared the fault, they encountered only a small zone of small faults and fractured rock that has prevented mining (D. G. Meier personal comm., 1985). Although some of the coal resources in Gibson County might be lost due to faults, the total resources not mineable would be insignificant.

Folds can be identified by an abrupt local change in the elevation of rock units in Gibson County. Folds are the warping and bending of rock strata induced by movements of the earth's crust. In Gibson County these include anticlines, domes, and weak synclines. An anticline is a fold characterized by a linear uplift of the strata. Several of these are near the Owensville Fault. The rocks west of the New Harmony Fault have moved downward between this fault and a fault farther west in Illinois and have formed a graben. The rocks within this graben, however, have been folded into an anticline near the middle of the graben. Along the margins of this anticline are some of the steepest dips in Gibson County over an extended distance. Neither this anticline nor any of the other anticlines have changes in elevation that are expected to prevent mining. Anticlines are commonly petroleum traps, and most have been drilled extensively for petroleum development.

Like an anticline, domal uplift is recognized by a stratum that is higher than predicted by the regional dip. Unlike an anticline, a domal uplift tends to be less defined and is not linear. Like the anticline, it is not a significant mining problem but is a potential petroleum trap and may be extensively drilled.

The fourth feature, a syncline, is downwardly folded rock, which is not as pronounced or as linear as the anticlines. This feature is found associated with the Owensville and New Harmony Faults. The association of the folds to these faults indicates that the origins of both are due to the same tectonic stresses and energy release.

The last feature is an elevation change that is not due to the horizontal stresses or uplifts in the earth's crust. Rather it is due to the compaction of older sediments. When sediments are deposited in fluvial-deltaic or marine settings, they contain water in the pore spaces between solid particles. After deposition the pore water is squeezed out by gravity and the weight from the downward push of later sediments. Sediment compaction is determined by the size of the particles; peat and muds compact more than coarser sediments. Therefore an area underlain by thick peat or mud will compact more than an area of sand. In Gibson County where an older sandstone lies beneath a younger coal, this coal may be higher than where the coal is above a shale. This is an example of differential compaction that may produce local changes in elevation in a coal mine and that may alter mining conditions by producing steep gradients along haulways or by ponding water in low areas.

These five features may not prevent mining, but all will have some effect. For example, roof falls along the crests of structural highs can be found associated with anticlines, domes, or compactional highs. The structural maps produced for this report are intended as background information to help in predicting such mining conditions.

Not commonly observable on structure maps are lineaments, features some believe to be related to joints and fractures in the rock strata caused by deep crustal stress or movement. Wier and others (1974) mapped lineaments in Gibson County by examining air photos, satellite photos, and topographic maps for linear features. Wier and others (1973) associated these features with joints and roof falls within the Kings Station Mine. But lineaments do not seem to be greater or less common in density or frequency in Gibson County than in other southwestern Indiana counties.

The preceding structural features are believed to be mostly products of past earth movements (Ault and others, 1980). Although Gibson County is in a minimal-risk region for earthquakes from future movements of the earth's crust, past experience indicates that if an earthquake occurs, areas of the county having thick unconsolidated sediments would experience more damage to buildings than areas with shallow bedrock.

## SURFICIAL DEPOSITS

The unconsolidated sediments above the bedrock surface in Gibson County are a major factor that will influence future mining, construction, and land use. Gray (1982a, 1982b) found that the bedrock surface in Gibson County had a significant amount of relief. But the present surface topography compared with the bedrock topography was rather subdued. Gray (1983a, 1983b) found that more than 150 feet (92 m) of unconsolidated sediments filled the deep bedrock valleys. These sediments included lake sediments, glacial tills and outwash, and postglacial fluvial sediments.

Gray and others (1970) and Gray (1971) mapped areas of lake beds in Gibson County. The lakebed deposits may pose engineering problems for both surface and underground mining, because a high clay and silt content of the lake clays results in poor strength and load-carrying characteristics that cause foundation failure. These deposits may also cause slumps if exposed in open holes or excavations.

Glacial sediments may also be present, but most likely these would not have the undesirable engineering properties associated with lake sediments. Bleuer (personal commun., 1985) believed that pre-Wisconsinan (late Quaternary) tills and outwash sediments were present and that some of the surface topography might represent moraines.

There are thick fluvial sediments, mostly thick sands and gravels, in the floodplains of the Wabash and Patoka Rivers. Fraser (personal commun., 1985) believed that these sediments were deposited during and after the pre-Wisconsinan glacial ages and the Wisconsinan Age.

Operators of deep mines may encounter significant problems with unconsolidated materials. Harper (1985) reported that operators of former deep mines had had problems, such as shaft failures and water entering the mine, from unconsolidated materials in the Wabash River floodplain in Vigo County, Indiana.

