FOSSIL SPORES OF THE ALLEGHENIAN COALS IN INDIANA

by

G. K. GUENNEL

Indiana Department of Conservation
GEOLOGICAL SURVEY
Report of Progress No. 4

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STATE OF INDIANA
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DEPARTMENT OF CONSERVATION
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CONTENTS

ILLUSTRATIONS

FOSSIL SPORES OF THE ALLEGHENIAN COALS IN INDIANA

BY G. K. GUENNEL

ABSTRACT

In this report the significance of spores in plant life cycles is discussed briefly. The term "miospore" is proposed for fossil spores and spore-like bodies under 200 micra in size. Sampling and coal preparation are outlined, the stratigraphy of the Alleghenian series in Indiana is sketched in broad strokes, and the underlying principles of the theory of coal correlation are discussed. Percentage relationships of miospore genera have been established for the nine known coal seams of the Alleghenian series in Indiana, and some unknown coal beds have been identified on the basis of the relative abundance of certain genera.

INTRODUCTION

PURPOSE OF SPORE ANALYSIS

Spore analyses of the nine known coal seams of the Alleghenian series have been made as an integral part of the coal resources studies now in progress in Indiana. The microfossil investigation of these coal seams is intended to establish definite standards by which coal seams can be identified and subsequently correlated. Although some workers previously had pointed out the stratigraphic significance of spore studies, Kosanke (1950, pp. 61-93) conclusively proved that correlation of coal seams by means of fossil spores is feasible.

ACKNOWLEDGMENTS

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BOTANICAL SIGNIFICANCE OF SPORES

Reproduction, the process whereby a given species is perpetuated, is vital in all plant and animal life. If only one kind of plant plays a part in the reproductive process, botanists term this type of reproduction asexual. If, however, each of two parent organisms participates in the production of a special reproductive cell, called a gamete, which must join with another gamete before a new organism can be developed, botanists call this reproduction sexual. In the reproduction of plants not only are gametes necessary, but also spores are needed in order to complete the reproductive cycle. The enumeration of the various types of spores which occur throughout the plant kingdom is beyond the scope of this paper, but the fact that most plants produce spores of one kind or another should be mentioned.

The term "spore" is derived from "spora," the Greek word for seed. Frequently, seeds and spores are confused as being similar, but actually they are not comparable at all. A seed is only a little plant, together with a small amount of food, packaged within two protective walls which are known as seed coats. A spore, on the other hand, is a definite part of the reproductive cycle.

In the fern plants, for example, if the young plant which grew on the gametophyte had been covered by a protective wall and thereby had been given a rest period, it would have been a seed (Fig. 1). As this development does not take place in the ferns but occurs first in the next higher group, the pines (Fig. 3), ferns do not produce seeds. Ferns, however, like most plants, produce spores. These spores are surrounded by walls and thus are stopped temporarily in the cycle of reproduction. As they germinate, the spores do not grow immediately into a fern plant; they mark only the beginning of the gametophyte generation, the gamete-producing phase of the life cycle (Fig. 1). These gametophytes produce gametes, and the latter, in turn, fuse to form a cell, the zygote, which finally will grow into a fern. Spores, therefore, are half-way marks in the cycle of reproduction, whereas the seed in seed-bearing plants is the end product.

Unlike the spores of non-seed-bearing plants, the spores of seed-bearing plants have no rest period but continue to develop into the gametophyte that gives rise to the gametes. As in non-seed-bearing plants, the gametes then fuse to form the zygote from which a little plant, such as a pine or bean, is developed. This little plant, enclosed within the seed coat, is protected and undergoes a rest period. When the seed germinates, the whole life cycle is completed. The little pine or bean then resumes growth and becomes a mature plant (Fig. 3).

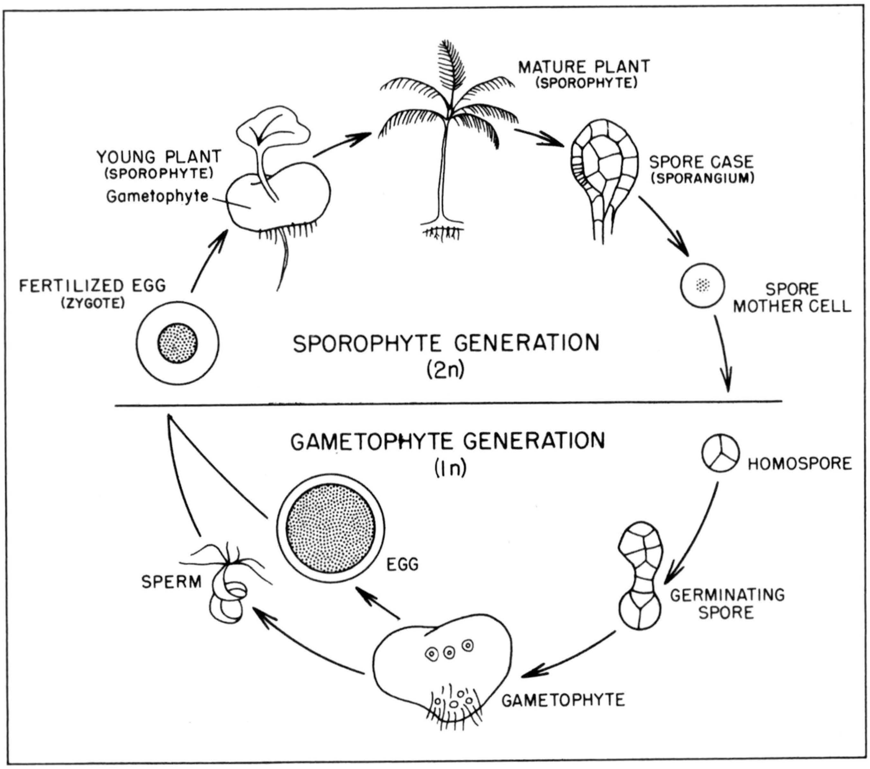


Figure 1. *Diagram of life cycle of typical homosporous pteridophyte.*

The phylum Pteridophyta, the group which includes the ferns, horsetails, and club mosses, contributed most to the formation of Pennsylvanian coal. The pteridophytes have life cycles with two distinct phases or generations. The gametes are produced in one phase and the spores in the other. Gametes are of two kinds, male and female. The fusion of two gametes results in the formation of a spore-producing plant (sporophyte). The spores which are produced by this plant are protected by walls and in such condition may rest a long time. When a spore germinates, it gives rise to a plant (gametophyte) which, in turn, produces gametes.

In some of the pteridophytes, the sporophyte produces two kinds of spores, a small one (microspore) and a large one (megaspore), each of which has different functions. The microspore develops into a male gametophyte, which can produce only male gametes (sperms); the megaspore, on the other hand, develops

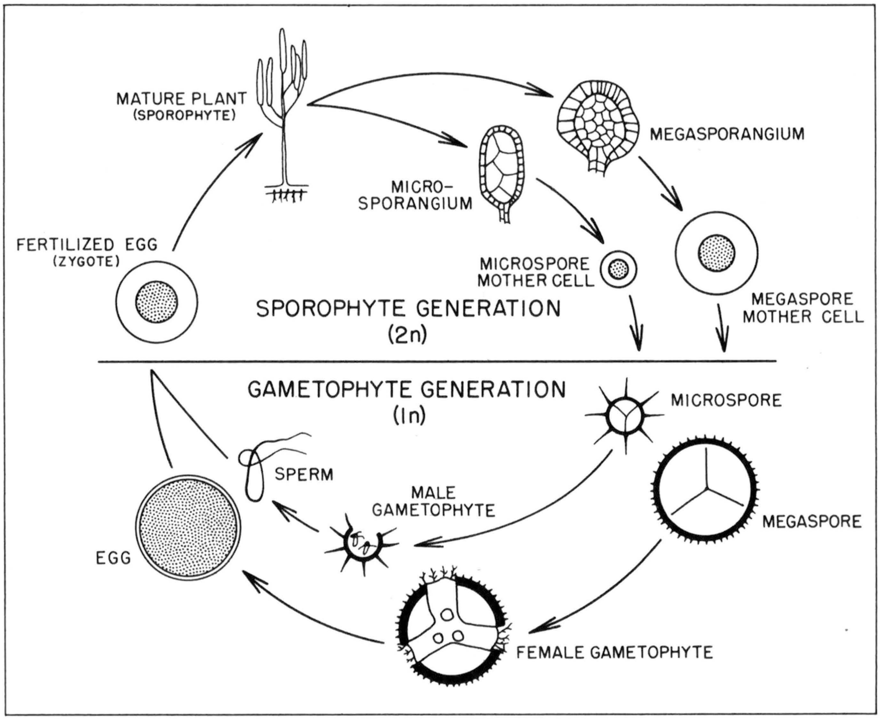


Figure 2. *Diagram of life cycle of typical heterosporous pteridophyte.*

into a female gametophyte, which can produce only female gametes (eggs). Plants which produce both microspores and megaspores are termed heterosporous (Fig. 2). Inasmuch as the microspores of heterosporous plants are small and wind-disseminated, they are dispersed over wide areas. The megaspores, however, because of their large size, are restricted greatly in their range of dissemination.

Pteridophytes which produce only one kind of spore are called homosporous. The spores of these plants are mostly small, are disseminated by wind currents, and upon deposition in favorable situations germinate into the gametophyte plants that produce both sperms and eggs, that is, male and female gametes respectively. These gametes fuse and eventually produce the sporophyte generation, the "fern plant." In turn, this fern plant produces spores, and thus the cycle is begun again (Fig. 1).

