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Development of Paleobotany in the Illinois Basin

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ABSTRACT

Plant compressions and impressions, petrified plant remains (particularly those in coal balls), and fossil spores from the Illinois Basin have proved valuable subjects of paleobotany studies for more than 100 years. In the late 1850s, Leo Lesquereux first began describing compression floras during stratigraphic studies made in cooperation with the Geological Surveys of Illinois, Indiana, and Kentucky. A second surge of interest in plant compressions began with the establishment of the present Illinois State Geological Survey in 1905 when David White and others continued Lesquereux's work.

Coal balls found in the Illinois Basin by G. H. Cady in 1922 and described by A. C. Noé in 1923 led to the first biologically oriented studies of fossil plants in Illinois. Coal-ball petrifactions are still the major source of research material for paleobotanists in the Illinois Basin.

Fossil spores of the Illinois Basin were investigated for the first time in the early 1930s by L. C. McCabe, O. J. Henbest, and J. M. Schopf of the Illinois Geological Survey. Palynology, as this branch of paleobotany was later called, proved to be a valuable tool in stratigraphy.

Present paleobotanical work in the Illinois Basin is largely concerned with fossils of Pennsylvanian age and includes studies in biostratigraphy, plant evolution and ontogeny, and ecological implications of the floras.

INTRODUCTION

Paleobotany is the study of plant life of the past. The orientation of paleobotanical studies varies considerably, depending on the age of the fossiliferous rocks, the mode of preservation, and, of course, the paleobotanist and his objectives.

The emphasis today placed on interdisciplinary approaches to science is by no means new to paleobotanists, who have for some time been aware of the need for a combined geological and biological approach to paleobotany. The story of paleobotany involves both geologists and botanists and includes their discoveries and interpretations.

The history of paleobotany in the Illinois Basin is largely centered around plants of Pennsylvanian age, although some studies of Devonian, Mississippian, Cretaceous, and Pleistocene plants have been made. The Pennsylvanian sedimentary rocks of the Illinois Basin, or Eastern Interior Basin, include vast coal resources, which make it natural that many important developments in paleobotany should originate there. The basin, a spoon-shaped structural depression, underlies most of Illinois and extends into adjacent portions of Indiana and Kentucky.

In about two-thirds of Illinois, Pennsylvanian rocks occur at the surface or immediately beneath Pleistocene glacial deposits. At least 75 coal seams of Pennsylvanian age are present in the Illinois Basin, and most of the fossil plants come from the coals, roof shales, and sideritic nodules in the shales. Many of the coals have been given numbers and/or names, but many of the designations differ from state to state (fig. 1).

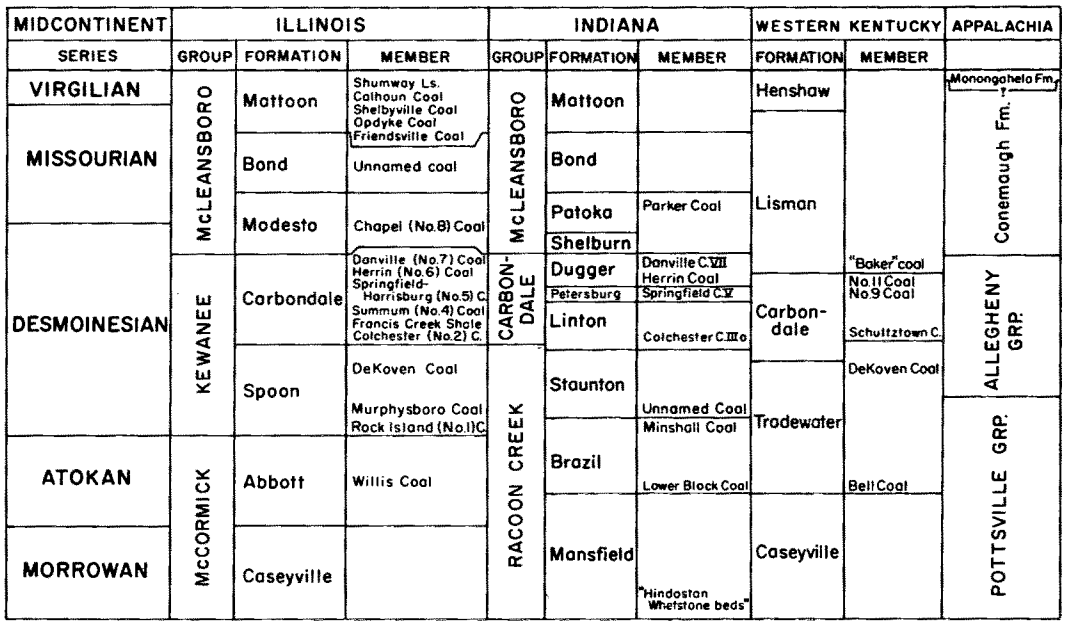


Fig. 1 - Correlation of Pennsylvanian strata in the Illinois Basin and adjacent regions. Names of significant members mentioned in text are shown (after Kosanke et al., 1960; Shaver et al., 1970; Smith and Smith, 1967; and Mullins et al., 1965).

Since the exploration for coal in the Illinois Basin revealed the widespread abundance, diversity, and complexity of fossil plants in the Pennsylvanian strata, much has been learned of the Pennsylvanian flora and its evolution. Most of the paleobotany studies of the Illinois Basin have been made in this century, and some of the pioneer paleobotanists are still active in research, although most of them no longer work in the basin. They have generously shared with us their recollections of past events and of paleobotanists they knew, some of whom are un-

known to the new generation of paleobotanists. We have quoted or paraphrased parts of their correspondence and writings to convey something of their insight, their close cooperation, and their friendships, and have recounted some of their experiences that have not been included in more technical accounts.

Branches of Paleobotany

Paleobotany may be divided into three main specialized areas of study that are largely based on the modes of preservation of the plant parts. An entire plant is rarely found, but even the microscopic forms that are preserved represent a stage or part of a stage in the life history of a plant. Various parts of a plant can be preserved in different environments.

The branch of paleobotany that was developed first was the study of plants preserved as compressions and impressions. Compressions are the pressed, carbonized remains of a plant; impressions show the imprint of a plant but lack organic matter. Both are found mainly in shales and lend themselves readily to determinations of the gross morphology of plant organs, particularly foliage. The second branch of paleobotany is the study of plants petrified in calcareous concretions called coal balls, which occur in certain coal seams. The actual cell walls of plants are preserved in these nodules, and with special techniques anatomical studies of the fossil plants can be made in many of the same ways that living plants are studied. The third major, and most recently developed, branch of paleobotany is called palynology. It involves the study of plant spores and pollen, which have been preserved in many types of sedimentary rocks, particularly coals.

The boundaries of the three branches of paleobotany are not always clear cut. For instance, small portions of compressions have been known to grade into petrifactions, and sporangia with spores or pollen are often preserved on compressions (Darrah, 1936a; Kosanke, 1955). Thus there is a narrow bridge of comparable data between the oldest branch of paleobotany and the more recently developed areas of plant anatomy and palynology.

Peripheral to paleobotany is the science of coal petrography, which yields information on plant structures and the ecology at the time the coal was deposited. As coal petrography is a discipline in its own right, we discuss it only briefly.

State geological surveys, especially the Illinois State Geological Survey, have been responsible for the initiation and early support of studies in each branch of paleobotany. As was true of past studies, present paleobotanical work is concerned mainly with studies in biostratigraphy, plant evolution and ontogeny, and ecological implications of the floras. The biostratigraphic applications of compression-impression floras and the palynology of coals are still, for the most part, the domain of the state geological surveys and geologically oriented paleobotanists. Most studies of coal-ball plants, however, are now being made in botany and biology departments of universities.

The backgrounds of the paleobotanists are almost as varied as those of the far more numerous amateur collectors and rock hounds who share the same enthusiasm for collecting plant fossils. Until very recently, formal paleobotanical training was available at relatively few universities, most of which are in areas near significant fossil plant deposits, such as the Illinois Basin. Many of us did not become acquainted with paleobotany until relatively late in our college training, and, consequently, many students have followed a rather circuitous path to a career in paleobotany.

Importance of the Illinois Basin to Paleobotany

Studies of Pennsylvanian plants of the Illinois Basin have had a major impact on American paleobotany. Twenty-five compression-impression floras, 14 coal-ball horizons, and at least 75 coals have been identified in the basin. The numerous publications on the Mazon Creek flora from northeastern Illinois have made it one of the best known Pennsylvanian floras in the world.

The early biologically oriented studies of fossil plants in the Illinois Basin—the investigation of plant evolution and ontogeny from coal balls—have provided much complementary data on the anatomy of coal swamp plants in the middle and upper parts of the Pennsylvanian, have stimulated similar studies in Iowa and Kansas, and have provided training for many paleobotanists. Some of the earliest studies in palynology in the United States were carried out in the Illinois Basin, and important contributions to the taxonomy of fossil spores and the palynological correlations of coals have been based on Illinois Basin floras.

General Reports on the Paleobotany of the Illinois Basin

The history of paleobotany in the Illinois Basin is a regional story, but it is intricately related to the widespread growth of American paleobotany. Contemporary botanists who first established paleobotany programs in a number of universities have prepared accounts of the several facets of paleobotany in the Illinois Basin. *The History of Paleobotany in Indiana* by Canright (1958) deals largely with the development of studies of compression-impression floras in Indiana, while Darrah's (1969) *A Critical Review of the Upper Pennsylvanian Floras of Eastern United States with Notes on the Mazon Creek Flora of Illinois* gives considerable background on the collection and study of that famous flora.

Broad treatments of coal-ball studies are to be found in Andrews (1951) and Darrah (1941b). Summaries and citations of palynological studies in the Illinois Basin were given by Kosanke's (1950) *Pennsylvanian Spores and Their Use in Correlation* and Winslow's (1959) *Upper Mississippian and Pennsylvanian Megaspores and Other Plant Microfossils from Illinois*.

A summary of the early geological studies in Illinois up to 1930 and the founding and history of the present Illinois State Geological Survey were presented by Rolfe (1931) and former directors of the Survey (Bain, 1931; DeWolf, 1931; Leighton, 1931) at that organization's Quarter Centennial Celebration in 1930.

The most complete bibliographies on the Illinois Basin, including many paleobotanical studies of the area, are the *Bibliography and Index of Illinois Geology Through 1965*, prepared by Willman et al. (1968), and the *Annotated Bibliography of Indiana Geology Through 1955*, compiled by Nevers and Walker (1962).

Our purposes in preparing this account of the development of paleobotany in the Illinois Basin are to introduce geologists, botanists, and others to all the branches of paleobotany, to illuminate the personal side of past research and the cooperation that has existed among researchers, to suggest some areas for future research, and to provide a guide for teachers and students of paleobotany.

SCHOOLCRAFT TO FOERSTE—A CENTURY

H. R. Schoolcraft

Probably the first reports on a fossil plant in Illinois were made by H. R. Schoolcraft (1822a, 1825). On one of his expeditions into the newly opened

"West, " Schoolcraft was guided by an Indian to a petrified log in the bed of the Des Plaines River, just above its junction with the Kankakee.

The horizontal log was partly embedded in a gray sandstone and had a coaly outer layer and a brown center; it was 51 feet long and $2\frac{1}{2}$ feet in diameter. It was petrified in a matrix of calcite and pyrite.

David Dale Owen

Scottish-born David Dale Owen, a physician and scientist with broad training, first discovered and reported fossil plants from the Pennsylvanian rocks in the Indiana portion of the Illinois Basin (Owen, 1843a, b). He found many tree trunk casts in upright positions in a shale along a creek bank in Posey County near New Harmony; they were erroneously interpreted as fossil palm trees, which are not known from Paleozoic time.

