ENVIRONMENTS OF DEPOSITION–COAL BALLS, CUTICULAR SHALE, AND GRAY-SHALE FLORAS IN FOUNTAIN AND PARKE COUNTIES, INDIANA

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Environments of Deposition Coal Balls, Cuticular Shale and Gray-Shale Floras in Fountain and Parke Counties Indiana

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DEPARTMENT OF NATURAL RESOURCES
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Contents

Illustrations

[Plates follow Literature Cited]

Illustrations

Tables

Environments of Deposition—Coal Balls, Cuticular Shale, and Gray-Shale Floras in Fountain and Parke Counties, Indiana

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Introduction

In the Illinois Basin (western parts of Indiana and Kentucky and most of Illinois) 99 percent of the identified bituminous coal resources occur in the Middle Pennsylvanian Series (Phillips and others, 1980). During deposition of this stratigraphic interval there was a marked rise and fall in the extent of successive coal-swamp environments because of changes in rainfall and freshwater availability as well as in local environmental factors. In early Middle Pennsylvanian time swamp environments were varied; they were usually small scale, and many were discontinuous in distribution. In western Indiana two such areas of coal deposits (fig. 1) were comparatively studied to interrelate environments of deposition, modes of plant preservation, plant assemblages with their ecologic implications, and coal qualities.

The two areas were chosen because the fossil plants of exceptional preservational modes and quality associated with coal were abundant and because the deposits were stratigraphically and geographically close enough to provide valid paleobotanic comparisons according to differences in environments of growth and deposition. The exposed coals of the two areas thin, thicken, or pinch out over relatively short distances within the mines or other exposures, and therefore their stratigraphic determinations are uncertain to some degree.

In Parke County at the Roaring Creek Mine and adjacent creek exposures are the Lower and Upper Block Coal Members of the Brazil Formation (fig. 2), which have been more extensively mined in the Brazil area of Clay County. According to Pepper's palynologic studies, the lowest coal exposed along Roaring Creek, just below the Block coals, is the Mariah Hill Coal Bed, which occurs in the upper part of the Mansfield Formation. The coals along Roaring Creek are late Atokan and late Westphalian C in age (fig. 3; Peppers, in preparation). In Fountain County at the Maple Grove Mine near Cayuga, the main seam is an unnamed member in the lower part of the Staunton Formation. According to palynologic studies by Peppers, this coal resembles most closely the Murphysboro Coal Member (Spoon Formation) of Illinois, which has been mined more extensively near Murphysboro in southern Illinois. The age of the coal is early Desmoinesian and early Westphalian D (Peppers, in preparation).

The two areas represent quite different depositional environments for peat accumulation and may represent upper and lower deltaic-plain sedimentation respectively. In the low-sulfur coals of the Roaring Creek area some plant deposits accumulated in place and some by limited transport in a dominantly fluvial sequence without later marine influence. The Lead Creek Limestone Member (Mansfield Formation), which represents the first major marine incursion into the Illinois Basin, overlies parts of the Mariah Hill coal (Shaver and Smith, 1974) and its western Kentucky equivalent, the Dunbar Coal Bed (Peppers and Popp, 1979), but does not extend into the Roaring Creek area. In contrast, the high-sulfur coal at the Maple Grove Mine is derived from in-place peat

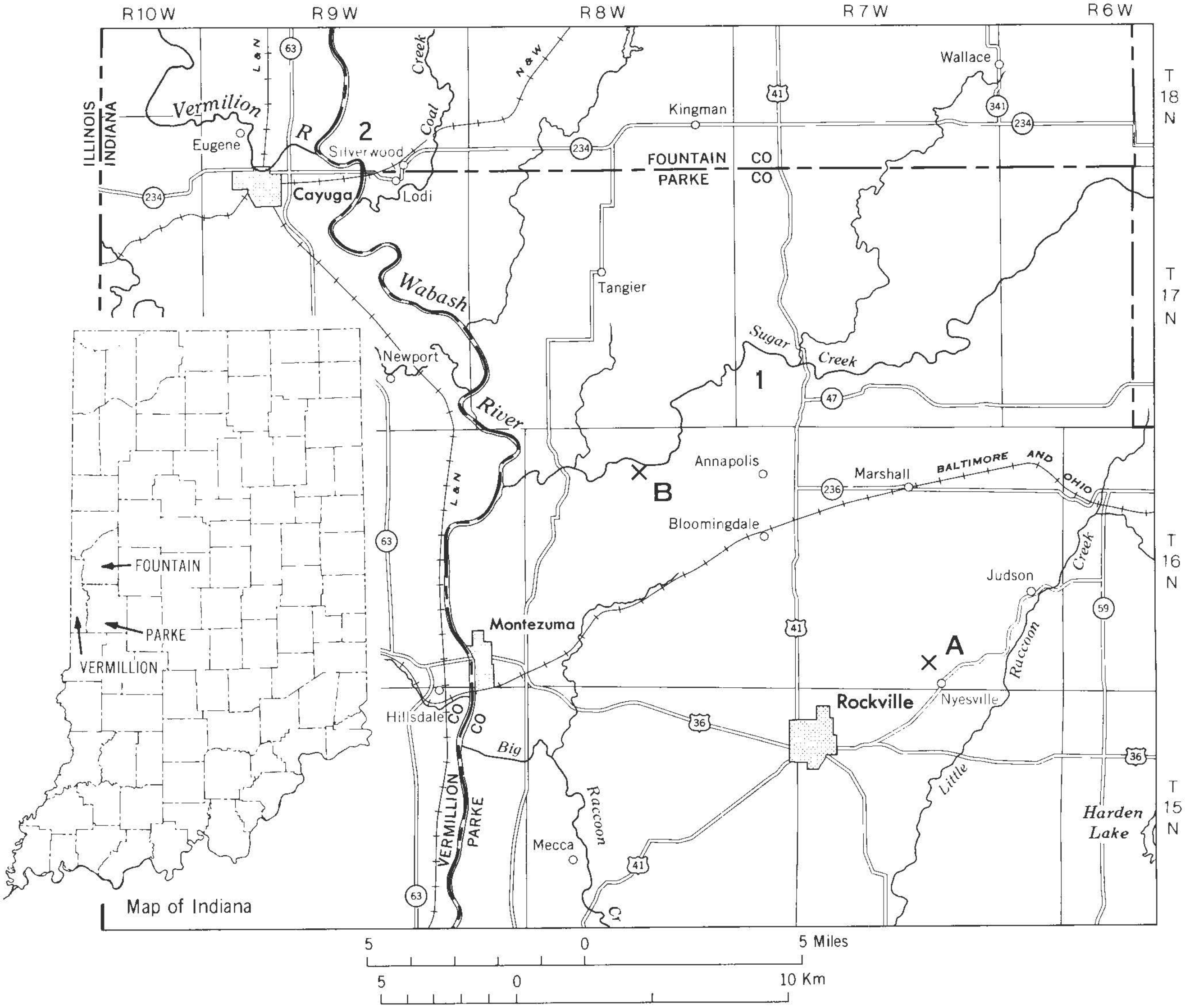

Figure 1. Map showing study areas and reported sites of cuticular coal or shale. 1, Roaring Creek Mine area; A, Nyesville locality; B, Coke Oven Hollow locality; 2, Maple Grove Mine area.

deposits on a lower delta plain subjected to brackish influences and succeeded by brackish-to-marine strata. The modes of plant preservation reflect the different depositional milieu of the sites. Plant compressions and cuticular coals and shales occur at Roaring Creek, and permineralized peat in coal-ball concretions occur in the upper half of the marine-influenced coal swamp at the Maple Grove Mine.

The respective floras represent differences in the responses of plant communities to available habitats and their proximity to environments of deposition. Most kinds of abundant wetland plants had long stratigraphic ranges and are represented in the spore floras of the coals in both areas, but there were significant environmental changes during early Middle Pennsylvanian time that led to the introduction of some plants into the wetlands and to the loss of others. Coal seams of the Roaring Creek area developed during late Atokan time when swamp floras were undergoing a change from lycopod-dominated

MIDCONTINENT	ILLINOIS			INDIANA			WESTERN KENTUCKY		APPALACHIA
SERIES	GROUP	FORMATION	MEMBER	GROUP	FORMATION	MEMBER	FORMATION	BED	GROUP OR FM.
VIRGILIAN	McLeansboro	Mattoon	Shumway Ls. Calhoun Coal Shelbyville Coal Opdyke Coal Friendsville Coal	McLeansboro	Mattoon		Sturgis		Monongahela Fm. ?
MISSOURIAN		Bond	Unnamed coal		Bond				Conemaugh Formation
		Modesto	Chapel (No. 8) Coal		Patoka	Parker Coal			
					Shelburn				
DESMOINESIAN	Kewanee	Carbondale	Danville (No.7) Coal Herrin (No.6) Coal Springfield (No. 5) Coal Summum (No. 4) Coal Francis Creek Shale Colchester (No. 2)	Carbondale	Dugger	Danville Coal (VII) Herrin Coal		"Baker" Coal	Allegheney Group
					Petersburg	Springfield Coal (V)	Carbondale	No. 11 Coal No. 9 Coal	
					Linton	Colchester Coal (IIIa)		Schultztown Coal	
		Spoon	De Koven Coal Murphysboro Coal Rock Island (No. 1) Coal	Raccoon Creek	Staunton	Unnamed coal	Tradewater	De Koven Coal	Pottsville Group
					Brazil	Minshall Coal Lower Block Coal		Bell Coal	
ATOKAN	McCormick	Abbott	Willis Coal		Mansfield		Caseyville		
MORROWAN		Caseyville							

Figure 2. Correlation of Pennsylvanian strata in the Illinois Basin and adjacent regions. Modified from Phillips and others (1973).

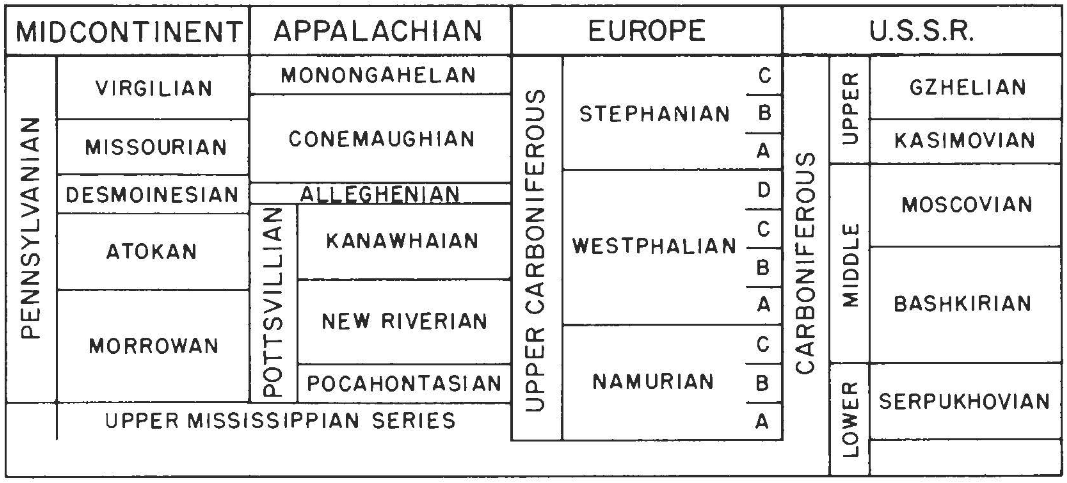

Figure 3. Correlation of time-rock units of the Pennsylvanian System in the United States with those of the Carboniferous System of Europe and the U.S.S.R. From Phillips and others (1973, fig. 1).

forests to those containing more diverse and abundant ferns, sphenopsids, and seed plants. Peppers (1979) proposed that this shift in floristic composition was caused by a decrease in precipitation and a change in depositional patterns as a result of the reduction of pre-Pennsylvanian topographic relief. Plants that had been growing mostly marginal to swamps could compete more effectively with aquatic lycopod trees that required some standing water for reproduction and dispersal (Phillips, 1979). In the early Desmoinesian wetter conditions brought back into the Illinois Basin an increased abundance of aquatic lycopod forests along with the recurrent brackish influences from the west with which cordaites are associated. The Minshall Coal Member (Brazil Formation) (fig. 2) represents the time of this significant change (Peppers, 1979), and the main seam at the Maple Grove Mine is just a little higher stratigraphically (fig. 2) than the Minshall coal.

These lower Middle Pennsylvanian coals present unique opportunities for examining relationships between fossil plants and their environments of growth and deposition. The so-called "Indiana paper coals" in the Roaring Creek and adjacent areas have drawn much attention from coal geologists because of their rarity and their problematic environmental significance. Exquisitely preserved cuticles of plants provide direct evidence of some plant source of the deposits as well as indications of their limited transport. The associated gray-shale floras give complementary information about the plants that lived nearby. The coal-ball plants from the Maple Grove Mine are of paleobotanic interest because they are the oldest presently known in-place peats of Pennsylvanian coal-swamp communities in the Illinois Basin. The in-place peats of coal balls provide the most direct evidence of the communities that actually lived in the swamp and from which the coal derived. Comparing data from the peat with data from coal palynology makes it possible to ascertain in such a small-scale swamp what kinds of plants lived nearby and also contributed spores to the depositional environment. Coal balls and "paper coals" are largely restricted to Upper Carboniferous and Permian rocks and are exceptional deposits even in this stratigraphic interval.

During the course of this study the Maple Grove Mine became inactive (1979), and the Roaring Creek Mine was opened (1978) and became inactive (1979). Accessibility to these mine areas was granted by the owners for a field trip of the Ninth International Congress of Carboniferous Stratigraphy and Geology in May 1979.

Stratigraphy and Sedimentology of the Raccoon Creek Group of Indiana

Indiana rocks assigned to the Raccoon Creek Group represent the lower and lower middle part of the Pennsylvanian System. This group is divided into the Mansfield, Brazil, and Staunton Formations (fig. 2). Shale and sandstone are the dominant lithologies; coal and limestone represent only a small percentage of the group (Wier, 1970).

The Mansfield Formation, originally named by Hopkins (1896), consists of all rocks from the Mississippian-Pennsylvanian unconformity to the base of the Lower Block Coal Member (Brazil Formation) (Hutchison, 1976). The Mansfield-Brazil contact is often difficult to determine in many areas because the Lower Block Coal Member is missing. The Mansfield is equivalent to the Caseyville Formation and the lower two-thirds of the Abbott Formation in Illinois. Studies of the Mansfield and its equivalent strata in Illinois have shown that the sediments are mostly fluvial in origin (Gray, 1962; Potter, 1963; Ethridge and others, 1973; Ethridge and Fraunfelter, 1976). The general source area was from the northeast. In some areas of Indiana the sediments exhibit upper lower and upper deltaic characteristics as outlined by Horne and others (1978). These include active channel-fill sand bodies, scoured contacts, lithic graywackes, relatively rare marine beds, possible levee deposits, and troughed cross-bedded sandstones. Many beds are lenticular in their distribution or truncated by later erosion, which is suggestive of the fluvial part of small-scale deltaic deposition.

The Brazil Formation, originally named by Fuller and Ashley (1902), consists of those rocks between the base of the Lower Block Coal Member and the top of the Minshall Coal Member in the northern counties of the Indiana coalfield (Hutchison, 1976). In the southern part of the Indiana coalfield the top of the Brazil Formation is generally considered to be the top of the Buffaloville Coal Member. Important coals within the Brazil Formation are the Lower Block, Upper Block, Minshall, and Buffaloville Coal Members. Parts of the Spoon and Abbott Formations of Illinois are correlative with the Brazil Formation of Indiana. The difficulties in separating the two formations in many parts of the Indiana coalfield suggest that the Brazil Formation represents a continuation of the depositional systems that produced the Mansfield. Low-sulfur coals are relatively common in both formations, but the extensively mined low-sulfur block-coal district near Brazil, in Clay and Owen Counties and southern Parke County, represents a more economically significant resource than known low-sulfur coal resources of the Mansfield. Low-sulfur coals are generally found in the eastern and midwestern United States in areas where the peats were not exposed to marine water or brines and were deposited within upper or upper lower delta plains.

The Staunton Formation, named by Cumings (1922), consists of rocks from the top of the Minshall Coal Member, or its approximate equivalent in the southern part of the Indiana coalfield, the Buffaloville Coal Member, to the top of the Seelyville Coal Member (Hutchison, 1976). The Staunton Formation generally consists of 75 to 125 feet (23 to 38 m) of sandstone, shale, coal, lenticular limestone, black fissile shale, and claystones. Coals within this formation are generally lenticular, variable in the amount of ash, and usually higher in sulfur than those in the Mansfield and Brazil Formations. The Staunton is equivalent to most of the Spoon Formation of Illinois. Unlike the lower formations in the study area the Staunton has fewer fluvial features; marine sediments are more common with rather complete cyclothemic sequences that include black fissile shales and marine limestones. A lower delta-plain environment seems to be a reasonable model for parts of the Staunton Formation in Indiana. The lateral discontinuities and repeated sequences are likely the product of progradation into and abandonment of small deltaic lobes in shallow marine environments.

Quality of Indiana Coals

Coal quality can be measured in different ways, but the more common parameters are rank, sulfur content, thermal value, and ash content. Coals in Indiana are generally of

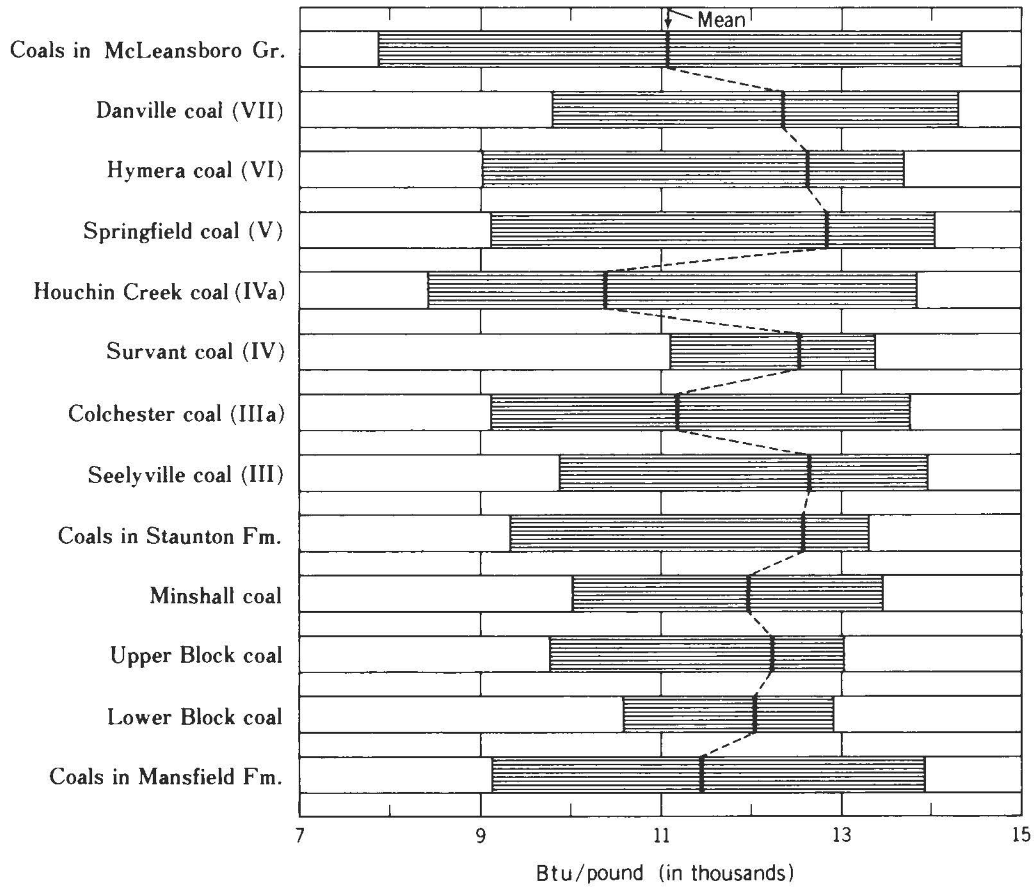

Figure 4. Range in value and mean value of Btu per pound of Indiana coals, ash-free basis. From Wier (1973, fig. 7).