Controversy has arisen over the use of the term "microspore." Botanists, overlooking the genetic and functional implications, use

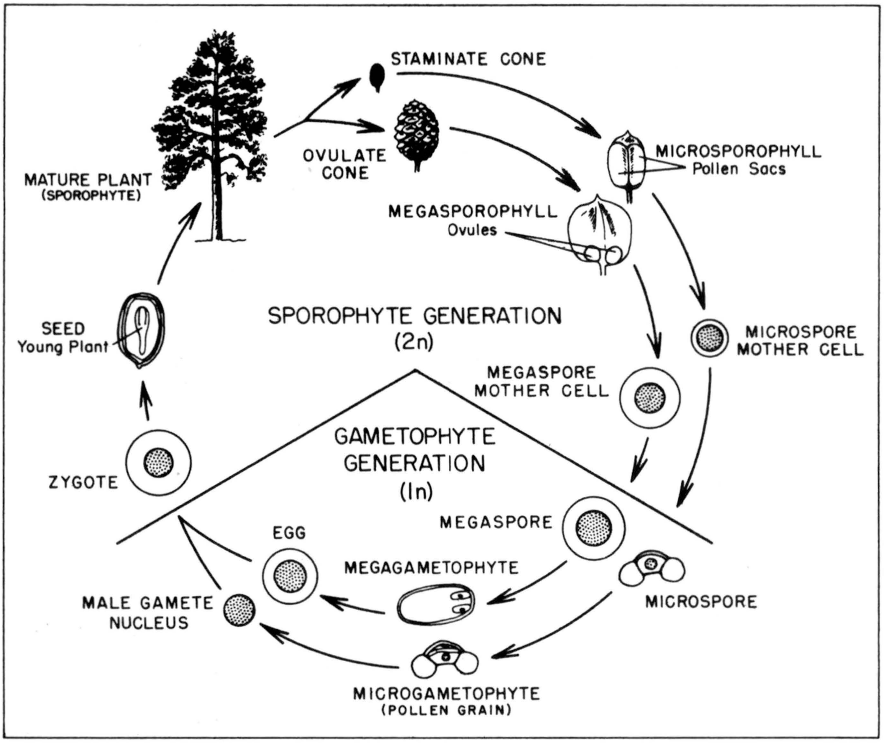


Figure 3. *Diagram of life cycle of typical gymnosperm.*

it too frequently to denote all spores of small size. Schopf, Wilson, and Bentall (1944, p. 9) described this problem as follows: "The common indiscriminate reference to all spores of relatively small dimensions as 'microspores' is to be lamented. Although true microspores frequently are small, by no means all small spores are microspores. The long established botanical usage of the term 'microspore' has reference to fundamentally functional distinctions that are entirely aside from relative or specific size." Wilson (1946, p. 111) also mentioned the dilemma by saying that "the term microspore as used by the British workers does not necessarily mean microspore in the morphological sense but rather it refers to all small spores and therefore may include homosporous species."

American workers have adopted the term "small spore" to denote spores of relatively small size, regardless of their functions. This term, however, seems rather vague and too general. In order to categorize spores of relatively small sizes and to differentiate them from macrospores[1] or large spores, the term "miospore"[2] is proposed. All fossil spores and spore-like bodies smaller than 0.20 mm, including homospores, true microspores, small megaspores, pollen grains, and pre-pollen, are arbitrarily called miospores. Large spores, on the other hand, are referred to as macrospores. The 0.20 mm measurement is used as the dividing line, because the standard screens which are used for sizing in the coal preparation process have openings of approximately 200 micra in size.

PROCEDURE OF SPORE ANALYSIS

METHOD OF SAMPLING

Most of the coal samples analyzed were collected during August 1949. William Flanagan assisted the writer in obtaining samples from widely scattered localities in the Indiana coal fields. Some samples were taken from outcrops, and others were procured from the working faces of deep mines. Most of the material, however, was obtained from the exposed faces of stripping operations. The localities from which samples were collected are shown in the table on page 13 and in Fig. 4.

As little information regarding sampling procedure can be found in previous reports, an account of the sampling method which the writer used may aid others in collecting coal samples for microscopic examination. The face of the coal seam which is to be sampled can be cleaned easily with a geologic hammer or a pick. After a clean surface has been exposed, the entire seam, if it is relatively thick, then is divided into benches. Partings and bands often make for natural benching. A continuous sample must be obtained in order to have complete representation vertically of any microfossils contained in the seam. A complete profile can be obtained by using a hammer and a chisel to chip out, along a line perpendicular to the bedding plane, pieces of coal approximately equal in size. The coal fragments then are collected in paper bags, labeled, and wrapped. This sampling procedure is repeated for each bench. In order to prevent contamination of the samples, the tools must be cleaned thoroughly after each sampling. The author is fully aware of the shortcomings

[1]Makros (Gr.)—long, large, great
[2]Meion (Gr.)—less, smaller

of his method. Until a suitable cutting instrument is devised, however, this method seems to be the simplest and certainly the most inexpensive.

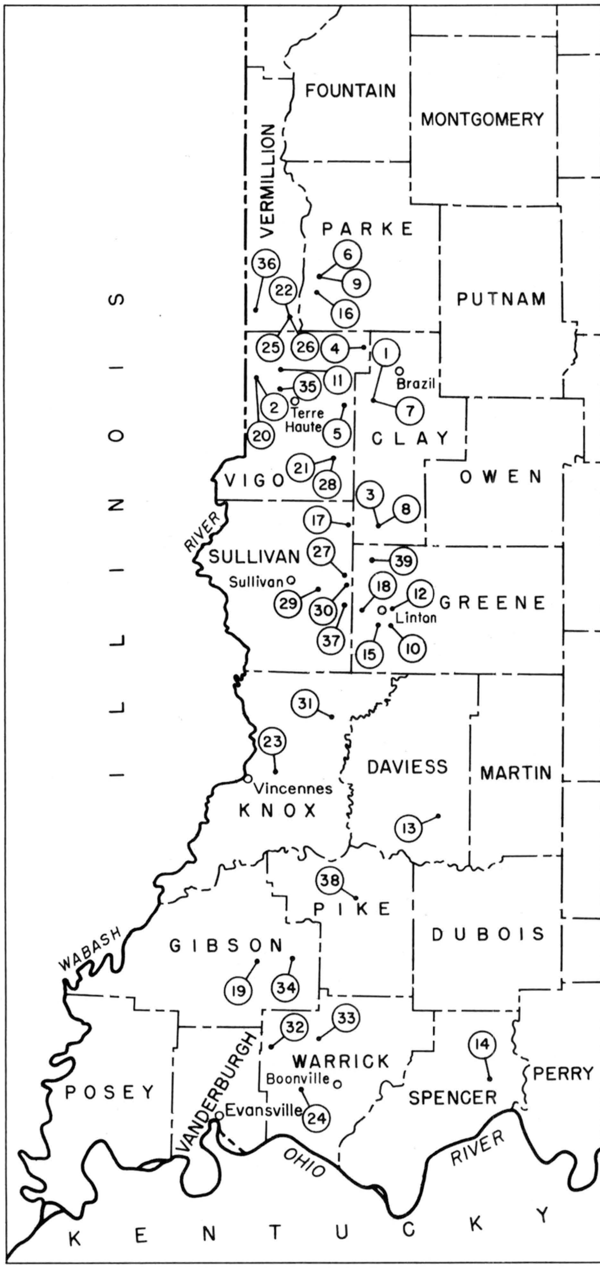
PREPARATION OF THE COAL

Preparation of the coal for microscopic examination was made according to the standard maceration method described in detail by Kosanke (1950, pp. 8-11). For the partial oxidation of the coal, Schulze's reagent, a mixture of one part of aqueous solution of $KClO_3$ and two parts of concentrated HNO_3, was used. The time necessary for oxidation varied with the rank of the coal, the amount of impurities present, and the degree of weathering. After the acid treatment, the partially oxidized coal was immersed in a 10 percent solution of KOH. This step resulted in the release of soluble salts of humic acids, which were separated from the insoluble organic materials, that is, spores and other botanic ingredients, by washing. The residue then was sized with a 70-mesh screen. The plus 70-mesh material was stored, and the minus 70-mesh residue was stained with saffranin. For dehydration the minus 70-mesh material was passed successively through 25 percent, 50 percent, 75 percent, and 100 percent solutions of alcohol. After the material had been mixed with diaphane solvent, transferred to microscopic slides with a camel hair brush, and mixed with diaphane, cover glasses were placed on the slides. The slides then were ready for miscroscopic examination.

STATISTICAL METHOD

Because miospores are small, readily distinguished, and abundant in coal, a quantitative analysis is possible. In pollen analysis, percentages based on a total count of 200 specimens per sample have proved extremely useful in reconstructing the vegetation of postglacial time. Barkley (1934, p. 288) found that "little significant shifting of relative percentages beyond the 200 count" occurred. This standard method of counting 200 specimens per given sample was adopted for this study.

In most macerations 200 miospores were identified and counted. In some samples in which the miospores were sparse, however, a count of 100 or 150 specimens was used as a statistical basis. A few samples showed so great an abundance of spores that 300 or even 400 were tabulated. Percentages for each bench, that is, layer of coal, were determined. In addition, percentages were ob-



LOCALITY NO.	COAL SEAM	COAL MINE
1	III	Chinook
2	III	Green Valley
3	III	Alum Cave
4	III	Lone Star No.4
5	III	Victory
6	III	Raccoon Station
7	IIIa	Chinook
8	IIIa	Alum Cave
9	IIIa	Raccoon Station
10	IV	Hamm
11	IV	Saxton
12	IV	South Linton
13	P	Hicks
14	P	Hagedorn
15	IVa	Maumee No.28
16	IVa	Tolin
17	V	Powder Mill
18	V	Maumee No.30
19	V	King Station
20	V	Wabash
21	V	Chieftain No. 20
22	V	Standard No.2
23	V	Enoco
24	V	Rudolph
25	Va	Standard No.2
26	Vb	Standard No.2
27	Vb	Friar Tuck
28	Vb	Chieftain No. 20
29	VI	Regent
30	VI	Friar Tuck
31	VI	Shasta
32	M	Ditney Hill
33	M	Sunlight No.11
34	VII	Kincaid
35	VII	Superior
36	VII	Sunspot
37	VII	Sullivan No. 27
38	VII	Landrey No.1
39	VII	Robin Hood