David Owen was the son of Robert Owen, who had established a communal settlement in Scotland and one in New Harmony. David Owen came to America in 1828 and completed his medical training. However, he then turned to geological work in Tennessee (Merrill, 1904) and in 1837 became the first State Geologist of Indiana. He became State Geologist of Kentucky in 1854 and later filled a similar post in Arkansas, where he called in Leo Lesquereux to study the coal flora. In 1859, upon returning to Indiana as State Geologist, he brought Lesquereux to study the fossil plants of that state (Lesquereux, 1862b, 1875). Lesquereux had established his competence with an outstanding study of Carboniferous plants for the Rogers (the first) Survey in Pennsylvania. Canright (1958) has presented a detailed background on the Owen family.

A. H. Worthen

Although the first Geological Survey of Illinois was established in 1851 with J. G. Norwood as State Geologist (Rolfe, 1931), paleobotanical studies did not begin in Illinois until 1858, when A. H. Worthen succeeded Norwood. Worthen collected invertebrate and plant fossils, which he used to establish a stratigraphic zonation. Although he published only a short article on plants of Mississippian age (Worthen, 1860), Worthen encouraged studies of paleobotany and provided most of the fossils. Worthen tried to persuade Lesquereux to accept a year-round position for the systematic study of the Mississippian and Pennsylvanian plants of Illinois, but Lesquereux instead began his study of the fossil plants of Indiana for Owen. Later, however, Lesquereux did study Illinois fossil plants.

Leo Lesquereux

Leo Lesquereux is a splendid example of a versatile scientist who made significant contributions in several areas. Of French descent and Swiss birth, Lesquereux was successively a school teacher, a watch engraver, a maker of watch springs, a student of mosses, and an expert on peat bogs (Rodgers, 1944). An accident and an ensuing illness that resulted in his loss of hearing had

necessitated those considerable changes in his livelihood. Political changes in Switzerland led to Lesquereux's emigration to the United States in 1847. His first employment in the United States was with Louis Agassiz, the Swiss naturalist, and involved the taxonomy of living plants from a Lake Superior expedition. In 1848 Lesquereux made Columbus, Ohio, his permanent home, and there he shared bryological research with the wealthy and noted American bryologist, William S. Sullivant. Lesquereux had become well known as a bryologist before his paleobotanical activities began in 1850, when he was 44 (Rodgers, 1940).

His studies of fossil plants from Illinois were published in 1866 and 1870 by the Geological Survey of Illinois. Lesquereux later used the studies of fossils from Illinois, Indiana, Kentucky, and much additional data in his three-volume work and atlas, *Description of the Coal Flora of the Carboniferous Formation in Pennsylvania and Throughout the United States* (1879, 1880a,b, 1884). Lesquereux's extensive studies of the Carboniferous floras and those from other geologic periods formed the foundation for North American paleobotany. Rodgers (1944) has recounted Lesquereux's paleobotanical activities in the United States.

The Illinois Collection

The Illinois State collection of fossil plants, gathered by Worthen and classified by Lesquereux, was damaged by fire in 1871 (Am. Jour. Science, 1871). Springfield newspapers (Ill. State Jour., 1871; Ill. State Register, 1871) reported that Worthen's private collection was safely removed by his son, who was in the second floor office at the time of the fire, but the likelihood of the collapse of the building prevented removal of the State collection.

Some type specimens from Lesquereux's studies are now scattered among the Illinois State Museum in Springfield, the U. S. National Museum of Natural History in Washington, D. C., the University of Illinois in Urbana, Harvard University, Yale University, the Geological Survey of Alabama, and probably also Princeton University (oral communication, Erling Dorf). There are no doubt other locations as well, because Lesquereux gave no clues to the repositories of certain plant specimens, and his type specimens were moved about and exchanged quite frequently. In 1912, A. R. Crook, curator of the Illinois State Museum in Springfield, published a short catalog of the plant fossils in the museum collection, in which he identified some of Lesquereux's type specimens for the first time since their description.

R. E. Janssen identified and revised some of the Lesquereux type specimens in the mid-1930s. Janssen explained the genesis of the project to us:

> ... Dr. Noé had been contacted by the Illinois State Museum director to suggest someone who could evaluate and classify a collection of plant fossils that had been discovered in storage during the museum's move to a new building. He recommended me for the job, and during its progress I recognized many of Lesquereux's type specimens which had long since been considered lost.

Janssen's paper was published by the museum in 1940 (Janssen, 1940b).

The history of the curating and some locations of Lesquereux's types were given by Sarton (1942) and Darrah (1969). Arthur D. Watt of the U.S. Geological Survey is now conducting a further search for the types, with the intention of publishing a catalog. He has already published a list of some of the Lesquereux

types in a catalog of the illustrated Paleozoic plant specimens deposited in the U.S. National Museum (Watt, 1970).

After the original Geological Survey of Illinois closed in 1875, little progress in paleobotany was made in Illinois until the turn of the century. Of considerable importance, however, was the establishment in Springfield of a Natural History Museum in 1877 with Worthen as curator. Of equal importance to paleontology, as well as to other natural sciences, both then and now, is the sustained support for such institutions, which preserve and encourage the study of specimens of the earth's natural resources.

Worthen's experiences as curator were frustrating; the collections were moved seven times between 1851 and 1888, and, shortly before his death, in spite of his protests and during his absence from Springfield, the museum specimens were moved to the basement of the State House, where they became encumbered with trash. Worthen's successor as curator, Josua Lindahl, wrote (*in* Crook, 1907), "I devoted years of assiduous work to save what could be saved."

Lindahl was asked to provide a geological exhibit for the World's Columbian Exposition in Chicago in 1893. The state bought, to serve as part of the exhibit, the Worthen private collection, and specialists in paleontology were asked to provide taxonomic determinations and descriptions for the various groups of fossils. Charles David White of the U. S. Geological Survey was asked to revise all the Illinois collections of fossil plants. His observations of the Illinois display specimens for the Exposition provided a basis for appraisal of the Illinois floras. The printed labels for the display specimens are now in the collections of the Illinois State Geological Survey and the Illinois State Museum. White wrote a report, but, "in the confusion unavoidably accompanying the closing days" of the Exposition, this report and the reports on invertebrate paleontology were lost (Lindahl, 1893). The Worthen collection was given to the University of Illinois, and the State collection was returned to Springfield.

E. H. Sellards

Pioneering studies of spores and prepollen from the compression flora of the Mazon Creek area were made by E. H. Sellards (1902a, 1903) and included descriptions of fructifications and spores of *Crossotheca*, *Myriotheca*, fertile pecopterids, and a new genus, *Codonotheca*.

Sellards was studying at Yale University, and the contribution on *Codonotheca*, a portion of his doctoral dissertation suggesting the relationship of the fructification to the Cycadofilicales, appeared the year before the noted discovery and recognition of the Cycadofilicales as seed ferns by Frank W. Oliver in England (Oliver and Scott, 1904).

Charles David White

In 1905 the present Illinois State Geological Survey was organized, and Charles David White, then Honorary Curator of Paleobotany of the U. S. National Museum, came to Illinois and worked with the new Survey during the summers from 1906 to 1908. White, a native of New York, had joined the U. S. Geological Survey in 1886 as a paleobotanical illustrator after receiving his undergraduate

degree at Cornell University. Although he was employed to help Lester F. Ward illustrate the Laramie and Fort Union floras, it was not long until White began his own paleobotanical research (Mendenhall, 1937).

White's first publication from the Illinois Basin was an investigation of the flora of the "Hindostan Whetstone beds" from western Indiana, which is the oldest known Pennsylvanian flora in the basin (White, 1896). The only other publications about this flora have been the description of two new species of *Lepidostrobus* by Hoskins and Cross (1940, 1943b) and a comparison of the flora with floras of the Westphalian A of Europe by Bode (1958).

White (1907, 1908, 1909) published short reports on his summer work and used plant fossils for stratigraphic correlation within the Illinois Basin and for correlation of the basin with the Appalachian region. He remarked on the peculiar *Megalopteris* flora in the northwestern part of Illinois and revised some of the statements on stratigraphy made by Lesquereux. White (1907) noted that plant fossils were extremely rare in roof shales of the Springfield (No. 5) and Herrin (No. 6) Coal Members of the Carbondale Formation. This difficulty in finding plant megafossils (compressions and impressions) in many places limited their use in correlation and led to the development of and preference for palynology in the 1930s. Nevertheless, White's stratigraphic interpretations were widely accepted by geologists of that time. Leighton (*in* Noé, 1925c), writing of White's contribution, said,

> White's work led to a general correlation of the strata of the Illinois coal field with the eastern field, and to a division of the Pennsylvanian System into three series: the Pottsville (lowest), the Carbondale, and the McLeansboro.

White also pointed out stratigraphic problems that still existed.

In his third summer in Illinois, White collected plant fossils mainly in Caseyville ("Pottsville") strata in southern Illinois and began to write a manuscript. Completion of the manuscript was delayed by administrative duties when White became Chief Geologist of the U. S. Geological Survey in 1912 and by his paleobotanical investigations in other parts of the United States. Schopf (*personal communication*, 1971) stated that the study of the Pottsville flora continued intermittently and was nearly complete at the time of White's death in 1935. According to J. A. Simon, the present Principal Geologist of the Illinois State Geological Survey, shortly after White's death, arrangements were made by the Illinois and United States Geological Surveys to complete the manuscript under supervision of Charles B. Read of the Federal Survey. Harold R. Wanless agreed to provide a chapter on stratigraphy, the first draft of which he supplied in 1938. As late as 1940, the Illinois Survey still hoped to publish the manuscript as a monograph, but shortly thereafter it deemed that the voluminous text and book of plates would be beyond Survey printing resources. The Federal Survey then planned to publish the report as a special paper. The stratigraphic section was revised by Wanless in 1952 and substantially revised again in 1970, just before his death.

Jackson and Foerste

From the lower part of the Pennsylvanian in the Indiana portion of the basin, Jackson (1916) described 50 species of plant compressions, including numerous new species of ovules.

Foerste (1915) described *Stigmaria*-like specimens from the Kentucky portion of the Illinois Basin, but their differences from other species of *Stigmaria* led him to designate them a new genus, *Dictyophlois*. He described similar specimens from Illinois (Foerste, 1923). White later gave the fossil its valid name, *Stigmaria wedingtonensis* . The description of this Mississippian species was revised by Pfefferkorn (1972). Foerste was well known as an invertebrate paleontologist, and his *Dictyophlois* papers are his only publications in paleobotany.

PENNSYLVANIAN PALEOBOTANY AFTER 1920

A. C. Noé

Two events in the early 1920s started a new era for paleobotany in the Illinois Basin—coal balls were discovered in the basin and A. C. Noé became the first professor of paleobotany at the University of Chicago.

Austrian-born Adolph Carl Noé von Archenegg came to this country in 1899. Noé had served as a demonstrator in paleobotany at the University of Graz, Austria, from 1893 to 1897 and had published two scientific papers. In America, however, he became a language teacher, completed work for his doctorate in Germanic languages at the University of Chicago in 1905, and later joined the language faculty there.

Noé's great interest in fossil plants emerged professionally in the early 1920s when, at the age of 47, he began teaching a course in paleobotany at the University of Chicago and secured support from the Illinois and Kentucky State Geological Surveys for investigations of plants of Pennsylvanian age. He became a colorful and articulate ambassador for paleobotany in the Illinois Basin. M. M. Leighton, then Chief of the Illinois Survey, said of Noé's task (*in* Noé, 1925c):

> In 1921, in connection with an intensive study of the coal resources of Illinois, the State Geological Survey undertook a program of more detailed study of the plant forms found in strata associated with the coal beds, fully realizing that the facts to be uncovered by such an investigation would likely be of inestimable value to a proper correlation of the coal beds in different parts of our State and to our knowledge of their extent and relationships.

As a result of Noé's preliminary studies and his effective communication of his ideas, the University of Chicago in 1923 created a chair of paleobotany, jointly sponsored by the university's Botany and Geology Departments, and Noé was transferred from the language faculty to fill the post. It was the first faculty appointment for a paleobotanist in the Illinois Basin. Indeed, there were relatively few chairs of paleobotany in the entire United States at that time.