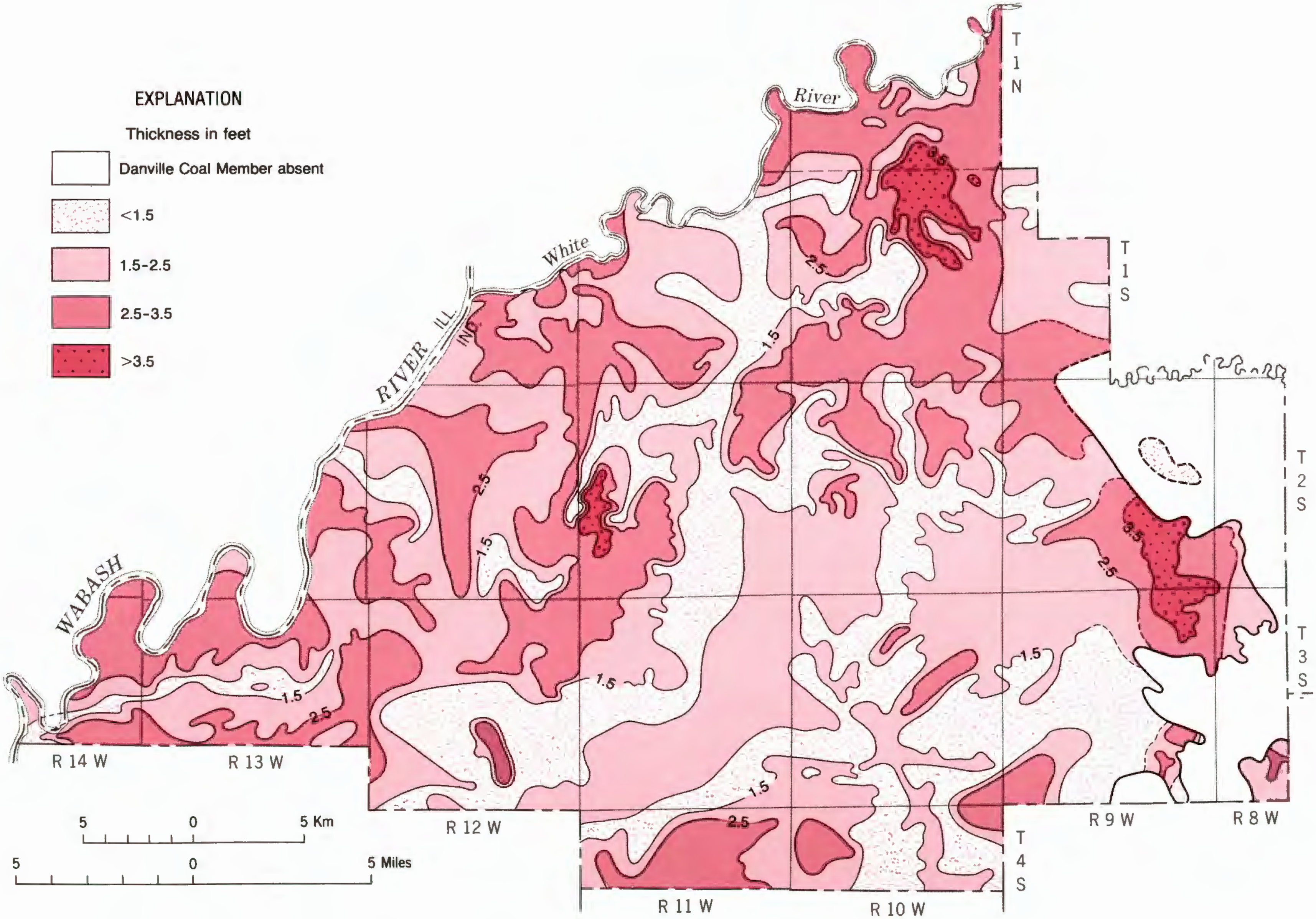


Figure 17. Map of Gibson County showing the distribution and thickness of the Danville Coal Member. Contour interval 1 foot.