high-volatile B and C bituminous rank, high in sulfur content, high in thermal value, and moderate in ash content (figs. 4-6). Each of these parameters varies from site to site. Rank does not vary as widely as other characteristics because it is not controlled by the environment of deposition. The sulfur content has a wide range of values and a mean value of about 3 percent. The range in sulfur is controlled by the environments of growth and deposition of vegetation from which the coal was derived and from the environments of deposition of the overlying strata. Various studies of coals in the Illinois Basin have shown that in areas where nonmarine sediments overlie the coal seam the sulfur is significantly lower than where brackish-to-marine sediments are close to the coal. Eggert (1982) and Eggert and Adams (in preparation) have suggested, however, that sulfur in coal is controlled by the salinity of the peat swamp and the salinity of the environments that succeed the peat environment. A low-sulfur coal forms in a freshwater environment and is overlain by fluvially derived sediments that prevent postdepositional sulfide mineralization by brines generated from saline environments. A high-sulfur coal can be formed by deposition in a peat swamp with a higher salinity or in one exposed to saline water after peat deposition. In the depositional model outlined by Horne and others (1978) one would expect to find low-sulfur coals in the upper deltaic plain or next to contemporaneous distributary channels in the lower delta plain. High-sulfur coals would be generally restricted to the lower delta-plain areas. Ash in Indiana coal also has

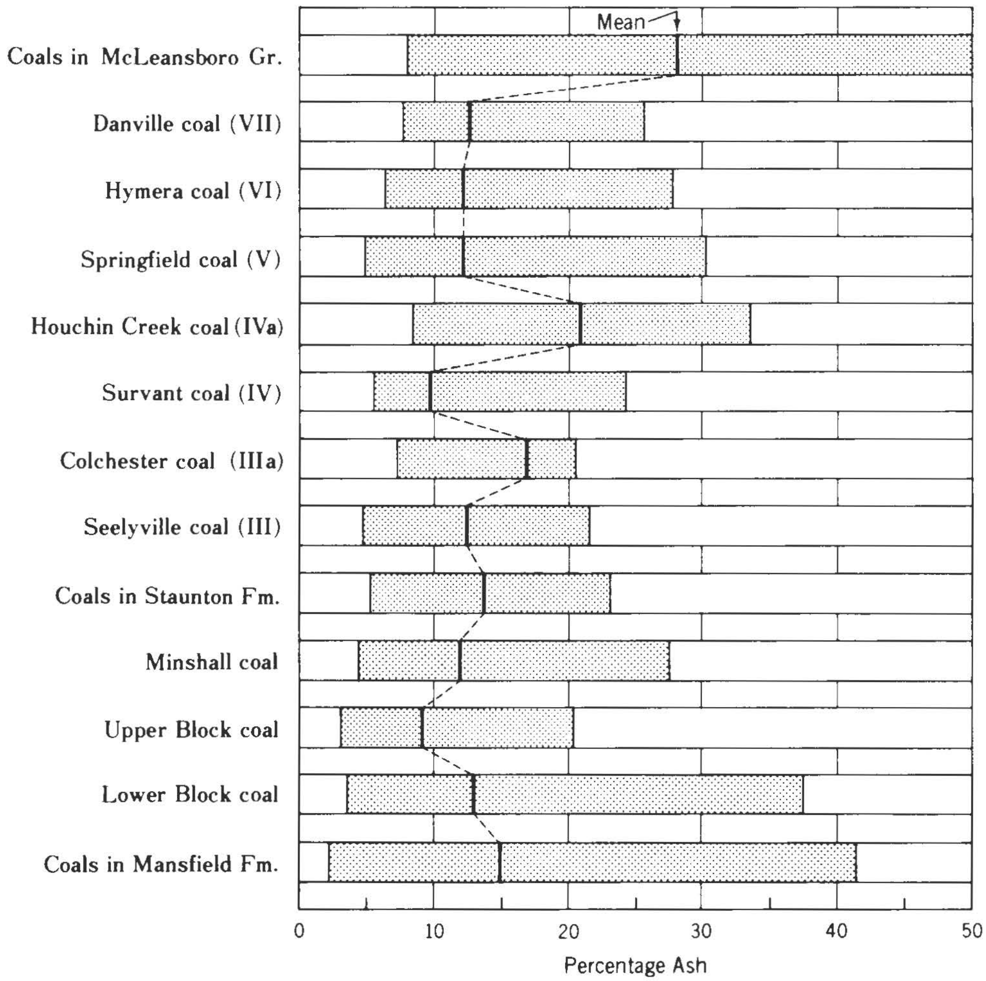

Figure 5. Range in value and mean value of percentage of ash in Indiana coals, dry basis. From Wier (1973, fig. 8).

a significant range in value because ash content is a function of mineral matter that was transported into the swamp by wind and water or that was preciptated from swamp waters. Thermal values of Indiana coals vary widely because of oxidation, water saturation of the coal, mineral-matter content, and rank. The mean thermal value of Indiana coals is almost 12,000 Btu per pound.

Use of Indiana coals depends principally on their rank, sulfur content, ash content, and thermal value. Particulate matter and thermal pollution have been largely controlled by recent technologic advances in electric-power generation, the major use for midwestern coal, but sulfur has remained a difficult problem. Therefore, understanding the origin of high-sulfur and low-sulfur midwestern coals is economically significant to our region. Experience suggests that plant communities, environments of deposition, and coal quality are closely interrelated.

Roaring Creek Mine Area Parke County

Cuticular shales and coalified compressions near the Roaring Creek Mine were studied in combination with spore floras from the coals and their shaly facies (fig. 7). A similar cuticular-shale deposit near Coke Oven Hollow (fig. 1) was also studied.

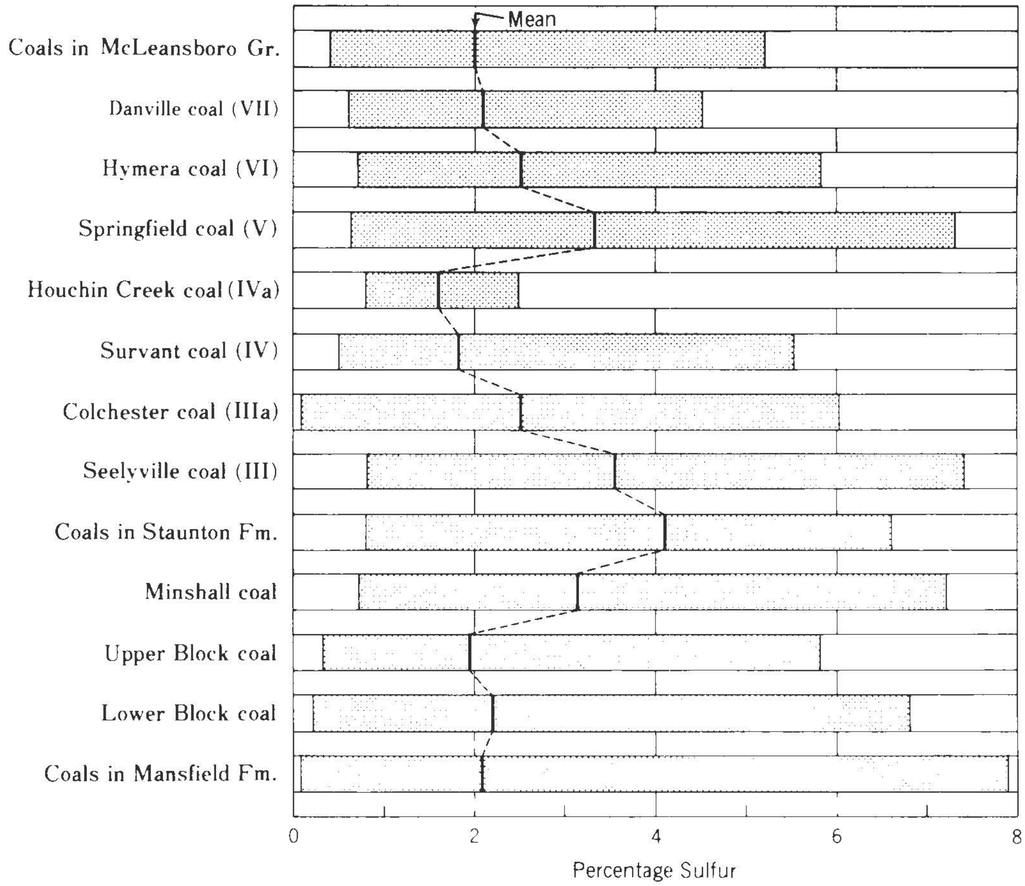

Figure 6. Range in value and mean value of percentage of sulfur in Indiana coals, as-received basis. From Wier (1973, fig. 9).

Sedimentary rocks containing high concentrations of the maceral cutinite are uncommon in the Carboniferous of North America. Cutinite in coal or other sedimentary rocks appears yellow to yellow brown in transmitted light, is pleochroic with an undulatory extinction in transmitted cross-polarized light, and is darker than the maceral vitrinite in reflected light. The maceral cutinite is believed to be derived from the cuticle layer of plants. The cuticle is believed to be derived from the cuticular layer of plants from outer cells of leaves and stems that are impregnated with the waxlike organic substance cutin. Plant cuticles restrict water loss (transpiration) and are a barrier to the entrance of external substances and many microorganisms because of the inert nature of cutin. Coal petrologists who are seeking pure samples of the maceral cutinite for physical and chemical analysis are interested in rare deposits of sedimentary rocks with high concentrations of cutinite. Paleobotanists seek the identity of the source plants, and sedimentologists are interested in such deposits as indicators of the depositional environment.

Several sites have been reported in Parke County where coals with unusually high cutinite (cuticular) content are exposed. Neavel and Guennel (1958) and Guennel and Neavel (1959) reported the first site near Nyesville (fig. 1). Guennel (1960) reported cuticular deposits along Roaring Creek, and Zangerl and Richardson (1963) noted a deposit near Coke Oven Hollow (fig. 1). The opening of the Roaring Creek Mine has provided a laterally continuous exposure of the strata associated with perhaps the same

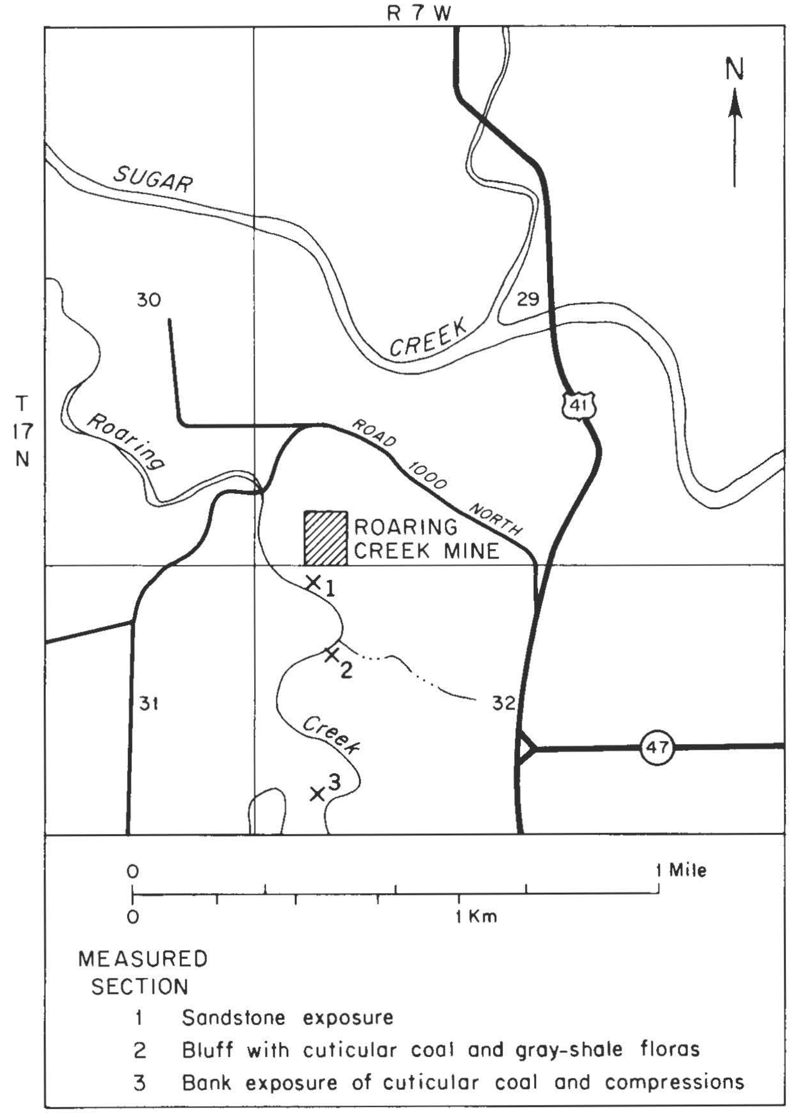

Figure 7. Map showing the Roaring Creek Mine area, Parke County.

cuticular unit examined by Guennel (1960). The quality of these exposures has permitted stratigraphic and sedimentologic study. These exposures have also provided materials for comparative paleobotanic and palynologic study with other related units nearby.

CHEMICAL ANALYSIS

Samples of coal, cuticular materials, and shales were collected from the Roaring Creek Mine and surface exposures along the creek. Analyses show the low sulfur content of these strata suggestive of nonmarine deposition (table 1). The ash content of the cuticular samples from the mine is more than 50 percent, which exceeds the limits of Schopf's (1966) definition of coal. These materials are more properly called cuticular shales. A significant 10-percent range exists between the two samples, however, and the unit could possibly be less than 50 percent in ash locally. The high ash content suggests detrital material was transported into the environment of deposition.

Table 1. Analysis of coals and shales from the Roaring Creek Mine (moisture free)

Sample No.	Material analyzed	Ash (pct)	Sulfur (pct)	Btu
78 x 25	Cuticular shale, Upper Block Coal Member	56.7	0.6	5,690
78 x 27	Middle seam, Upper Block Coal Member	9.3	1.0	12,790
78 x 26	Lower seam, Upper Block Coal Member	6.4	0.9	13,420
DE78 x 72	Shale	87.9	0.1	73
DE78 x 71	Shale	79.6	0.2	1,820
DE78 x 70	Cuticular shale	67.5	0.4	4,040

STRATIGRAPHY

Neavel and Guennel (1958, 1960) assigned their cuticular coal to the Brazil Formation in the lower Middle Pennsylvanian of Indiana. Our data suggest that the cuticular shale in the Roaring Creek Mine is probably similar in age and that the upper cuticular shale exposed in the bluff is probably, as Guennel (1960) reported, associated with the Upper Block Coal Member, or at least younger than the Lower Block Coal Member. From our field observations there appear to be several different cuticular shales of similar age that are gradational laterally and (or) vertically into shale, cuticular coal, or coal. All are within the Brazil Formation or near the top of the Mansfield Formation. Pepper's palynologic analyses suggest approximate correlations among some of the exposed coals along Roaring Creek with each other and with equivalent coals in Illinois and Indiana.

There are at least four or five coal seams in the Roaring Creek Mine and in three sections along Roaring Creek (figs. 8 and 9). Coals exposed in the mine have been designated as upper, middle, and lower, and those exposed along the creek have been designated as coals A, A′, B, C, C′, and D. These designations are intended as aids in local correlation of the seams.

The lowermost coal is coal A in section 2, which is believed to be correlative with coal A′ in section 3. This coal seam grades laterally and vertically into a dark-gray cuticular organic shale above and below the coal or into a gray-shale roof. The gray shale and cuticular shale associated with this seam contain abundant plant fossils. Peppers (p. 14) has found that the spore assemblage of this coal is similar to that of the Mariah Hill Coal Bed of the Mansfield Formation. This coal is about 20 feet (7 m) below the lower coal in the mine.

The lower coal in the mine breaks into large cubic blocks and is overlain by a gray sandy undulating shale, which contains upright trees and poorly preserved plant fossils. Coal C in section 1 is underlain by dark-gray organic shale with vitrain bands and is overlain by fine- to medium-grained sandstone. Coal B in section 2 is both overlain and underlain by gray shale. Coal C′ is overlain by fine- to medium-grained sandstone and underlain by a root horizon above a flaser-bedded sequence of fine-grained sandstone and shale. The sandstone that overlies Coals C and C′ has an erosional contact with the coal, and coal clasts are common in the base. Each of these coal seams is at about the same elevation and could be physically correlative. But Peppers (p. 14) found that the palynologic assemblage of Coal B is similar to the Lower Block Coal Member and the assemblages of coals C and C′ are similar to the Upper Block Coal Member.

The middle, blocky coal seam in the mine and coal D in section 2 are overlain by cuticular shale. Exposures of this unit in the mine have illustrated the transition from unweathered cuticular shale to the weathered

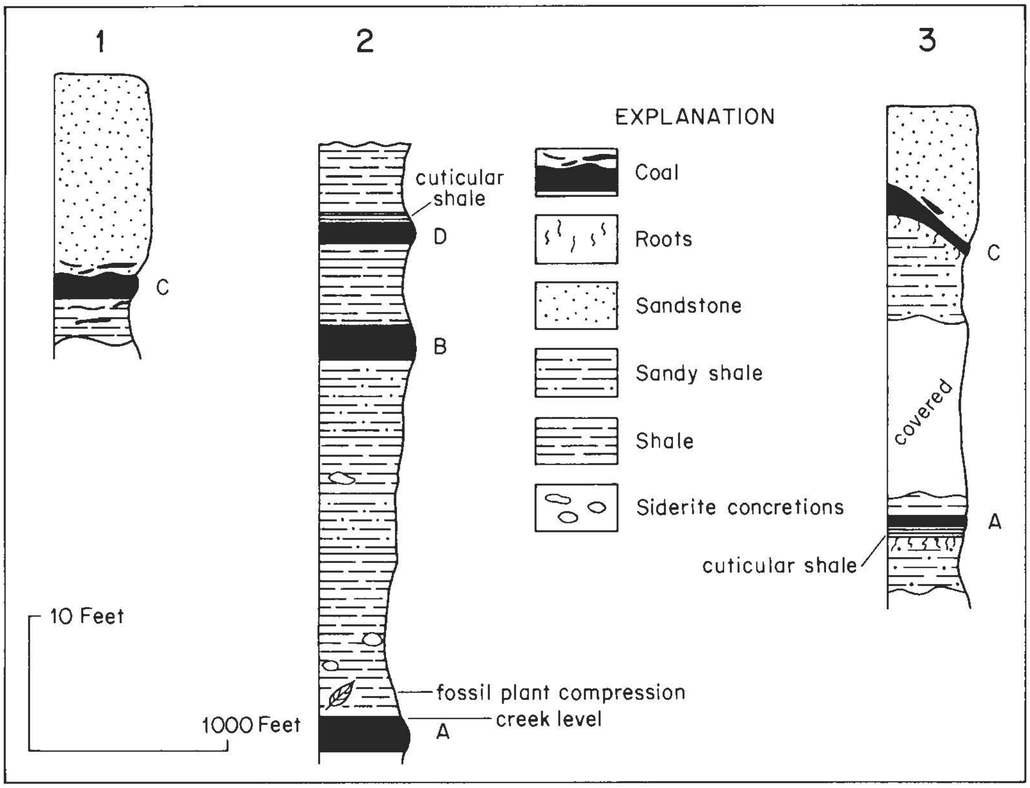

Figure 8. Measured sections along Roaring Creek, Parke County. (See the text for an explanation of the lettered deposits. See fig. 7 for location of the sections.)

"paper coal" where the unit intersects the present erosion surface. Plant cuticles as well as fossil-fish excrement can be observed on the bedding surfaces. The argillaceous cuticular shale grades upward into dark-gray organic shale. This unit in the mine thickens to the southeast and becomes less dark upward from the cuticular shale where the interval is thick. Examining and sampling the cuticular shale and overlying shale at section 2 have been difficult and dangerous. During the mid-1950's geologists of the Indiana Geological Survey reported that there was a thin coal higher in the bluff, but we did not observe it when we were doing fieldwork. This coal may correlate with the upper seam at the Roaring Creek Mine.

ENVIRONMENTS OF DEPOSITION

The sediments observed in the Roaring Creek area represent the following environments of deposition: fluvial channel—crossbedded sandstone; crevasse splay—thin-bedded laminar sandstone, some flaser-bedded sandstone and shale, sandy shale, and some gray shale; overbank and levee deposits—some gray shale; swamp—coal; backswamp deposits—organic dark-gray shale; interdistributary bay or lake—some gray shale and gray flaser-bedded shale and sandstone; and lacustrine—some dark-gray shale, cuticular shale, and some gray shale. Some environments of deposition produce deposits that are not specific, and all environments are gradational into some others. Therefore, determining the exact depositional environment for some lithologic units is not always possible. The sedimentary sequence observed in this area most resembles what one would expect in an upper delta plain as outlined by Horne and others (1978).