Both the Mazon Creek compression-impression plant fossils and coal balls were intensively studied by Noé in the twenties. To collect fossils for study, he visited coal mines in the Illinois Basin and made friends with the mine operators, amateur collectors, and miners. He became a familiar figure at the mines and the miners called him "the flower man." James M. Schopf of the U. S. Geological Survey Coal Geology Laboratory at Columbus, Ohio, who was a pioneer in many branches of paleobotany in the Illinois Basin, wrote concerning Professor Noé:

> Noé had a considerable interest and acquaintance with coal and coal mining. During part of the '20s he usually worked for the Illinois Survey during the summer, and with a Survey driver, for he did not drive a car himself, Noé would make the rounds of the coal company field offices in the state, dispensing good will and advice, and bringing back any available collections of coal balls and plant fossils to Chicago for his students to work on. I think he was truly an ambassador of good will between the coal operators and the Illinois Survey. They were all good friends of Professor Noé.

Noé joined organizations such as the American Institute of Mining and Metallurgical Engineers and the Illinois Mining Institute to be in closer contact with coal operators and obtain their cooperation in collecting fossils and paleobotanical data. He was very much at ease in groups and especially enjoyed the annual meeting and boat trip of the Illinois Mining Institute.

According to Schopf:

> For a couple of years during this period of the '20s Noé also was an advisor of the Allen and Garcia Coal Commission that studied and made recommendations to the Soviet Government about coal mining practices in the Donetz Basin in Russia. He wrote a small book about his experiences, called "Golden Days of Soviet Russia" [Noé, 1931d].

As a result of his interest in coal mining, Noé made arrangements to translate and revise Otto Stutzer's book, *Kohle*. He believed that the translation would be his major contribution. It was a formidable undertaking, but it was essentially complete at the time of his death in 1939. Dr. Gilbert H. Cady of the Illinois Geological Survey was asked to complete the manuscript and bring it up to date for publication by the University of Chicago Press. Cady's instructions from the publisher were to introduce no revisions that had not been in Noé's manuscript, so Cady's part of it is a direct translation of the German. Nonetheless, it took him several months to complete, working before and after his regular working hours. The book appeared in 1940 as "*Geology of Coal*, by Otto Stutzer, translated and revised by Adolph Noé."

Discovery of American Coal Balls

Coal balls are masses of fossilized peat that are found in coal seams. These peat masses escaped the coalification process that transformed the surrounding material, and the plant structures in many are well preserved.

Coal balls were first reported in England by Hooker and Binney in 1855, about the same time that the first collections of plant impressions were being made in the Mazon Creek area (Darrah, 1969). They were called coal balls because they came exclusively from the coal seam and had a crustal covering of coal; indeed, many of the European specimens were quite rounded and ball-like. The term "coal ball," however, is not particularly appropriate because they are not composed of coal, and American coal balls vary considerably in shape and size, from tiny spheres to gigantic masses of many tons. They have curved surfaces and many are somewhat flattened, biconvex, or lenticular. However, they have no single characteristic shape.

Although coal balls had subsequently been found in other parts of Europe, including Russia (Zalessky, 1910), none had been reported in America at the time Noé became interested in them. Noé was convinced there must be American coal balls and suggested why they had not been found:

> When I started to work on the paleontology of plants, I was very anxious to find coal balls in America. They had not been found for two reasons. One reason was that botanists do not go into coal mines, and geologists who go into coal mines are not interested in plant structures.

According to Chester A. Arnold, who recently retired from the staff of the Museum of Paleontology and the Botany Department of the University of Michigan:

> Noé's chief contribution to American paleobotany was his "discovery" of coal balls in North America. I put discovery in quotes because he really was not the discoverer...Noé apparently was the first to realize that these things were something of significance to American paleobotany and that they were worthy of investigation.

Actually, the first discovery of coal balls in the United States is a rather strange story, first noted by Andrews (1951). The first American coal balls discovered and reported were from Iowa in the 1890s, and W. S. Gresley (1901) of Erie, Pennsylvania, illustrated beautifully preserved reproductive structures of *Cordaites* (*Cardiocarpus* and *Cordaianthus*) and paradermal views of *Pecopteris* from the Iowa material. Two peculiar aspects of the Gresley papers are, first, that no one in paleobotany seemed to know that the described petrified structures were from coal balls, and, second, that White had known of his work and had offered him advice but had not associated the material with coal balls. Gresley did not use the term "coal ball," but he stated (Gresley, 1901, p. 13):

> In these pyrites concretions in the coal bed at What Cheer in Iowa, this species of Pecopteris is rather common. It was by grinding and polishing that the structural details were brought to light, and I am greatly indebted to Dr. David White of the United States Geological Survey for suggesting that this fossil be figured....

Schopf wrote us:

> Although Gresley compared some of the seeds with British coal-ball material described by Williamson, and later Tilton (1912) and Coulter and Land (1911, 1921) described a Lepidostrobus cone from Iowa that showed typical coal-ball preservation, neither White nor anyone else made the connection.

The Coulter and Land studies, ironically enough, were carried out in the Hull Botanical Laboratory at the University of Chicago, where Noé was working.

Gresley's coal balls, because of their high pyrite content, apparently required polishing instead of the thin-sectioning technique usually applied in those days, and perhaps that was misleading. Darrah (1941b), who later pioneered in the study of Iowa coal balls, reported to us:

> The most striking difference between Iowa coal balls and those from the Illinois Basin mineralogically is the high pyrite content of most of the Iowa balls. This is also true of the Kansas material from Frontenac. There are, however, a great many nodules from Iowa with low pyrite content. The botanical difference between Iowa and Illinois coal balls is largely the scarcity of lepidodendrids and the abundance of cordaiteans in Iowa.

Highly pyritic coal balls also occur in the Illinois Basin, but they are generally avoided by collectors because the plants they contain are likely to be poorly preserved.

R. W. Baxter, who was one of the first to study Kansas coal balls (Baxter, 1951a; Baxter and Hornbaker, 1965), told us:

> Henry Andrews and Sergius Mamay remarked on the differences between the Kansas and Illinois coal balls in one of their early papers on the West Mineral locality [Andrews and Mamay, 1952]. Basically they seem to be that the Kansas material is more varied, without the concentration of Psaronius characteristic of the Berryville site [Calhoun Coal Member] or the concentration of Lepidodendron characteristic of the Pinckneyville site [Herrin (No. 6) Coal Member]. In general I think Kansas coal balls are much more comparable to those of central Iowa than they are to Illinois, both in occurrence of similar species and in a general dominance of the cordaitean complex.

W. H. Smith, Illinois State Geological Survey, has pointed out that descriptions of coal-ball masses also were given by Gilbert Cady (1915, p. 76), although they were not recognized as coal balls. Cady recorded:

> In parts of the Black Hollow mine, in the clay pits south of Starved Rock Park, and in Bottomly's country bank on the Vermilion River below Lowell, altogether occurring from place to place over 15 to 20 square miles along the anticline and east of it, large calcareous, boulder-like masses of rock lie in the coal bed, and in some places entirely eliminate the coal.

Again, in 1919, he wrote (p. 55-56), "At places along the Vermilion River, masses of calcareous rock interrupt the continuity of the coal bed, but the distribution of the irregularity is local." He was referring to the Colchester (No. 2) Coal Member.

Apparently White was the paleobotanist most difficult to convince that there were American coal balls. White had a reputation as a master of the paleobotanical literature, and his personal contacts among geologists and the few paleobotanists were frequent and linked by much correspondence. It seems reasonable to assume, therefore, that he was not convinced of the coal-ball origin of the material described by Gresley, Tilton, or Coulter and Land. From White's writings (White and Thiessen, 1913, p. 33-34) it is quite evident, however, that he was aware of pyritic and siliceous petrifactions in American coals, and it is quite possible that semantics and/or the preference on the part of paleobotanists for coal balls of high carbonate content accounted for White's remarks about the absence of coal balls in American coals. The Gresley specimens were pyritic and the Tilton specimens were apparently weathered out, probably were not found in place, and had been passed from one person to another. Schopf recently pointed out, too, that our modern knowledge of coal-ball occurrences depends largely on the development of open-cut mining methods, which may expose coal balls in great abundance. Few such exposures were afforded before 1925.

Several paleobotanists called our attention to an incident at the University of Chicago prior to the first coal-ball discovery in the basin. Recollections of the story by C. J. Chamberlain, a renowned authority on gymnosperms of that time, stemmed from an unpublished tribute to Noé prepared by Fredda D. Reed, Noé's second doctoral student. She kindly related the story to us and provided a copy of the tribute, from which the following lines are quoted:

> David White, Chief of the United States Geological Survey, had come to the University of Chicago to lecture before a joint meeting of the botany and geology departments. During the discussion that followed Dr. Noé...ventured

> to ask why, in America, they did not study the Carboniferous flora as preserved in coal balls. David White replied that there were no coal balls to be found in American coal. And Dr. Noé again, "But you have coal mines, do you not?" Whereupon David White reiterated with some asperity, "We have looked for them and there are no coal balls in American coal." Dr. J. M. Coulter and Dr. T. C. Chamberlin hastily brought to an end this turn of the discussion. Later, however, they went to Dr. Noé and asked him for an explanation of his comments. Did he believe there were coal balls in America, and if so, did he think he could find them?

Noé soon substantiated his view with the recognition of an American coal ball, although there is some confusion in his writings as to which coal ball actually was the first. One can imagine his delight, however, when he related (Noé, 1932, p. 317):

> In Autumn, 1922, I wrote a letter to Dr. David White informing him that coal balls had recently been found in Illinois, and at a conference during the Christmas vacation of the same year, I showed a sectioned coal ball to him....In December 1929, Dr. David White showed me some concretions taken out of a coal seam in 1910 which undoubtedly can be called coal balls, but which were not recognized as such at the time.

Noé's announcement of the discovery of the first coal balls from the Illinois Basin appeared in *Science* (Noé, 1923a). A second paper (Noé, 1923b), on the flora of the Western Kentucky coal field, he heavily slanted toward informing people about and interesting them in what he was searching for—coal balls. Although he illustrated a number of Pennsylvanian compression-impression specimens from Kentucky and Illinois, the first figure was of an uncut coal ball, about which he wrote, "The first discovery of a real American coal ball occurred in Mine No. 12 of the West Kentucky Coal Company near Sturgis, Kentucky. The coal ball...is unusually large compared with European material and promises to give valuable information when it will be cut." He also included three photographs of anatomical sections of plants from English coal balls.

Later, apparently in contradiction of his Kentucky paper, Noé (1932) related that Gilbert Cady had collected the first coal ball in Illinois in 1922 at the O'Gara No. 9 Mine near Harrisburg. Cady saw in it enough plant material to suspect its importance. It was shown to Noé by Dr. Harold E. Culver, then Head of the Coal Section of the Illinois Geological Survey, and Noé recognized it as a coal ball. Noé stated, "This was the first known coal ball found in North America and recognized as such."

Although not paleobotanists, Culver and Cady, who succeeded Culver as Head of the Illinois Survey's Coal Section, encouraged all aspects of paleobotanical research in the Illinois Basin for many years.

The O'Gara Mine coal ball from the Harrisburg (No. 5) Coal Member triggered the growth of a new branch of Pennsylvanian paleobotany in the United States. Noé at a meeting in Pittsburgh spoke of his coal-ball collecting at the O'Gara Mine:

> In Harrisburg they were found in a mine which had been abandoned. The mine had been shut down for about two years and it was rather hard to get to the coal balls. I had my assistant, a mining engineer of the O'Gara Company, and a foreman with me and we had to climb about 425 feet down the air shaft. I dreaded the idea of carrying the balls up because we had collected over 500 pounds. I could have gotten 5000 pounds. We let a rope down in the shaft and had one man stay underground. He filled our knapsacks and tied

> them to one end of the rope and we tied the other end to a car and lifted the balls out that way. It proved to be wonderful material.

Noé published many short notes on coal balls, mostly lists of the taxa found at various localities and stratigraphic horizons, with occasional summaries of progress in coal-ball studies and reports of new coal-ball discoveries (Noé, 1922a, 1925a, 1934a, b, 1935; Fisher and Noé, 1938).