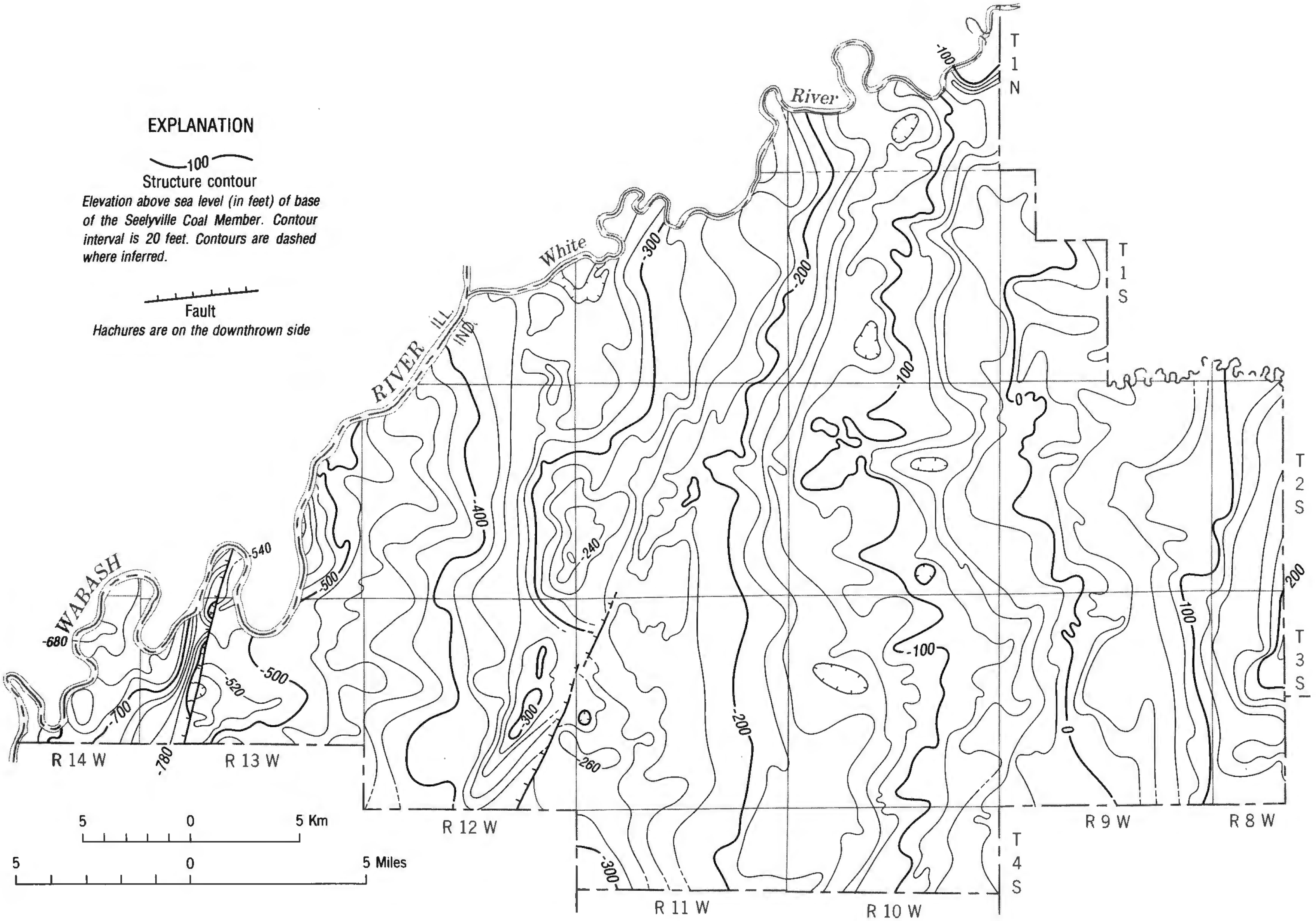


Figure 18. Map of Gibson County showing the structure on the base of the Seelyville Coal Member. Contour interval 20 feet.