Perhaps the most readily recognized depositional environment in the area is the fluvial-channel environment, represented by two sand bodies exposed in sections 1 and 3.

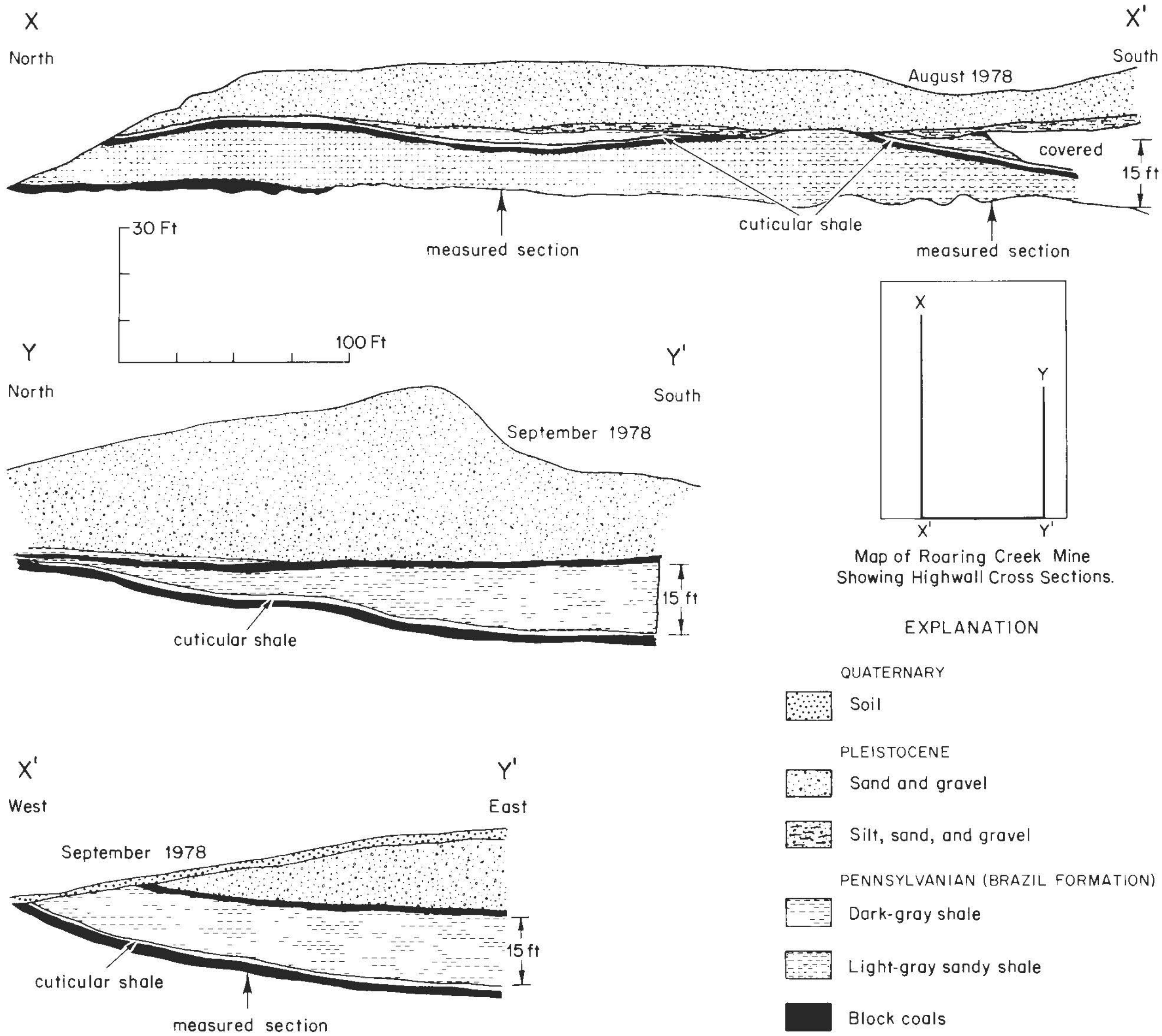

Figure 9. Diagrammatic cross sections of active highwalls of the Roaring Creek Mine. (See fig. 7 for location of Roaring Creek Mine.)

These are crossbedded sandstone and have coal clasts near the contact with underlying coal seams.

Crevasse-splay deposition is most clearly represented by the interval between the lower and middle coal seams within the mine. The thickness of this interval is undulating, thin where the sandy shale is fine grained and thicker where the shale contains more coarse sand. Two erect trees were observed extending from the lower seam into the shale. Leaf and stem fossils show high levels of breakage. Bedding is massive to poorly laminated. These relationships suggest rapid deposition within a relatively high flow regime. A second possible crevasse splay may be represented by some of the gray-shale interval between the cuticular coal that overlies the middle seam and the uppermost seam. The interval thickens rapidly to the southeast. Unlike the sandy shale of the lower splay, this shale is less sandy and more laminated and may represent distal crevasse-splay, overbank-levee, and lacustrine sedimentation.

The medium-gray shale near the base of section 2 contains abundant compression fossils. This unit represents an example of a deposit that may have formed in several different environments within the framework of the deltaic milieu. The base of the unit is gradational with the cuticular shale below. If the underlying unit is lacustrine, the base of the basal gray shale may also be lacustrine. Some zones are dominated by roots and others by aerial parts of plants, and there are vertical changes in taxonomic groups. These repeated sequences of differing plant fossils suggest a history of repeated periods of in-place plant growth (roots) and deposition of transported plant remains (aerial organs). The fine preservation suggests rapid burial within the low-flow regime. Such deposition could be expected in some parts of flood-plain, distal crevasse-splay, and levee environments. Deposition in these environments is episodic and under relatively low-flow regime, which results in a cyclic sequence of strata and fossil communities. Shifting in habitat would be expressed in vertical changes in the taxonomic composition of the strata.

Swamp deposition is represented by the coals in the area. Root zones beneath the coal and gradational contacts to overlying strata suggest the in-place development of peat swamps. Backswamp deposition produced some of the dark organic shales that overlie or underlie some coal seams in the area. The dark organic shale beneath coal C in section 2 is such a deposit.

Interdistributary-bay sediments may be represented by flaser-bedded sediments below coal C′ in section 3. These flaser-bedded sediments do not contain abundant plant fossils.

That the origin of cuticular coals and shales of Pennsylvanian age was unusual is indicated by their limited occurrence within the Pennsylvanian and in general in the geologic record. Neavel and Guennel (1960) believed that "paper coal" at the Nyesville locality formed in a swamp subjected to periodic inundation by marine water and that the in-place plants were adapted to withstand dry periods. Higher concentrations of boron and nickel in cuticular-coal ash than in the overlying gray shale were believed to indicate marine transgression into the swamp. Thick cuticles in the cuticular coals were believed to indicate an adaptation to xerophytic (dry) environment. More recent studies of boron in coal do suggest that some swamps may have been subjected to marine influence, but boron ratios are not infallible. Besides, it is now recognized that there are many adaptive reasons for cuticle to vary in thickness. It should also be noted that *Eusphenopteris* cuticles are the only ones that are really thick, and that such cuticles are found in various coal and shale lithologies in the lower part of the Brazil Formation.

The specific environments of deposition of the several beds of cuticular shale in the Roaring Creek area may have been lacustrine within the overall deltaic system. Evidence for this conclusion rests in the petrographic (Crelling and Bensley, 1980) and textural relationships and in the paleontology of the cuticular coal and shale. These lithologies consist of thin vitrain bands, cutinite, and clay and are undisturbed by root or burrow bioturbation. The fine particle size and plant-derived bioclasts (fine micrinite, small vitrain bands, and leaf and stem cuticles) suggest quiet-water sedimentation. Relatively complete leaf cuticles suggest rather short transport from neighboring source areas. The gradational upper and lower contacts of the coals may reflect gradual changes in the local water level. Fine clastics and suspended leaves and stems were transported into the quiet-water bodies. Bacterial activity was limited but combined with transportational breakage to produce fine micrinite. Gradually the lake was filled by crevasse-splay and overbank sedimentation. The distinction between these two environments like the contact between the gray shale and cuticular coal is gradational. Some gray shales may therefore be lacustrine. The plants surrounding such a stagnant freshwater lake were possibly different from those found in the swamp environment; this would be consistent with the difference in the spore assemblage of the cuticular coal from the associated coal swamps.

No marine invertebrate or vertebrate fossils were observed in the Roaring Creek area. The low sulfur content of the coals at the mine is a contrast to that of Staunton coals in Parke and Fountain Counties (table 3). Available evidence suggests that the coals and associated sediments are nonmarine and include fluvial and lacustrine deposits that most likely would be found in the landward part of a delta system.

Palynology of Coals Along Roaring Creek

By Russel A. Peppers

Palynologic study of some coals along Roaring Creek was carried out before the opening of the Roaring Creek Mine in 1978 to aid in correlating exposed coals and to provide a paleobotanic background for compressions studies by DiMichele (p. 19-21). Therefore, inferences about physical correlations of the coals from the creek exposures to the surface mine lack a comparative basis from spore assemblages.

The distribution and relative abundances of spore taxa in the coals along Roaring Creek in sections 1, 2, and 3 are given in table 2, and representative specimens are shown on plate 1. Illinois State Geological Survey macerations 2421A, 2421B, and 2421C were taken from coals A, B, and D in section 2 on the east bank (fig. 8). Coal A′ was sampled (maceration 2648) in section 3 on the west bank and upstream from section 2. Coal C was sampled in section 1 (maceration 2647) and coal C′ in section 3 (maceration 2423C). Coals C and C′ are directly overlain by channel sandstone.

Spore analyses of the coals along Roaring Creek have been compared with analyses of coals in the same interval in other parts of the Illinois Basin. The spore assemblages in coals A and A′ are similar to those in the Mariah Hill Coal Bed of Indiana. *Lycospora* dominates the spore assemblage in the Mariah Hill coal, and *Radiizonates difformis*, which first appears in the Mariah Hill coal, is fairly common. The Mariah Hill Coal Bed is correlated with the Dunbar Coal Bed of western Kentucky (Peppers and Popp, 1979), but a coal of the same age has not been identified in Illinois.

Coal B, whose spore assemblage is comparable to that in the Lower Block Coal Member of Indiana, is also dominated by *Lycospora*, but *Radiizonates* is rare or absent. The Lower Block Coal Member is correlated with the Tarter Coal Member (Abbott Formation) of Illinois and an unnamed coal in Kentucky (Peppers and Popp, 1979).

Coals C and C′ are palynologically most similar to the Upper Block Coal Member and contain abundant *Laevigatosporites globosus* and a large percentage of *Lycospora granulata*. The Upper Block coal or in some places an Upper Block rider coal is the youngest coal in the Illinois Basin that contains *Radiizonates*. *Torispora* is usually well represented in the Upper Block coal, but coals C and C′ do not contain as many *Torispora* as would be expected. However, coals C and C′ are directly overlain by channel sandstones, and the upper part of the coal, which in many places contains the highest percentage of *Torispora*, could have been removed. The Upper Block Coal Member is correlated with the Pope Creek and Willis Coal Members (Abbott Formation) in Illinois and the Ice House Coal Bed in Kentucky (Peppers, 1977; Peppers and Popp, 1979). The geology of the Lower Block and Upper Block members and the Mariah Hill Coal Bed was summarized by Hutchison (1970). The palynology of the Lower Block and Upper Block coals and other coals in the Pottsvillian Series was described by Guennel (1958).

Coal D, which underlies a dark-gray shale, is interpreted as being an upper split or rider of the Upper Block coal. A rider coal of the Upper Block coal occurs in the Brazil Quadrangles and has been mined in a few places (Hutchison, 1960). *Lycospora* is rare in coal D, but *Laevigatosporites globosus*, *L. minutus*, *Punctatisporites minutus*, and *Torispora securis* are well represented. A "paper coal" that grades upward into a dark-gray shale is exposed at Coke Oven Hollow (fig. 1). The spore assemblage in that coal is similar to that in the Upper Block coal (coal D).

Table 2. Occurrence and relative abundance (in percent) of spore taxa in coals along Roaring Creek (NW¼ sec. 32, T. 17 N., R. 7 W.), Parke County
[Based on Illinois State Geological Survey macerations 2421A, 2421B, 2421C, 2648, 2423C, and 2647]

Spore taxa	Section[1]	1	2	2	2	3	3
	Coal	C	A	B	D	A′	C′
Leiotriletes levis						0.5	
L. parvus		X[2]	X	X	1.0	X	
L. priddyi			X	1.0	X	1.0	
L. sphaerotriangulus			X	X		X	
L. sp.					X	X	
Punctatisporites curviradiatus			X		1.5	X	
P. edgarensis						X	
P. flavus				X	X		X
P. minutus		X		2.5	12.0	0.5	0.5
P. obesus		X	X	X	X	X	X
P. obliquus					1.5		0.5
Calamospora breviradiata				2.0		0.5	0.5
C. flexilis						X	
C. hartungiana		0.5	0.5		0.5	X	X
C. liquida			X	X		X	
C. mutabilis					X	X	
C. straminea			X	X		X	
C. sp.		0.5					
Granulatisporites granularis			X	2.0		X	
G. microgranifer					0.5	X	
G. minutus		X	0.5	4.0		0.5	
G. pallidus			X	X		0.5	
G. parvus			X	X	2.0	0.5	X
G. verrucosus				0.5		0.5	
G. sp.					0.5	1.0	
Cyclogranisporites aureus			X		0.5	X	
C. leopoldi			1.0		2.0	2.0	
C. minutus			X		0.5	0.5	0.5
C. orbicularis						X	
Converrucosisporites sp.					X		
Verrucosisporites microtuberosus		X	X		0.5	0.5	X
V. sifati					X	X	X
V. verrucosus		X					

Table 2. Occurrence and relative abundance (in percent) of spore taxa in coals along Roaring Creek (NW¼ sec. 32, T. 17 N., R. 7 W.), Parke County—Continued

Spore taxa	Section	1	2	2	2	3	3
	Coal	C	A	B	D	A′	C′
V. cf. *verrucosus*		X	X		X		X
Lophotriletes commissuralis						0.5	
L. gibbosus					X		X
L. granoornatus				0.5			
L. microsaetosus		0.5	X	0.5		1.0	
L. mosaicus				X			
L. pseudoaculeatus				X	X	X	
Anapiculatisporites spinosus			X	X		0.5	
Pustulatisporites crenatus				X	X		
P. sp.			X				
Apiculatisporis abditus		X	X	X		0.5	
A. setulosus					X	X	
A. spinosaetosus		X				X	
A. (*Punctatisporites*) *variusaetosus*			X			X	
Planisporites granifer			X				
Acanthotriletes aculeolatus			2.0	X	1.0	1.0	
A. echinatus		0.5	X			X	
Raistrickia aculeolatus		X			X		
R. breviminens			X			X	X
R. crocea		X	X		X	0.5	
R. pilosa			X		X	X	
Spachmanites facierugosus		X				X	
Convolutispora sp.			X			X	
Microreticulatisporites nobilis			X			X	0.5
M. sulcatus			X	X		X	
Dictyotriletes bireticulatus					X	X	
D. reticulocingulum			X		X	X	
Camptotriletes sp.				X			
Ahrensisporites guerickei						X	
Zosterosporites triangularis			X	X		X	
Triquitrites additus			X	X			
T. bransonii					X		
T. sculptilis		X	X	4.5		1.5	
T. tribullatus					X		

Table 2. Occurrence and relative abundance (in percent) of spore taxa in coals along Roaring Creek (NW¼ sec. 32, T. 17 N., R. 7 W.), Parke County—Continued

Spore taxa	Section	1	2	2	2	3	3
	Coal	C	A	B	D	A′	C′
Knoxisporites stephanephorus							X
K. triradiatus		X				X	
Reticulatisporites polygonalis						X	
R. reticulatus			X		X	X	
Cuneisporites rigidus			X				
Savitrisporites asperatus			X			X	
S. nux				X			
Crassispora kosankei		0.5	0.5	X		0.5	X
Cappasporites distortus		3.0	1.0	5.0	9.0	1.0	3.0
Densosporites annulatus			X			X	
D. sphaerotriangularis						0.5	
D. triangularis				X	X		
Lycospora granulata		56.0	56.5	50.0	0.5	41.0	45.5
L. micropapillata			1.5	1.5		X	
L. pellucida		1.0	2.0				0.5
L. punctata		1.0	3.5	3.0		10.0	
L. rotunda			0.5	0.5	X	X	0.5
Cristatisporites indignabundus			X			X	
Cirratriradites annulatus						X	
C. maculatus				X	0.5		
C. reticulatus					X		
C. saturni		X	X	X	X	0.5	X
Cingulizonates loricatus		X					
Radiizonates difformis		2.5	8.0		X	6.0	8.5
R. rotatus		X				X	4.5
Endosporites globiformis		X	X		X	X	
E. plicatus			X			X	
E. staplinii			X			X	
E. zonalis			X	X	X	X	X
Paleospora fragila							X
Alatisporites hexalatus		X			X		
A. hoffmeisterii					X	X	X
A. pustalatus						X	X
A. trialatus		X			X	X	

Table 2. Occurrence and relative abundance (in percent) of spore taxa in coals along Roaring Creek (NW¼ sec. 32, T. 17 N., R. 7 W.), Parke County—Continued

Spore taxa	Section	1	2	2	2	3	3
	Coal	C	A	B	D	A′	C′
Laevigatosporites desmoinesensis		0.5	0.5	X		X	X
L. globosus		18.0	3.5	4.5	33.5	17.0	25.5
L. medius		X	0.5		1.0	0.5	1.5
L. minutus		2.0	10.0	2.5	7.5	6.0	2.5
L. ovalis		11.0	3.5	4.0	11.0	6.5	8.5
L. striatus		0.5				X	
L. vulgaris		X	X	X		X	
Renisporites confossus				X			X
Torispora securis				X	10.0		0.5
Vestispora fenestrata				1.5	X	X	
V. foveata			X	X			
V. magna		X	X	X			X
V. pseudoreticulata		X	0.5			X	X
Pseudoillinites diversiformis					X	X	
Florinites mediapudens		2.0	6.5	3.5	2.5	1.5	2.0
F. millotti				X		1.0	0.5
F. similis						X	
F. visendus			X			X	
F. volans					X	X	
F. sp.						0.5	
Wilsonites circularis						X	
W. delicatus						X	
W. vesicatus				1.0	X	0.5	
Potonieisporites elegans						X	
Trihyphaecites triangulatus			X		X		

[1]Locations are shown in figure 7.

[2]X = less than 0.5 percent.

Spore assemblages in coals A and A′ on opposite sides of Roaring Creek in sections 2 and 3 are quite similar and are dominated by *Lycospora*, which represents 51 to 64 percent of the spores present. *Crassipora* (*Sigillaria*) and *Cappasporites* (*Lepidodendron-Achlamydocarpon varius*) are of minor importance, but the spores attributed to herbaceous lycopods, *Radiizonates*, *Densosporites*, and *Cirratriradites*, constitute 7.5 percent on the east bank and 7 percent on the west bank. Spores from marattiaceous tree ferns, *Laevigatosporites minutus*, *L. globosus*, and *Punctatisporites minutus*, were second in abundance with about 14 percent of the flora in the coal on the east bank. The same spores account for 23.5 percent of the spore assemblage on the west bank, where the coal is somewhat shaly. Some of the fern spores, along with fine detritus, may have been brought into the peat swamp by sluggish, meandering streams. *Florinites* (cordaites) with 6.5 and 3.0 percent total and *Calamospora* and *Laevigatosporites ovalis* (sphenopsids) with 5.0 and 7.0 percent are about equally represented.

The spore assemblage of the upper 16 inches (40.6 cm) of coal A′, where it is most shaly, suggests a greater similarity with the compression flora described by DiMichele (p. 19-21) than the channel sample of the entire coal. The sample contains 7 percent *Crassispora* (sigillarian spores) and 1 percent *Endosporites globiformis* (*Polysporia* spores), which are consistent with compression fossils found by DiMichele. However, fern spores still account for 46.5 percent of the assemblage.