Scale of Miles

0 5 10 20 30

Figure 4. *Map of Indiana coal area showing collecting localities.*

Localities from which coal samples were collected for spore analyses

Site No.[1]	Coal	Type of Exposure	Name of mine	Company	County	Location Quarter	Sec.	T.	R.
1	III	Strip pit	Chinook	Ayrshire Collieries Corp.	Clay	NW	28	12N	7W
2	III	Shaft mine	Green Valley	Snow Hill Coal Corp.	Vigo	SW SW	3	12N	10W
3	III	Strip pit	Alum Cave	Siepman Coal Co.	Clay	NW SE	22	9N	7W
4	III	Strip pit	Lone Star No. 4	Lone Star Coal Co.	Vigo	NE SW	17	13N	7W
5	III	Slope mine	Victory	Pyramid Coal Corp.	Vigo	SW NE	26	12N	8W
6	III	Outcrop	Raccoon Station		Parke	SW NE	29	15N	8W
7	IIIa	Strip pit	Chinook	Ayrshire Collieries Corp.	Clay	NE SW	21	12N	7W
8	IIIa	Strip pit	Alum Cave	Siepman Coal Co.	Clay	NW SE	22	9N	7W
9	IIIa	Outcrop	Raccoon Station		Parke	SW NE	29	15N	8W
10	IV	Strip pit	Hamm	Hamm Coal Co.	Greene	NE SE	35	7N	7W
11	IV	Shaft mine	Saxton	Walter Bledsoe & Co.	Vigo	NW SE	32	13N	9W
12	IV	Shaft mine	South Linton	South Linton Coal Co.	Greene	SW SW	26	7N	7W
13	P[2]	Strip pit	Hicks	Hicks Coal Co.	Daviess	NE	17	2N	5W
14	P[2]	Strip pit	Hagedorn	Hagedorn Coal Co.	Spencer	SW	21	5S	4W
15	IVa	Strip pit	Maumee No. 28	Maumee Collieries Co.	Greene	NE NE	34	7N	7W
16	IVa	Drift mine	Tolin	Tolin (owner)	Parke	SW NW	5	14N	8W
17	V	Strip pit (abandoned)	Powder Mill	Siepman Coal Co.	Sullivan	SW SE	24	9N	8W
18	V	Strip pit	Maumee No. 30	Maumee Collieries Co.	Greene	NE SW	20	7N	7W
19	V	Shaft mine	King Station	Princeton Mining Co.	Gibson		25	2S	10W
20	V	Shaft mine	Wabash	Snow Hill Coal Corp.	Vigo	SW SW	3	12N	10W
21	V	Strip pit	Chieftain No. 20	Maumee Collieries Co.	Vigo	SE SW	4	10N	8W
22	V	Strip pit	Standard No. 2	Standard Collieries	Vermillion	SW NW	27	14N	9W
23	V	Shaft mine	Enoco	Enoco Collieries, Inc.	Knox	Don. 74		4N	9W
24	V	Shaft mine	Rudolph	Rudolph Coal Co.	Warrick	NE NE	36	5S	9W
25	Va	Strip pit (abandoned)	Standard No. 2	Standard Collieries	Vermillion	SW NW	27	14N	9W
26	Vb	Strip pit (abandoned)	Standard No. 2	Standard Collieries	Vermillion	SW NW	27	14N	9W
27	Vb	Strip pit (abandoned)	Friar Tuck	Sherwood-Templeton Coal Co.	Sullivan	SE NW	25	8N	8W
28	Vb	Strip pit	Chieftain No. 20	Maumee Collieries Co.	Vigo	SE SW	4	10N	8W
29	VI	Slope mine	Regent	Linton-Summit Coal Co.	Sullivan	NE SW	5	7N	8W
30	VI	Strip pit	Friar Tuck	Sherwood-Templeton Coal Co.	Sullivan	SE NE	35	8N	8W
31	VI	Strip pit	Shasta	Shasta Coal Corp.	Knox		3	4N	8W
32	M[3]	Slope mine	Ditney Hill	Ingle Coal Corp.	Warrick		32	4S	9W
33	M[3]	Strip pit	Sunlight No. 11	Sunlight Coal Co.	Warrick	SE NE	29	4S	8W
34	VII	Strip pit	Kincaid	Kincaid Coal Co.	Gibson	NE NE	26	2S	9W
35	VII	Strip pit	Superior	Superior Coal Strippers, Inc.	Vigo	NW SW	8	12N	9W
36	VII	Strip pit	Sunspot	Ayrshire Collieries Corp.	Vermillion		23	14N	10W
37	VII	Strip pit	Sullivan No. 27	Maumee Collieries Co.	Sullivan	SW NW	14	7N	8W
38	VII	Strip pit	Landrey No. 1	Landrey Mining Co.	Pike	NW SE	11	1S	7W
39	VII	Strip pit	Robin Hood	Sherwood-Templeton Coal Co.	Greene	NW NE	15	8N	7W

[1]Site nos. refer to those in Fig. 4, p. 12.
[2]Pottsville
[3]Millersburg

tained for the entire vertical thickness of a coal at any particular locality, as well as for the whole vein. Thus, in Figure 8, the graph representing Coal VII is the composite of 17 benches derived from six localities. Simple bar graphs were adopted for graphic presentation.

IDENTIFICATION OF CARBONIFEROUS SPORES

CLASSIFICATION OF GENERA

The entire system of spore classification is of necessity an artificial one. Spores showing morphological similarities of gross characteristics are grouped under one generic heading. Minor features, warranting distinction among types grouped under a given genus, then are used for specific classification. Thus the term "genus" as used in fossil spore literature refers only to the classification of spores. Affinities to parent plants generally are unknown, although a form genus may well be synonymous with a true genus. Morphology is unquestionably a useful tool in spore classification. To illustrate analogously, one can point to Recent pollen grains. Although spruce, fir, and pine, which are related genera of the family Pinaceae, have winged pollen grains, their other morphological characteristics enable differentiation. Thus, on the basis of morphological differences, the pollen grains of the three winged genera can be separated without consideration of the multitude of other features which are distinctive for the entire plant. In the same way, *Wilsonia, Florinites, Endosporites,* and *Schulzospora,* Carboniferous form genera characterized by bladder-like appendages, may be spores of related plants and possibly could be spores of four genera of the same family. In the light of pollen grain morphology and taxonomy, assumptions that spore characteristics are indicative of differentiating features of the parent plants themselves seem justified. Until considerably more information of paleobotanic significance is obtained, this artificial system of classification must suffice.

With the accumulation of information on spore morphology, some semblance of taxonomic organization is evolving. Kosanke (1950, pp. 50-55) added five new genera, which make a total of 19 to date. His generic characteristics, as well as those previously set forth by Schopf, Wilson, and Bentall, delineate the genera adequately. Knox (1950, pp. 312-322) also created four additional genera, but she did so by reclassification of previously named and defined spores. As her paper appeared after this study was in progress, the classification changes which she advocated were not included. Identification of miospores was made according to the criteria set forth by Schopf, Wilson, and Bentall (1944, pp. 29-37, 39-40, 43-47, 49-60). Plates 2, 3, and 4 show miospores representative of the genera commonly found in the Alleghenian coals in Indiana.

KEY TO MIOSPORE GENERA

The need of a simple key becomes apparent when one attempts to study genera as systematic entities. This need makes itself especially felt when uninitiated persons are faced with the task of spore identification. Moreover, as spore analysis is extended to the classroom and field laboratory, a key to the genera and subsequently to the species is useful. With these needs in mind, the author has undertaken to supply a generic key (Pl. 1). No claim to originality regarding the differentiating features is made. The author is fully aware of the limited life expectancy of such a key, because the taxonomy of Carboniferous plant spores is, owing to the activity in the field, in such a fluid state. Nevertheless, he feels that, because of the immediate need of a usable tool, such a key is justified.

STRATIGRAPHY

The Upper Carboniferous or Pennsylvanian system of Indiana has been divided into three series, the Pottsville, the Allegheny, and the Conemaugh. Most of the commercially important coals of Indiana are found in the Alleghenian series, which, according to the most recent classification, comprises the Staunton, Linton, Petersburg, and Dugger formations (Fig. 5).

STAUNTON FORMATION

The Staunton formation, which averages approximately 85 feet in thickness, is composed of sandstones, shales, some coal lenses, and one relatively thick coal seam at the top. This coal, known as Coal III or Seelyville coal, is mined in the northern part of the Indiana coal area. According to Ashley (1909, p. 107), Coal III shows typical development in northeastern Vigo County at Coal Bluff and Seelyville. In most places, the coal seam is marked by one or more partings. The roof mostly is shale, although in some places sandstone overlies it and even cuts into the coal. Soft underclay lies beneath the coal. In the type locality, the coal averages 6 feet in thickness.