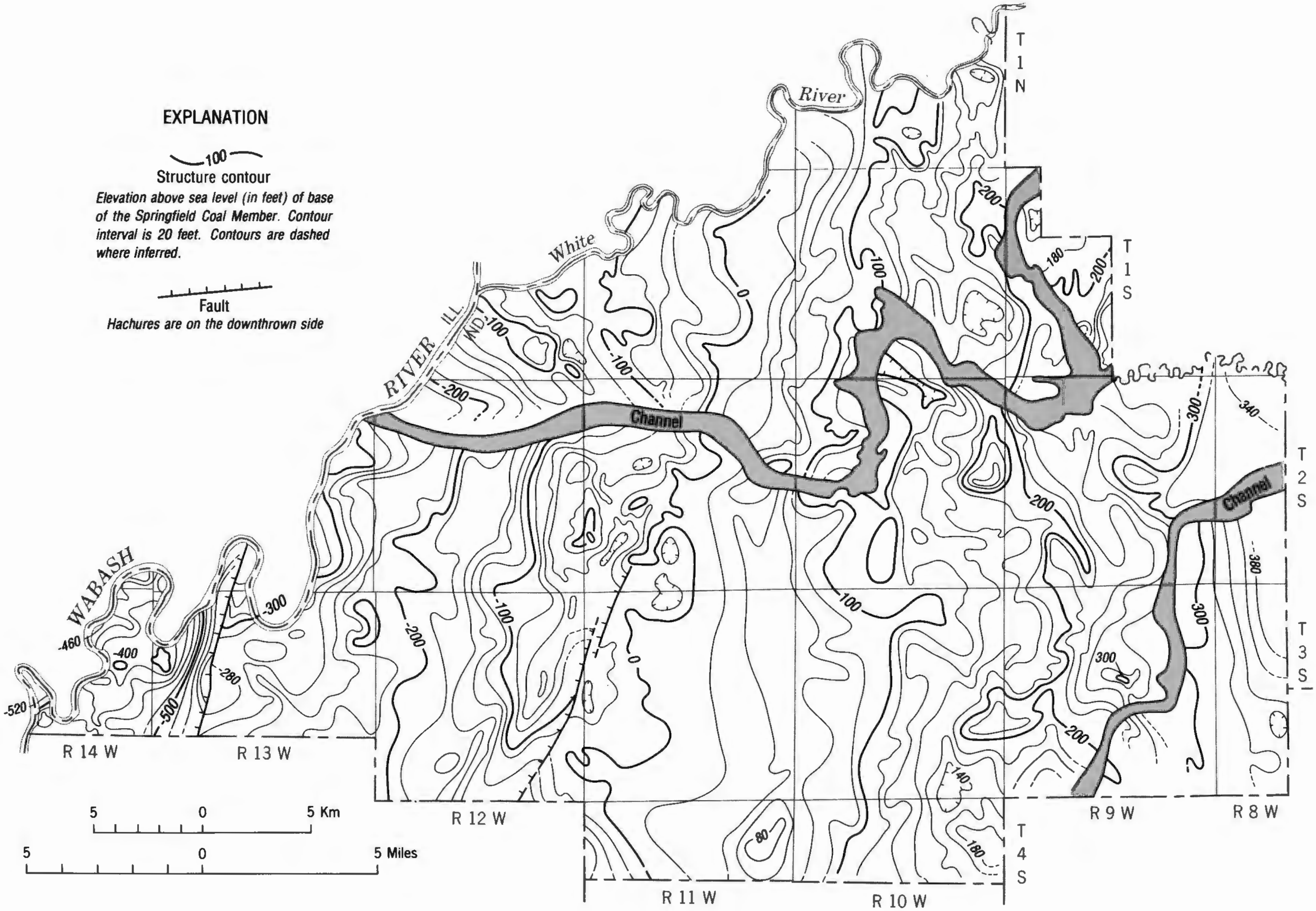


Figure 19. Map of Gibson County showing the structure on the base of the Springfield Coal Member. Contour interval 20 feet.