The spore flora in coal B is dominated (60 percent) by arborescent lycopods. Ferns, mostly filical types, are represented by 20 percent of the miospore assemblage. Sphenopsids (8.5 percent) and cordaites (3.5 percent) were also contributors to the coal-swamp flora.

Spores produced by lycopods account for 62.5 to 64 percent of the spore assemblage in coals C and C′. Most of these spores (*Lycospora* and *Cappasporites*) represent arborescent lycopods. The assemblage in section 3 contains more herbaceous lycopod spores (*Radiizonates*) than does the assemblage in section 1. The miospore assemblage in coals C and C′ also contain abundant *Laevigatosporites globosus* and *L. minutus*, which were produced by marattiaceous ferns. *Calamospora*, *Vestispora*, *Laevigatosporites desmoinesensis*, and *L. ovalis*, which have their affinity with sphenopsids, are not common in section 3, but sphenopsids account for 12 percent in section 1. *Florinites* from cordaites is a rare constituent.

The most distinguishing feature about coal D is the abundance of *Laevigatosporites globosus* (33.5 percent), *L. minutus* (7.5 percent), and *Punctatisporites minutus* (12 percent), which are produced by tree ferns. *Torispora* (10 percent), which was borne by tree ferns, is more abundant in coal D than in other coals along Roaring Creek. *Laevigatosporites ovalis* (sphenopsids) with 11 percent and *Cappasporites distortus* (*Lepidodendron-Achlamydocarpon varius*) with 9 percent represent a small part of the spore population. *Lycospora* accounts for less than 1 percent, and only one specimen of *Radiizonates* was observed. *Florinites* is also uncommon (2.5 percent).

Fossil Plants of Shales and Coals in the Roaring Creek Area

By William A. DiMichele

Distinct fossil floras occur in the dark-gray shales and coals, gray shales, sandstones, and cuticular shales in the Roaring Creek area. Differences in floral composition among the lithologies are attributed to ecologic differentiation of vegetation in adjacent areas near different kinds of depositional environments previously described and to the effects of taphonomy, such as transport, rapidity of burial, and rates of decay. The Roaring Creek floras of megascopic size are all basically coalified compressions. Cuticular shales, coal deposits, and the shaly partings of coals provide unusually fine compression-impression preservation. Representative specimens are shown on plates 2 and 3.

DARK-GRAY-SHALE AND COAL FLORAS

The oldest floras along Roaring Creek occur in coals A and A′ in the thin shaly partings and in the dark-gray-shale facies. These swamp floras are similar. Although there is a greater clastic influx in the shaly parts, there appears to have been little differential transport. Fossils of a wide range of sizes, including intact ones, are present, and there is heavy fossil-plant cover of bedding planes with random orientations of axes.

The swamp floras consist mostly of *Sigillaria* (*S.* cf. *brardii*) and *Lepidodendron aculeatum*. *Stigmaria* occurs in places. The robust herb, *Polysporia*, is present and identified from rare axes surrounded by masses of *Valvisporites* megaspores. The pteridosperms are represented by *Neuropteris scheuchzeri*, *Alethopteris serlii*, and numerous isolated pinnules of several genera. Seeds consist of *Trigonocarpus*, smaller radiospermic specimens, and common *Samaropsis* spp. similar to *S. emarginata* and *S. crampii* as defined by Crookall (1976). *Cordaianthus* (cordaites) is rare.

GRAY-SHALE FLORAS

Gray-shale floras vary laterally and vertically within sites. The greatest diversity is found in shales between coal A and the higher Block coals. Sampling from several sites along the creek, including profiles of shale and ironstone layers, indicates temporal variability in the amount of transport and sorting of the floras. This apparently occurred within an overall trend toward an increase in the areal extent of deep standing water, beginning with the cessation of deposition of the dark-gray-shale facies of coal A. Observations of trends include an upward decrease in the following: taxonomic diversity, diversity of kinds of organs, and frequency of in-place rooting zones indicative of water shallow enough to allow growth of vegetation.

The pteridosperm assemblages are represented by *Neuropteris rarinervis*, *N. scheuchzeri*, *N. heterophylla-obliqua*, *N. macrophylla*, *Alethopteris serlii*, *Sphenopteris schatzlarensis*, *Sphenopteris* spp., *Eusphenopteris* (*E. striata* group of Ameron, 1975), *Mariopteris muricata*, *Crossotheca*, and *Trigonocarpus*. Tree ferns are represented by *Pecopteris miltoni* and lycopods by *Lepidodendron aculeatum* and *Sigillaria* (*S.* cf. *brardii*). The sphenopsids were abundant with *Sphenophyllum cuneifolium*, *S. myriophyllum*, *Asterophyllites grandis*, *Annularia radiata*, *A. sphenophylloides*, *Calamites* stems, and *Paleostachya* cones. *Samaropsis* (*S.* cf. *emarginata*) and *Cordaites* leaves were also present. This flora can be correlated with those in the upper part of the Kanawhanian Stage (interval of the Winifrede to Coalburg Coal Members) of the proposed Pennsylvanian stratotype in West Virginia (Gillespie and Pfefferkorn, 1979).

Abundant compressions also occur in the shales of the Block-coal interval along Roaring Creek, but the shales are sandy and the fossils appear to have been transported as in overbank deposits. Qualitatively the floras are similar to those described above, but lycopods represented by large sheets of bark from *Lepidodendron* and *Sigillaria* are much more common.

SANDSTONE FLORAS

Relatively few fossils were recovered from the channel-sandstone deposits, and these were large logs or sheets of bark from *Sigillaria* and *Lepidodendron aculeatum* derived from the basal part of the deposits.

CUTICULAR-SHALE FLORAS

The cuticular-shale facies of the Block coals contain a relatively diverse flora. The apparent dominance of stem and leaf cuticles of one species of *Eusphenopteris* is probably the result of differential weathering of the cuticular facies. The *Eusphenopteris* belongs to the *E. striata* group (Ameron, 1975) but was originally identified as *Sphenopteris bradfordii* (Arnold, 1949) by Neavel and Guennel (1960). Other plants of the flora include *Lepidodendron aculeatum*, *Sigillaria*, *Alethopteris*, *Neuropteris* spp., and radiospermic ovules and abundant large striated axes probably of pteridosperm origin.

COMPARISON OF FLORAS

Coal-swamp assemblages of the dark-gray shales and coal in the Mansfield Formation and the cuticular shales in the Brazil Formation are the richest sources of lycopod stems among the Roaring Creek environments of deposition. The lycopods are *Lepidodendron aculeatum* and *Sigillaria;* no *Lepidophloios* has been found. In contrast, the palynologic data of coals A and A′ indicate dominant *Lycospora granulata* (attributed to *Lepidophloios*) and abundant tree-fern spores. The spore flora of coal D is strongly dominated by tree ferns. The abundance of *Lycospora granulata* in the coals, as will also be noted in the flora at the Maple Grove Mine, is the result either of transport into the swamp from surrounding outlying areas or of production of similar spores by a lycopod not presently recognized as the source, such as *Lepidodendron aculeatum*. *Pecopteris miltonii* foliage of tree ferns is a significant element of the gray-shale floras. Tree ferns are not abundant as megafossils in the dark-gray-shale or coal floras but may have grown in the swamp in patchy patterns that have not been sampled. According to Pepper's (1979) stratigraphic analysis of the coals in the Illinois Basin, tree-fern spores first became abundant in swamps during early Middle Pennsylvanian time, but tree ferns have not been verified as in place in the Illinois Basin in rocks older than the coal-ball peats in the lower part of the Staunton Formation.

The gray-shale floras closely resemble each other qualitatively above coal A and are dominated by diverse pteridosperms with locally abundant sphenopsids. This kind of flora formed a repetitive succession above the swamp floras and was apparently more diverse. Scott (1978), in describing similar assemblages in ironstones and irregularly bedded gray shales with rooting zones in Westphalian B rocks of Yorkshire, England, interpreted the environment of deposition as a flood plain subjected to repeated water influx and drainage. Such a model as previously described is reasonable for the shales above coal A. The overall trend is one of increasing water depth following coal A, up to the deposition of the Block coals when shallow conditions again prevailed. The vegetational patterns and environments of deposition are consistent with shallow-water deltaic sedimentation going from stable swamp conditions to a flood plain with fluctuating-water conditions to development of a shallow interdistributary bay or lake devoid of vegetation. Shallow-water conditions recur with the peat deposition of the Block coals.

Maple Grove Mine Area Fountain County

STRATIGRAPHY

Strata of the Staunton Formation are partly exposed in the Maple Grove Mine, along the Wabash River to the west, and along Coal Creek to the east (fig. 10). The main coal that contains coal balls at the Maple Grove Mine is not exposed along Coal Creek, less than 1.5 miles (2.4 km) east of the mine. The exact stratigraphic position of the unnamed coal that was the major mined seam at the Maple Grove Mine is somewhat uncertain; it is above the Minshall Coal Member in the lower part of the Staunton Formation and identified by Peppers (p. 27) as approximately correlative with the Murphysboro Coal Member of Illinois. The Staunton Formation in the northern one-third of the Indiana coalfield is represented by thin and laterally nonpersistent coal, gray shale, dark-gray shale, and marine limestone. Exposures at the Maple Grove Mine are rather typical for this area in variability of thickness, lateral discontinuity, and difficulty of correlation even over short distances.

Within the Maple Grove Mine three seams have been exposed, but two coal seams represent most of the coal mined. The middle and most extensive coal seam is 2 to 5 feet (.6 to 1.5 m) thick and contains coal balls in the top one-third to one-half. A very dark gray fissile shale as much as 2 feet thick overlies the coal. A marine limestone commonly overlies the shale and, where present, is as much as 2 feet or more thick. In places dark-gray calcareous marine shale is interbedded with the limestone. These units are very fossiliferous with fusilinids, nautiloids, brachiopods, and echinoderms. A gray shale with abundant sideritic nodules generally separates the limestone from the upper coal. The gray shale is 15 to 30 feet (4.6 to 9.1 m) thick, and the upper coal is as much as 2 feet (.6 m) thick and may be termed a "rider seam." Where the latter is present, it is generally overlain by dark-gray shale that contains some *Alethopteris* leaves and *Calamites* stems. The unconsolidated Pleistocene sediments at the mine consist of outwash sand and gravel that are part of the Wabash valley train.

Physical correlation of the coals at the Maple Grove Mine with other sections to the east and to the west has not been practical, but palynologic analyses have provided approximate correlations with coals in Illinois. The different names applied by earlier workers to the main coal convey the nature of the problem. Coal balls were first collected in the Maple Grove Mine area in the early 1920's by A. C. Noé; Feliciano (1924) reported their occurrence in what he called "Coal No. 2 of Indiana" at the Silver Island strip mine near Cayuga (fig. 10). The coal was later called the Minshall Coal by Wanless (1939) and is locally

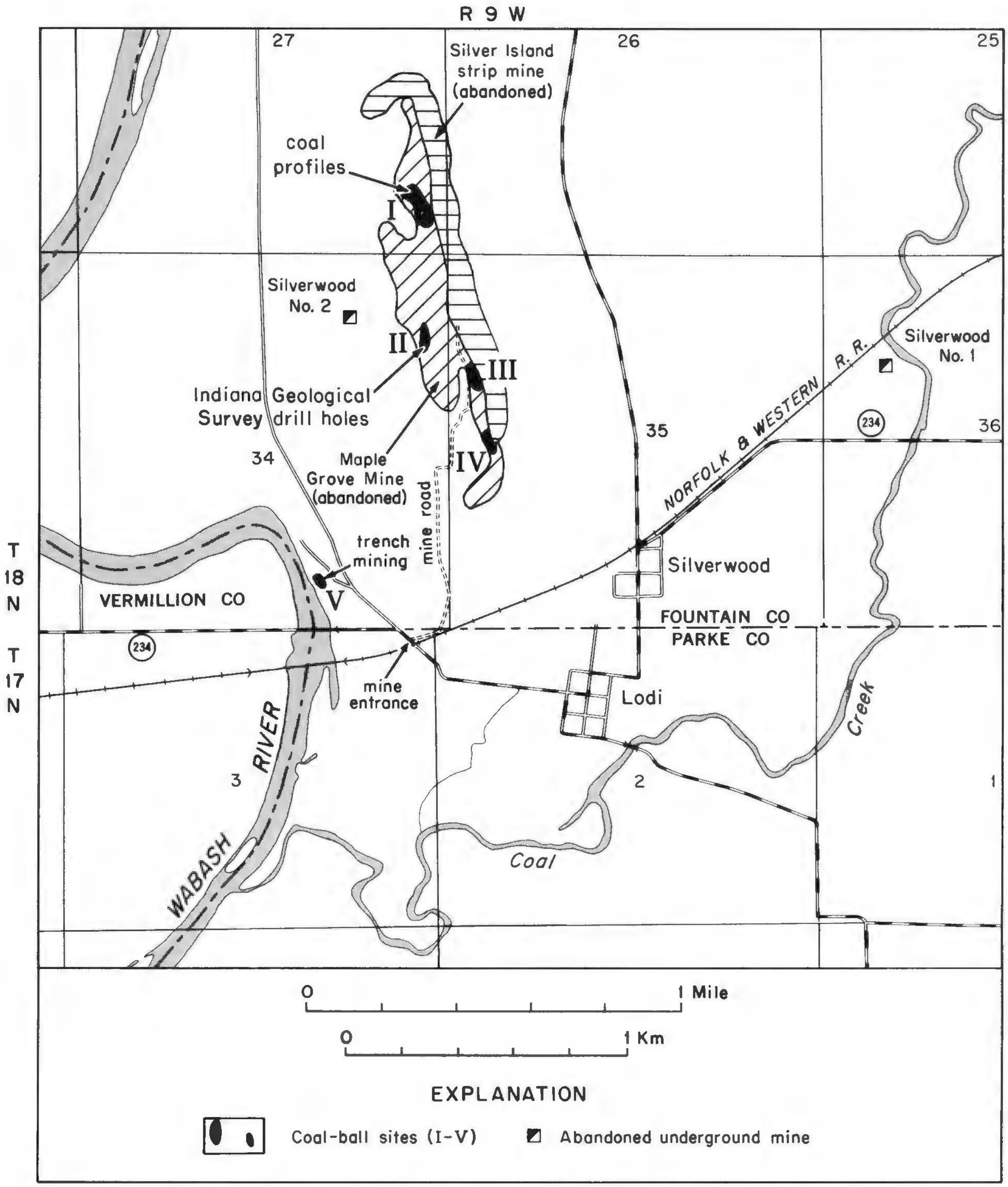

Figure 10. Map showing the Maple Grove Mine area and coal-ball sites in Fountain County. Coal profiles are shown in figure 12.

known to some miners by that name. Spore analyses of several samples of the seam bearing the coal balls at the Maple Grove Mine indicate that it is equivalent to the Murphysboro Coal Member of Illinois and is early Desmoinesian (early Westphalian D) in age.

The Minshall Coal Member at the top of the Brazil Formation is just above the flood plain of the Wabash River near coal-ball site V (fig. 10; no. 90 of Hutchison, 1961) and is no longer exposed, but it was sampled in the 1930's or 1940's by the Illinois State Geological Survey. Spore analysis of the sample corroborates the identification of the coal as the Minshall coal. The lowest coal in the Maple Grove Mine is probably the Minshall.

During the early 1970's the upper coal, or "rider seam," was exposed between coal-ball sites I and II at the Maple Grove Mine, but it has been mined out. The interval separating the upper coal from the one bearing the coal balls ranges from about 15 feet (4.6 m) at the north end of the pit to at least 30 feet (9.1 m) toward the south where the upper coal is truncated by Pleistocene sediments. Spore analysis of the upper coal indicates that it is equivalent to the Wise Ridge Coal Member (Spoon Formation) of Illinois. This upper coal is also correlative with the coal below the Silverwood Limestone Member (middle part of the Staunton Formation) at the type section of the Silverwood along Coal Creek, just north of Indiana Highway 234 (fig. 10).

ENVIRONMENTS OF DEPOSITION

The brackish-to-marine environments of deposition represented by the upper part of the coal balls and the marine transgression that closed out the swamp are of particular interest as they relate to the swamp vegetation, coal-ball origins, and high sulfur content of the coal. Direct evidence of brackish-to-marine influence in the swamp peats is derived from the invertebrate clastics in the coal balls and in the immediately overlying sediment. Less direct evidence is derived from the C^{13}/C^{12} ratios of the coal-ball carbonates and inferences about the species of cordaitalean trees as environmental indicators.

Coal balls are concretionary structures in coal seams that, at least locally, are an enormous accumulation of precipitated mineral matter with only 2 to 3 percent organic matter by weight. In coal balls of Middle Pennsylvanian age in the Illinois Basin the major mineral is calcite. Variable amounts of pyrite are also present. The pyrite content tends to be consistently high in the lowest and the highest coal-ball zone or zones, particularly in the lower zones at the Maple Grove Mine.

While specific sources of the large quantities of calcium carbonate still defy identification, evidence of the general source and relative influences of terrestrial organic carbon (δ C^{13} of a standard for a marine limestone = +2) can be considered. Faunal and mixed (invertebrates and plants) coal balls occur in several coal-ball zones 15 to 30 cm from the top of the coal and in the top bench, where they are more abundant. The carbonates of mixed coal balls below the top of the coal have a δ C^{13} value of -8.85 per mil. The coal-ball carbonates below the mixed coal balls are isotopically lighter with δ C^{13} values of -10.02 to -19.78. Research on carbon isotopes of carbonate coal balls was carried out by Brownlee (1975), Geology Department, University of Illinois.

The in-place cordaitalean component of the upper part of the seam is considered a probable brackish-saline indicator because of its importance in cordaite-dominated swamps of early Desmoinesian time in the Western Region of the Interior Coal Province and because of its repeated association with coal balls containing marine invertebrates and coal-ball carbonates with less negative δ C^{13} values (Weber and Keith, 1962). Variable but moderate saline influences in the upper part of the seam are consistent with the collective evidence and also relate to the model of coal-ball origin suggested by Stopes and Watson (1909), which emphasizes a terminal marine transgression as the source of carbonates. Mamay and Yochelson (1962) also cited marine transgressions to account for transported invertebrates below the top of the coal. Saline influence is also consistent with the high sulfur content of the coal.

Table 3. Moisture-free analyses of unnamed coals in the Staunton Formation at the Maple Grove Mine

Coal	Sample No.	Sulfur (pct)	Ash (pct)	Btu
Upper (rider)	75 x 38	4.0	10.2	11,250
Main (bearing coal balls)	63 x 2	6.7	10.7	12,980
	72 x 34	7.2	13.0	12,630
	75 x 1	8.4	14.6	12,060
	75 x 24-26	6.6	14.0	9,010
	75 x 27-29	6.4	14.2	12,330
	75 x 76	6.2	11.8	12,410

The dark-gray to black fissile shale overlying the coal probably formed in the transgressive brackish-to-marine environment that buried the peat deposits. As the relative water depth increased, the oxygen content of the water increased and salinity probably reached near-normal marine concentrations. Normal marine conditions were favorable for the formation of carbonate shelves and marine mudbanks. Open marine deposition was terminated, however, by the influx of silt that formed the dark-gray shale. The shale probably derived from the progradation of the deltaic lobe into the shallow marine environment. When aquatic conditions became favorable for plant growth and peat accumulation, a smaller swamp was colonized and the upper, or "rider" seam, was developed. A gray, perhaps nonmarine, shale was deposited over the later swamp. The "rider" seam has a lower sulfur content than the coal bearing the coal balls (table 3).

The overall depositional environment for the Staunton Formation in Fountain County is that of a small-scale lower delta plain. Marine fossils and strata are abundant, but fluvial channel sediments and leaf compressions are uncommon for this area. Prodelta and intradistributary-bay sediments are common. Lateral discontinuities of several lithologies suggest that the depositional environments producing these units were small in their areal distribution, quite unlike the later coal swamps of the Carbondale Formation of Illinois.

Coal Petrography of the Maple Grove Mine

By Peter R. Johnson

A section of the main unnamed coal (correlated by Peppers with the Murphysboro Coal Member of Illinois) was macroscopically described in terms of coal lithotypes (fig. 11) and subjected to a qualitative microlithotype analysis (table 4). Quantitative maceral or microlithotype analyses have not been made.