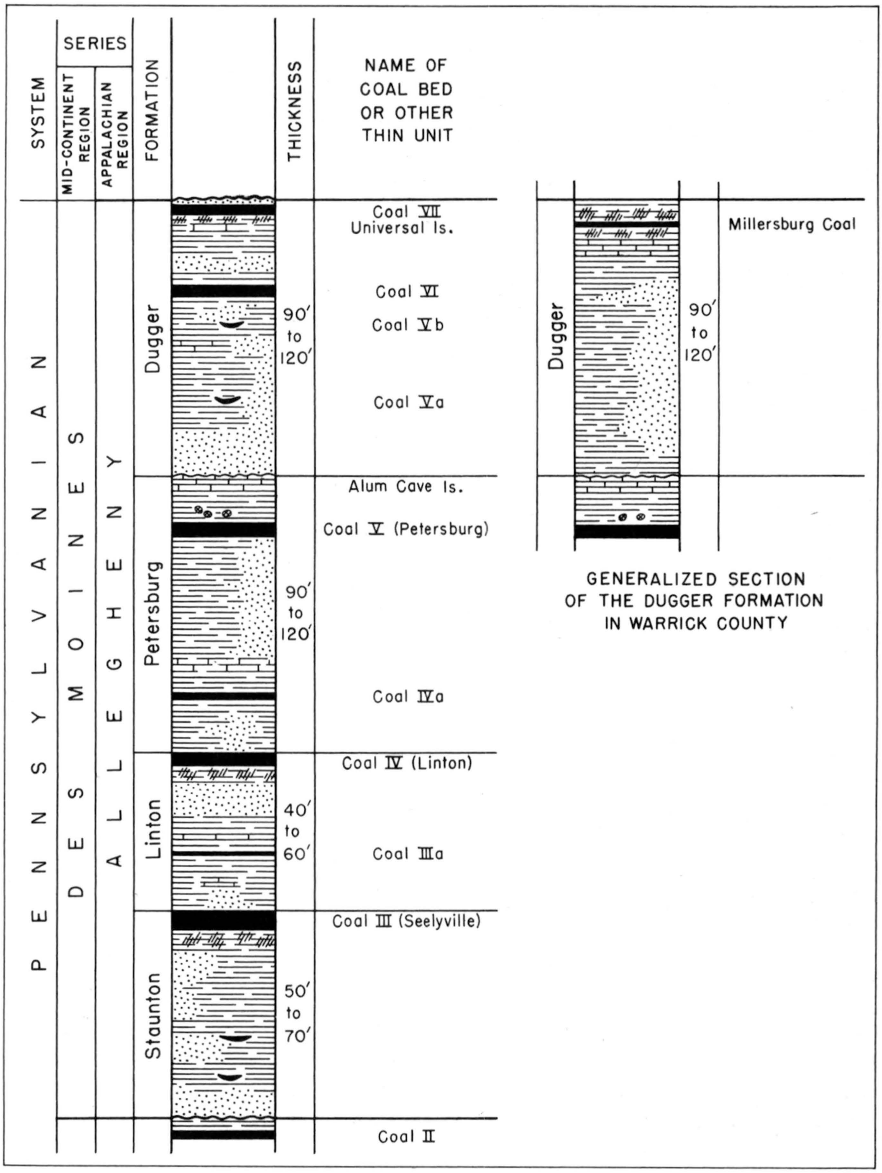


Figure 5. *Generalized stratigraphic column of Alleghenian series in Indiana.*

The localities from which samples of Coal III (and Coals IIIa, IV, IVa, V, Va, Vb, VI, and VII) were taken are shown in Figure 4 and in the table on page 13. The Parke County outcrop revealed a 13-inch seam of coal with half an inch shale parting running

KEY TO MIOSPORE GENERA

DESCRIPTION — GENERA

- Spore with one or more wings or perisporal membranes
  - Three or more wings present .... *Alati-sporites* Ibrahim
  - Less than three wings present
    - Two wings present .... *Illinites* Kosanke
    - One wing or perisporal membrane present
      - Trilete ray absent .... *Florinites* Schopf, Wilson, and Bentall
      - Trilete ray present
        - Shape, inclusive of membrane, spherical .... *Wilsonia* Kosanke
        - Shape, inclusive of membrane, not spherical, but elliptical, triangular or oval
          - Spore body extending nearly to margin; membrane finely punctate .... *Schulzospora* Kosanke
          - Spore body extending only to within one-third of margin; membrane finely reticulate .... *Endosporites* Wilson and Coe
- Spore without wings or perisporal membranes
  - Spore bean-shaped; ray monolete .... *Laevigato-sporites* Ibrahim
  - Spore not bean-shaped; ray trilete
    - Spore with digitate, blunt or round projections
      - Appendages short, round, on distal surface only .... *Schopfites* Kosanke
      - Appendages digitate, blunt, over entire surface of spore .... *Raistrickia* Schopf, Wilson, and Bentall
    - Spore without digitate, blunt or round projections
      - Spore coat definitely reticulate; muri of network distinct, raised .... *Reticulati-sporites*
      - Spore coat not distinctly reticulate
        - Spore with equatorial flange
          - Flange entire .... *Cirratriradites* Wilson and Coe
          - Flange not entire, consisting of separate setae or spines .... *Reinschospora* Schopf, Wilson, and Bentall
        - Spore without equatorial flange
          - Spore with thickened opaque ridge .... *Densosporites* Berry
          - Spore without thickened ridge
            - Spore distinctly triangular
              - Corners thickened, opaque .... *Triquitrites* Wilson and Coe
              - Corners not thick, not opaque .... *Granulati-sporites* Ibrahim
            - Spore round, oval, possibly subtriangular
              - Spore wall thin, membraneous, laevigate to faintly punctate .... *Calamospora* Schopf, Wilson, and Bentall
              - Spore wall relatively thick, not laevigate
                - Branches of trilete ray forked .... *Cadiospora* Kosanke
                - Branches of trilete ray not forked
                  - Thin equatorial ridge present; ray usually to periphery .... *Lycospora* Schopf, Wilson, and Bentall
                  - No equatorial ridge present; ray usually short; hardly ever to periphery .... *Punctati-sporites* Ibrahim

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through the middle. The seam mined southeast of Fontanet, Vigo County, measured 4½ feet in thickness, including a 1-inch shale band. At the Green Valley mine northwest of Terre Haute, Coal III was 6 feet 3 inches thick. At the Victory mine south of Seelyville, Vigo County, 5½ feet of coal was measured. Two distinct partings which ran through the latter coal were observed, whereas at Green Valley only one band was apparent. At the Chinook strip pit south of Staunton, Clay County, the thickness of the coal also was 5½ feet, but a band of shaly coal parted the seam 20 inches from the top. In the Siepman pit at Coalmont, Clay County, the same lithology was noticed. There the coal was divided into two benches by a "dirty band" 5 inches thick. Including this "dirty band," the coal measured 5 feet in thickness.

LINTON FORMATION

The Linton formation, as defined by Wier (1950), comprises the rocks between the stratigraphic break above Coal III and the unconformity above Coal IV. He described the composition of the formation as sandstone, shale, limestone, and Coals IIIa and IV, totalling 65 feet in thickness. The type locality is near Linton, Greene County.

Cumings (1922, p. 529) stated that Coal IIIa is about 20 feet above Coal III and observed that locally limestone underlies and overlies Coal IIIa. Ashley (1909, p. 108) traced Coal IIIa as an "18-inch rider" from central Clay County to the mouth of Jonathan Creek in Vermillion County. In the Jasonville area, Wier (1950) found that coal IIIa is uniformly thick, about 9½ inches, and is overlain by 2 to 5 feet of black fissile shale. Above this roof is a black, impure limestone. In Pike County, where this "rider" thickens to 20 inches, it is called the Velpen coal.

At the Chinook pit of the Ayrshire Collieries, south of Staunton, Clay County, a thin shale parting divided the seam into two benches. The top coal was 7 inches thick and the lower, 4 inches. North of Raccoon Station, Parke County, the seam measured 18½ inches in thickness; a "dirty band," half an inch thick, parted the coal into layers of 10 and 8 inches respectively. The "rider" in the Siepman pit northeast of Coalmont, Clay County, was 12 feet above Coal III.

Coal IV, or Linton coal, averages 5 feet in thickness. Locally, it has a medial parting and is underlain by sandy fireclay or shale.

The roof in most places is gray shale, although sandstone occurs locally. At the Saxton mine north of Terre Haute, Vigo County, a pronounced band was present. There the coal, including the parting, measured 5 feet 3 inches in thickness. The coal mined at the South Linton mine, Greene County, was 5 feet thick, but it showed no evidence of a distinct parting. In the Hamm strip pit southeast of Linton, Greene County, the coal measured 5½ feet in thickness and did not show "dirty bands."

PETERSBURG FORMATION

Wier (1950) reduced Cumings' (1922, p. 529) Petersburg formation to the rocks bound by the unconformity at the top of Coal IV and the unconformity above the Alum Cave limestone. This newly defined Petersburg formation averages 115 feet in thickness and is composed principally of sandstone, some shale and limestone, and two coal seams, Coal IVa and Coal V. According to Cumings (1922, p. 529), Coal IVa is separated from Coal IV by 25 feet of sediments. Wier (1950) stated that the rocks between the unconformity above Coal IV and the base of Coal IVa are 30 to 50 feet thick. Coal IVa is underlain by shale and overlain by black fissile shale which is surmounted by black, impure limestone. South of Linton, Greene County, Coal IVa measured 19 inches, and at the Tolin drift mine northwest of Coxville, Parke County, a thickness of 39 inches was recorded.

Cumings (1922, p. 529) called Coal V, also known as the Petersburg or Alum Cave coal, "the most important and persistent coal bed of Indiana." He placed the interval between Coal IV and Coal V at 120 feet. The roof of Coal V is marked by the presence of pyrite concretions within a black shale. Above this layer is found the Alum Cave limestone, usually 4 to 6 feet thick. Ashley (1909, p. 104) stated that Coal V had been reported to have a thickness up to 11 feet, and Wier (1950) gave its thickness as more than 7 feet near Coalmont in the Alum Cave region of northeastern Sullivan County. In the Maumee Collieries Chieftain pit south of Riley, Vigo County, Coal V varied from 4 to 6 feet in thickness. At the Wabash mine northwest of Terre Haute, Vigo County, the bed was 4½ feet thick. Southwest of Clinton, Vermillion County, in the Standard Collieries pit, 5 feet of coal was measured. In the abandoned Powder Mill pit northwest of Coalmont, Sullivan County, 33 inches of coal was sampled, and at the Maumee No. 30 pit southwest of Linton, Greene County, the coal was 6 feet 3 inches thick but contained a 3-inch "dirty band" 2 feet from the top. Coal V was 6 feet thick in Knox County at the Enoco deep mine southeast of Bruceville, whereas at the King Station mine south of Princeton, Gibson County, a thickness of 9 feet was exposed at the face. At the Rudolph mine northeast of Chandler, Warrick County, Coal V measured 4 feet 7 inches.

DUGGER FORMATION

Wier (1950) proposed the name Dugger formation for the rocks between the unconformity above the Alum Cave limestone and the unconformity above Coal VII. This formation thus includes four coal seams, Va, Vb, VI, and VII, and averages about 110 feet in thickness. Fifty-five feet of sandstone and shale, which locally contain either Coal Va or Coal Vb, or both, and a conglomeratic limestone, make up the interval between Coal V of the Petersburg formation and Coal VI of the Dugger formation. Cumings (1922, p. 529) stated that Coal VI is "normally about 75 feet above Coal V." Between Coal VI and Coal VII, 40 to 50 feet of sandstone and shale are found. These grade into limestone in some places. In the Standard Collieries pit southwest of Clinton, Vermillion County, Coal Va was 16 inches thick. Coal Vb, exposed in the high wall of the same pit, measured 20 inches in thickness. The top 8½ inches, however, was shaly. The interval between Coal Va and Coal Vb was approximately 20 feet, and only 2 feet of shale separated Coal Va from Coal V. In the Friar Tuck pit northwest of Dugger, Sullivan County, Coal Vb was only seven-eighths of an inch thick and was separated from Coal V by 25 feet of sediments. At the Maumee Chieftain strip pit, Vigo County, however, Coal Vb occurred 37 feet above Coal V and measured 35 inches in thickness. There two shale partings cut the bed into three benches.