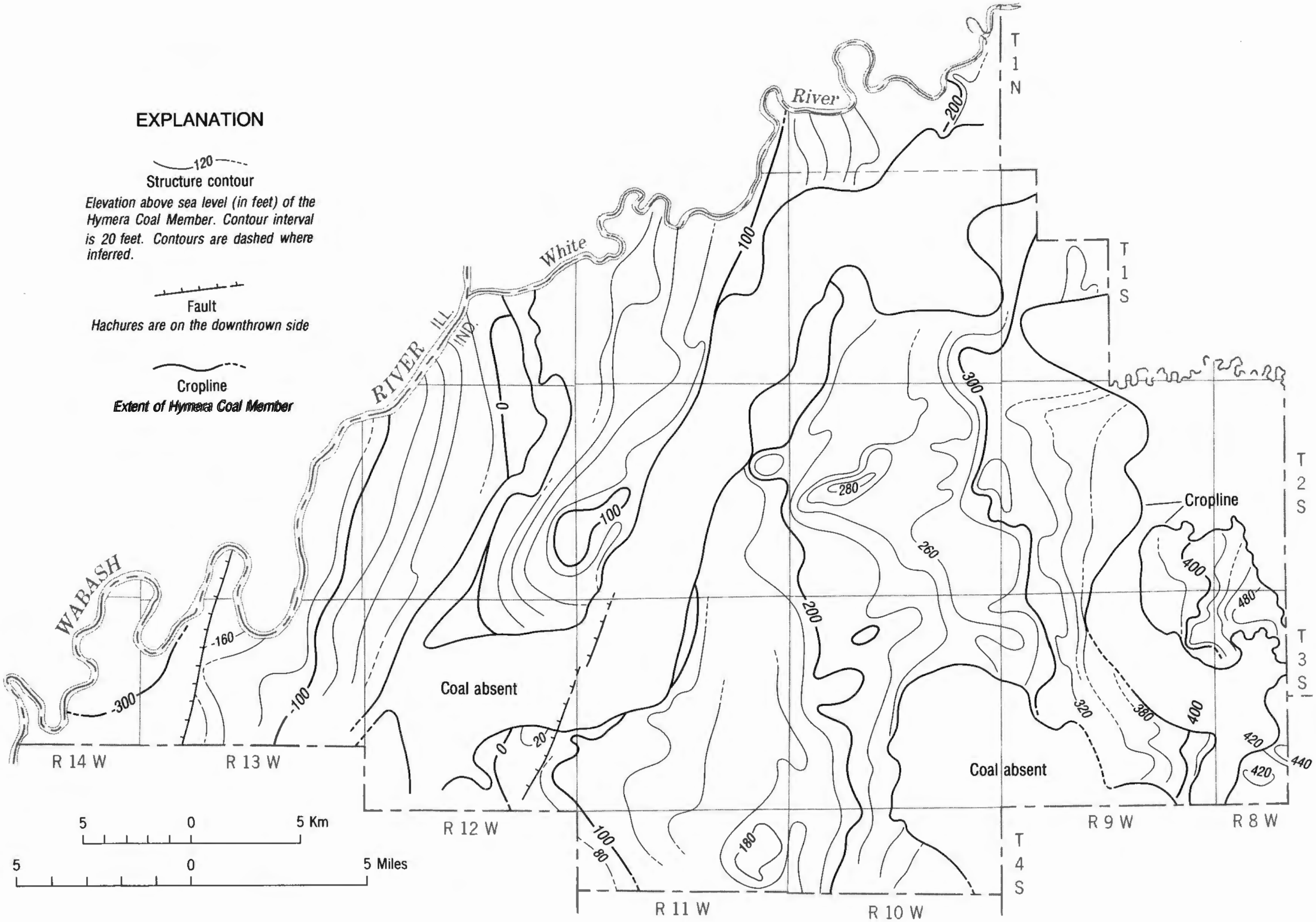


Figure 20. Map of Gibson County showing the structure on the top of the Hymera Coal Member. Contour interval 20 feet.