Noé's (1923c) first and only paper on the anatomy of American coal-ball plants, entitled *A Paleozoic Angiosperm*, was a nearly disastrous beginning for American studies. The first description of plants from coal balls in the Harrisburg (No. 5) Coal Member acquired at the O'Gara Mine was given by J. Hobart Hoskins (1923). Hoskins, who was one of Noé's most successful students in coal-ball studies, mistook the frond anatomy of *Myeloxylon*, an organ genus belonging to the seed fern (pteridosperm) stem *Medullosa*, for a monocotyledon stem that has scattered collateral bundles superficially similar to a corn stem. Hoskins named the plant *Angiospermophyton americanum*. Noé (1923c) unfortunately reproduced two figures from Hoskins' paper and endorsed the discovery. Angiosperms, or flowering plants, have not been identified with certainty in rocks older than Cretaceous. Seward (1923) pointed out the misinterpretation.

Noé's Influence on Paleobotanists

Noé, in addition to his own work on coal balls, furthered coal-ball investigation by supplying significant research material to his students, encouraging their efforts, and providing an interesting and pioneering atmosphere. He was also generous to paleobotanists who visited the Illinois Basin. C. A. Arnold wrote of his acquaintance with Noé:

> I first met him in 1926 when he attended the 4th International Botanical Congress held at Cornell University. I was about midway in my career as a graduate student at Cornell at the time, and we struck up a friendship that lasted until he died. After I came to the University of Michigan in 1928, I visited him a couple of times in Chicago. With his large build, steel-gray hair, penetrating eyes, thick mustache that overarched a wide mouth, and a scar on his cheek, the result of a duel during his younger days, he did not fit his kind, congenial, and generous disposition.... it was during one of these visits that he gave me some coal balls. He led me to the pile and told me to help myself. When I glanced toward him, he had purposely turned his back to me so I would not think I was being watched. It was in that group of coal balls that Steidtmann and I later found Medullosa noei and Rotodontiospermum illinoense [Arnold and Steidtmann, 1937; Steidtmann, 1937, 1944; see also Stewart, 1954].

One of Noé's objectives in paleobotany was expressed in an address in 1927, "If I develop six, eight, or ten new paleobotanists, then I shall have done all and more than I could have hoped for. It is a science not many need follow, but it has a place and use."

Indeed, Noé's paleobotanical contributions were extended by means of his students. J. Hobart Hoskins became Head of the Botany and Bacteriology Department at the University of Cincinnati; Roy Graham was a geologist and paleobotanist before he died, in the same year as Noé, in a rock fall in British Columbia at the age of 31; Fredda D. Reed, who helped section the coal balls from the O'Gara No. 9 Mine, continued her coal-ball studies at Mount Holyoke College and became head of the Botany Department there; Harriet V. Krick [Bartoo] taught at Western

Michigan University; Raymond E. Janssen became head of the Department of Geology at Marshall College, Huntington, West Virginia. Noé mentioned other students in his publications (1934b, 1935), and many geology students at the University of Chicago took the course in paleobotany from Noé and profited from the association.

While Professor Noé was not noted as being a particularly demanding teacher in either German or paleobotany, he was a brilliant lecturer and a most interesting personality. He was regarded as a great storyteller and, with a typical Austrian accent to add to the showmanship, he fascinated the students. Janssen wrote us, "I was impressed by Dr. Noé's wealth of knowledge in both fields of botany and geology, and also the background of paleobotanical experience which he brought from Europe. Studying under him was most exceptional because he took a personal interest in his students."

Theodor K. Just

Another Austrian-born botanist who contributed in quite different ways from Noé to the development of paleobotany was Theodor K. Just, a graduate of the University of Vienna, who came to the Midwest in 1929. Paleobotany was only one of many interests for Just, and many of his activities at Notre Dame, the University of Chicago, and the Field Museum of Natural History* were administrative, curatorial, and editorial. Among his many editorial efforts was the joint founding of *Lloydia* with Hoskins in 1938.

Of his writings, which were slanted toward plant evolution, *The Rates of Evolutionary Processes* (Just, 1944) and *Gymnosperms and the Origin of Angiosperms* (Just, 1948) are of particular interest. His *Fifty Years of Paleobotany 1906-1956* (Just, 1957b) provides a perspective on the major events in paleobotany, with special recognition of the palynological studies from the Illinois Basin by Schopf, Wilson, and Bentall (1944) and by Kosanke (1950).

Just's (1959) last contribution was the *Bibliography of American Paleobotany, 1952-1957*, which appeared in the same issue of *Lloydia* as his obituary, written by Simons (1959). The bibliography is now printed annually and is still compiled under the auspices of the Paleobotanical Section of the Botanical Society of America. Arthur D. Watt of the U. S. Geological Survey is now the compiler.

Compression-Impression Studies

Restoration of a Pennsylvanian Coal Swamp Forest

One of the most impressive restorations of Pennsylvanian plants to be seen anywhere in the world is the famous Carboniferous Swamp Forest Group in the Ernest R. Graham Hall of the Field Museum of Natural History* in Chicago, which was described by Dahlgren (1933). Noé (1934b) made a list of the plants and provided specimens from the University of Chicago's Walker Museum for use in the restoration. Bartoo wrote that Noé spent much of his extra time at the Field Museum of Natural History and the Museum of Science and Industry, giving enthusiastic advice on the preparation of the exhibits and the construction of the coal mine

* The museum was called the Field Museum of Natural History from 1905 through 1942. From 1943 through 1965 it was known as the Chicago Natural History Museum, but it again became the Field Museum of Natural History in 1966 and has retained that name.

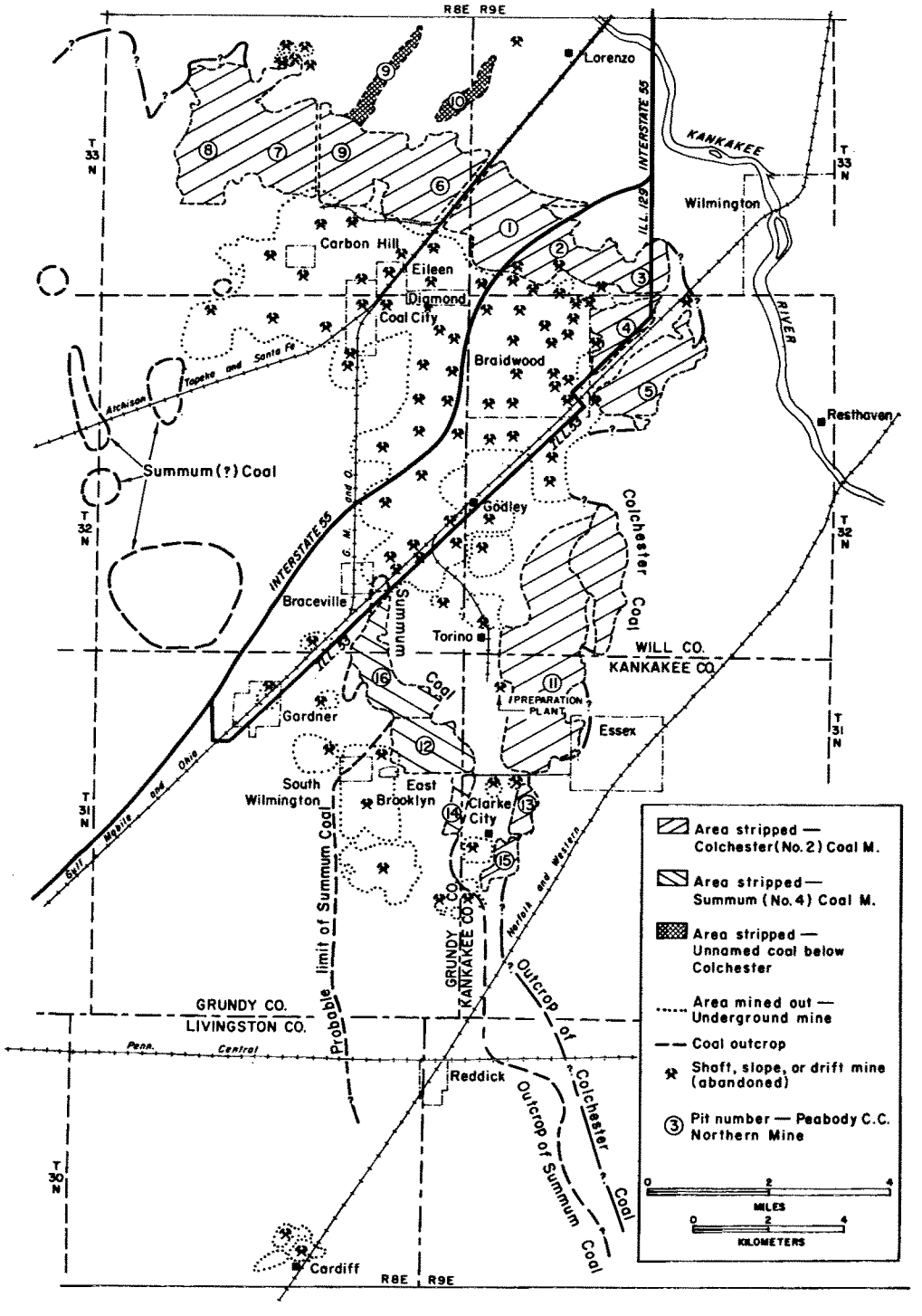


Fig. 2 - Mazon Creek area, famous for its compression-impression plant flora. (Map prepared by W. H. Smith, Illinois State Geological Survey.)

at the latter museum, and the displays of fossil plants at both. According to Dahlgren (*in* Croneis, 1940), Noé's name was added to the botanical staff of the Field Museum of Natural History as Research Associate in Paleobotany in recognition of his services. Dahlgren (1933, p. 12-13) also stated:

> A selected number of the most common and typical plants of the Pennsylvanian flora, especially as this is represented in the Middle Pennsylvanian Series of Illinois and adjoining states to the east, has been restored to three-dimensional form from the flattened impressions and casts in the rocks which constitute the fossil record. So many of the fossils on which these reconstructions are based are from Mazon Creek, Illinois, and of the others so many are to be found there, that the group may be considered a restoration of the Carboniferous vegetation of that famous locality, which has yielded so much fossil material.

The restoration of the Pennsylvanian forest in the Field Museum of Natural History was completed in 1933 and still gives the best available picture of the coal-forming forest. It is, however, partly a botanical garden of the ages rather than a representation of a specific location of any one time. For instance, the older plant *Lyginopteris hoeninghausi*, which does not occur in the Mazon Creek flora, is included because when the exhibit was made *Lyginopteris* was the only monostelic pteridosperm that could be reasonably reconstructed. Remarkably few Pennsylvanian plants are known in their entirety even today, and certain extrapolations are necessary for completion of three-dimensional restorations. Two of the common smaller plants, *Selaginella* and *Sphenophyllum*, are shown in the restoration, but coenopterid ferns, which occur abundantly in coal balls, were not well enough known even from Europe to permit restorations.

Noé's Studies

Noé devoted much of his research to the flora of the Mazon Creek area (fig. 2). From 1921 to 1925 and 1928 to 1936, Noé worked for the Illinois Geological Survey during the summers, doing field work in coal geology and paleobotany. His work with compression-impression fossils was stratigraphically oriented. Noé's first manuscript on the Mazon Creek flora was sent to White for review in 1922. The benefit of White's interest and his 35 years of paleobotanical experience was welcomed by Noé, although the criticism was rather severe and several taxonomic determinations were questioned. White was incorrectly dubious about the large number of species that Noé reported, but Noé accepted his advice calmly and, submitting to White's opinion, withheld the descriptions of new species.