Overall, the seam consists dominantly of clarain and secondarily of durain (dull coal). Fusain and vitrain are present in only minor amounts. The lithotype description indicates that the lower half (0 to 77 cm) of the seam is generally duller than the upper half (85 to 140 cm). The lower half is characterized by finely banded clarain, but bands of durain are common. The upper half of the seam changes from a sequence (85 to 113 cm) that consists of finely banded clarains, interrupted by bands of dull clarain, bright clarain, and vitrain, to a sequence (113 to 140 cm) that consists of clarain, interrupted only by bright clarain and vitrain.

The increased brightness of the upper half of the seam is reflected by subtle changes in the microlithotype composition. Table 4 lists six petrographic zonations within the seam. The predominant microlithotypes in each zone are listed in order of their relative abundance within the seam. These compositional changes are gradational. The changes are in relative abundances of the various microlithotypes rather than the kinds of

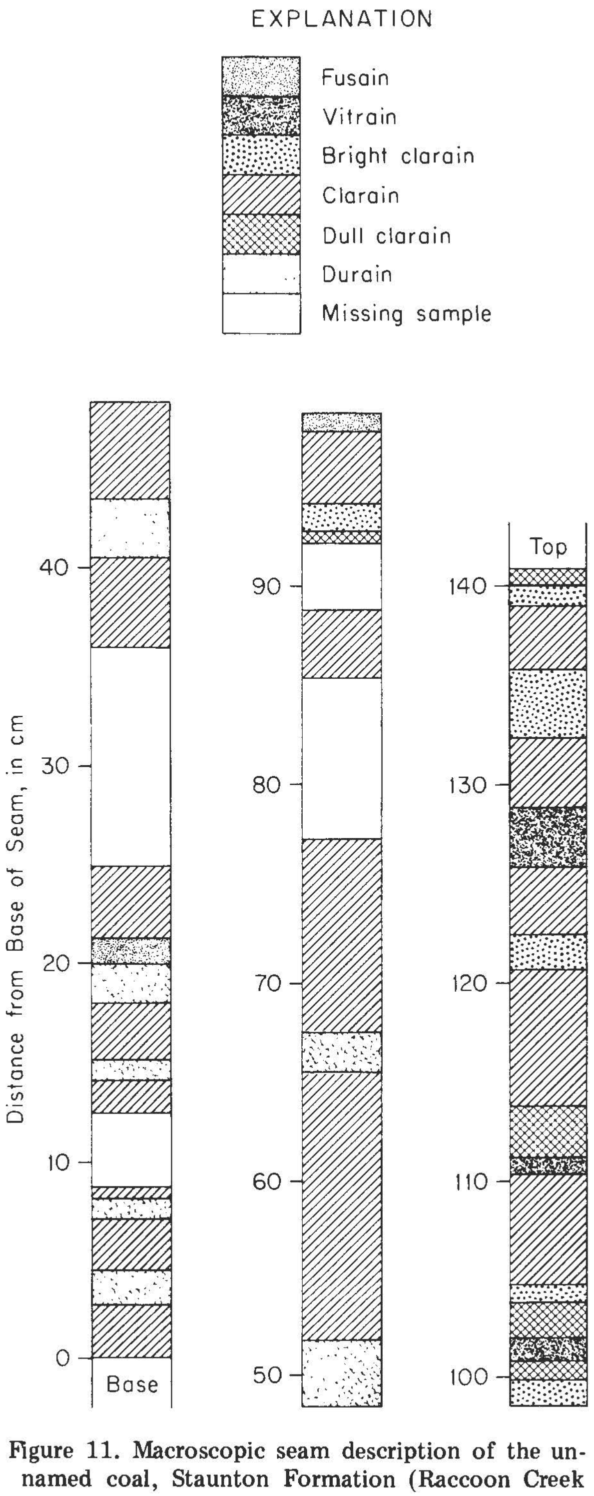

Figure 11. Macroscopic seam description of the unnamed coal, Staunton Formation (Raccoon Creek Group), Maple Grove Mine (site I, fig. 10), Fountain County.

microlithotypes. The increased proportion of bright constituents within the seam can be seen by the change in relative abundance of vitrite from zone to zone (table 4).

By detailed comparisons of the lithotype and microlithotype composition of the coal with the botanic composition of the peat (fig. 12), some specific correlations between petrographic and paleobotanic trends were determined. These are summarized below.

137-141 cm	Peat zone 1.
130-137 cm	Peat zones 2 and 3: predominant vitrite corresponds to high cordaites content; fusain is common in both peat and coal; identifiable primary fusain is largely contributed by pteridosperms.
129-130 cm	Peat zone 4.
126-129 cm	Peat zone 5: prominent vitrain band may correspond to abundant cordaites wood and *Lepidodendron* bark.
114-126 cm	Peat zones 6 and 7: clean clarite and vitrites may reflect the good peat preservation (2 to 7 percent unidentifiable peat); bright clarain may correspond to maximum *Lepidodendron* content of peat zone 6.
111-114 cm	Peat zone 8: dull clarain indicating poor peat preservation; pyritized fusite and trimacerite-I correspond to fusain of peat.
105-111 cm	Peat zones 9 and 10: fusite occurs within this interval and corresponds in part to fusain content of peat zone 9.
100-105 cm	Peat zones 11-15?: dull clarain contains abundant trimacerite (detrital) with detrital silt; detrital content of coal corresponds to poor peat preservation (28 percent unidentifiable peat).
0-100 cm	No coal balls.

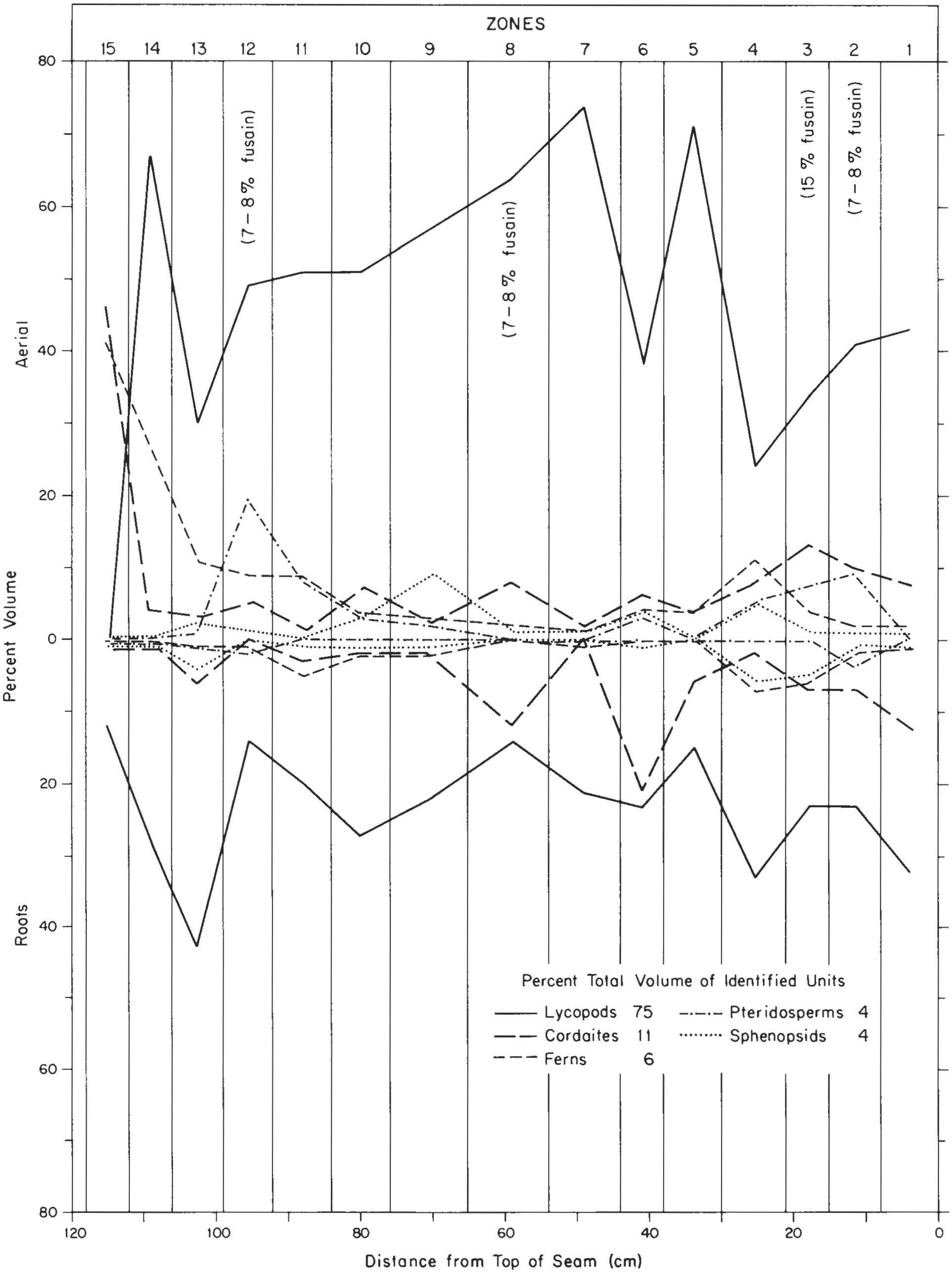

Figure 12. Profile of peat from coal balls from the upper half of the unnamed coal, Staunton Formation, Maple Grove Mine. Total thickness of coal balls equals 118 cm. Total identification units (cm^2) equal 5,073.

Table 4. Vertical zonation of microlithotype composition of the unnamed coal, Staunton Formation, Maple Grove Mine

Petrographic zone	Position from the base of the seam	Predominant microlithotypes (in order of abundance)
F	137-141 cm	Cuticloclarite Sporoclarite Vitrite
E	125-137 cm	Vitrite Sporoclarite Cuticloclarite Fusite
D	100-125 cm	Sporoclarite Vitrite Cuticloclarite Trimacerite
C	85-100 cm	Sporoclarite Cuticloclarite Vitrite Fusite
B	21- 77 cm	Sporoclarite Cuticloclarite Vitrite Trimacerite
A	0- 21 cm	Sporoclarite Cuticloclarite Trimacerite Vitrite

Pyrite framboids and isolated euhedral crystals of pyrite are the predominant forms of pyrite throughout the seam. They are most abundant in the lower 125 cm of the seam. Both are considered to be of primary origin and indicate a slightly brackish swamp environment. Secondary pyrite commonly occurs as cell fillings within fusinite lenses throughout the seam.

Palynology of the Unnamed Coal in the Staunton Formation Maple Grove Mine

By Russel A. Peppers

The spore assemblages in the unnamed coal that contains coal balls at the Maple Grove Mine were examined from four sites: two from the south end of the mine (site IV, fig. 10) where the coal is 61 to 91 cm thick, one from near the middle (site II, fig. 10) where the coal is 147 cm thick, and one just to the north of the mapped mined area where the coal is 80 cm thick. The spore assemblages in the unnamed coal (tables 5, 6, and 7) are most similar to those in the Murphysboro Coal Member of Illinois (Phillips and others, 1973). The Murphysboro coal was mined near Murphysboro, Jackson County, Ill., in the southwestern part of the Illinois Basin and in places is as much as 1.5 m thick, but it is discontinuous. The geology of the Murphysboro coal was briefly described by Hopkins and Simon (1975). The Murphysboro coal has been identified in the subsurface by use of spores (Peppers, unpublished data) at several

Table 5. Abundance (in percent) of major spore taxa constituting 90 percent of the spore assemblage in the unnamed coal, Staunton Formation, Maple Grove Mine[1]

Major spore taxa	Sample 1[a] (pct)	Sample 2[b] (pct)	Sample 3[b] (pct)	Mean percentage
Lycospora granulata	25.6	25.0	26.5	26
Laevigatosporites minutus	29.3	16.5	23.3	23
Laevigatosporites globosus	13.3	12.5	13.3	13
Cappasporites distortus	19.5	25.0	15.3	20
Florinites mediapudens	5.8	7.5	14.5	9

[1]The parent plants of *Cappasporites distortus* (*Lepidodendron vasculare*) and of *Florinites mediapudens* (cordaites) are the dominant and subdominant trees of the coal-ball peats.

[a]Collected at site II (fig. 10).

[b]Collected at site IV (fig. 10).

localities in southern and eastern Illinois. Most of the spore population in the Murphysboro coal is rather evenly divided among *Lycospora granulata*, *Laevigatosporites globosus*, *Laevigatosporites minutus*, *Cappasporites distortus*, and *Florinites mediapudens*.

The spore flora in the coal at the Maple Grove Mine consists of 33 genera and 75 species, but four genera and five species account for 90 percent of the spores (table 5). The range in percentage from one sample site to another is very small for *Lycospora granulata* and *Laevigatosporites globosus* compared with that for *Cappasporites distortus* and *Florinites mediapudens*, whose parent plants, *Lepidodendron* and *Cordaites*, represent about 90 percent of the peat in the upper part of the seam. The spore assemblages from different parts of the coal differ. *Lycospora granulata* is generally more abundant in the lower part, and *Laevigatosporites minutus* is more abundant in the upper parts, but both species and *Laevigatosporites globosus* are abundant throughout most or all of the seam at all sites.

Lycospora granulata, which was produced by *Lepidophloios* trees, and *Laevigatosporites globosus* and *L. minutus* from tree ferns account for 61 percent of the spore assemblage. *Punctatisporites minutus*, with as much as 7 percent in one coal sample, was also produced by a tree fern. But vegetational analyses of the peats from coal balls in the upper part of the coal indicate that *Lepidophloios* (*Lepidostrobus oldhamius* and *Lepidocarpon*) is very rare and that tree ferns are poorly represented. Most of the tree ferns may have been living outside the coal swamp or in other parts of the swamp not represented by the coal balls. These plants were massive producers of small spores that were easily transported by wind and water into small discontinuous swamps, such as that represented by the coal at the Maple Grove Mine.

The peats of the Murphysboro coal of Illinois and the unnamed coal at the Maple Grove Mine were probably deposited in swamps locally developed on a delta plain. The swamps of such areas supported mostly lycopods (*Lycospora* and *Cappasporites*) and a minor number of cordaites (*Florinites*) and pteridosperms. These swamps were bordered by many tree ferns and perhaps some sphenopsid plants (*Calamospora*, *Laevigatosporites desmoinesensis*, *L. ovalis*, and *Vestispora*) that were growing on a flood plain.

Table 6. Occurrence and relative abundance (in percent) of spore taxa in the unnamed coal (seam bearing coal balls), Staunton Formation, Maple Grove Mine

Spore taxa	Sample No.	1[a, c]			2[b]		3[b, c]
	Thickness of seam	147 cm			91 cm		61 cm
	Divisions of sample	Bottom	Middle	Top	Bottom	Top	Whole seam
Leiotriletes levis						X[1]	X
L. priddyi						X	X
L. pseudolevis					X		
L. sphaerotriangulus						X	X
Punctatisporites edgarensis		X					
P. minutus				1.0	2.0	4.5	7.0
P. obesus				X		X	X
Calamospora breviradiata		X	X		0.5	0.5	
C. hartungiana			X	0.5		X	X
C. mutabilis				X			
C. straminea				X			X
Granulatisporites granularis			X	1.0			
G. pallidus				X			
G. parvus				0.5			
G. sp.		X					
Cyclogranisporites microgranus						X	X
C. staplinii				X			
Verrucosisporites microtuberosus			X	X		X	X
V. sifati		X					
V. verrucosus			X				
V. cf. *verrucosus*		X					X
Schopfites sp.		X					
Lophotriletes granoornatus				X		X	X
L. microsaetosus						1.0	
L. mosaicus				X			X
L. rarispinosus						0.5	
Anapiculatisporites grundensis			0.5			0.5	
A. spinosus		X	0.5	2.0	0.5	X	X
Apiculatisporis setulosus		X				X	X
A. spinosaetosus							X
Acanthotriletes aculeolatus		0.5	X				
A. sp.				X			
Raistrickia breviminens				0.5	X	X	

Table 6. Occurrence and relative abundance (in percent) of spore taxa in the unnamed coal (seam bearing coal balls), Staunton Formation, Maple Grove Mine—Continued

Spore taxa	Sample No.	1[a, c]			2[b]		3[b, c]
	Thickness of seam	147 cm			91 cm		61 cm
	Divisions of sample	Bottom	Middle	Top	Bottom	Top	Whole seam
R. crocea						X	
R. subcrinita							X
Microreticulatisporites nobilis		X	X	X	X		
M. sulcatus				X		X	X
Dictyotriletes falsus						X	
D. reticulocingulum						X	
Camptotriletes triangularis						X	
Ahrensisporites angulatus			X				
Triquitrites additus			X				X
T. bransonii			X	X	X		1.5
T. exiquus		X	X		X	X	X
T. spinosus			X				
Reinschosporites triangularis				X		X	
Mooreisporites inusitatus			X	X	0.5		
Knoxisporites stephanephorus				X			
Reticulatisporites reticulatus				X		X	
Crassispora kosankei			X	1.0		X	X
Cappasporites distortus		19.5	26.0	13.5	12.5	18.5	25.0
Densosporites triangularis			X				
Lycospora granulata		37.5	17.5	18.0	42.0	10.0	25.0
L. micropapillata				0.5			
L. pellucida		1.5	1.0		1.5	1.5	
L. punctata							1.5
Cirratriradites annulatus		X					
C. annuliformis		X	0.5			X	
C. maculatus			X	X		X	X
C. saturni							X
Endosporites globiformis		0.5	1.0	X		X	1.5
Wilsonites vesicatus							0.5
Alatisporites hoffmeisterii					X		
Laevigatosporites desmoinesensis			1.5			X	0.5
L. globosus		11.0	12.0	17.5	11.5	15.0	12.5
L. medius						X	

Table 6. Occurrence and relative abundance (in percent) of spore taxa in the unnamed coal (seam bearing coal balls), Staunton Formation, Maple Grove Mine—Continued

Spore taxa	Sample No.	1[a, c]			2[b]		3[b, c]
	Thickness of seam	147 cm			91 cm		61 cm
	Divisions of sample	Bottom	Middle	Top	Bottom	Top	Whole seam
L. minutus		25.5	24.0	39.5	10.0	36.5	16.5
L. ovalis		2.0	4.5	1.5		4.5	
L. punctatus						2.0	
L. striatus							X
L. vulgaris			X			X	
Thymospora pseudothiessenii						X	
Vestispora fenestrata		X	X				0.5
V. laevigata				X		0.5	
Florinites mediapudens		4.0	10.5	3.5	19.5	9.5	7.5
F. similis							X

[a]From site II (fig. 10).

[b]From site IV (fig. 10).

[c]Collected adjacent to coal-ball profiles.

[1]X = less than 0.5 percent.

The source area of most of the fluvial and deltaic sediment was to the east and northeast (Wanless, 1975; McKee, 1975; Hopkins and Simon, 1975; Peppers and Popp, 1979), and the shoreline was probably southwest of the Eastern Region of the Interior Coal Province during deposition of the Murphysboro coal. Since *Florinites* is in greater abundance in the coal in southern and southwestern Illinois than in Indiana, cordaites in the Murphysboro coal probably grew on the margin of the sea or under brackish influence.