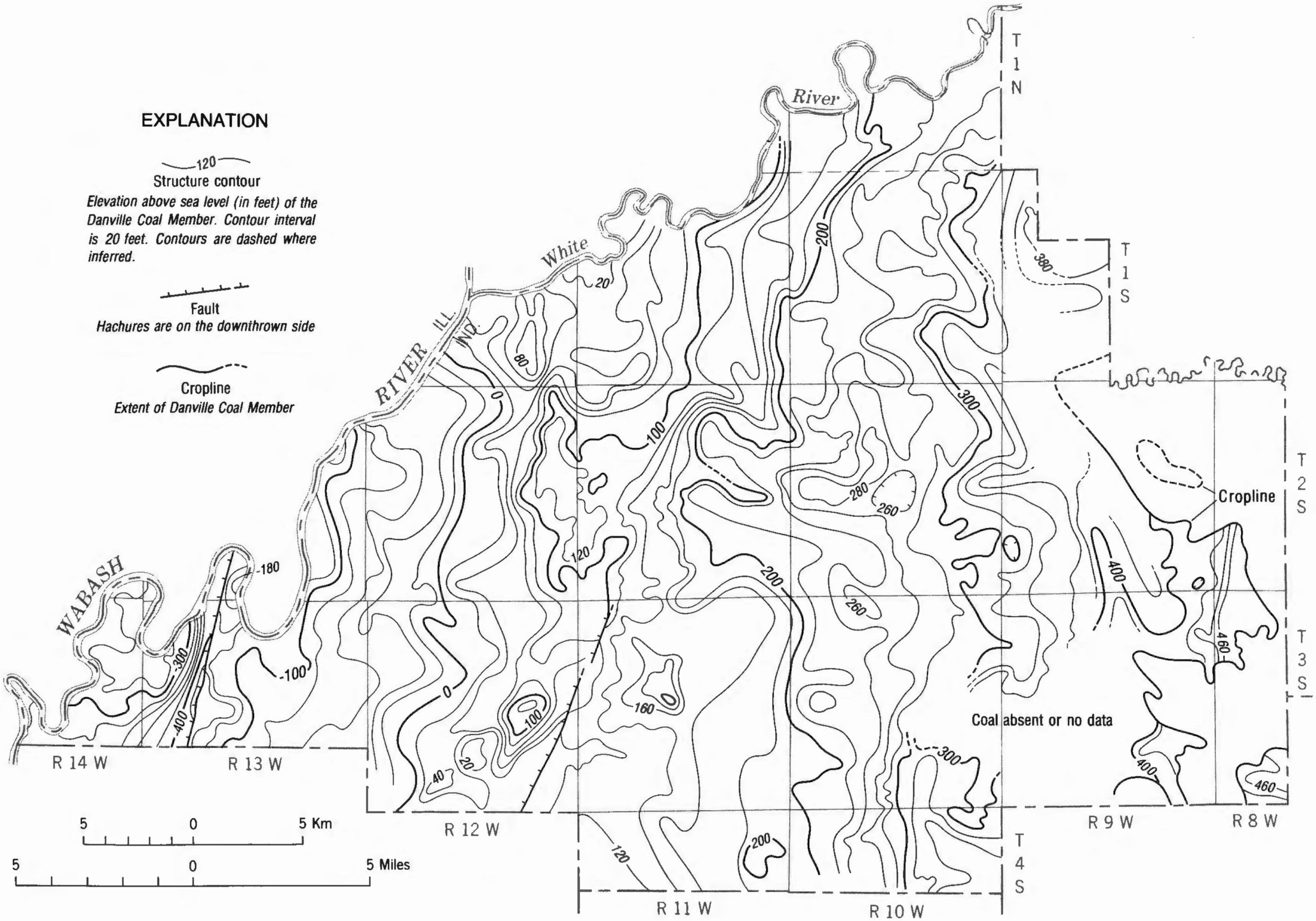


Figure 21. Map of Gibson County showing the structure on the top of the Danville Coal Member. Contour interval 20 feet.

Popp (1977) found deep mine subsidence was most evident in areas overlain by thick glacial and fluvial fill.

Surface mining will be influenced by the surficial deposits, including the present good soils. Most of Gibson County has been mapped as an area of prime farmland soils (U.S. Department of Agriculture, 1977). Therefore, surface mining of these areas of prime soils would require careful reclamation. The stability or instability of unconsolidated materials must be considered in proper mine planning. Highly unstable material, such as the lake beds, require careful handling. The chemical and physical nature of the lake clays, tills, and fluvial sediments will determine the success of surface-mine reclamation. Byrnes and others (1980) found significant differences for potential plant growth of unconsolidated materials.

## IMPACT OF COAL DEVELOPMENT

Acid mine drainage, mine subsidence, reduced agricultural production, and higher cost of petroleum drilling are some common effects on the environment and land usage caused by surface and underground coal mining in Gibson County.

Acid mine drainage is the contamination of water by the acid-forming oxidation products of sulfide minerals exposed during mining operations. Coal wastes from many old mines contain high concentrations of sulfide minerals. Eggert (1979) identified two significant coal-refuse sites in Gibson County, the Kings Station and the Buckskin Mines. Little coal refuse is on the surface at the former Kings Station Mine, even though it was the largest of Indiana's underground coal mines. Al Lawson (personal commun., 1985) reported that some refuse from the mine was used by the railroad as fill and some was pumped underground to reduce mine subsidence. The Buckskin Mine dump consists of coarse coal refuse (gob) and sand-sized refuse (tailings). This unreclaimed site is a source of acid drainage. Fortunately, most of the other mines in Gibson County were smaller and so are their refuse piles. The gob pile at the Francisco No. 2 Mine has burned since the mine closed, and today the former wastes consist of a glassy bricklike ash called "red dog," which could be used as a lightweight aggregate for roads.

Mine subsidence associated with underground or surface mining may result in damage to surface roads or buildings and may reduce the productivity of agricultural land. Gravity causes overlying rocks and unconsolidated sediments to settle and fill in the mined-out space. Surface mining increases the volume of the rocks and unconsolidated sediments in the cast overburden by creating void spaces between the materials. After mining has ceased, graded cast overburden slowly sinks because of gravity, and the spoil is further compacted.

Harper (1982) recognized subsidence above the former underground Kings Station Mine. Mine subsidence has occurred and will eventually occur above all coal-mined lands, but its surface expression will be highly variable because of differences in depth of the coal mined, thickness of unconsolidated materials, types of rocks present, surface topography, surface land use, and amount of time since mining.

Mining can reduce the agricultural yield by mine subsidence or improper reclamation of surface-mined lands that results in poor soil conditions or too steep slopes. Where the coal is near the surface, underground-mine subsidence may result in sinkholes at the surface that will prevent row-crop land use. Where the coal mined is at greater depth, mine subsidence may interfere with surface drainage and cause temporary ponds that may kill or stunt row crops. In some parts of eastern Gibson County surface-mine soils that are acidic, overly compacted, or lacking in plant growth nutrients can yield significantly less than properly reclaimed mine soils and unmined land. Much of the land surface mined before the recent laws governing surface-mine reclamation was left in steep slopes, a practice no longer permitted.

Mined lands can pose significant problems for petroleum exploration. Mine subsidence may tip the drill or bend the drill stem, thus delaying drilling or damaging or destroying the equipment. Drilling into a mine void can cause loss of drilling fluid, explosions, and fires from released methane gas or damage to drilling equipment from sudden drops of the drill stem when it enters a mine void or encounters abandoned mine equipment. The Indiana Geologic Survey maintains an open file of photographs of maps depicting mined-out areas of former underground mines. These former underground mines have been plotted onto quadrangle maps and a map of Gibson County (Weber, 1984). Unfortunately, mine maps are not available for all abandoned mines in Indiana's coal counties, and not all the maps on file are accurate. It is therefore difficult for a driller to site his rig above blocks of unmined coal.