Cumings (1922, p. 529) stated that "Coal VI is uniformly from 6 to 8 feet thick and has very persistent thin partings near the center of the vein." He described the roof as "a crumbling shale, with overlying sandstone." At the Regent mine west of Dugger, Sullivan County, the seam was 5½ feet thick and contained three shale partings. The main parting was 25 inches from the top. At the Friar Tuck strip mine north of Dugger, Coal VI measured 5 feet 8 inches in thickness and had one distinctive "dirty band" running through it 32 inches from the top. In Knox County at the Shasta strip pit, Coal VI was 6 feet in thickness. A shale band, 1½ inches thick, cut the coal 6 inches from the bottom.

In Warrick County, a relatively thick coal seam, called the Millersburg coal, is of considerable interest. Fuller and Ashley (1902, p. 7) placed this bed from 70 to 90 feet above the Petersburg coal and listed its thickness as 3 feet or more. In their columnar section, Fulley and Ashley correlated the Millersburg coal with Coal VII. In mining circles, however, the Millersburg coal is considered to be the equivalent of Coal VI. Samples of the Millersburg coal from the Ditney Hill and Sunlight workings showed thicknesses of 92 and 53 inches respectively. A pronounced shale parting, 28 inches from the bottom, ran through the coal from the Ditney Hill mine. In the Sunlight pit, a limestone, 18 inches thick, separated the coal into two distinct layers.

Coal VII, as described by Cumings (1922, p. 529), "is from 2 to 6 feet thick, and is overlain disconformably by a sandstone or 'rolly roof'." Coal VII usually is underlain by fireclay and/or limestone which varies from 2 to 10 feet in thickness. At the Ayrshire Sunspot mine in Vermillion County, Coal VII measured 4 feet in thickness. At the Superior pit north of West Terre Haute, Vigo County, 5½ feet of coal was sampled. At the Robin Hood pit northwest of Dugger, Greene County, the coal was 3½ feet thick, and at the Maumee No. 27 pit south of Dugger in Sullivan County, 4 feet, 4 inches.

On the basis of spore composition, two samples of uncertain identity, obtained from the Landrey pit in Pike County and the Kincaid pit in Gibson County, are thought to be correlative with Coal VII. The coal measured 30 inches in thickness in Pike County, and in Gibson County it was 4 feet thick.

THEORY OF CORRELATION

The fact that coal is carbonized vegetation is now universally accepted. Weaver and Clements (1938, p. 1) defined vegetation as "the sum total of plants covering an area." Vegetations, in the broad ecological sense, are considered to be entities having definite structure and showing development.

The main factor which determines the structure or composition of vegetation is climate. Thus, depending on climate, the vegetation of a certain area may consist of forest, grass, tundra, or chaparral. These major structural divisions of vegetation are called plant formations. If climatic conditions are not uniform throughout the areal extent of a formation, the formation may be subdivided into so-called plant associations.

The first stage in development is migration, which accounts for the invasion of a bare area and which includes all processes by which a plant can "move," mainly vegetative propagation and dissemination of seeds and spores. Although wind-borne germules may travel great distances and although even water-disseminated propagules may come to rest at considerable distances from the parent plants, the process obviously is a slow one. The propagules must germinate, and the resultant plants must grow to maturity and reproduce to vegetate an area.

Weaver and Clements (1938, p. 4) termed the state of development just after migration "aggregation," because the individuals are formed into groups. Aggregation soon results in competition, as the plants compete for light, moisture, and mineral nutrients. As vegetation develops, different plant communities successively occupy an area. In a successional series beginning with open water, such as lakes or ponds, submerged aquatic plants are succeeded by floating species, which in turn are crowded out by swamp plants, as the depression or basin tends to become solidified. The swamp species are replaced by meadow types and these in turn by shrubs. As the area becomes drier and more solidified, a forest formation is the result. Each final formation or climax, determined primarily by the climate of the region, is differentiable into types. For example, a forest climax can be boreal, alpine, subalpine, or deciduous. A forest type in turn can be differentiated on the basis of dominants or controlling genera and/or species. Thus, in Indiana today, the deciduous forest may be dominated by a beech-maple association or an oak-hickory association.

In pollen analysis of peat bogs, the seres, or stages of succession due to climatic changes, can be distinguished clearly. The present-day climax and the developmental stages within the climax are reflected in pollen profiles. Although the climate may be uniform for a given area, different dominating associations may exist under the control of microclimatic variations. These variations, due mainly to topographic differences and soil conditions, are not destructive to the climax; but, as Weaver and Clements (1938, p. 80) so aptly expressed it, are "within the fabric of the climax***." Thus in the great broadleaved forest of eastern North America one can recognize beech-maple, oak-hickory, oak-chestnut, or a mixed broadleaved forest.

In any given area, climax may never be attained because development is arrested during one of the seres leading to the climax.

Similarly, the association best suited for an area may not gain expression due to interruptions, although the climax formation itself has become established. On the other hand, if the climate was uniform and if no other drastic changes occurred for a long period of time, the climax, as well as the dominant association, would continue uninterruptedly during that period.

Paleobotanists agree that climate during Pennsylvanian time was uniform over large areas of the earth's surface. Evidence of this fact is the presence of identical fossil genera and species in coal-bearing rocks in both hemispheres, as well as in the polar and tropical regions. The causes which are given for this uniformity in climate are varied. The presence of large amounts of carbon dioxide in the air, the relation of the sun to the earth, and changes in the land-sea relationship are all theories which, at least in part, explain this condition. White and Thiessen (1913, p. 68) characterized the climate during coal formation as tropical or subtropical, uniform, and humid, with heavy rainfall throughout the year. They concluded that "the essentially uniform climatic conditions were truly extraordinary in geographic extent, with little regard to modern climatic zones***." Noé (1931, p. 289) agreed with the above conclusions but disagreed with the characterization of climate during Pennsylvanian time as tropical. He averred that "it must have been warm but not necessarily tropical."

If the climate was uniform during the period of coal formation, the chief interruptions of normal plant succession were caused by inundation. That flooding was a major factor in the determination of thicknesses and extent of the coal seams is evidenced by the accumulation of thick sediments in the intervals between the various coal seams and the numerous shale partings which cut the seams.

Wilson (1946, p. 111) listed three factors which are involved in correlation of strata by means of fossil spores: "(1) the evolution of floras, (2) the geographic distribution and migration of floras, and (3) the edaphic ecological relations of plants." Raistrick and Marshall (1939, p. 129) stated two assumptions underlying coal correlation theory: "(a) the spores, and especially the microspores, were distributed from the parent trees by wind, and, like the pollen of modern trees and plants, were capable of being carried for great distances. The result was that at any one particular time in the coal swamp the myriads of microspores produced would be mixed and wafted about in the wind so that a fairly uniform scatter was obtained, and the mixing would be such that at most localities a statistical average of all the types of spores being produced in the coal forest at that time would be found. (b) It is also assumed—and the assumption is again supported by observation—that there would be sufficient difference in the make-up of the flora of successive coal-seam swamps to give the spore average a recognisably different proportional make-up."

Any given layer of coal in the basin of coal deposition should show uniform spore composition, if the climate was uniform throughout the basin and if a thorough mixing of the miospores occurred. Because of the long time involved in depositing Pennsylvanian strata, evolution must have affected the flora. Even without evolutionary modifications, the floral make-up of any one coal bed should differ from that of any other, owing to the fact that inundation occurred at different times of floral succession. If the inundation, for instance, occurred long after the climax had been reached, layer after layer of this climax vegetation would be represented. The major portion of the spores found in a coal seam which is composed mostly of the climax vegetation would be derived from the plants that formed that climax vegetation. Considering the factors of (1) thorough mixing of the spores by wind, (2) uniformity of the climate throughout the area of coal deposition, (3) interruption of plant succession by inundation, (4) floodings which occurred at different stages of vegetation development, and (5) long time intervals between periods of coal deposition, one can reasonably assume that each coal seam should differ in floral composition from any other seam and that any given bed of coal should show similar floral patterns throughout the area of coal deposition.

This study demonstrates the soundness of the above assumptions. A certain spore composition characterizes each coal bed in the Alleghenian series of Indiana (Fig. 9). Within each bed the spore pattern is persistent, regardless of geographical diversity. Relative abundances of genera are a useful tool in the correlation of coal seams, for these relative abundances enable one to identify and to date many coals of uncertain identity.