Table 7. Occurrence and relative abundance (in percent) of abundant spore taxa in the unnamed coal (seam bearing coal balls), Staunton Formation, Maple Grove Mine

Abundant spore taxa	Divisions of sample 4[1]							
	A	B	C	D	E	F	G	H
Leiotriletes priddyi					0.5			
L. sphaerotriangulus	0.5							
Punctatisporites minutus	0.5	1.5	0.5		0.5	4.0	4.0	2.5
P. variusaetosus							0.5	
Calamospora breviradiata		0.5			0.5	1.5	4.5	1.5
Granulatisporites minutus	1.0		0.5	1.0				
G. pallidus			0.5					
G. verrucosus					0.5			
Cyclogranisporites aureus		0.5						
C. minutus	0.5							
C. sp.			0.5					
Verrucosisporites microtuberosus			0.5					
Lophotriletes commissuralis							0.5	
Pustulatisporites crenatus			0.5					
Apiculatisporis lappites		1.0				1.0		
A. spinosaetosis							1.5	
Microreticulatisporites nobilis							0.5	
M. sulcatus	2.0							
Triquitrites bransonii	6.5			0.5			1.0	
T. protensus			0.5					
T. sculptilis							0.5	
T. subspinosus				0.5	0.5			
Mooreisporites inusitatus		0.5						
Cappasporites distortus	1.5	16.0	9.5	22.5	14.5	11.5	26.0	41.5
Lycospora granulata	5.5	22.5	23.5	28.0	26.5	50.0	7.5	18.5
L. micropapillata		2.0	1.5			6.5	1.0	4.0
L. pellucida		0.5					4.5	2.5
L. punctata	25.0	1.5		1.0	1.0	0.5		1.5
L. rotunda					0.5			
L. subjuga		0.5						
Cirratriradites annuliformis			0.5					
Endosporites globiformis	1.5		1.0	1.5		0.5		
Wilsonites vesicatus							0.5	
Vesicaspora wilsonii		2.5		1.0		0.5		

Table 7. Occurrence and relative abundance (in percent) of abundant spore taxa in the unnamed coal, Staunton Formation, Maple Grove Mine—Continued

Abundant spore taxa	Divisions of sample 4							
	A	B	C	D	E	F	G	H
Laevigatosporites desmoinesensis							0.5	
L. globosus	33.0	12.0	8.0	10.0	35.0	10.0	14.5	16.5
L. medius		0.5	1.0					
L. minutus	33.5	32.5	44.0	27.0	15.0	4.5	24.5	9.5
L. ovalis	2.0	0.5	5.0	3.5	4.5	4.0	5.0	1.0
L. punctatus	2.0	0.5	0.5			1.0		
Thymospora pseudothiessenii	2.0	0.5		0.5				
Vestispora fenestrata								0.5
Florinites mediapudens	5.5	6.0	2.0	2.5	0.5		3.0	0.5

[1]Sample 4 was collected just north of the mapped mine area where no coal balls were found. The 80-cm-thick profile was divided into eight intervals of about the same thickness with A at the bottom. The very top of the coal was missing as a result of erosion.

Coal Balls and In-Place Swamp Vegetation of the Maple Grove Mine

The in-place coal balls in the lower unnamed coal at the Maple Grove Mine provide direct information about the lycopod-cordaites swamp vegetation and the environments of deposition in the upper part of the seam. In the Illinois Basin this is stratigraphically the lowest known coal to yield abundant in-place coal balls, although a few coal balls have been reported from the Buffaloville and Lower Block coals of Indiana (Phillips and others, 1974). Interrelated aspects of the upper part of the seam include coal-ball origins, evidence of brackish-to-marine influences, quantitative data on the vegetation, and relationships of peat to coal palynology and petrography.

Coal balls occur only in the upper one-third to one-half of the coal except in the south end of the mine where the seam is thin and coal balls occupy the entire thickness. The maximum thickness of the seam is 223 cm near site II (fig. 10) in the north end of the pit where coal balls occupy the top 118 cm. Adjacent seam thicknesses without coal balls are as much as 1.5 m. The coal balls are usually 5 to 10 cm thick, markedly rounded or biconvex, and somewhat longer than thick in the planes of deposition. Sizes and shapes are variable, and there are some larger coal balls. Coal balls occur mostly as densely packed aggregates from the very top of the coal downward. They commonly become scattered, rarer, more flattened, and pyritic toward the lowermost occurrences. Exposures of in-place coal balls indicate major areas of dense concentrations along the linear trend of the mining operation (sites I to III) with east-west dimensions of as much as 20 m (site II).

Distinct layers of coal balls are fairly rare because of displacement during coalification. Collections of the peat for quantitative analysis of the vegetation were limited to vertical profiles a meter or less wide. Examinations of some sliced intact coal-ball aggregations allowed realignment of coal balls into original peat layers by following distinctive axes or peat patterns from one coal ball to another.

The permineralized peat in coal balls is preserved at fairly early stages in most of the coal balls, particularly those in the middle and top zones. Compression and collapse of plant tissues into denser peat layers are more characteristic of lower layers in thick profiles and some of the topmost layer in some areas. Coal balls in the upper two-thirds have an increasingly open mineral matrix with loosely arranged plant material, common calcite infillings of fractures, and minimal compression of peat. Pyrite content is moderate, and pyrite grains are largely dispersed throughout the peat except in the lower coal-ball zones. As previously mentioned, marine invertebrates are commonly encountered in faunal or mixed coal balls in the top zone of coal balls and, in some places, in several coal-ball zones below the top. Although there are many variables to be considered in determining peat-coal compaction ratios, an estimate of 4:1 is derived from peat-coal measurements.

The collective evidence of the occurrences of marine invertebrates in coal balls, δ C^{13} values of coal-ball carbonates, the occurrence of cordaitean trees with associated small plants, and the general geologic setting indicate that the formation of the coal balls was causally related to the brackish-to-marine incursions. It seems likely that the upper part of the seam bearing the coal balls may have been subjected to these influences after the peats of the lower part had already accumulated. The coal-ball vegetation, in part, is thought to reflect such influences by the abundance of subdominant cordaitean trees. Such trees bore *Cardiocarpus spinatus* ovules and *Florinites mediapudens* pollen and occur with *Botryopteris tridentata*, *Microspermopteris aphyllum*, and *Stelastellara parvula*. The same distinctive suite of plants occurs in coal-ball peats in the early Desmoinesian of the Western Region of the Interior Coal Province (Kansas and Iowa) where faunal coal balls and other evidence of brackish-to-marine influence are found (Mamay and Yochelson, 1962; Perkins, 1976). This particular association of plants, which seems to be environmentally specific, is not known to extend stratigraphically above the Bevier Coal Bed of Kansas or the Summum Coal Member (Carbondale Formation) of Illinois. These coals mark the end of the paralic cordaitean interval of the Desmoinesian Epoch in the Interior Coal Province.

Fusain content in the coal-ball peats is moderate compared with that of coals sampled in the Middle Pennsylvanian of the Illinois Basin. In the thickest profile, C2, 3.9 percent of the peat is fusinized. About two-thirds of the fusain is taxonomically identifiable. One-half of the total fusain is lycopod tissue, 9 percent is pteridosperm, and 6 percent is cordaitalean. Pteridosperms are the only group more abundantly represented as fusain than their proportional content of the peat would suggest (9 percent compared with 4 percent). The peat zones with most of the fusain are indicated in figure 12; zones 2 to 3 and 12 coincide with the most abundant occurrences of pteridosperms, and zones 2 to 3 and 8 are preceded by the most abundant occurrences of sphenopsids. Phillips and others (1977) have noted the relationships between fusain and abundant pteridosperms and sphenopsids in the Herrin Coal Member (Carbondale Formation) as have others in the Katharina Seam of the Ruhr.

Quantitative analyses of peat profiles from coal balls were carried out by the techniques given by Phillips and others (1977). The following list records the taxa recognized from the unnamed Staunton coal from the Maple Grove Mine.

Lycopods
- *Achlamydocarpon varius* (Baxter) Taylor & Brack-Hanes
- *Lepidocarpon lomaxii* Scott *sensu* Balbach [very rare]
- *Lepidodendron vasculare* Binney
- *Lepidophloios hallii* (Evers) DiMichele [very rare]
- *Lepidophylloides* sp.
- *Polysporia mirabilis* Newberry (emend. Chaloner)
- *Selaginella fraipontii* (Leclercq) Schlanker & Leisman
- *Stigmaria ficoides* (Sternberg) Brongiart

Cordaites
- *Amyelon* sp.
- *Cardiocarpus oviformis* Leisman [very rare]
- *Cardiocarpus spinatus* Graham
- *Cordaianthus* sp.
- *Cordaites* sp.
- *Pennsylvanioxylon* sp.

Sphenopsids
- *Arthropitys* sp.
- *Bowmanites* spp.
- *Calamocarpon insignis* Baxter
- *Calamostachys* sp.
- *Peltastrobus reedae* Baxter
- *Sphenophyllum constrictum* Phillips
- *Sphenophyllum plurifoliatum* Williamson & Scott
- *Sphenophyllum reedae* Good

Incertae Sedis
- *Stelastellara parvula* Baxter

Ferns
- *Anachoropteris gillotii* Corsin
- *Anachoropteris involuta* Hoskins *sensu lato*
- *Anachoropteris pautetii* Corsin
- *Ankyropteris glabra* Baxter
- *Botryopteris cratis* Millay & Taylor
- *Botryopteris forensis* Renault
- *Botryopteris tridentata* (Felix) Scott
- *Corynepteris* sp.
- *Etapteris scottii* P. Bertrand
- *Psaronius* spp.
- *Scolecopteris* spp.
- *Sermaya* sp.
- *Stipitopteris* spp.

Pteridosperms
- *Dolerotheca* sp.
- *Heterangium lintonii* Stidd
- *Johnhallia lacunosa* Stidd & Phillips
- *Medullosa* spp.
- *Microspermopteris aphyllum* Baxter
- *Myeloxylon* sp.
- *Pachytesta* spp.
- *Schopfiastrum decussatum* Andrews
- *Sullitheca dactylifera* Stidd, Leisman & Phillips

Fernlike foliage
- *Alethopteris sullivantii* (Lesquereux) Schimper
- *Pecopteris* spp.

Profiles of coal balls were collected at sites I, II, and IV (fig. 10) in the north, middle, and south ends of the mine. Thousands of other coal balls were collected from sites I to V. *Lepidodendron vasculare* is the dominant tree of the swamp represented by coal-ball peats. It accounts for practically all of the lycopod peat, which ranges in volume from 71 percent to 75 percent in the major thick areas of the seam and is 85 percent in the south part of the mine where the seam is thinner. This coal seam represents the highest known stratigraphic occurrence of *Lepidodendron vasculare* in Euramerica. The lower Westphalian A coal-ball peats of England are also dominated by this species. The cone associated with *L. vasculare* is *Achlamydocarpon varius*, which produced *Cystosporites varius* megaspores or *Cappasporites distortus* microspores (Leisman and Phillips, 1979). As noted by Peppers (table 5), *Cappasporites*, which makes up 20 percent of the miospore assemblage from the coal, is only third in generic abundance because of the introduction of large quantities of *Lycospora granulata* (*Lepidophloios*) and two species of *Laevigatosporites* (tree ferns). There were only two identifiable specimens of vegetative parts of *Lepidophloios* in the peat and three *Lepidocarpon* specimens. The other lycopods present occur in very small numbers.

One species of *Pennsylvanioxylon* (cordaites) is the subdominant tree or shrub of the peats. It contributed 11 to 20 percent of the peat and most of the wood in the middle and north parts of the mine but only 8 percent in the south end. *Cardiocarpus spinatus* ovules and *Cordaianthus* account for almost one-third of the total fructifications in the peat, but the numerical percentage of the pollen, *Florinites mediapudens*, averages only 9 percent and is fifth in abundance in the coal palynology. The three remaining groups of swamp plants account for 7 to 16 percent of the peat volume; none individually exceeds 6 percent.

Table 8. Major plant groups (in percent of volume) by zone, coal-ball peat in the upper one-half of the unnamed coal, Staunton Formation, Maple Grove Mine

	Coal-ball zones	Volume of identified taxa by zone (pct)					Unidentified (pct)	Thickness (cm)	Number of coal balls
		Cordaites	Ferns	Lycopods	Pteridosperms	Sphenopsids			
Top	1	17	4	76	0	3	6	8	17
	2	21	6	62	8	3	5	7	13
	3	20	10	56	8	6	14	6	11
	4	9	18	57	5	11	7	9	7
	5	18	7	74	0	1	5	8	10
	6	28	6	54	4	8	5	6	5
	7	2	3	94	0	1	3	10	8
	8	21	3	75	0	1	10	11	6
	9	6	9	73	2	10	5	11	13
	10	13	9	70	3	5	12	8	8
	11	3	16	73	6	2	16	8	11
	12	5	15	62	17	1	21	7	9
	13	11	15	68	2	4	15	7	6
	14	5	5	90	0	0	12	6	3
Mid seam	15	47	41	12	0	0	28	6	7
Totals for samples cm^2 = 5,073		11	6	75	4	4	10.5	118	134

Table 9. Major plant groups (in percent of volume) in coal-ball peat in the unnamed coal, Staunton Formation, Maple Grove Mine

A. Peat profile C2, site II, 118 cm thick, 15 zones, 134 coal balls, and 5,073 cm^2

Taxa	Volume of organs within taxa (pct)				Total peat by taxa (pct)
	Organs				
	Fructifications	Leaves	Stems	Roots	
Cordaites	5	24	21	50	11
Ferns	4	54	6	36	6
Lycopods	1	7	61	31	75
Pteridosperms	0	39	47	14	4
Sphenopsids	2	2	64	32	4

Organs	Volume of total organs by taxa (pct)						Total peat by organs (pct)
	Taxa						
	Unidentified	Cordaites	Ferns	Lycopods	Pteridosperms	Sphenopsids	
Fructifications	0	31	12	50	1	4	2
Leaves	1	22	26	39	11	1	12
Stems	3	4.5	1	84	3	4.5	52
Roots	5	17	6	67	2	3	34

B. Peat profile 1, site I, 28 cm thick, 5 zones, 52 coal balls, and 1,022 cm^2

	Volume of organs within taxa (pct)				Total peat by taxa (pct)
Taxa	Organs				
	Fructifications	Leaves	Stems	Roots	
Cordaites	33	40	17	10	20
Ferns	8	55	2	35	5
Lycopods	1	10	68	21	71
Pteridosperms	0	100	0	0	1
Sphenopsids	0	0	91	9	3
Total peat by organs (pct)	7	19	55	19	100

Table 9. Major plant groups (in percent of volume) in coal-ball peat in the unnamed coal, Staunton Formation, Maple Grove Mine—Continued

C. Peat profile 5, site V, 38 cm thick, 6 zones, 51 coal balls, and 2,192 cm^2

Taxa	Volume of organs within taxa (pct)				Total peat by taxa (pct)
	Organs				
	Fructifications	Leaves	Stems	Roots	
Cordaites	8	55	26	11	8
Ferns	6	67	0	27	2
Lycopods	1	8	35	56	85
Pteridosperms	0	100	0	0	1
Sphenopsids	3	0	56	41	4
Total peat by organs (pct)	2	13	34	51	100

From the data for in-place peat it seems that the abundance of *Lycospora granulata* and *Laevigatosporites* spores in the upper part of the seam largely reflects transport into this swamp area. The actual dominant and subdominant trees are represented by the third and fifth most abundant palynomorph types, *Cappasporites* and *Florinites*.

The profile shown in figure 12 indicates that the *Lepidodendron vasculare* assemblage dominated all the zones except perhaps the lowest. Zone 15 has such a large amount (28 percent) of unidentifiable peat that its significance should be questioned (fig. 12). Apart from that, there are some sequential alterations of abundant *Lepidodendron* aerial parts with stigmarian root systems through the peat.

In some zones with abundant cordaites (zones 6 and 8) (table 8) the roots are about twice as abundant as shoots and fructifications. Ferns and pteridosperms are abundant at the base and the top of the profile. Sphenopsids are well represented either following or concurrent with fern-pteridosperm abundances. The abundance of cordaites in the topmost coal-ball zone varies greatly among the sites sampled. In the top zone cordaites account for only 2 percent of the peat at site IV, 20 percent at site II, and 71 percent at site I. The pattern at sites I and II shows either a constant or an increasing abundance of cordaites near the top of the peat; at site IV it shows a decreasing pattern from a maximum of 17 percent. A study of 10 randomly selected coal balls from site I indicates that lycopods make up 75 percent of the peat and cordaites 15 percent, compared with 71 percent lycopods and 20 percent cordaites in the peat profile (table 9) from the same exposure.

Table 9A, B, and C gives summary percentage data of the peat composition of the coal balls by taxa and by organs for three profiles. In table 9A the data from profile C2 allows comparison of the contribution of each plant group to the peat. As examples, 5 percent of the cordaitean peat consists of fructifications (upper table). This is 31 percent of the total fructifications but only 2 percent of the total peat volume (lower table). Lycopods, 75 percent of the peat volume, contribute 50 percent of the fructifications, 39 percent of the leaves, 84 percent of the stem, and 67 percent of the roots. Cortex and periderm are the major tissues from lycopods accumulated in the peat.

The flora of the coal-ball peats is apparently not as diverse as those of younger coals in the midcontinent region, such as the Mineral or Fleming Coal Bed of Kansas or the Herrin coal of Illinois. Some of the plants are shown on plates 4, 5, and 6. All the common genera are well known from other seams bearing coal balls in Euramerica. Most of the species are known from other lower Middle Pennsylvanian coal balls (primarily from the Western Region of the Interior Coal Province), although some have not yet been described and named.

Restorations of lycopod and cordaitean trees usually imply tall trees of large diameter, but in most coal-ball peats, including the ones at the Maple Grove Mine, we do not find corroborative evidence of such large plants. In general such reconstructions are largely based on dimensions of specimens found outside the coal. The trees were not so large in most coal swamps known from coal balls; there are some exceptions in the Summum and Herrin coals. The preserved specimens of *Lepidodendron* and cordaitean trees in the coal balls at the Maple Grove Mine are small, even in the large coal balls. The largest diameter *Lepidodendron vasculare* tree observed was about 20 cm; the wood was about 3 cm in diameter. The largest cordaitean stems and roots, which are mostly wood, were 6 to 7 cm in diameter.

Summary and Conclusions

The salinity of the peat swamp and of the deposits that buried it is generally considered the mechanism that controls the sulfur content of coal seams. Low-sulfur coals are deposited in freshwater swamps and buried by nonmarine sediments. High-sulfur coals are deposited in brackish-water swamps or are overlain by brackish-to-marine strata or both. These relationships were found in the sedimentologic and stratigraphic study of the low-sulfur coals in the Roaring Creek Mine area and the high-sulfur coals in the Maple Grove Mine area.

The differing habitats and dissimilar floras associated with the environments of peat accumulation are evident from the coordinated study of coal petrography, geochemistry, paleobotany, palynology, sedimentology, and stratigraphy. The plant megafossils associated with the freshwater deposits and low-sulfur coals along Roaring Creek are *Lepidodendron aculeatum*, *Sigillaria*, pteridosperms, ferns, and sphenopsids. The upper one-third to one-half of the main seam at the Maple Grove Mine differs petrographically from the lower part and was deposited in a setting of increasing salinity, being buried by sediments ranging from brackish to normal marine. The dominant trees of this habitat were *Lepidodendron vasculare* and one species of *Pennsylvanioxylon* (cordaites).

Palynologic analyses provided biostratigraphic correlations of coals within the study areas and with approximate equivalents in Illinois and Kentucky. These analyses also indicated significant quantitative differences between the miospore floras and the megafossil floras from which the coals were largely derived in both study areas. The differences partly reflect the broader areal representation of vegetation by palynology perhaps indicative of small-scale swamps with large perimeters of differing habitats. Some overrepresentation of small spores results from prolific spore-producing plants, such as the tree ferns and *Lycospora*-bearing trees that lived in the region. The spore floras of the coals from the Roaring Creek Mine area and the Maple Grove Mine were dominated by *Lycospora granulata* and *Laevigatosporites*. Although *Lycospora granulata* is considered to be derived from *Lepidophloios*, this genus was not observed in the Roaring Creek area, and it was extremely rare at the Maple Grove Mine. The possibility exists that another kind of lycopod tree produces similar spores.

The dissimilar floras in the two study areas indicate significant differences in the vegetational patterns during the early Middle Pennsylvanian. Although the habitats associated with the different environments of deposition are consistent with those of upper deltaic and lower deltaic peat swamps, there were probably also significant differences in the availability of freshwater from rainfall during the two intervals represented.

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This report is dedicated to the memory of our friend and former colleague, Harold C. Hutchison, Indiana Geological Survey, who contributed so much to our knowledge of the Pennsylvanian stratigraphy and geology of western Indiana.

—Donald L. Eggert and Tom L. Phillips

Literature Cited

Ameron, H. W. J. van

1975 - Die eusphenopteridischen Pteridophyllen: Medelingen Rijks Geologische Dienst, Serie C - III - No. 7, 208 p., 48 pls., 53 figs.

Arnold, C. A.

1949 - Fossil flora of the Michigan coal basin: Michigan Univ. Mus. Paleontology Contr., v. 7, p. 131-269, 34 pls., 2 figs., 2 maps, 1 table.

Brownlee, M. E.

1975 - Stable carbon and oxygen isotopes of carbonate coal balls and associated carbonates of the Illinois Basin [unpub. master's thesis]: Urbana, Illinois Univ., 102 p.

Crelling, J. C., and Bensley, D. F.