## PETROLEUM DEVELOPMENT AND ITS EFFECT ON COAL RESOURCES

Petroleum, like coal, is a major mineral resource in Gibson County. For most of this century Gibson County has been the major oil-producing county, first in southwestern Indiana and later in the entire state. One-quarter of all oil produced in Indiana may have been produced in Gibson County (Dan M. Sullivan, personal commun., 1985).

Coal mines can increase the cost and risk of petroleum exploration. Conversely, the development of petroleum resources in a county can have undesirable consequences on coal mining. More than 7,300 petroleum tests have been drilled in Gibson County. These include active producing wells, abandoned wells, dry holes, active water-injection wells, and abandoned injection wells. If these holes are not properly cemented, water and methane gas may enter a coal mine from other strata penetrated by the drill. Methane gas is generally given off by the roof, floor, and coal within a mine. Additional methane gas from a petroleum hole increases the risk of an explosion. Water from a petroleum hole results in a greater risk of roof falls, squeezes, and muddy flooded areas. If a water-saturated aquifer is above the mine, a significant volume of water might enter the mine. The U. S. government recognizes the safety risks to underground coal mines and requires a 50-foot (15 m) barrier of unmined coal between properly plugged holes and a 150-foot (46 m) barrier of unmined coal from an unplugged or active well. It is possible for a mining engineer to develop a mine plan that will permit recovery of coal and comply with safety regulations. However, the more oil wells in an area, the lower the percentage of recoverable coal.

It is therefore essential for mining engineers and exploration geologists to know the location of these wells. The state of Indiana for the last half-century has required that persons drilling petroleum wells have a permit. The state has also regulated the spacing between wells. The Indiana Geological Survey Energy Resources Section maintains records of these wells and their locations. Maps are prepared for each county of Indiana at a scale of approximately 1 inch equals 1 mile. These maps show the locations and total depths of wells. The petroleum exploration map for Gibson County (Sullivan and Cazee, 1985) shows that the distribution of oil wells in the county is not uniform but rather reflects the distribution of structural or sedimentary traps from which oil has been produced. Some areas of older oil production were drilled with irregular spacing between holes having some closely spaced holes. Many of these holes were abandoned long ago and were not properly cemented. Such areas of closely, irregularly spaced, or unplugged holes are never likely to be deep mined, because the high cost of plugging and the complex mine plan needed would make mining unprofitable. Most of Gibson County's oil fields are regularly spaced, and it would be possible to work a deep mine through an orderly field. The thousands of drill holes in this county may reduce the mineable coal, but they also provide geologic insight into the coal resources of the county.

## COAL USAGE

Coal from Gibson County needs a market and adequate transportation to ship the coal from the mine to the consumer. Coal mined in Gibson County was once used for fuel to heat homes, for railroad fuel, and for the production of electric power. Today most of the coal mined in the county is used to produce power for electric generating stations. One of the largest coal-fired electric power plants, the Gibson Station plant of Public Service Indiana, is in northwestern Gibson County along the Wabash River. This plant uses about 8 million tons of coal produced from mines in Indiana and Illinois, including nearly all the coal mined at the Wabash Mine. Gibson Station is a power plant that will be used well into the next century, and it will likely consume a large percentage of the future coal production from Gibson County, unless future environmental controls prohibit the use of local coal. Electric power plants probably will be the major users of coal mined in this county for a considerable time.

Other coal markets exist today, and more will continue to exist in the future. Several steel firms use midwestern coal by blending it with low-volatile coals from eastern states to produce coke for their blast furnaces. Several firms have found that they can use higher percentages of midwestern coal than they are now using. Another future market are producers of synthetic fuels and chemicals. As the world's supply of natural gas and oil decline, these natural resources will need to be replaced both as fuels and as the raw materials for fertilizers, plastics, and chemicals.

To meet the future demand of local and distant markets good transportation systems must be available. Today, a locally produced coal has an advantage in that its shipping costs are lower than a coal mined farther from the consumer. The two principal railroads can ship coal to both local markets or markets far away. This is also true for the federal and state highways in Gibson County. Coal from the county could be shipped by rail or highway to the Ohio River for shipment by barge along the inland-waterway network. The transportation net that exists today would allow the export of coal to foreign markets by the railroads or the waterway to the Great Lakes or to the Gulf of Mexico. Coal lands that have good transportation systems have an advantage over those that are isolated from markets. Gibson County has good transportation facilities, which will help in developing its regional resources.

## SUMMARY AND CONCLUSIONS

Gibson County has several mineable coals with more than 5.1 billion short tons of coal thicker than 2.5 feet (0.8 m), but most of the mineable resources are found in the Springfield coal. Mineable resources are also in the Hymera, Seelyville, Herrin, and Danville coals and in unnamed coals of the Staunton Formation. The distribution of mineable resources in each seam is controlled by its sedimentologic setting.