Analyses of samples of Coal V, for example, prove that the coal forest during the time of the deposition of that coal was uniform over a relatively large area. Figure 6 illustrates this uniformity of floral composition. Undoubtedly the similarity of pat-

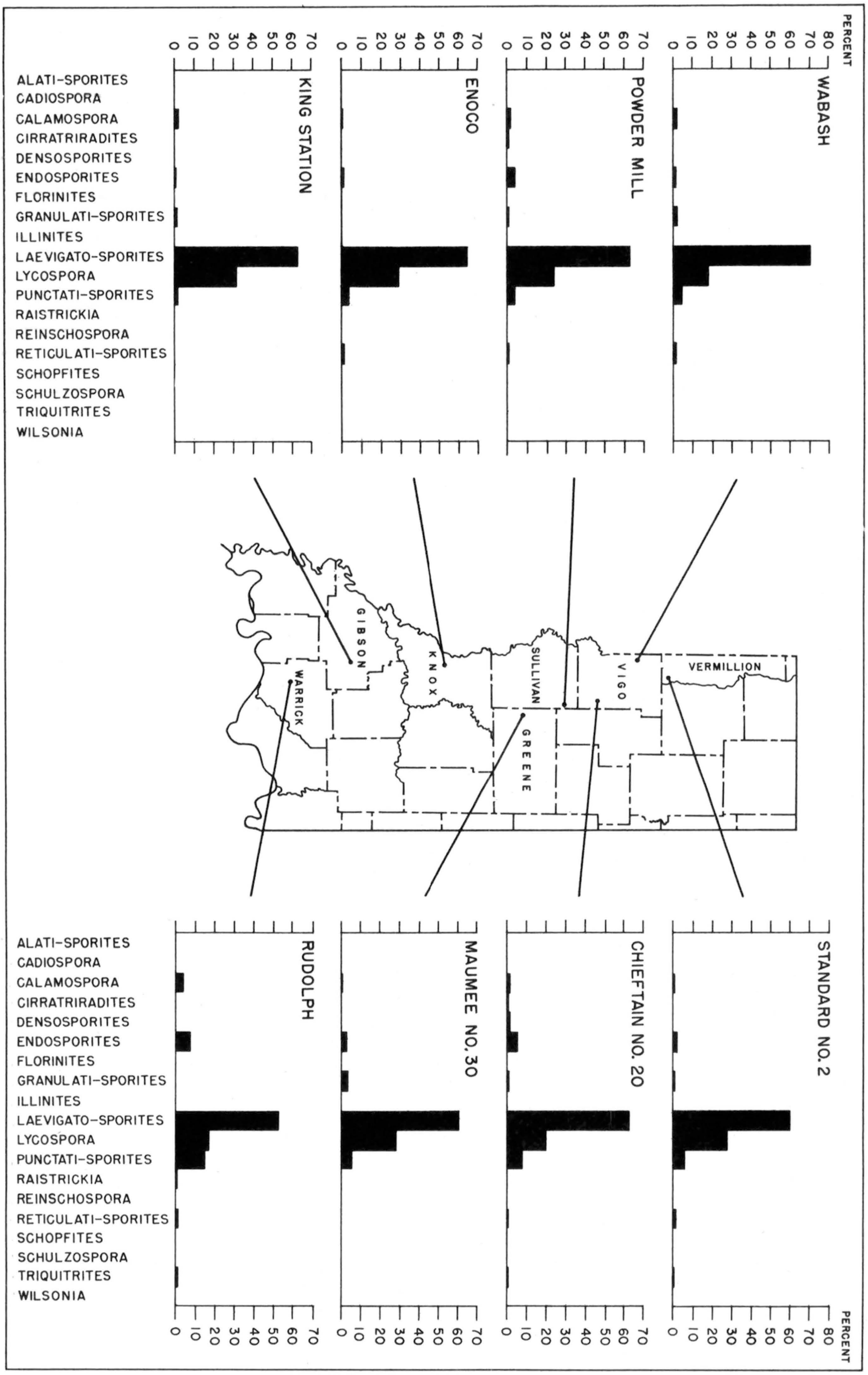

Figure 6. Graphs showing relative abundances of miospore genera in eight samples of Coal V.

tern cannot be attributed to coincidence. Figures 7 and 8 adequately illustrate that the floral composition differs from coal bed to coal bed. Kosanke (1947, p. 282), in his work with Illinois coal beds, also confirmed this fact by stating that "through a knowledge of the genera and their abundance, one can place an unknown coal bed in one of the four groups of the Pennsylvanian system, and in many cases even identify it specifically."

A few similarities in spore patterns do occur among coals of the Alleghenian series in Indiana. Generic percentage graphs of Coals III and VII possibly could be mistaken for each other (Fig. 9). Nevertheless, these coals are differentiable. *Endosporites* and *Florinites,* winged genera, provide the criterion of differentiation. In Coal III the two genera total 10.16 percent, but in Coal VII the combined average is a mere .66 percent.

Through future studies, the author hopes to derive abundance figures of species for each coal bed in Indiana. In coal beds in which the lithologic and stratigraphic evidence is insecure and in which the generic patterns fail to fit the standards, relative abundances of species may aid in dating the unknown coal. If the percentage relationship method of dating suffices, however, no need is seen to apply the much more detailed and time-consuming method of deriving abundance figures of species.

RESULTS OF SPORE ANALYSES

COAL III

Samples of Coal III were obtained at six localities (Fig. 4 and the table on page 13) from a total of 18 benches. No appreciable change was evident from a comparison of the bottom and top parts of the coal. *Lycospora*, the dominant genus, averaged 56.39 percent of the spores (Fig. 7). *Laevigato-sporites* and *Calamospora* were accessory genera which represented 11.49 percent and 10.20 percent respectively of the spores. Because of considerable difficulty in differentiating *Florinites* from *Endosporites* in the early stages of Coal III analysis, especially when the specimens were crumbled, folded, fragmentary, or abraded, the two genera were combined and together averaged 10.16 percent. *Punctati-sporites* accounted for 4.39 percent, and of the other seven genera which occurred in Coal III only *Reticulati-sporites* and *Triquitrites* topped the 1 percent mark.

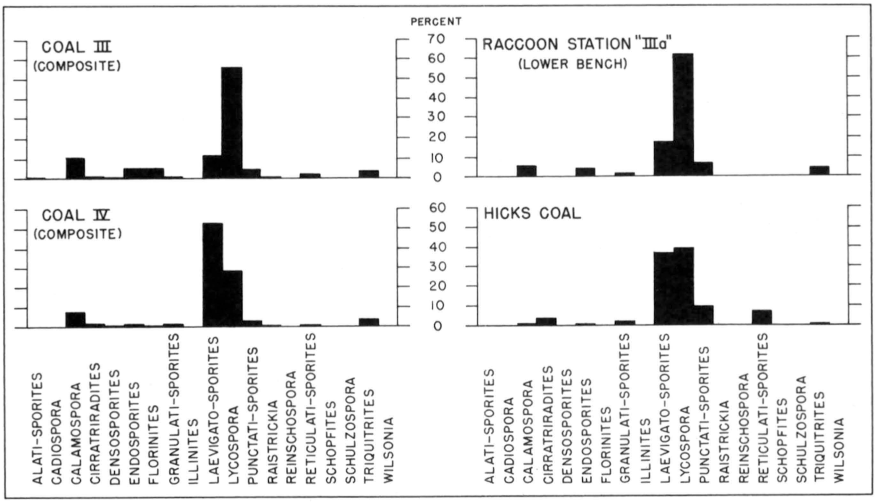

Figure 7. ***Graphs showing percentage relationships of miospore genera in Coals III, IIIa, IV, and Hicks coal.***

COAL IIIa

Three samples of this "rider vein" were obtained and analyzed (Fig. 4 and the table on page 13). The coal at the Siepman pit and the two benches obtained from Ayrshire's Chinook pit showed striking similarities in spore content. The top of this coal was not differentiable from the bottom on the basis of generic relationships. Coal IIIa at Raccoon Station, on the other hand, showed diversity. The 8-inch bench of coal below the "dirty band" closely resembled Coal III in spore content (Fig. 7). *Lycospora* accounted for 61.33 percent of all the spores counted; *Laevigato-sporites,* 17.33 percent; *Punctati-sporites,* 6.66 percent; *Calamospora,* 5.33 percent; and *Endosporites* and *Triquitrites* each had 4 percent. The upper 10 inches of coal, however, showed *Laevigato-sporites* and *Lycospora,* with 41.33 percent and 36 percent respectively, as dominants. *Endosporites* and *Punctati-sporites* each had representations of 4 percent. Averages derived for the "rider" at the Chinook and Siepman pits showed *Laevigato-sporites* and *Lycospora,* with 30.7 percent and 21.5 percent respectively, as dominants. *Calamospora, Punctati-sporites, Endosporites,* and *Granulati-sporites* were accessory genera.

The similarity in spore composition between the upper bench of Coal IIIa at Raccoon Station and the "rider vein" at the Chinook and Siepman pits seems to indicate that these layers of coal are the same age. Because it shows abundance patterns similar to those in Coal III 10 feet below it, the lower part of Coal IIIa at Raccoon Station is believed to be correlative with Coal III. This fact means, therefore, that the 10-foot shale interval at Raccoon Station is equivalent to the thin parting normally found in Coal III. Coal III at Raccoon Station has no parting. Thus the half an inch shale band in Coal IIIa is the much thinned-out interval between Coals III and IIIa. Coal IIIa, inclusive of the upper bench of Raccoon Station IIIa, revealed the following generic percentages: *Laevigato-sporites*, 32.4 percent; *Lycospora*, 23.78 percent; *Calamospora*, 11.68 percent; *Punctati-sporites*, 8 percent; *Endosporites*, 6.5 percent; and *Granulati-sporites*, 6.5 percent.

COAL IV

Samples of coal that was being mined and sold as Coal IV were collected from five localities (Fig. 4 and the table on page 13). Bench samples from the Saxton, South Linton, and Hamm mines showed striking similarities in spore relationships. On the basis of stratigraphic and lithologic evidence, the coal from these three mines belongs to the same bed, Coal IV. Spore analysis verified this fact. The coal from the Hicks pit, also gathered as representative of Coal IV, disclosed a pattern of spore genera quite different from that of Coal IV (Fig. 7). The genus *Laevigato-sporites*, which averaged 52.6 percent in Coal IV, showed only 36.5 percent in the sample from the Hicks pit. *Lycospora*, with 39 percent, on the other hand, was high in the Hicks pit, and in the composite figures for Coal IV this genus ranked second with 27.9 percent. *Calamospora*, an accessory genus in Coal IV with 7.75 percent, showed less than 1 percent in the Hicks coal. *Triquitrites*, with a 3.36 percent representation in Coal IV, was recorded as only 0.5 percent in the Hicks sample. *Punctati-sporites*, 3 percent in Coal IV, was relatively high in the Hicks coal with 9.5 percent. Of further note in the latter coal were the 7 percent representation of *Reticulati-sporites* and the 3.5 percent recorded for *Cirratriradites*. The graph representing the Hicks coal (Fig. 7) has no duplicate among the graphs derived from spore analysis of Allegheny coal. The Hicks coal, therefore, may be equivalent to a seam of the Pottsville series.