Noé's short statement (1922b) on the Braidwood flora in northeastern Illinois indicated that it correlated with the upper part of the Westphalian or lower part of the Stephanian in Europe (fig. 3). The Braidwood flora occurs just above the Colchester (No. 2) Coal Member and is thus of the same age and identical to the Mazon Creek floras of Wilmington and Coal City. In a short paper (1925b) Noé correlated the Colchester Coal more distinctly with the Stephanian and the "Ottweiler Schichten" in Germany, which is also of Stephanian age. An atlas of the forms found in strata directly overlying the Colchester Coal in northern Illinois was published the same year (Noé, 1925a). Following its publication Noé expressed his intent and plans to Leighton in a 1925 letter, "I have withheld new species from the paper on the fossil flora of Northern Illinois because all of my

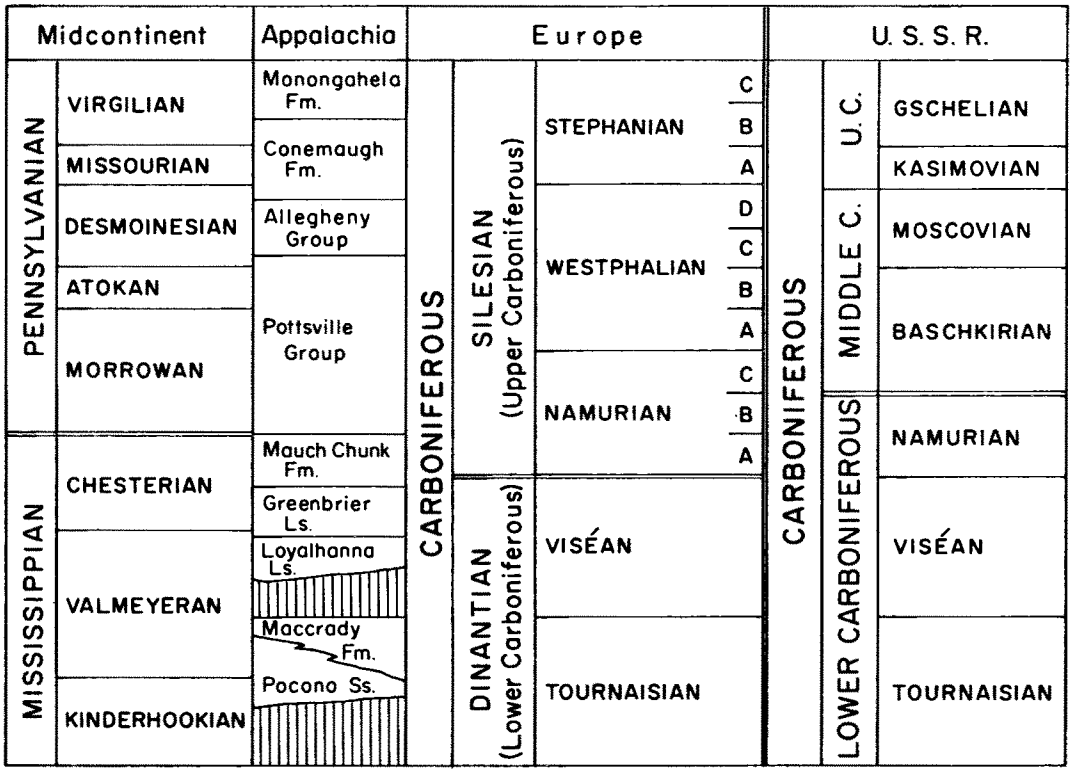


Fig. 3 - Correlation of the time-stratigraphy of the Mississippian and Pennsylvanian Systems in the Midcontinent with that of the Carboniferous of Europe and the U.S.S.R. (based on data published by the International Carboniferous Congresses).

new species are reserved for the Monograph, which will contain complete descriptions of all species found in Illinois." The monograph was never completed, but Noé's paper (1925c) on the Pennsylvanian flora of northern Illinois was well received by amateur collectors, and it provided a source of initial interest to outstanding collectors Frederick O. Thompson and George Langford, Sr. (Darrah, 1969).

The following year Noé prepared a short list (Noé, 1926) of the compression flora immediately above the Harrisburg (No. 5) Coal at Harrisburg in southern Illinois and correlated it with the upper part of the Westphalian. This contradicted his correlation of the Colchester (No. 2) Coal with the Stephanian. Trying to use plant fossils more extensively for stratigraphic purposes, Noé sent plant collections to Walther Gothan, a leading, stratigraphically oriented paleobotanist in Germany. Gothan and Hans Bode (both at the Prussian Geological Survey) correlated the plant fossils from Mazon Creek with those of the Westphalian D of the Piesberg and Saar districts. Noé (1930a) discussed their findings and added information on other plant-bearing beds and their position in the European time stratigraphy.

Noé (1931b) and White (1931) presented general papers on the climate of the Pennsylvanian as indicated by plant fossils and summarized some of their accumulated knowledge.

Noé intended to transfer his collection from the Walker Museum to the Illinois State Geological Survey after retirement because he had collected most of

it while employed by the Survey. After Noé's death, part of the collection was transferred to Urbana, but the rest was taken to the Field Museum of Natural History a few years ago.

Other Studies of Illinois Compressions

There were still very few American paleobotanists in the United States in the early 1930s, but improvements in transportation permitted a number of them, as well as some Europeans, to collect and/or study plants from the Illinois Basin; interest thus continued in compression-impression plants.

Darrah (1969) became interested in compression-impression plants in 1926 before his Iowa coal-ball studies began, and he recalled:

> I became interested in the Mazon Creek flora in about 1930. While a student I was employed part-time by Carnegie Museum in Pittsburgh to begin to put a fossil plant collection in some order. It was a very famous Belgian collection gathered by a Baron de Bayet. He had purchased, sometime about 1890, a considerable amount of material from Mazon Creek. Around 1932 and 1933 I was attempting to correlate the floras of the Allegheny formations with those of Henry County, Missouri, and Illinois. Between August 1929 and May 1934 I tried to locate and collect at as many classic localities mentioned or described by Lesquereux, David White, and I. C. White as could be identified, about 175 in all. In 1932 I made my first collection in the Wilmington strip mines, then close to Coal City [Illinois]. In 1934 I went to Harvard and there found a huge new collection gathered by Frederick O. Thompson of Des Moines. I became an intimate friend of Thompson over the years and collected with him in the ever-enlarging strip mines in 1937-1939. The account in my monograph indicates how much I depended on Thompson's collections and the way he gathered them.

Compte Rendu of the Second International Congress of Carboniferous Stratigraphy and Geology, held in 1935, contains articles by Jongmans (1937a, b) and Darrah (1937a) that mention Illinois fossil plants. Darrah (1937b, 1938a) and Arnold (1938) also made contributions on fertile structures from Mazon Creek. Arnold wrote:

> I do not recall how many collecting trips I have made to Illinois, but while collecting was good near Braidwood and Coal City I would make annual trips to pick up the "Mazon Creek" nodules. We finally amassed a rather sizable collection, and I think we have somewhere around 2000 catalogued specimens. Our collection is not a bad one, although it does not approach in size some of the real large ones around the country.

Joseph M. Wood worked up the Mazon Creek collection at the University of Michigan, which included Arnold's fossils.

Two of Noé's students completed their theses on compression-impression floras of the Illinois Basin, Raymond Janssen in 1937 and Franklin C. MacKnight in 1938. MacKnight's study dealt with the flora of the Herrin ("Grape Creek") Coal near Danville, Illinois; Janssen's dealt with Pennsylvanian plants from the basin. MacKnight is now at the University of Buffalo.

Janssen continued his interest in Illinois Basin plants and published several papers (Noé and Janssen, 1938; Janssen, 1939, 1940a, b, 1945, 1946). He

wrote concerning his acquaintance with Noé and the development of his doctoral thesis:

> I became interested in paleobotany while employed as a preparator in the Botany Department of the Field (Chicago) Museum of Natural History in the late 1920s. Among other duties, I was assigned to work on the Carboniferous Forest Diorama Restoration in the Geology Department, which work lasted for several years. It was then that I became acquainted with Dr. Noé, as he was consultant on this project. As a result, I became interested in fossil plants, particularly from the geological aspect, and decided to do my graduate work in this field under Dr. Noé.

His thesis was an important work and involved the revision of Lesquereux's types (Janssen, 1940a, b). The Museum published Janssen's thesis as the first volume in their new Scientific Series.

Janssen applied quantitative techniques to the Mazon Creek flora (1945, 1946), as was later done with larger collections, such as the Carr and Daniels collections at the University of Illinois, which were studied by Stewart (1950). Janssen (1939) also prepared the first of the Illinois State Museum series in Popular Science, *Leaves and Stems from Fossil Forests*, which, according to Janssen, "...was the outgrowth of a feeling by Dr. Noé and Director Deuel of the State Museum that there was a need for such a book because there were no others of this nature being published in the United States. I was not at any time on the permanent staff of the Illinois State Museum." Janssen continued to write articles for the interested public, including *Fossil Forests of the Great Coal Age* and *The Beginnings of Coal* (Janssen, 1942, 1948). He retired as head of the Geology Department, Marshall University, Huntington, West Virginia, in 1969.

In the last 25 years Geological Surveys have made numerous contributions on fertile specimens of the Mazon Creek flora (Schopf, 1948a; Kosanke, 1955; and Pfefferkorn, Peppers, and Phillips, 1971). Additional studies have been made by Delevoryas (1964a) and Taylor (1967a). From nodules found in the roof shale above the Herrin Coal at the Carterville locality, Hibbert and Eggert (1965) described a species of *Paracalamostachys*. Visiting paleobotanists from Europe also have been interested in the compression-impression plants (Chaloner, 1956, 1958; Bode, 1958, 1960; Lacey and Eggert, 1964). Read and Mamay (1964) included considerable information on Illinois compression floras in their discussion of the upper Paleozoic floral zones and provinces of the United States, as did Darrah (1969) in his review of upper Pennsylvanian floras. A brief stratigraphic comparison of Pennsylvanian plants from Kansas with those from the Illinois Basin was made by Cridland, Morris, and Baxter (1963).

In connection with the Geological Society of America meeting in 1970, a field trip was made into the northeastern Illinois area of the Colchester (No. 2) Coal and the Francis Creek Shale. The field guidebook (Smith et al., 1970) prepared for the trip contained several articles of interest to paleobotanists, particularly *Depositional Environments in the Francis Creek Shale*, by C. W. Shabica, and *A Comparison of the Floras of the Colchester (No. 2) Coal and Francis Creek Shale*, by Peppers and Pfefferkorn. The latter is the first integrated comparison of floras from the coal and overlying shale of the Illinois Basin. It lists the taxa present, gives percentages of taxonomic groups, and considers both spore succession in coals and the paleoecological aspects of compression floras.

Collections of Illinois Basin Plant Fossils by Amateurs

Amateur collectors have played a very significant part in locating and collecting materials for paleobotany research and teaching in the Illinois Basin. Many of the outstanding collections of the Mazon Creek flora have been made by people who had no formal training in paleobotany.

George Langford, Sr., made two important collections of the Mazon Creek flora. The Langford collection in the Illinois State Museum at Springfield was largely collected between 1937 and 1941 by Langford and his son. It has been systematically arranged by Richard W. Leary, the museum's Curator of Geology. Langford then gathered another collection of Mazon Creek flora, which is now at the Field Museum of Natural History, where Eugene S. Richardson, Jr., is curator. According to Janssen, the Langfords became interested in fossil collection as a result of litigation. When their manufacturing company in Joliet was involved in patent proceedings, lengthy litigation ensued. Janssen wrote:

> While awaiting its outcome the father and son became interested in the fossils which were found in the area not far from their home. To my knowledge, their business was never resumed and they retired to the fossil collecting.

Langford wrote two books (1958, 1963) on the Wilmington coal flora, another name for the famous Mazon Creek flora. The books are of value to all students of paleobotany because they contain many photographs, although some of the taxonomy is in error.

The late John McLuckie of Coal City, Illinois, and his wife, Lucy, amassed one of the most significant collections of Mazon Creek nodules. Many paleobotanists are indebted to them for making important research specimens available for study and for their kindness to visiting paleobotany students. Harriet Krick [Bartoo] wrote us:

> As in Dr. Noé's case, I never had many students and, unlike him, had no laboratory facility of my own for sectioning and polishing except for space borrowed from the geology department here. Even with such limitations we managed to get a sizable collection together for each student, making peels and casts and molds from whatever material was available. I am deeply indebted to Mr. McLuckie of Coal City and his wife who both were willing to have my students view his collection, and they even went with us to collect concretions for our collections.