1980 - Petrology of cutinite-rich coal from the Roaring Creek Mine area, *in* Langenheim, R. L., and Mann, C. J., Middle and Late Pennsylvanian strata on margin of Illinois Basin: Tenth Ann. Field Conf. Guidebook, Great Lakes Sec., Soc. Econ. Paleontologists and Mineralogists, p. 93-104, 5 tables.

Crookall, Robert

1976 - Fossil plants of the Carboniferous rocks of Great Britain (Second Section): Great Britain Geol. Survey Mem., Paleontology, v. 4, pt. 7, p. 841-1004, 14 pls., 19 figs.

Cumings, E. R.

1922 - Nomenclature and description of the geological formations of Indiana, *in* Logan, W. N., and others, Handbook of Indiana geology: Indiana Dept. Conserv. Pub. 21, pt. 4, p. 403-570, 31 figs.

Eggert, D. L.

1982 - A fluvial channel contemporaneous with deposition of the Springfield Coal Member (V), Petersburg Formation, northern Warrick County, Indiana: Indiana Geol. Survey Spec. Rept. 28, 20 p., 14 figs., 1 table.

Eggert, D. L., and Adams, S. C.

19__ - Distribution of fluvial channel systems contemporaneous with the Springfield Coal Member (Middle Pennsylvanian) in southwestern Indiana: Ninth Internat. Cong. of Carboniferous Stratigraphy and Geology [in preparation].

Ethridge, F. G., and Fraunfelter, George

1976 - Variability within a high constructive lobate delta — the Pounds sandstone of southeastern Illinois: Sixth Ann. Field Conf., Great Lakes Sec., Soc. Econ. Paleontologists and Mineralogists, 76 p., 18 figs., 3 tables.

Ethridge, F. G., Fraunfelter, George, and Utgaard, John

1973 - Depositional environments of selected Lower Pennsylvanian and Upper Mississippian sequences of southern Illinois: Thirty-seventh Ann. Tri-State Conf., Carbondale, Ill., 158 p., 30 figs., 6 tables.

Feliciano, J. M.

1924 - The relation of concretions to coal seams: Jour. Geology, v. 32, p. 230-239, 2 tables.

Fuller, M. L., and Ashley, G. H.

1902 - Description of the Ditney Quadrangle: U.S. Geol. Atlas, Folio 84, 8 p., 14 figs., 3 maps.

Gillespie, W. H., and Pfefferkorn, H. W.
1979 - Distribution of commonly occurring plant megafossils in the proposed Pennsylvanian System stratotype, *in* Englund, K. J., and others, Proposed Pennsylvanian System stratotype, Virginia and West Virginia: Ninth Internat. Cong. of Carboniferous Stratigraphy and Geology, Guidebook Field Trip No. 1, p. 87-96, 3 pls., 1 fig., 1 table.

Gray, H. H.
1962 - Outcrop features of the Mansfield Formation in southwestern Indiana: Indiana Geol. Survey Rept. Prog. 26, 40 p., 8 figs., 3 tables.

Guennel, G. K.
1958 - Miospore analysis of the Pottsville coals of Indiana: Indiana Geol. Survey Bull. 13, 101 p., 6 pls., 20 figs., 11 tables.
1960 - Comparative paleobotanical investigation of the Indiana and Russian paper coals [unpub. Ph. D. thesis]: Bloomington, Indiana Univ., 301 p., 33 pls.

Guennel, G. K., and Neavel, R. C.
1959 - Paper coal in Indiana: Science, v. 129, p. 1671-1672, 1 fig.

Hopkins, M. E., and Simon, J. A.
1975 - Pennsylvanian System, *in* Willman, H. B., and others, Handbook of Illinois stratigraphy: Illinois Geol. Survey Bull. 95, p. 163-201, 16 figs.

Hopkins, T. C.
1896 - The Carboniferous sandstones of western Indiana; an economic report on the sandstones of a portion of western Indiana, accompanied by two atlas sheets showing the outcrops and distribution of the sandstone: Indiana Dept. Geology and Nat. Resources Ann. Rept. 20, p. 186-327, 9 pls., 7 figs., 2 maps.

Horne, J. C., Ferm, J. C., Caruccio, F. T., and Baganz, B. P.
1978 - Depositional models in coal exploration and mine planning, Appalachian region: Am. Assoc. Petroleum Geologists Bull., v. 62, p. 2379-2411, 29 figs., 2 tables.

Hutchison, H. C.
1960 - Geology and coal deposits of the Brazil Quadrangles, Indiana: Indiana Geol. Survey Bull. 16, 50 p., 2 pls., 3 figs., 2 tables.

Hutchison, H. C.
1961 - Distribution, structure, and mined areas of coals in Fountain and Warren Counties and the northernmost part of Vermillion County, Indiana: Indiana Geol. Survey Prelim. Coal Map 9.
1970 - Lower Block Coal Member, Upper Block Coal Member, and Mariah Hill Coal Bed, *in* Shaver, R. H., and others, Compendium of rock-unit stratigraphy in Indiana: Indiana Geol. Survey Bull. 43, p. 100-101, 181-182, and 106.
1976 - Geology of the Catlin-Mansfield area, Parke and Putnam Counties, Indiana: Indiana Geol. Survey Bull. 54, 57 p., 4 pls., 5 figs., 2 tables.

Leisman, G. A., and Phillips, T. L.
1979 - Megasporangiate and microsporangiate cones of *Achlamydocarpon varius* from the Middle Pennsylvanian: Palaeontographica, v. 186B, p. 100-128, 11 pls., 2 figs.

McKee, E. D.
1975 - Interpretation of Pennsylvanian history, *in* McKee, E. D., and others, Paleotectonic investigations of the Pennsylvanian System in the United States — Pt. 2, Interpretive summary and special features of the Pennsylvanian System: U.S. Geol. Survey Prof. Paper 853, p. 1-21, 1 fig.

Mamay, S. H., and Yochelson, E. L.
1962 - Occurrence and significance of marine animal remains in American coal balls: U.S. Geol. Survey Prof. Paper 354-I, p. 193-224, pls. 26-34, figs. 42-45, 3 tables.

Neavel, R. C., and Guennel, G. K.
1958 - Occurrence of paper coal in Indiana [abs.]: Geol. Soc. America Bull., v. 69, no. 12, pt. 2, p. 1622-1623.
1960 - Indiana paper coal — Composition and deposition: Jour. Sed. Petrology, v. 30, p. 241-248, 1 pl., 3 figs., 3 tables.

Peppers, R. A.
1977 - Palynology and correlations of some coals in the Tradewater Formation (Pennsylvanian) in western Kentucky, and in the Abbott Formation in southeastern Illinois [abs.]: Geol. Soc. America, North-Central Sec. Mtg., Abs., p. 640-641.

Peppers, R. A.
1979 - Development of coal-forming floras during the early part of the Pennsylvanian in the coal basin, *in* Palmer, J. E., and Dutcher, R. R., Depositional and structural history of the Pennsylvanian System of the Illinois Basin — Pt. 2, Invited papers: Ninth Internat. Cong. of Carboniferous Stratigraphy and Geology, Illinois Geol. Survey Guidebook Ser. 15a, p. 8-14, 1 fig.
19__ - Comparison of miospore assemblages in the Pennsylvanian System of the Illinois Basin with those in the Upper Carboniferous of western Europe: Ninth Internat. Cong. of Carboniferous Stratigraphy and Geology [in preparation].

Peppers, R. A., and Popp, J. T.
1979 - Stratigraphy, depositional environments, and correlation of Pennsylvanian strata in northeastern Illinois, *in* Palmer, J. E., and Dutcher, R. R., Depositional and structural history of the Pennsylvanian System of the Illinois Basin — Pt. 2, Invited papers: Ninth Internat. Cong. of Carboniferous Stratigraphy and Geology, Illinois Geol. Survey Guidebook Ser. 15a, p. 65-72, 3 figs.

Perkins, T. W.
1976 - Textures and conditions of formation of Middle Pennsylvanian coal balls, central United States: Kansas Univ. Paleon. Contr. Paper 82, 13 p., 5 figs., 2 tables.

Phillips, T. L.
1979 - Reproduction of heterosporous arborescent lycopods in the Mississippian-Pennsylvanian of Euramerica: Rev. Paleobotany and Palynology, v. 27, no. 3/4, p. 239-289, 17 pls., 2 figs.

Phillips, T. L., Kunz, A. B., and Mickish, D. J.
1977 - Paleobotany and permineralized peat (coal balls) from the Herrin (No. 6) Coal Member of the Illinois Basin, *in* Given, P. N., and Cohen, A. D., Interdisciplinary studies of peat and coal origins: Geol. Soc. America Microform Pub. 7, p. 18-49, 13 figs., 4 tables.

Phillips, T. L., Peppers, R. A., Avcin, M. J., and Laughnan, P. R.
1974 - Fossil plants and coal — Patterns of change in Pennsylvanian coal swamps of the Illinois Basin: Science, v. 184, p. 1367-1369, 1 fig., cover.

Phillips, T. L., Pfefferkorn, H. W., and Peppers, R. A.
1973 - Development of paleobotany in the Illinois Basin: Illinois Geol. Survey Circ. 480, 86 p., 5 figs.

Phillips, T. L., Shepard, J. L., and DeMaris, P. J.
1980 - Stratigraphic patterns of Pennsylvanian coal swamps in Midcontinent and Appalachian regions of the United States [abs.]: Geol. Soc. America Abs. with Programs, v. 12, no. 7, p. 498-499.

Potter, P. E.
1963 - Late Paleozoic sandstones of the Illinois Basin: Illinois Geol. Survey Rept. Inv. 217, 92 p., 54 figs., 7 tables.

Schopf, J. M.
1966 - Definitions of peat and coal and of graphite that terminates the coal series (graphocite): Jour. Geology, v. 74, no. 5, pt. 1, p. 584-592.

Schopf, J. M., Wilson, L. R., and Bentall, Ray
1944 - An annotated synopsis of Paleozoic fossil spores and the definition of generic groups: Illinois Geol. Survey Rept. Inv. 91, 73 p.

Scott, A. C.
1978 - Sedimentological and ecological control of Westphalian B plant assemblages from West Yorkshire: Yorkshire Geol. Soc. Proc., v. 41, p. 461-508, 5 pls., 19 figs.

Shaver, R. H., and Smith, S. G.
1974 - Some Pennsylvanian Kirbyacean ostracods of Indiana and Midcontinent series terminology: Indiana Geol. Survey Rept. Prog. 31, 59 p., 3 pls., 5 figs.

Smith, A. H. V., and Butterworth, M. A.
1967 - Miospores in the coal seams of the Carboniferous of Great Britain: London, Palaeont. Assoc. Spec. Paper 1, 324 p., 27 pls., 72 figs., 7 tables.

Stopes, M. C., and Watson, D. M. S.
1909 - On the present distribution and origin of the calcareous concretions in coal seams, known as coal balls: Royal Soc. London Philos. Trans., v. 200B, p. 167-218, pls. 17-19, 5 figs., 2 maps, 4 tables.

Wanless, H. R.
1939 - Pennsylvanian correlations in the Eastern Interior and Appalachian coal fields: Geol. Soc. America Spec. Paper 17, 130 p.

Wanless, H. R.
1975 - Illinois Basin region, *in* McKee, E. D., and others, Paleotectonic investigations of the Pennsylvanian System in the United States — Pt. 1, Introduction and regional analyses of the Pennsylvanian System: U.S. Geol. Survey Prof. Paper 853, p. 71-95, figs. 12-14, tables 11-15.

Weber, J. N., and Keith, M. L.
1962 - Carbon-isotope composition and the origin of calcareous coal balls: Science, v. 134, p. 900-902, 1 table.

Wier, C. E.
1970 - Raccoon Creek Group, Pottsvillian and Alleghenian Series, Pennsylvanian System, *in* Shaver, R. H., and others, Compendium of rock-unit stratigraphy in Indiana: Indiana Geol. Survey Bull. 43, p. 136-137.
1973 - Coal resources of Indiana: Indiana Geol. Survey Bull. 42-I, 40 p., 19 figs., 6 tables.

Zangerl, Rainer, and Richardson, E. S.
1963 - The paleoecological history of two Pennsylvanian black shales: Fieldiana — Geology Mem., v. 4, 352 p., 56 pls., 51 figs., 12 tables.

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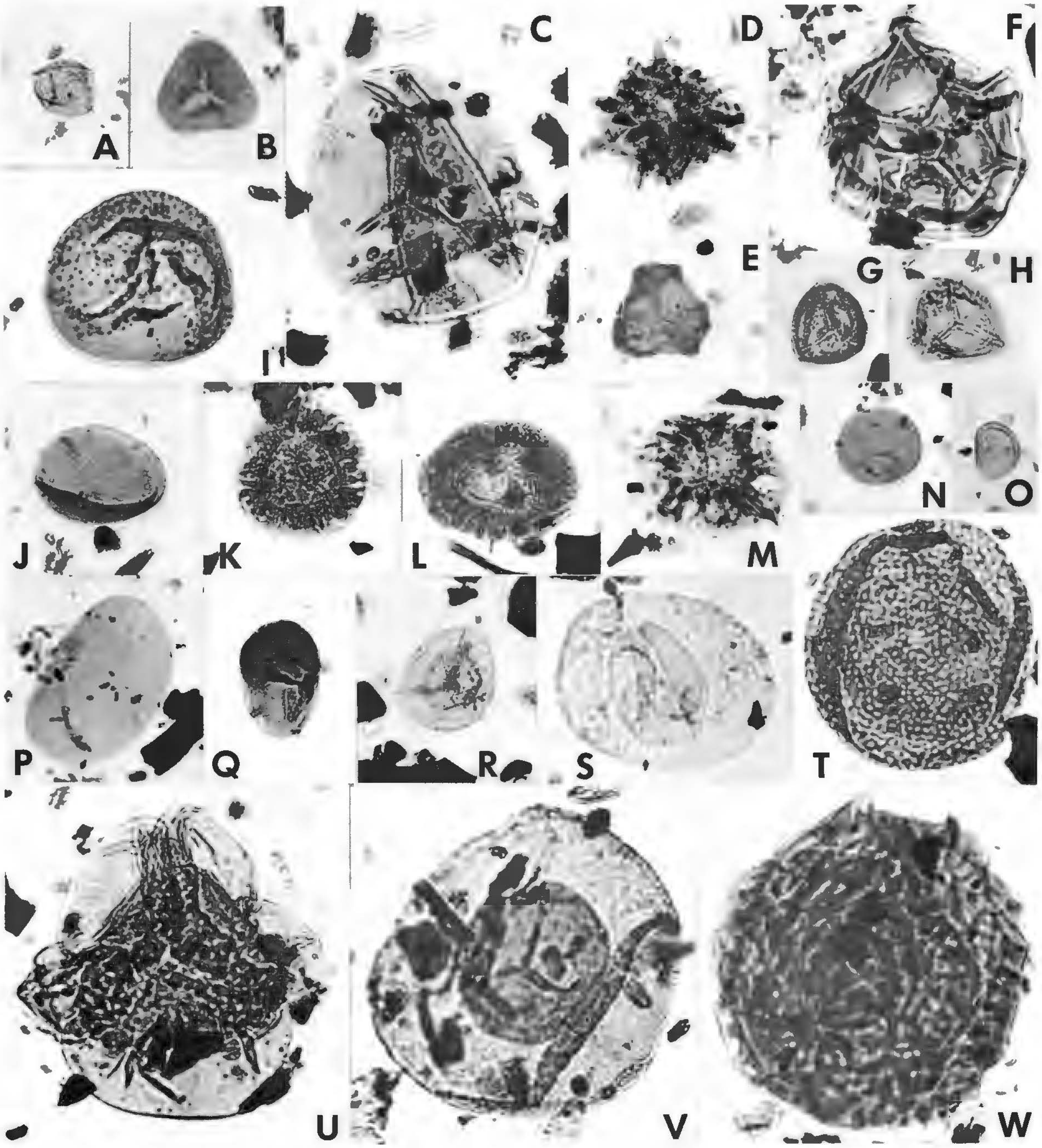
Plates 1-6

PLATE 1

All figures are × 500

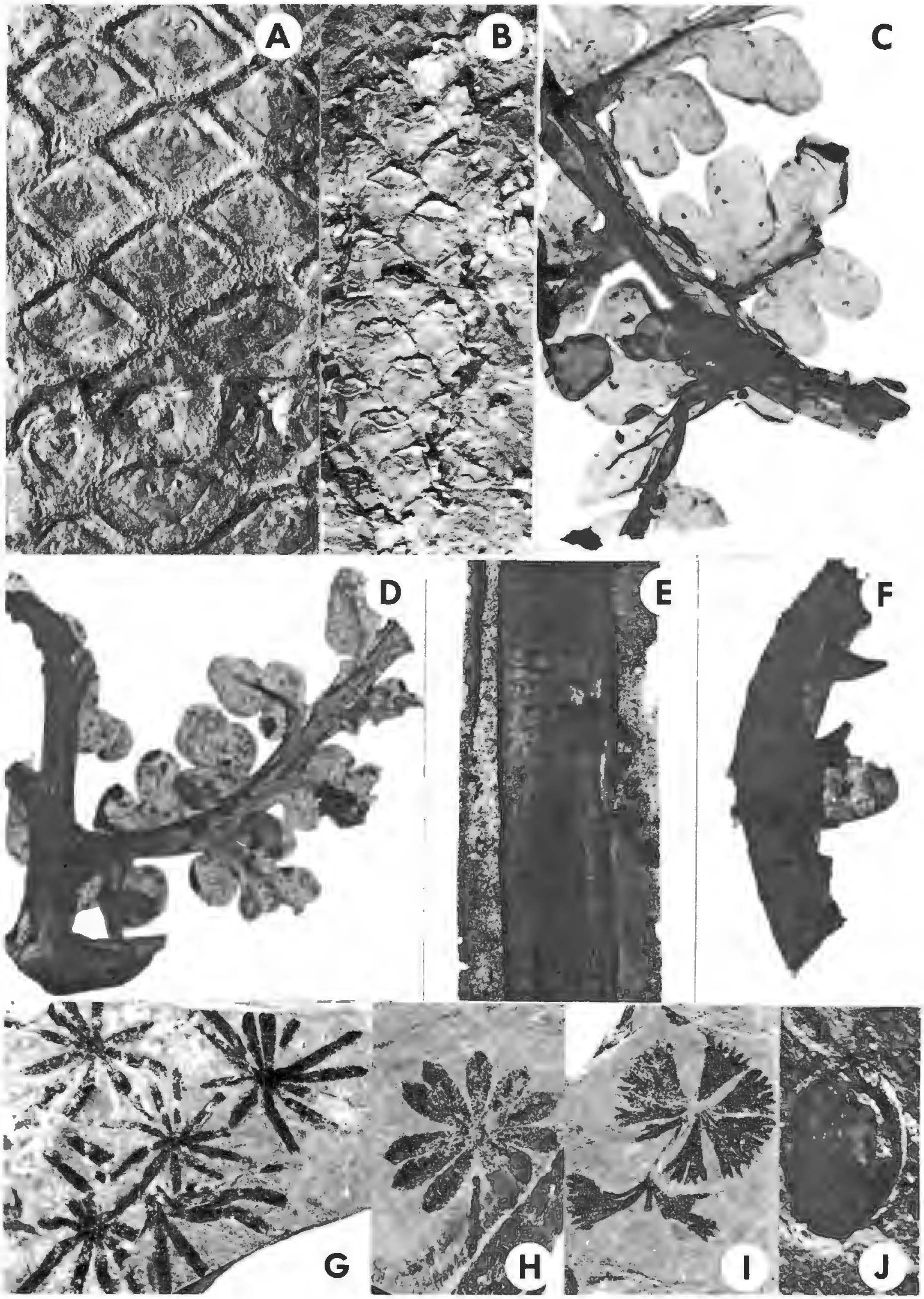
A, *Punctatisporites minutus* (Kosanke) Peppers, maceration 2423b, slide 11; B, *Granulatisporites parvus* (Ibrahim) Potonié & Kremp, 2423b, slide 8; C, *Calamospora hartungiana* Schopf (*in* Schopf and others, 1944), 2423c, slide 9; D, *Raistrickia crocea* Kosanke, 2423b, slide 12; E, *Triquitrites sculptilis* (Balme) Smith & Butterworth, 2423b, slide 5; F, *Reticulatisporites reticulatus* (Ibrahim) Ibrahim, 2423c, slide 10; G, *Lycospora granulata* Kosanke, 2421a, slide 8; H, *Lycospora pellucida* (Wicher) Schopf, Wilson & Bentall, 2423c, slide 10; I, *Crassispora kosankei* (Potonié & Kremp) *sensu* Sullivan, 2423b, slide 7; J, *Cappasporites distortus* Urban, 2421b, slide 9; K, *Radiizonates difformis* (Kosanke) Staplin & Jansonius, 2423c, slide 1; L, *Densosporites triangularis* Kosanke, 2423c, slide 10; M, *Radiizonates rotatus* (Kosanke) Staplin & Jaonsonius, 2423c, slide 10; N, *Laevigatosporites globosus* Schemel, 2423c, slide 9; O, *Laevigatosporites minutus* (Ibrahim) Schopf, Wilson & Bentall, 2421a, slide 5; P, *Laevigatosporites ovalis* Kosanke, 2423c, slide 1; Q, *Torispora securis* Balme, 2423c, slide 9; R, *Endosporites staplinii* Gupta & Boozer, 2423c, slide 8; S, *Florinites mediapudens* (Loose) Potonié & Kremp, 2421a, slide 5; T, *Vestispora fenestrata* (Kosanke & Brokaw) Spode (*in* Smith and Butterworth, 1967), 2421b, slide 10; U, *Alatisporites pustulatus* Ibrahim, 2423c, slide 5; V, *Endosporites globiformis* (Ibrahim) Schopf, Wilson & Bentall, 2423b, slide 11; W, *Vestispora magna* (Butterworth & Williams) Spode (*in* Smith and Butterworth, 1967), 2423c, slide 5.