The fifth sample, from the Hagedorn strip pit in Spencer County, differed from both coal IV and the Hicks coal. The dominant genus in the Hagedorn sample was *Lycospora* with 42.25 percent. *Laevigato-sporites* ranked second with 23.5 percent. *Densosporites*, either absent or rare in the coals which were examined and which were known to be in the Alleghenian series, showed prominence with 11 per cent. As *Densosporites* was sparsely represented in the coals of the Alleghenian series and had been shown by Kosanke (1950, pl. 17) to be present only in the Tradewater and Caseyville groups of Illinois, one can safely conclude that the Hagedorn coal is of Pottsvillian age.

COAL IVa

Two samples of this "rider vein" were analyzed (Fig. 4 and the table on page 13). The Maumee No. 28 sample was divided into two layers, the top bench measuring 7 inches and the bottom bench 12 inches. From the Tolin mine three bench samples were obtained. Because the upper part was mostly "bone", it was combined with the 12-inch bench below it. The top of Coal IVa at the two localities sampled differed from the bottom in spore content. *Laevigato-sporites* was represented by 42.8 percent in the upper part, but in the lower part it averaged only 22.5 percent. *Lycospora*, on the other hand, averaged 29.6 percent in the top layer but showed a 44 percent average in the bottom benches. *Punctati-sporites* accounted for 11.6 percent and 12.5 percent in the upper and lower parts respectively. *Calamospora*, the fourth important genus in this coal, showed a 7.6 percent representation in the top layer and 10.5 percent in the bottom bench. None of the other seven genera present averaged more than 5 percent.

COAL V

Twenty-one benches (eight locality samples) of this coal were examined (Fig. 6). The prevalent pattern of high *Laevigato-sporites*, followed by *Lycospora* and *Punctati-sporites*, was repeated in bench after bench of Coal V. The average percentages of the genera which occurred in Coal V were: *Laevigato-sporites*, 62.23; *Lycospora*, 25.28; *Punctati- sporites*, 5.52; *Endosporites*, 3; *Calamospora*, 1.71; and *Granulati-sporites*, 1.04.

COAL Va

Unfortunately, only one sample of Coal Va could be obtained. The sample, from a 16-inch seam, was found in the Standard Collieries strip pit in Vermillion County. *Lycospora*, with a 60 percent representation, dominated the spore count in this sample.

Laevigato-sporites with 15.5 percent, *Calamospora* with 8.5 percent, and *Punctati-sporites* with 5 percent representation completed the spore complex. Of the other three genera found, only *Granulati-sporites* attained a 1 percent representation.

COAL Vb

Three samples of this vein were analyzed. *Lycospora,* with an average of 49.66 percent, dominated the spore assemblage. *Laevigato-sporites* averaged 17.33 percent; *Punctati-sporites,* 15.58 percent; and *Calamospora,* 12.41 percent. *Granulati-sporites,* with a 4.25 percent representation, was the only other genus of note.

COAL VI

Six samples of coal thought to be Coal VI were collected and analyzed (Fig. 4 and the table on page 13). The coal from the Regent and Friar Tuck mines in Sullivan County and the Shasta pit in Knox County showed similar spore patterns and thus is believed to be the same bed, Coal VI. Coal samples from the Sunlight and Ditney Hill workings in Warrick County were alike in spore composition, a fact which indicates that the coal which is mined at these localities is the same vein, namely, the Millersburg coal of Fuller and Ashley (1902, p. 7). The Ditney Hill-Sunlight coal, however, differed considerably from Coal VI in spore pattern. The exact age of the Millersburg seam has not been determined. The fact remains, however, that the generic relationships of the spores are so different from those obtained for Coal VI around Dugger and Bicknell that one can reasonably assume that the coal is of a different age. Not only is the composite generic relationship different for the two seams, but also the spore make-up of the individual benches, that is, top and bottom, differs greatly between the two coals.

The top part of Coal VI from the Shasta, Regent, and Friar Tuck mines averaged 52.8 percent for *Laevigato-sporites,* 32 percent for *Lycospora,* 6.33 percent for *Calamospora,* and 5.5 percent for *Punctati-sporites.* Of the six additional genera which occurred in the upper layer, only *Triquitrites* exceeded 1 percent. In the bottom bench the picture was reversed as far as the dominants were concerned. *Lycospora* was high with 49 percent; *Laevigato-sporites* had only a 37.66 percent representation; *Calamospora* was only slightly more abundant in the lower bench than in the upper, with an average of 8.33 percent in the latter; and the representation of *Punctati-sporites* was reduced to 2.82 percent. None of the other genera had even a 1 percent representation in the lower part.

The coal from the Sunlight and Ditney Hill mines was divided into upper and lower benches by the main parting. In the Ditney Hill coal the main parting was 28 inches from the bottom of the coal, and in the Sunlight coal a parting, 1½ feet thick, occurred 14 inches from the base of the coal. Because of the pronounced and thick parting, greater diversity in spore relationships seemed more likely in the Ditney Hill-Sunlight coal than in Coal VI. The coal from the two Warrick County locations, however, showed only slight changes in spore composition between the upper and lower parts. *Lycospora* was high in both the upper and lower parts of this coal. In the top bench *Lycospora* averaged 51.2 percent, and in the bottom bench this genus averaged 49.5 percent. *Laevigato-sporites* averaged 29.9 percent and 31.25 percent respectively in the upper and lower parts. *Calamospora* had 9.43 percent and 11.5 percent representations in the top and bottom benches respectively. *Punctati-sporites*, which had a 4.07 percentage in the top bench, was recorded as 5.5 percent in the bottom bench (Fig. 8).

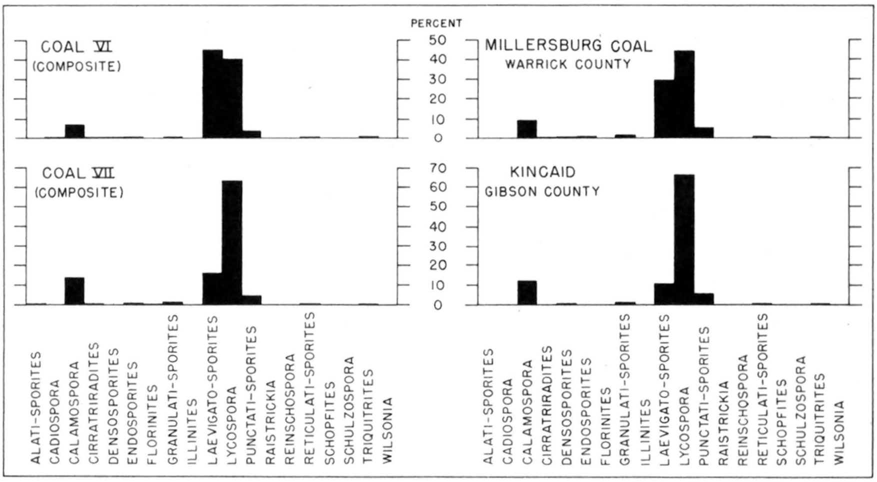

Figure 8. ***Graphs showing relative abundances of miospore genera in Coals VI and VII and Millersburg and Kincaid coals.***

The percentages of genera in the Millersburg coal differed not only from Coal VI but also from Coal VII in Greene and Sullivan Counties. The sample from the Kincaid pit, thought to be either Coal VI or Coal VII, showed a spore assemblage different from that of Coal VI as well as that of the Millersburg coal. A comparison of the spore complex of that sample to that of Coal VII revealed a striking similarity (Fig. 8). Because of this fact, the Kincaid coal is included in the averages obtained for Coal VII.

COAL VII

Fourteen benches from five localities were used in the analysis of Coal VII (Fig. 4 and the table on page 13). Three miospore genera occurred abundantly in this coal (Fig. 8). *Lycospora,* which averaged 63 percent, was the dominant genus. *Laevigato-sporites* and *Calamospora,* the accessory genera, had representations of 16.5 percent and 13.8 percent respectively. In addition, only *Punctati-sporites,* with 4.6 percent, and *Granulati-sporites,* with 1.22 percent, topped the 1 percent mark.

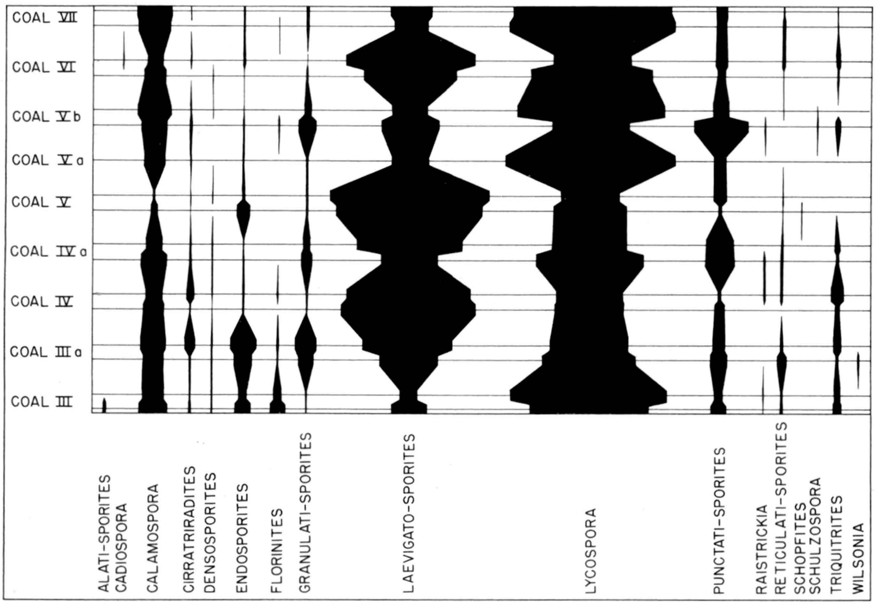

Figure 9. *Distribution and relative abundance of miospore genera in coal beds of Alleghenian series in Indiana.*

SUMMARY

In order to clarify the controversial terminology prevailing in fossil spore literature, the author has proposed the term "miospore." This term includes all fossil spores and similar bodies less than 200 micra in size, regardless of functional or genetic implication. A key to the 19 miospore genera has been presented in this report to aid newcomers to the field of spore analysis in solving problems of identification and morphology.

Coal samples of the nine known seams of the Alleghenian series in Indiana were analyzed. Relative abundances of genera were determined and established to serve as standards for each of the coal beds. Some coals were shown to differ more in spore compostion than previous correlations would indicate. For most of the coals, correlations based on lithologic and stratigraphic evidence were verified.