Mining conditions in Gibson County are controlled by the sedimentology, petroleum drilling, structural geology, and unconsolidated deposits. Although these conditions might prevent some mining, the total area in which coal mining would be prohibited is small compared to the area of the county where mining might take place.

Mining coal has changed land use and affected other industries. Present and future environmental laws are and will continue to attempt to reduce serious problems resulting from coal mining.

Because a greated demand for coal is indicated for the future, the coal resources of Gibson County will find a large market. And because the county has good transportation systems in place, getting the coal to these new markets will be possible.

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# OVERSIZED DOCUMENT

The following pages are oversized and need to be printed in correct format.

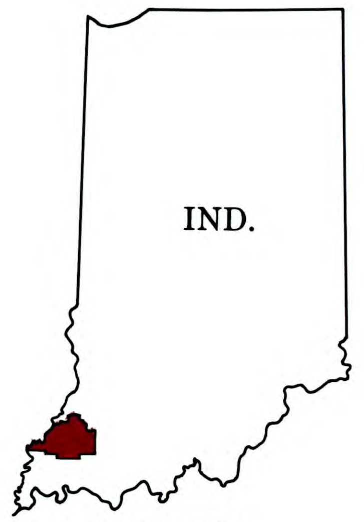
NORMAN C. HESTER, STATE GEOLOGIST

INDIANA UNIVERSITY
INDIANA GEOLOGICAL SURVEY

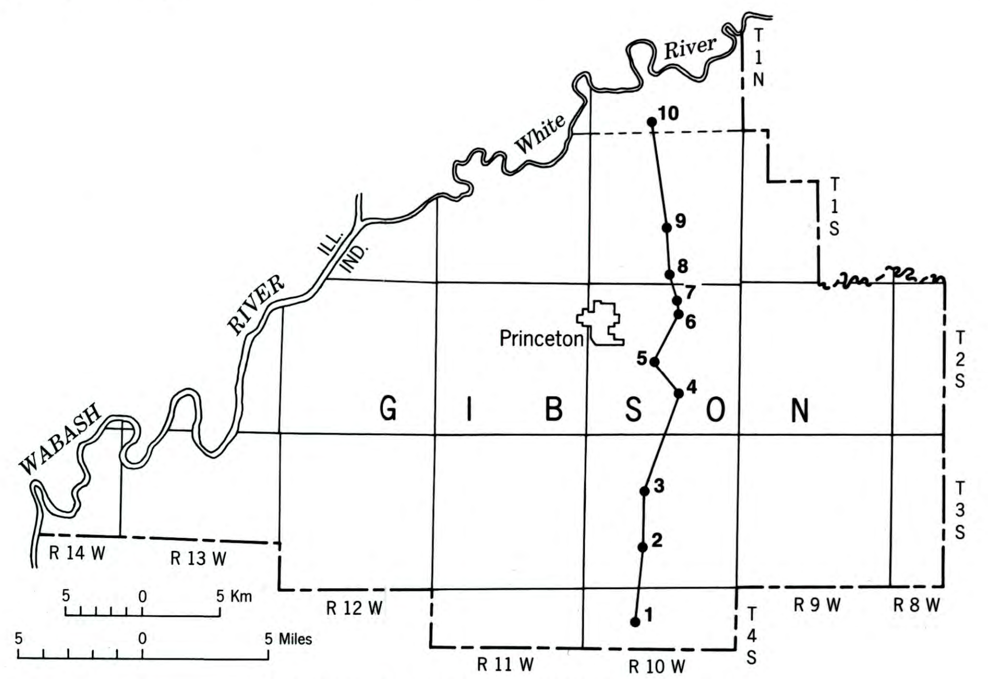
SPECIAL REPORT 50, PLATE 1

## SELECTED STRATIGRAPHIC UNITS

| | |
|---|---|
| Da | Danville Coal Member |
| Hy | Hymera Coal Member |
| Po | Providence Limestone Member |
| Bk | Bucktown Coal Member |
| AC | Alum Cave Limestone Member |
| Fo | Folsomville Member |
| Sp | Springfield Coal Member |
| HC | Houchin Creek Coal Member |
| US | 'Upper' Split Survant Coal Member |
| LS | 'Lower' Split Survant Coal Member |
| Cc | Colchester Coal Member |
| Se | Seelyville Coal Member |
| A | Unnamed Staunton coal |
| B | Unnamed Staunton coal |



Location Map



MAP SHOWING LINE OF CROSS SECTION

# CROSS SECTION SHOWING REPRESENTATIVE GEOPHYSICAL LOGS FROM GIBSON COUNTY, INDIANA

By Donald L. Eggert

1993

Drafted by Roger L. Purcell