SPORES AND POLLEN REPRESENTATIVE OF COALS IN THE ROARING CREEK AREA

PLATE 2

A, *Sigillaria* (*S.* cf. *brardii*), rhomboidal leaf-cushion impressions with pairs of parichnos scars in the upper part of each cushion and with interareas between leaf cushions, coal A′, section 3, Roaring Creek, × 2; B, *Lepidodendron aculeatum*, coalified leaf cushions of small stem, coal A′, section 2, Roaring Creek, × 2.5; C, *Eusphenopteris* sp., cuticle of pinna rachis and pinnules, cuticular shale, Coke Oven Hollow, × 4.5; D, *Eusphenopteris* sp., cuticular shale, Coke Oven Hollow, × 4.5; E, *Eusphenopteris* sp., compressed cuticle from rachis on stem, cuticular shale, Coke Oven Hollow, × 3.0; F, *Eusphenopteris* sp., spinose part of distal frond, cuticular shale, Coke Oven Hollow, × 5; G, *Annularia radiata*, × 2; H, *Annularia sphenophylloides*, × 2; I, *Sphenophyllum cuneifolium*, × 2; J, Radiospermic ovule, compression, coal A′, section 3, Roaring Creek, × 2.5.

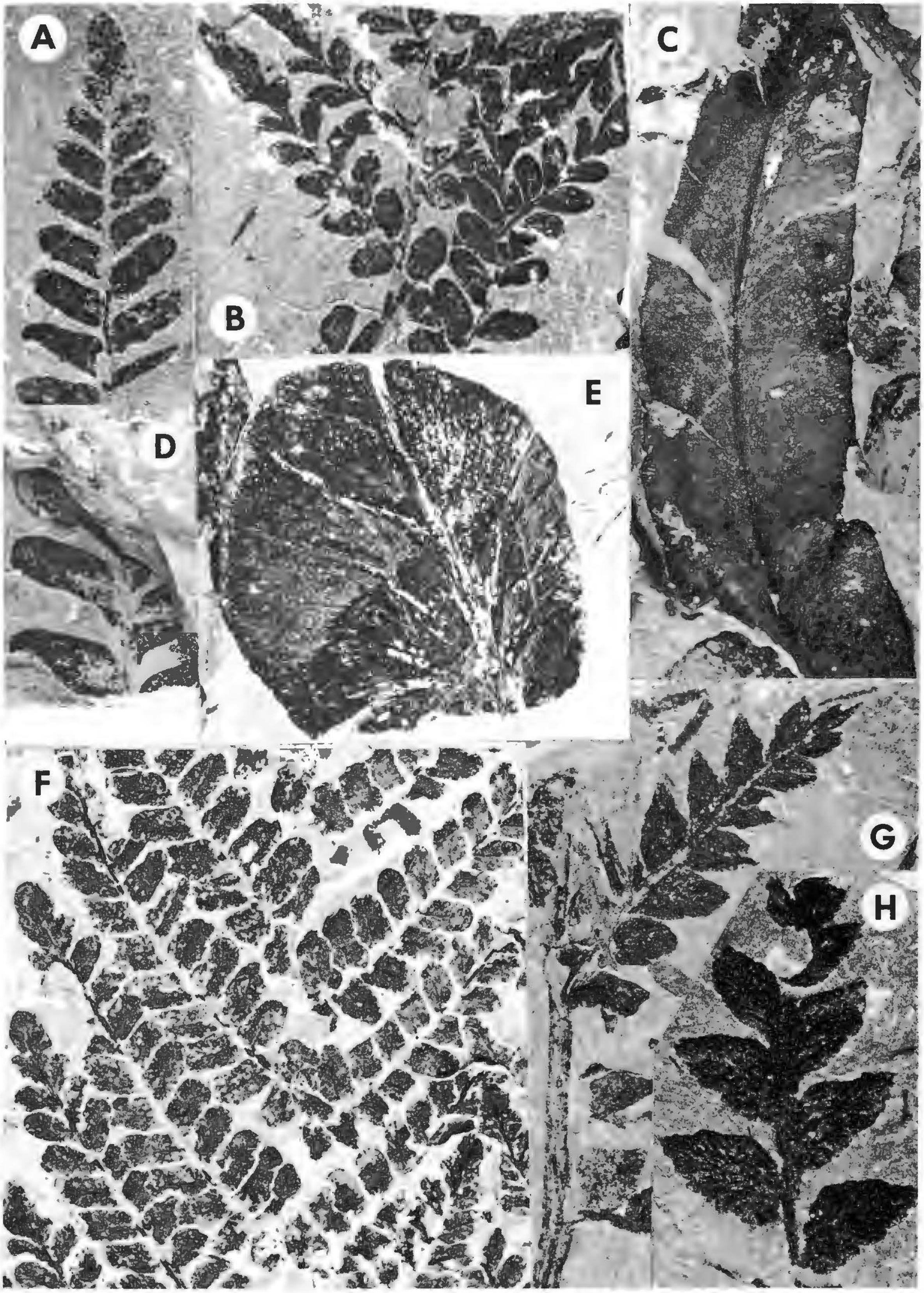


CUTICLES AND PLANT COMPRESSIONS FROM INDIANA CUTICULAR SHALES (A–F, J) AND COMPRESSIONS FROM THE GRAY SHALE (G–I) ABOVE COAL A′, SECTION 3, ROARING CREEK

PLATE 3

All figures are $\times$ 2

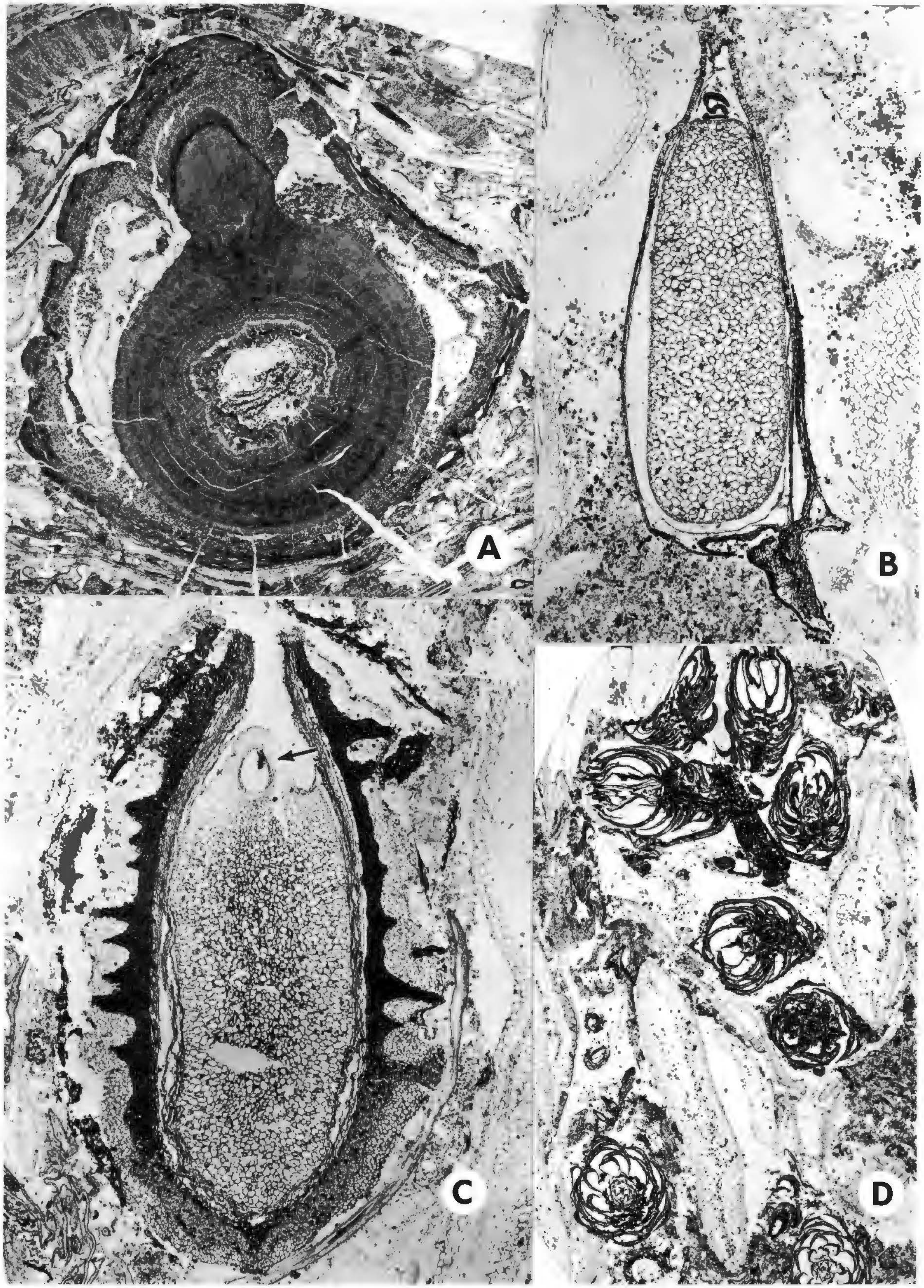
A, *Neuropteris heterophylla-obliqua;* B, *Neuropteris heterophylla-obliqua;* C, *Neuropteria scheuchzeri;* D, *Neuropteris heterophylla;* E, *Cyclopteris* sp., probably from *N. heterophylla;* F, *Neuropteris rarinervis;* G, *Mariopteris muricata;* H, *Mariopteris muricata.*



PTERIDOSPERM FOLIAGE FROM THE GRAY SHALE ABOVE COAL A,
SECTION 2, ROARING CREEK

PLATE 4

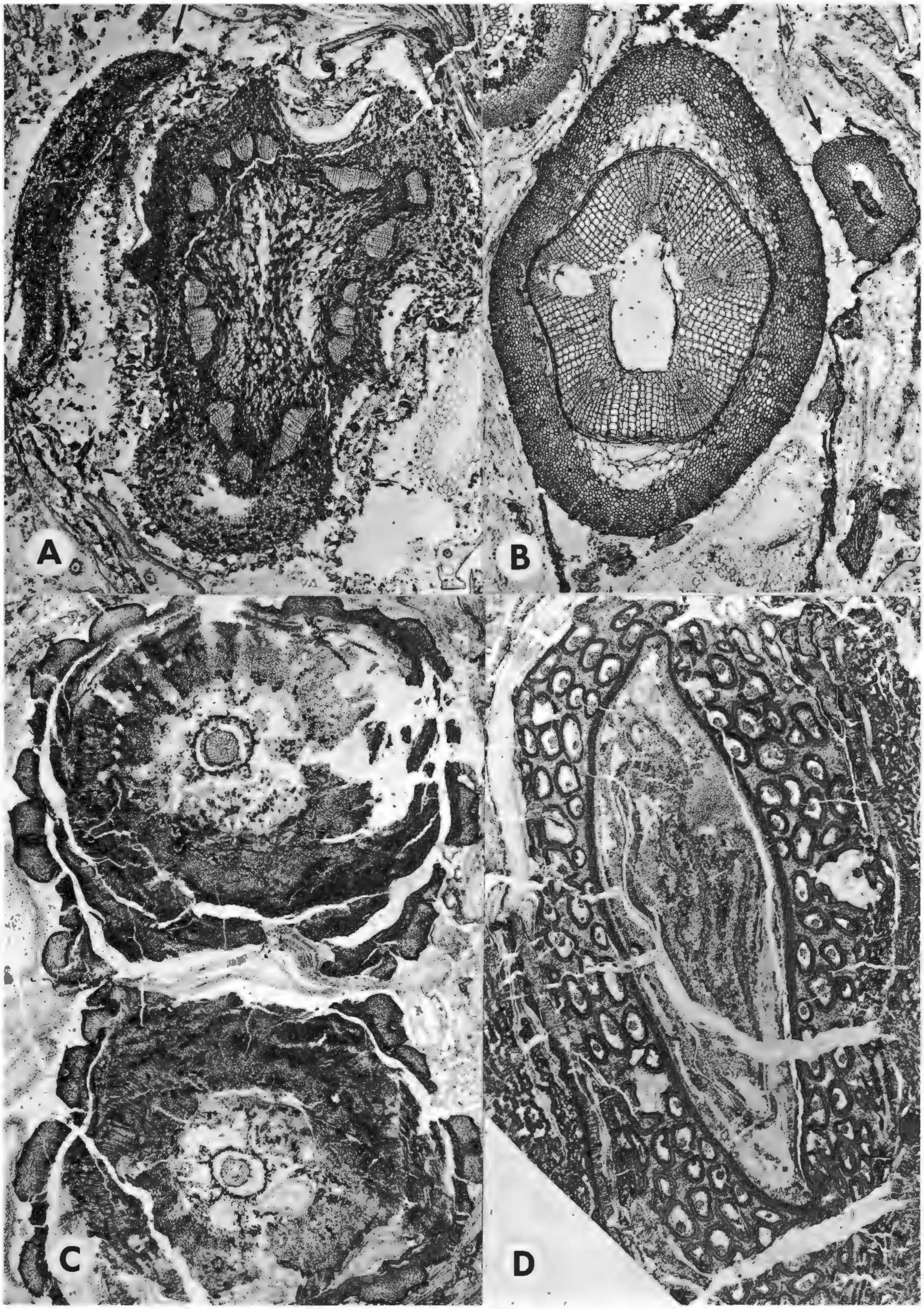
A, Cross section of *Pennsylvanioxylon* (cordaites) stem with branch trace, specimen 14834, × 2.5; B, Saggittal section of megasporangium with gametophyte of *Achlamydocarpon varius;* proximal end at top, adaxial face at left, specimen 21579, × 12; C, Median longitudinal section of narrow width of *Cardiocarpus spinatus* ovule with gametophyte and archegonium (arrow), specimen 22722, × 20; D, *Cordaianthus* shoots with *Florinites*, specimen 9468, × 5.



COAL-BALL PLANTS FROM THE UNNAMED COAL, STAUNTON FORMATION,
MAPLE GROVE MINE

PLATE 5

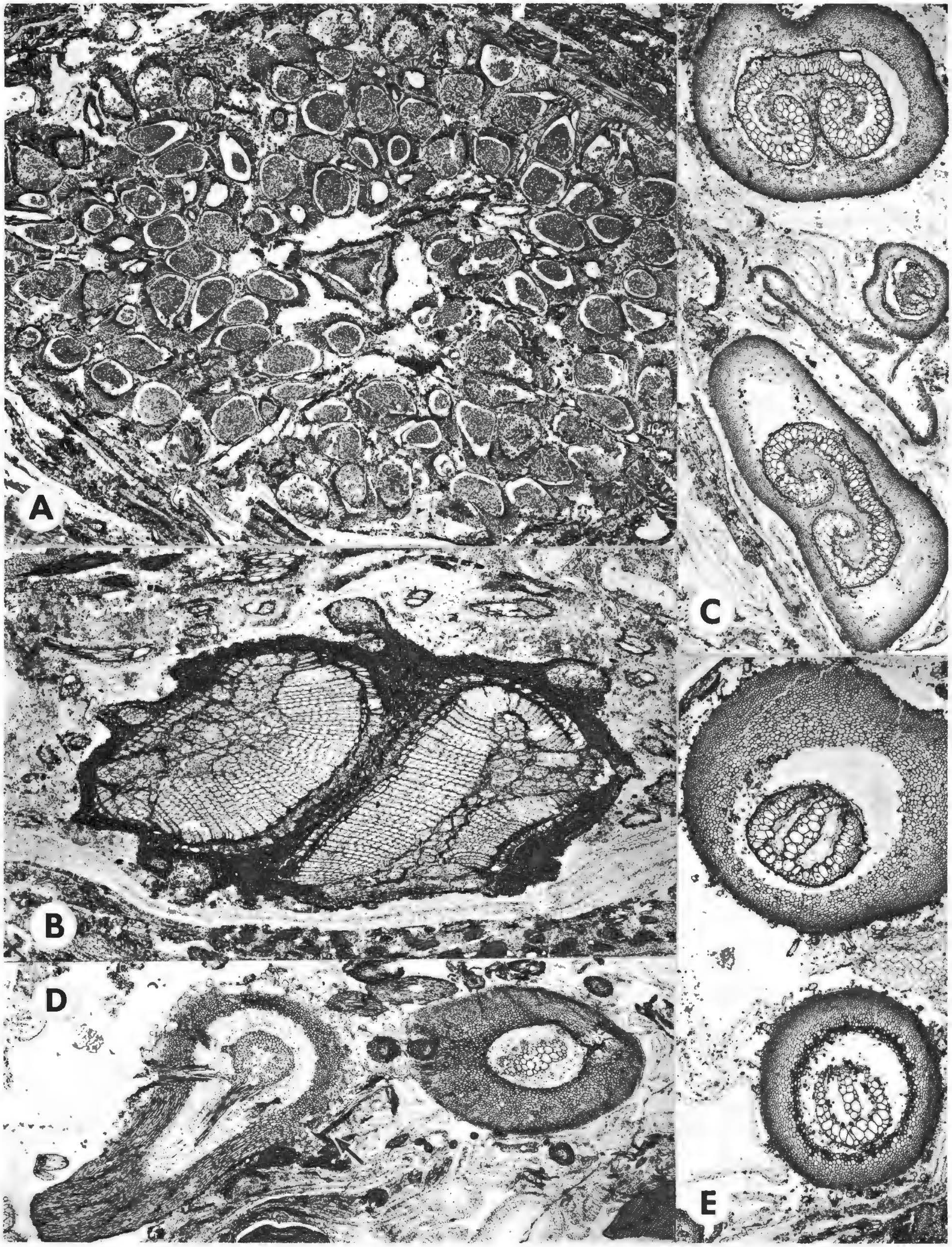
A, Cross section of young *Pennsylvanioxylon* (cordaites) stem with thick cuticle and adjacent leaf base (arrow), specimen 9251, × 12; B, Cross section of *Johnhallia* stem with petiole (arrow), specimen 8350, × 12; C, Cross section of isotomously dichotomized branch of *Lepidodendron vasculare*, specimen 14883, × 4; D, Cross section of *Psaronius* stem with inner root-zone mantle, specimen 22188, × 2.5.



COAL-BALL PLANTS FROM THE UNNAMED COAL, STAUNTON FORMATION, MAPLE GROVE MINE

PLATE 6

A, Cross section of *Bowmanites* (*Sphenophyllum*) cone, specimen 22611, × 5; B, Cross section of *Medullosa* stem, specimen 19259, × 5.5; C, Cross sections of *Anachoropteris* cf. *involuta* foliar members, specimen 19803, × 8; D, Cross sections of foliar member and derived shoot (arrow) of *Botryopteris tridentata*, specimen 21592, × 8; E, Cross sections of foliar members of *Botryopteris forensis*, specimen 8413, × 8.



COAL-BALL PLANTS FROM THE UNNAMED COAL, STAUNTON FORMATION, MAPLE GROVE MINE