Frederick O. Thompson of Des Moines, a graduate of Harvard and a successful businessman, began collecting plant fossils at the strip mines near Coal City in 1930. He also collected coal balls from Iowa, and invertebrate animal fossils. He gave most of his plant collection to Harvard University and, in recognition of his generosity and significant contributions, particularly to paleobotany, Harvard named him a Research Fellow of its Botanical Museum in 1949 (Barghoorn, 1953). Thompson also gave part of his collection to Washington University in St. Louis.

The Mazon Creek area is unique in its influence on both amateur and professional fossil collectors and there is a special sharing of interests among local residents and visitors. Most serious-minded collectors who have frequented the area in and around the Northern Illinois Mine of the Peabody Coal Company have been fortunate to receive the kind cooperation of Melbourne A. McKee, coal chemist at the mine.

Students, interested youngsters, and elderly people alike are still encountered, particularly in the spring, scouring the spoils piles of the vast strip mine areas of Will and Grundy Counties. Much of the Mazon Creek area is closed to collectors, so permission to enter private property must be obtained. Visitors usually must sign liability waivers before collecting on mine property.

Students on a brief, one-day excursion to the Mazon Creek area may be disappointed that their discoveries are not as spectacular as those in museum or university collections. But the Langford, McLuckie, Carr, Daniels, Thompson, and other significant amateur collections were built up over many years and before the area had been visited by so many collectors.

Several colleges in Illinois have important local plant collections. The Jelliff collection is at Knox College in Galesburg, and Augustana College in Rock Island also has an outstanding collection. The collecting of local fossil floras for special projects or theses is good training for students, and the resulting collections are useful for broader investigations. Collinson and Skartvedt (1960) prepared a field book for the Illinois Geological Survey Educational Series that describes the Pennsylvanian plant fossils found in Illinois and discusses collecting areas.

Visits of European Paleobotanists

Rudolph Florin (1933) from Sweden visited the U. S. National Museum in Washington and prepared a study on *Megalopteris* specimens, some of them from the Illinois Basin. The same year, W. J. Jongmans came to the United States in connection with the International Geological Congress in Washington. Jongmans had made important contributions to Carboniferous stratigraphy in Europe and he had long considered the correlation with North American strata. After the Congress in Washington, D. C., Jongmans toured the United States for several weeks, spending nine days in Illinois. A. C. Noé, Harold R. Wanless, and J. Marvin Weller took him to all the better known plant localities. Jongmans and Noé had some intense arguments about the nomenclature of the plants, and at the end of the trip Jongmans stated that none of the more common species observed in Illinois were unknown in Europe (H.R. Wanless, *personal communication*). Jongmans published a paper (Jongmans and Gothan, 1934) in which he stated that there was no Stephanian equivalent in Illinois. This was criticized by Noé (1936), who was in better agreement with modern interpretations when he placed the McLeansboro Group in the Stephanian. Bertrand (1935), after perusal of published data and some collections, came to a conclusion similar to Noé's.

Recalling the visits of Jongmans and Bertrand to the United States in 1933, Darrah wrote us:

> Paul Bertrand and W. J. Jongmans arranged extensive private field trips through the American Carboniferous, ranging from the anthracite region to the bituminous region of western Pennsylvania, West Virginia and Ohio, then to Illinois and Kansas. Each wished to examine the Carboniferous extensively—Jongmans from the Mississippian to the Permian; Bertrand the Pennsylvanian only. David White arranged for me to meet Jongmans in Pottsville, accompany him through the anthracite region and then escort him in the field in western Pennsylvania. Other persons escorted Jongmans in the several states he visited. A bitter feeling developed over Jongman's American

> visit. David White had asked for a gentlemen's agreement that Jongmans (and Bertrand) would not publish any new species based on their American collections without his knowledge and consent because White was preparing a comprehensive manuscript (still unpublished) including the descriptions of nearly 150 new taxa. Jongmans serenely ignored this agreement and, with Gothan, published a hasty, inaccurate list of species collected in America, in which the names of about 15 nomina nuda were given. White was furious... Paul Bertrand covered virtually the same ground. We got along well and I learned a great deal from him too, especially my first introduction to histologically preserved material. The impasse between these two men was the boundary between the Westphalian and Stephanian. In my monograph I explained the nature of the controversy [Darrah, 1969]. You must remember that in the late 1920s and early 1930s one could count on two hands the paleobotanists in the United States. Bertrand's major comment on American paleobotany was that we needed more paleobotanists because our country was so vast and there were so many problems to be undertaken.

Hans Bode, a German paleobotanist, traveled extensively through the coal basins of North America, including the Illinois Basin, in 1956. He was guided by local geologists and collected fossils in many localities. Bode (1958) published a paper on the floristic division of the Pennsylvanian in the United States, in which he correlated the strata of all major coal basins in the United States with the European time stratigraphy. He criticized the floral zones of Read (1947), which were made without regard to the previous work done in Europe, although Noé and Jongmans had shown earlier that the same floral zones were applicable in the United States. Bode's older conception of the definition of the Westphalian D forced him to assume that all higher beds belonged to the Westphalian D and that the Stephanian was totally missing. Strata correlative to at least part of the Stephanian are present in Illinois.

Paleobotany in Indiana

Paleobotany was introduced at Indiana University by James E. Canright, a graduate of Harvard. Canright's thesis work at Harvard, under the distinguished anatomist I. W. Bailey, was on the comparative morphology of the Magnoliaceae. His contributions on the stamens of living, primitive magnolialean flowers (Canright, 1952) are well known. Canright had already begun his thesis work when Elso Barghoorn's first paleobotany course aroused his interest. In 1949 at Indiana University he gave his first courses in anatomy and vascular plant morphology. His first course in paleobotany was introduced 7 years later, and shortly after he established the first palynology course.

Canright's experiences in 1954 at the Eighth International Botanical Congress in Paris influenced his teaching program. He wrote:

> There I participated in the founding of the International Organization of Paleobotany and attended most of the sessions of the newly-established Palynology Section of the Congress. There I met such people as Hamshaw Thomas, Tom Harris, Gothan, Jongmans, Leclercq, Erdtman, Kräusel, Cookson, etc. This experience, together with my fossil plant experience in Indiana caused me to inaugurate a course in paleobotany at Indiana University in 1956. C. E. Wier, G. K. Guennel, A. S. Horowitz, and Marcia R. Winslow were among the many geologists who took my course; Guennel worked on the macro- and micro-fossils of the Indiana paper coal for his Ph.D. with me [Neavel and Guennel, 1960; Guennel and Neavel, 1961]. Don Engelhardt came

> down from Wabash College (where Shutts was teaching at the time) and wrote a Ph.D. dissertation on the palynology of the Pleistocene interstadials in Indiana [1962].

Palynological studies of the Indiana coals began in the early 1950s when G. K. Guennel joined the Coal Section of the Indiana Geological Survey in Bloomington. Guennel had received graduate training at Butler University in Indianapolis and had analyzed several peat bogs in northern Indiana. The Director of the Indiana Geological Survey, Charles Deiss, who also was head of the Geology Department at Indiana University, was interested in exploring the paleobotanical aspects of Indiana along lines of research similar to those developed by the Illinois Geological Survey.

Canright wrote us about his cooperative efforts with the Indiana Geological Survey:

> After I gave a talk to the Geology Colloquium on the paleobotany of the Paleozoic, Deiss invited me to be Field Party Chief during the summers of 1953 and 1954 to study the plant megafossils associated with the Indiana coals. Joe Wood was my field assistant during the 1953 season, and C. F. Shutts assisted me in the 1954 season. The fossil plants and coal balls collected during these two field seasons were accessioned into the collections of the Coal Section of the Indiana Geological Survey.

In 1954 Joseph M. Wood and Canright published a paper on the status of paleobotany in Indiana, with special reference to the fossils of Pennsylvanian age. Papers on the collections of Pennsylvanian plants (Shutts and Canright, 1955), the history of paleobotany in Indiana (Canright, 1958), and the paleobotanical potential in the Indiana portion of the basin (Canright, 1959) followed.

Part of the older compression-impression floras of the Illinois Basin were described by Wood. In 1957 he published a paper on the morphology and relationships of sigillarian fructifications from the lower Pennsylvanian of Indiana and in 1963 a description of the Stanley Cemetery flora (early Pennsylvanian) of Greene County, Indiana, which was the subject of his thesis.

Canright wrote us, "I regard this discovery as one of our most important contributions in the Illinois Basin. Most of the fossils were preserved in ironstone concretions similar to (but not as hard to break) those of the so-called Mazon Creek type." Wood studied with Canright for his doctorate at Indiana and then joined the faculty at the University of Missouri, where collections from his study are located.

Coal-Ball Studies

The 1930s saw a new generation of paleobotanists working in and around the Illinois Basin, paleobotanists visiting from Europe, and the beginnings of palynology. Much of the activity resulted from the impetus provided by Noé and the discovery of coal balls.

Studies of coal-ball plants from the Illinois Basin began at the University of Chicago under Noé's supervision, and somewhat later were taken up at the Illinois Geological Survey by Schopf. Sustained programs then developed at Washington University in St. Louis under Andrews and at the University of Illinois under Stewart.

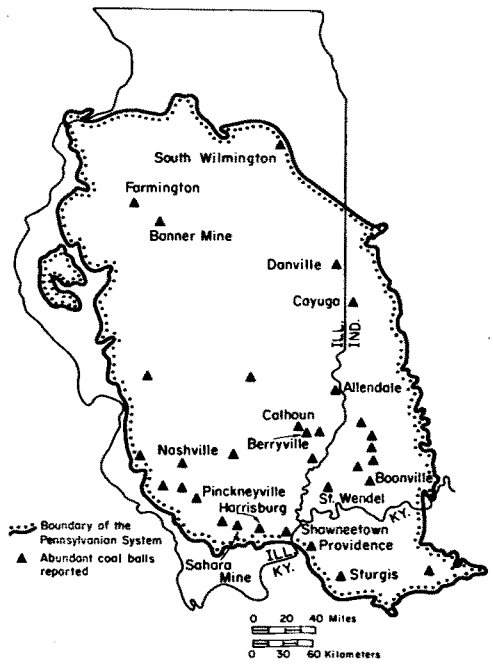


Fig. 4 - Coal-ball localities in the Illinois Basin.

Plant lists published by Noé, his students, and other new paleobotanists interested in coal-ball plants soon established the general nature of the coal-ball floras of the middle and upper part of the Pennsylvanian of the Illinois Basin. Lower vascular plants were generally predominant and included large arborescent lycopods, calamites, *Psaronius* ferns, smaller seed ferns, and relatively few cordaites. The fairly common, smaller plants included *Sphenophyllum*, *Selaginella*, *Botryopteris*, *Zygopteris*, and *Anachoropteris*.

Nature and Occurrence of Coal Balls

Coal balls are spherical to irregular masses of fossilized peat that occur in coal seams. Plant structures in the peat survived coalification of the surrounding material and are remarkably well preserved. The plant material is impregnated with calcite, dolomite, siderite, pyrite, or silica. Calcareous, dolomitic, and pyritic coal balls are restricted to seams formed under marine influence.

One of the questions most often asked about coal balls is how they are formed. It is a complex problem still under investigation by geologically oriented paleobotanists and geologists. Many answers have been offered; the first from the United States was by Feliciano (1924). Kindle (1934), Evans and Amos (1961), Weber and Keith (1962), and Cross (1969) also contributed answers. Perhaps the best picture of coal-ball origin can be found in the outstanding publications of Stopes and Watson (1909), Teichmüller (1952), and Mamay and Yochelson (1962). The mineralogy and petrography of coal balls from Illinois and other areas are now being investigated by Prasada Rao.