The vertical distribution of miospore genera as observed in this study provides a most useful means of identifying and subsequently correlating coal beds.

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PLATE 2

Figs. 1 and 2.—*Calamospora* Schopf, Wilson, and Bentall, 1944. 500X.

Figs. 3, 4, and 5.—*Triquitrites* Wilson and Coe, 1940. 500X.

Figs. 6 and 7.—*Densosporites* (Berry, 1937) emend., Schopf, Wilson, and Bentall, 1944. 500X.

Fig. 8.—*Cadiospora* Kosanke, 1950. 500X.

Figs. 9, 10, and 11.—*Punctati-sporites* (Ibrahim, 1933) emend., Schopf, Wilson, and Bentall, 1944. 500X.

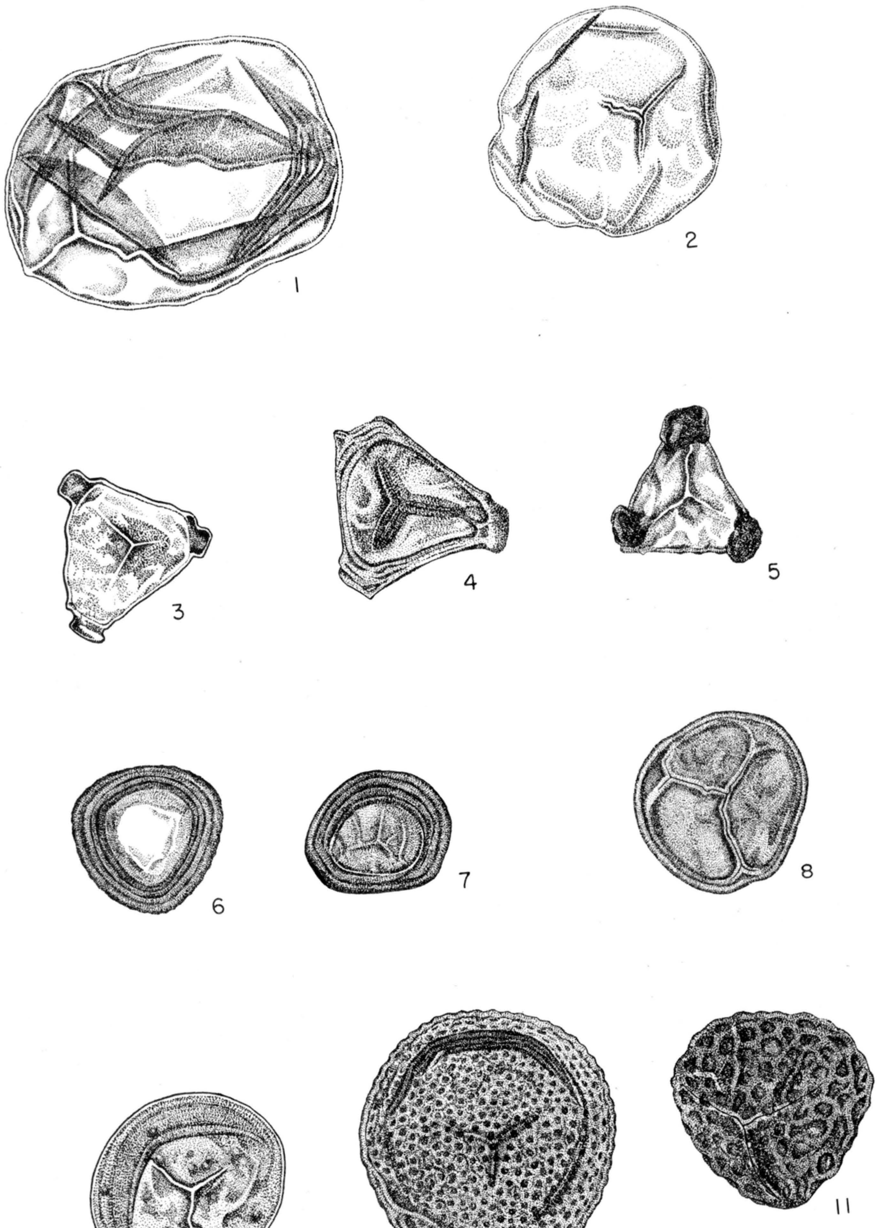
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PLATE 3

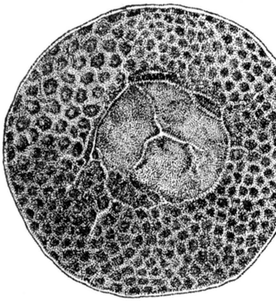
Fig. 1.—*Wilsonia* Kosanke, 1950. 500X.

Fig. 2.—*Endosporites* Wilson and Coe, 1940. 500X.

Figs. 3, 4, and 5.—*Cirratriradites* Wilson and Coe, 1940. 500X.

Figs. 6 and 7.—*Raistrickia* Schopf, Wilson, and Bentall, 1944. 500X.

Fig. 8.—*Florinites* Schopf, Wilson, and Bentall, 1944. 500X.



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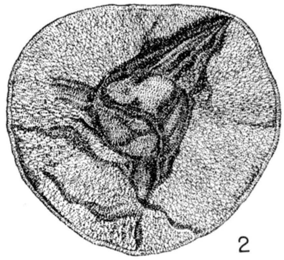

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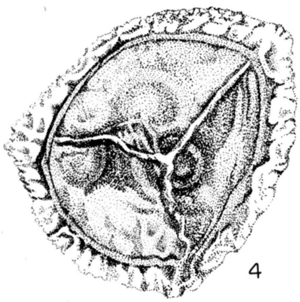

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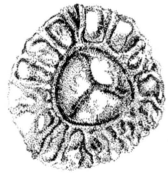

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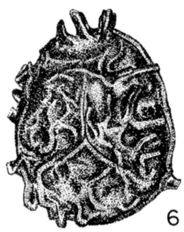

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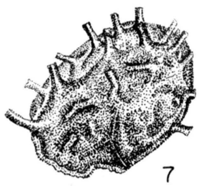

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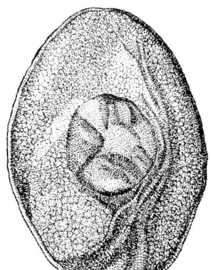

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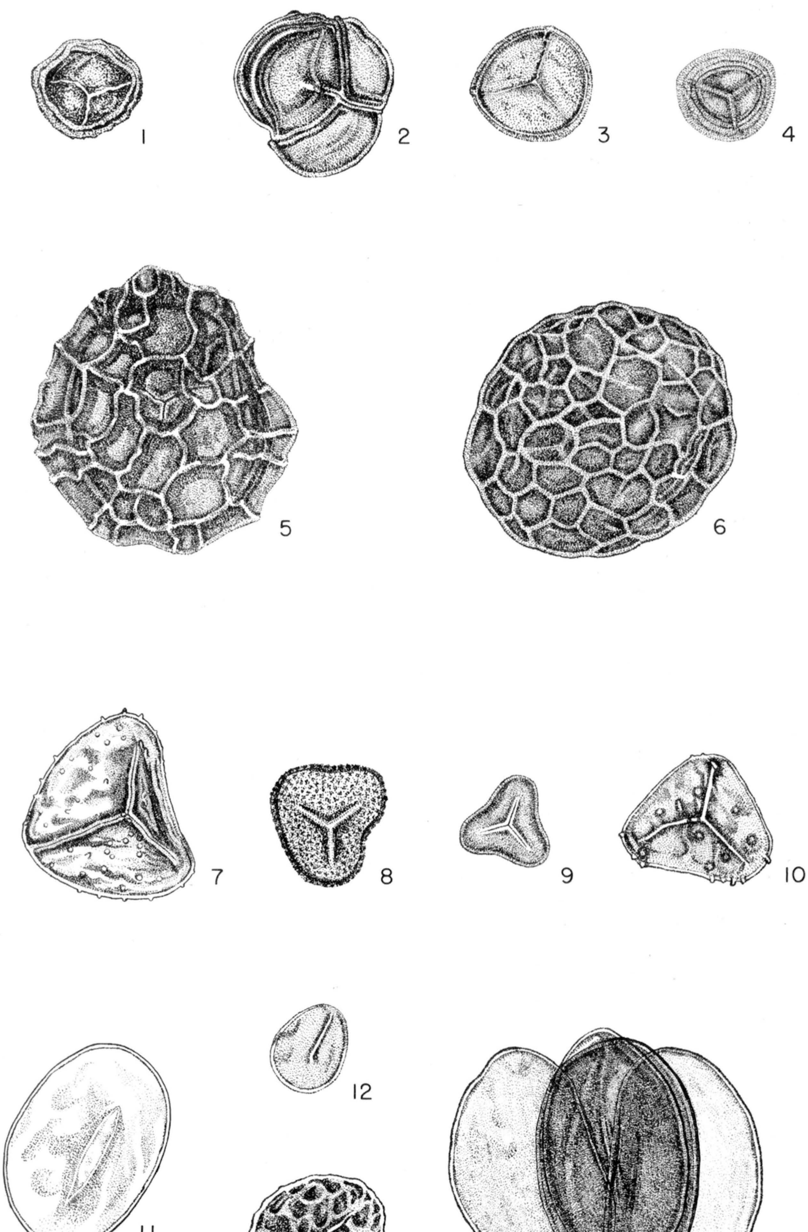
PLATE 4

Figs. 1, 2, 3, and 4.—*Lycospora* Schopf, Wilson, and Bentall, 1944. Fig. 2 is a tetrad. 500X.

Figs. 5 and 6.—*Reticulati-sporites* (Ibrahim, 1933) emend., Schopf, Wilson, and Bentall, 1944. 500X.

Figs. 7, 8, 9, and 10.—*Granulati-sporites* (Ibrahim, 1933) emend., Schopf, Wilson, and Bentall, 1944. 500X.

Figs. 11, 12, 13, and 14.—*Laevigato-sporites* (Ibrahim, 1933) emend., Schopf, Wilson, and Bentall, 1944. Fig. 14 is a tetrad. 500X.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