A likely explanation, derived from various publications, for the origin of calcareous coal balls is that marine calcareous material was transported into the peat, either in solution or as calcareous ooze. The calcareous material was then dissolved by the acid in the water of the peat bog. Slight changes in the pH value, usually triggered by the carbonates themselves or by the incoming sea water, allowed the carbonates to flocculate as a gel. Later, devitrification resulted in needle-shaped crystals, often spherulitically arranged.

Early discoveries of coal balls in the basin included those from an unnamed coal a few feet above the Minshall Coal Member of Indiana near Cayuga, from the Harrisburg (No. 5 Coal) near Harrisburg, from the No. 9 Coal at Sturgis, Kentucky, from the Herrin (No. 6) Coal, from the Danville (No. 7) Coal near Danville, and from the Calhoun Coal of Richland County (Feliciano, 1924; Noé, 1925a) (fig. 4).

Although coal balls were known from all six of these coals by 1930, the sequence of discovery and the quality and abundance of coal balls in each coal led to emphasis on plants from the Harrisburg Coal first, on those from the Danville Coal next, on those from the Calhoun Coal third, and later and quite extensively

on those from the Herrin Coal. No plants were described from the then oldest known coal-ball horizon in the Illinois Basin, the one reported by Feliciano (1924) and sampled by Noé (1925a). Feliciano identified the coal as the Indiana Coal II at the Silver Island Strip Mine, Cayuga, Indiana. Schopf (1941a) later pointed out that, according to Wanless (1939), the coal balls were from the Minshall Coal, not the Indiana Coal II. Noé's collection notes indicate the locality as Silverwood, Fountain County, Indiana. The identity of this coal is at present under investigation, but it is a little above the Minshall and probably equivalent to the Murphysboro Coal Member of Illinois. No further mention was made of the coal ball from Sturgis, Kentucky, that Noé (1923b) had originally mentioned as being the first.

Techniques Used in Studying Coal Balls

In Noé's laboratory, fossils were prepared for study by making thin sections. Bartoo described this cumbersome technique:

> ...[Noé] had a supply of coal balls which he had collected in large sacks in his laboratory workshop in the basement of Hull Botanical Laboratory Building, where in the northwest corner next to an outside window stood the large bandsaw, next to it the rotary saw with which we "sliced" the coal balls and across on the opposite side of the room a couple of polishing laps at which we took turns working when we were in class, and I later worked at alone when doing my thesis work. Hoskins and Reed had both sectioned and worked in the same room, as far as I know, before me. It was before the days of the "peel" method, so each section had to be carefully glued with marine glue to the slide and polished until thin enough to see through (and sometimes was lost in the process). I well remember the first time Dr. Noé showed us the new method, but it was too late to save some of the material which had been lost in our grinding away at the wheel.

Preparation of sections was vastly improved when thin sectioning was replaced by the liquid peel technique, which involved etching with hydrochloric acid and re-embedding the cell walls of plants in a liquid parlodion solution (Walton, 1928; Walton and Koopmans, 1928; Noé, 1930b; Graham, 1933; Darrah, 1936b). When the parlodion dried, it was peeled from the specimen, and the peel retained the cell walls of the fossil. Peels greatly facilitated the examination of larger numbers of specimens and, despite the many hours required to dry the liquid, the liquid peel technique was not replaced until Joy, Willis, and Lacey (1956) applied a preformed sheet of cellulose acetate to the etched coal-ball surface with acetone. The peel is easily removed and can be mounted on a microscope slide or examined directly with reflected light. This is now the most frequently used technique.

University of Chicago Contributions

Fredda Reed, who had provided some of the first detailed anatomical accounts of plants from the Calhoun Coal in her doctoral thesis (1926), continued her work on coal balls after receiving her degree. Coal-ball plants from the Harrisburg (No. 5) Coal became known largely from her research (1936, 1938, 1939, 1941), which also included studies of plants from the Springfield Coal Member (V) of the Petersburg Formation from "Polk's Patch near Brownsville" and Petersburg, Indiana (Reed, 1939, 1952). While on the faculty at Mount Holyoke College, Reed

spent several summers at the University of Chicago to obtain research material; she also worked with coal balls provided by Schopf and with Iowa coal balls loaned from Harvard University by Barghoorn.

J. Hobart Hoskins and one of his students, Aureal T. Cross, prepared some of the earliest generic monographs on coal-ball plants in the United States, including those on *Bowmanites* (*Sphenophyllum* cones) and *Pachytesta* (pteridosperm seeds) (Hoskins and Cross, 1943a, 1946a, b). Plants from coal balls found in the Danville (No. 7) Coal from the Hegler Zinc Company Mine, Danville, Illinois, were described in Hoskins' doctoral thesis and in later papers (Hoskins, 1926, 1933). Most of his publications on Illinois coal balls, however (1926, 1928a, b, 1930, 1931, 1934), gave only the "McLeansboro Formation" and no locality data.

Two of Hoskins' students contributed significantly to paleobotanical studies of the Illinois Basin and adjacent areas, Cross and Maxine L. Abbott, both of whom later served on the faculty at the University of Cincinnati. Abbott, Hoskins' last student, continued her studies of compressions at Cincinnati. She produced monographs on ferns, sphenopsids, and lycopods (Abbott, 1954, 1958, 1963, and 1968) that included some specimens from the Illinois Basin.

Krick's doctoral thesis, part of which was published in the *Botanical Gazette* (1932), had, she told us, the following genesis:

> In several of the Harrisburg coal balls which we were sectioning, I happened to run across several good specimens and I was naturally intrigued with what to call them. I got around the question by calling them—seed-like fructifications. The question as to why no embryos were present, although otherwise the structure was well preserved, came up. As far as I know, I was the first to write about them.

A promising young geologist attracted into paleobotany by Noé was Roy Graham from Staffordshire, England. Graham was a fellowship student at the University of Chicago from 1931 to 1933 and in his research relied heavily on E. J. Kraus, who was a well known plant anatomist. Graham's publications (1934, 1935a), based on his doctoral dissertation, dealt exclusively with coal-ball plants from the Calhoun Coal and exhibited great promise. The following year Graham accepted a National Research Fellowship that enabled him to study for a year at Cambridge University with A. C. Seward. Graham then became an instructor in geology at the University of British Columbia, working in the summers with the Canadian Geological Survey until 1937, when he became a mine geologist at the Britannia Mining and Smelting Company in Britannia, British Columbia. He was killed there in a rock fall in 1939 (Bastin, 1940). Graham's last contribution on plants from the Illinois Basin was in 1935 (1935b). In his publications on the Calhoun flora, he described a number of new taxa and provided insight into the differences between the younger American coal-ball flora and the lower Westphalian A coal-ball flora of western Europe.

The J. H. Hoskins Memorial Paleobotanical Collections, originally arranged by Abbott, are now in the Geology Department at the University of Cincinnati, where Richard A. Davis is curator. Type and figured slides of coal-ball plants described by Graham and others from the Noé collection are preserved at the Illinois Geological Survey in Urbana.

Illinois State Geological Survey Studies

The 1930s were formative years in all branches of paleobotany in the Illinois Basin, and the Illinois State Geological Survey provided significant leadership and pioneering, especially through the contributions of James M. Schopf.

Schopf received his doctoral degree in 1937 from the Botany Department, University of Illinois, with a thesis on *Larix* (Schopf, 1943). Schopf recalled in a letter to us:

> When I first went with the Illinois Survey in early 1934, my work was concerned with plant microfossils but, because I had more botany than others on the staff, I also got introduced to a variety of topics. Also, I was sincerely interested in questions about the coal petrography and origin of coal. It seemed to me that coal geology, in general, was the reasonable field of economic interest for someone who was in paleobotany, and it always seemed strange to me that so few paleobotanists have had more than a very generalized acquaintance with coal. David White, of course, was much the exception, but his interest dates back to the period in which there was a Coal Section in the U. S. Geological Survey organization. I must say that Cady and the other people at the Illinois Survey encouraged me in this broader interest.

Cady took Schopf to a 1935 meeting on the classification of coal. Schopf wrote, "In the course of that Pittsburgh committee meeting, and in subsequent reflections on it, I did formulate a number of impressions that have stuck with me ever since."

The further discovery of coal balls in the Herrin (No. 6) Coal and the real beginning of studies of the Herrin Coal flora (Cady, 1937; Schopf, 1937a) began with a trip to the Clarkson Mine at Nashville, Illinois. Flooding in the mine shaft from an unmapped drill hole had prompted the mine superintendent to request a visit from Cady. Schopf related:

> Clayton Ball and Louis McCabe, who were in process of other studies in the same area, were also interested in a trip underground to see it. Doc [Cady] also took Bill McCabe and me along to help out. This proved to be my first view of coal balls in situ....I finally was able to concentrate on one specimen from the collection that I named Medullosa distelica [Schopf, 1939]. I know there are other things there that also deserve description. But the deposit meant a great deal more than that to me because it gave me a chance to observe and compare the condition and composition of the pre-coal peat with compressed top coal that we had represented in coal thin sections, and with the spores, cuticles, and other materials obtained from the same layer by maceration. As a result, I have felt ever since that the lustrous silky top-coal, commonly found in the upper 6 or 8 inches of the No. 6 Coal, was derived from a dominance of Psaronius and Stigmaria roots [Schopf, 1938a]. In other words, I was greatly interested in the paleoecology of the deposit. It seems to me that this is still a very important objective because coal-ball assemblages stand a better chance of characterizing the coal measures peat swamp environment than almost any other source of information.

Schopf later wrote Noé concerning the plants discovered in the coal balls. Noé (1934a) had earlier reported on coal balls from the Herrin (No. 6) Coal from the Pyramid Coal Company near Du Quoin, Illinois.

Schopf's pioneering contributions to the paleobotany of coal are interwoven with the whole development of Pennsylvanian plant studies in the Illinois Basin, as is his lasting influence on the directions of paleobotanical studies by his colleagues and their students.

Washington University Studies

While Henry N. Andrews was a botany graduate student at Washington University in St. Louis, taxonomist Robert E. Woodson encouraged him to go to England to study with the noted paleobotanist, H. Hamshaw Thomas at Cambridge University in 1937. Andrews wrote us:

> I believe the first time that I actually saw a coal ball and made peel preparations was when I was a student at Cambridge in 1937-38. Hamshaw Thomas suggested that I look into the anatomy of the secondary wood of the pteridosperms, and I obtained some coal-ball specimens of Lyginopteris oldhamia from Hemingway.

Andrews' doctoral thesis, which was later published (1940), discussed, along with the pteridosperm petrifactions from Great Britain, some coal-ball material from the Illinois Basin supplied by Schopf. Schopf recalled one of his early meetings with Andrews, "I had gotten more coal-ball material, and I invited him to look at some of it. As I recall, he took back with him the material he later described as *Heterangium americanum* [Andrews, 1942b]."

Andrews joined the staff of the Henry Shaw School of Botany at Washington University and the Missouri Botanical Garden in St. Louis, where he established their first paleobotanical program. For most of his 25 years at the university he was Dean of the School of Botany.

Andrews and his students contributed significantly to the early studies of coal-ball floras of Iowa, Kansas, and the Illinois Basin (Andrews, 1951) and to the compression-impression flora of the basin (Andrews, 1943; Andrews and Mamay, 1948).

The first time large numbers of specimens of a given plant were examined to establish variation in anatomy and dimensions was in the study of *Lepidodendron sclerotioum* by Eloise Pannell (1942), a student of Andrews. The coal balls came from the Illinois Herrin (No. 6) Coal, and Andrews wrote:

> Eloise Pannell came from Carbondale and had been told about coal balls by her professor there. We went to the Pyramid Mine near Pinckneyville and we found coal balls in the dump where the coal was cleaned and explored the seam itself. We made several trips there during the two years that she was at Washington University.

Andrews and Pannell (1942) also described cellular preservation within the megaspore of *Lepidocarpon*.

During World War II Andrews wrote the delightful book, *Ancient Plants and the World They Lived In* (Andrews, 1947). Andrews was teaching mathematics to servicemen, and, in order to maintain contact with fossil plants, he wrote in the evenings about areas of paleobotany that keenly interested him. In 1951 he prepared the most detailed account of the history of American coal-ball studies to date, which contained an extensive list of flora and a bibliography.

Another of Andrews' students, Robert W. Baxter, who later taught at the University of Kansas at Lawrence, studied *Sphenophyllum* and pteridosperm stems and fructifications, particularly the Medullosaceae (Baxter, 1948, 1949). Plants from the basin were included in both studies. Baxter wrote concerning the development of his interest in paleobotany:

> I had done nearly all of my undergraduate work in botany under R. E. Woodson through whose help I later put in a year at the University of Hawaii

> working on the systematics of some of the Hawaiian flora. My interests at this time were mainly concerned with the morphology and taxonomy of living vascular plants. However, World War II broke out about this time and, when I finally got out of the Navy in 1946 and decided to return to Washington University to complete graduate work, Henry Andrews was very helpful and cooperative so that I felt fortunate in being accepted by him to complete my work for my master's...by that time I was so hooked on "coal ball" fossil plants that I continued on with a thesis on pteridosperms and a Ph.D. in 1949.

At the University of Kansas, where Baxter later served as Chairman of the Botany Department, he began to study coal-ball plants from Kansas (Baxter, 1951a; Baxter and Hornbaker, 1965; Leisman, 1968). He also described a beautifully preserved fern, *Ankyropteris glabra*, collected from the Springfield Coal Member (V) of the Petersburg Formation at the Wasson Coal Mining Corporation near Boonville, Indiana (Baxter, 1951b). Andrews (1956) further added to the variation in anatomy of *Ankyropteris*.

Baxter's classmate, Sergius H. Mamay, contributed significantly to our knowledge of fossil ferns, particularly those from the Illinois Basin. His doctoral thesis on American Carboniferous fern fructifications (Mamay, 1950) has served as a basic reference for later studies on marattiaceous and coenopterid fructifications. He, with Andrews, first discovered the main rhizome system of the common Permo-Carboniferous fern *Botryopteris* at the Berryville locality in the Calhoun Coal (Mamay and Andrews, 1950). They also described a new species of *Bowmanites* (Andrews and Mamay, 1951).

Andrews and Mamay (1952) wrote and illustrated a brief synopsis of American coal-ball studies, which deals with many of the practical aspects of coal-ball paleobotany. The taxonomic groups represented were discussed by Andrews and Mamay in 1955. Mamay went to Cambridge as a Guggenheim Fellow, where he studied *Tubicaulis* (Mamay, 1952). The many peels of petrified plants from English coal balls and calciferous sandstone material from Scotland that he collected were thus made available for teaching in this country. Excellent teaching material from English coal balls also was obtained by Darrah when he purchased choice specimens from J. Lomax, who had supplied a number of English paleobotanists with coal-ball preparations before he discontinued his business. Upon returning to the United States, Mamay joined the U. S. Geological Survey. He later described (1957) the zygopterid fructification *Biscalitheca* from Berryville (Calhoun Coal) and co-authored a comprehensive study on the nature of coal balls (Mamay and Yochelson, 1953, 1962).

Charles J. Felix, who also studied under Andrews, turned to palynology after completing his graduate work on coal-ball lycopods (Felix, 1952, 1954), in which he gave the first description of *Lepidostrobus diversus*, from the Springfield Coal Member (V) ("Petersburg coal") near Boonville, Indiana. Felix worked two years (1954-1956) with Schopf at the U. S. Geological Survey Coal Geology Laboratory in Columbus, Ohio, and then joined Sun Oil Production Research Laboratory at Richardson, Texas.

A later student of Andrews (jointly advised by Edgar Anderson) was William H. Murdy of Emory University, who studied corn anatomy for a thesis but contributed significantly to papers with Andrews on *Botryopteris* (Murdy and Andrews, 1957) and the classic, *Lepidophloios—and Ontogeny in Arborescent Lycopods* (Andrews and Murdy, 1958), in which the concept of determinate vegetative growth in lycopod trees was first presented.

Andrews' last two students in coal-ball studies were Tom L. Phillips, who studied *Sphenophyllum* (1959) and *Botryopteris* (1961), and Shirpad N. Agashe. Agashe's (1964) dissertation study of *Calamites* anatomy is one of several such contributions made from Andrews' laboratory (Andrews, 1952; Anderson, 1954; Andrews and Mahabale, 1961; and Andrews and Agashe, 1965). Agashe returned to Bangalore University, India, where he published a report on fungi in coal balls from the Illinois Basin (Agashe and Tilak, 1970). Phillips is now in the Botany Department, University of Illinois. Andrews and Phillips carried out several joint projects on coal-ball plants from the Illinois Basin (Phillips and Andrews, 1963, 1965, 1966, 1968) before Andrews moved to the University of Connecticut and changed his research emphasis to plants of Devonian age.

Type and figured slides of plants described by Andrews and his students are housed in the paleobotanical collections, Systematics and Evolution Section, Life Sciences, University of Connecticut.

University of Illinois and Derivative Programs

The program in paleobotany at the University of Illinois at Urbana was instituted in 1947 when Wilson N. Stewart joined the botany faculty. Stewart, who became one of the outstanding teachers and an enthusiastic supporter of paleobotanical research, has guided many students in graduate studies of fossil plants. Stewart had completed his master's work on comparative study of stigmarian appendages and *Isoetes* roots (1947) at the University of Illinois under the extended guidance of Schopf. His interest in the unique lycopod roots and root systems had developed before the war (Stewart, 1940), and he continued the study of *Isoetes* for his doctorate at the University of Wisconsin. In relating how he became interested in paleobotany, Stewart wrote us:

> I received an assistantship at the University of Illinois (1940-1941) and signed up with John Buchholz to do a master's thesis. When we sat down to discuss the problem, I told him of my interest in the evolutionary study of Isoetes. He said he was not well enough versed in the subject, but thought Jim Schopf, who had just gotten his degree with Buchholz the previous year, might help out. So that is how I got interested in paleobotany. At the time Jim Schopf was working with the Illinois State Geological Survey. It was in Jim's laboratory that I saw my first coal ball. As I recall, they were from the Nashville, Illinois, locality. I never had a course in paleobotany or one in geology. So you might say I came into paleobotany through the back door—a door that Jim Schopf opened for me.

In turning to paleobotany Stewart brought his morphological training to bear on the medullosan pteridosperm assemblages that had been studied by Noé (1923c), Hoskins (1923), Steidtmann (1937, 1944), Arnold and Steidtmann (1937), Schopf (1939), Hoskins and Cross (1946a, b), Baxter (1949), and Andrews and Mamay (1953), and he and his students (Stewart, 1951a, 1954, 1958; Warren, 1955; Delevoryas, 1955a; Stewart and Delevoryas, 1952, 1956; Taylor and Delevoryas, 1964; Taylor, 1965) complemented the work on *Dolerotheca* by Schopf (1948a). Stewart recalled, "The first medullosas I saw were in Jim Schopf's laboratory. I started getting interested in them at that time (1940s). Jim was working on *Dolerotheca*. I remember the original illustrations for the paper. They were beautiful. Jim did much to stimulate my interest in the group."

Not since David White had a paleobotanist brought such illustrative talents to bear on fossil plants. Stewart was responsible for several of the often-reproduced plant restorations of *Medullosa noei* (Stewart and Delevoryas, 1956) and *Psaronius blicklei* (*in* Morgan, 1959). Stewart's students and others greatly influenced by him in paleobotany included Florence E. Neely, whose significant doctoral thesis on petrified seeds was published in 1951; John W. Hall (1952, 1954); Alice J. Warren, whose master's thesis (1955) was on *Dolerotheca*; Robert M. Kosanke, whose study of *Mazostachys* (Kosanke, 1955) is a classic in combining three branches of paleobotany; Theodore Delevoryas, whose dissertation on the *Medullosae* structure (Delevoryas, 1955a) became a prototype for later monographic studies of coal-ball plants; E. Jeanne Morgan [Willis], whose thesis was on the morphology and anatomy of American species of *Psaronius* (Morgan, 1959); Grace S. Brush, who studied pollen organs for a master's thesis and completed her doctoral work on the spores and pollen from identifiable Carboniferous fructifications with Barghoorn (Brush and Barghoorn, 1962, 1964); Thomas N. Taylor, who published from his thesis a monograph on the American species of *Pachytesta* (Taylor, 1965); and Margaret Kain Balbach, who studied arborescent lycopod fructifications (Balbach, 1962, 1965, 1966a, b, 1967).

While Taylor and Balbach were doing graduate work, Delevoryas was also at Urbana, on the botany faculty. David L. Dilcher, angiosperm paleobotanist, began his graduate studies on epiphytic fungi (Dilcher, 1965) with Delevoryas at Urbana and followed him to Yale to complete them.

Hall, who completed his degree work at Urbana under Oswald Tippo, recalled how he became interested in paleobotany:

> My interest in paleobotany really goes back to my undergraduate days, and the influence of R. E. Torrey. His course in morphology really leaned heavily on the fossil record, and he had some of the old Lomax slides which I thought were quite outstanding. Then, when I got to Illinois, Stewart began organizing a course in paleobotany. It was an easy step into his lab, and I not only took his first course but also assisted in it.

Torrey taught at the University of Massachusetts and influenced many other students, including Henry Andrews, Theodore Delevoryas, and William H. Murdy, all of whom later contributed significantly to paleobotany in the Illinois Basin. Judging from the paleobotanists who studied with Stewart, Hall, Andrews, and Delevoryas, excellent and enthusiastic teaching of paleobotany has attracted a number of paleobotanists into the field at rather late stages in their training.

Stewart wrote of his teaching:

> The paleobotany course just grew like Topsy. If students like the course, it may have something to do with a natural enthusiasm I have for the material and the fact that I have tried to build a teaching collection that will illustrate many of the things we talk about. If I have any objective in teaching paleobotany or any other course, it is to stimulate students' interest in their world. Some want to investigate it in detail and become graduate students in paleobotany.

Hall wrote:

> When Bill Stewart began teaching paleobotany, I was also well along in my thesis so that it was not feasible to change. There is no question about Stewart's influence, however. In my final year at Illinois, Bill was in-

> terviewed for a position at Minnesota, teaching general botany. He turned it down, and in turn recommended me for the position. When I accepted it, realizing that there was already one morphologist-anatomist there (Ernst Abbe), and that a paleobotanist (Banks) had once been there, but left two years before I arrived, it was a logical move to declare myself a paleobotanist. The summer after graduating, I scrambled around collecting coal balls at a number of localities and also got a number of peels from Stewart's material. These formed the nucleus of my paleobotany course.

Of Hall's teaching, Gilbert A. Leisman of Kansas State Teachers College recalls:

> I first became interested in paleobotany while taking Hall's course at Minnesota. In cutting coal balls from Iowa, I had the good fortune to find a new pteridosperm male fructification and I also tried my hand at macerating coal-ball fragments to obtain leaf cuticles. Both of these research experiences really fired my enthusiasm. However, by this time I was so far along in my Ph.D. research in ecology that it was impractical to change. Probably the lack of Ph.D. thesis research in paleobotany was my biggest drawback when I started serious paleobotanical research at Kansas State Teachers College. I almost literally had to train myself in the basics of research and literature search. Conversely, many ecological concepts and principles have proven useful to me in paleobotanical research.

Hall shifted his primary research interest to Cretaceous palynology in the 1950s.

The last students at Urbana to begin their doctoral studies with Stewart were Benton M. Stidd and Julian M. Frankenberg. Stidd completed his master's work with Leisman (Leisman and Stidd, 1967) and his doctorate with Phillips, studying the morphology and anatomy of the frond of *Psaronius* (Stidd, 1971). He also discovered the first young sporophytes of *Psaronius* (Stidd and Phillips, 1968). After two years at the University of Minnesota, where Stidd and Hall (1970 a, b) collaborated on papers on seeds and microsynangia, Stidd joined the biology faculty at Western Illinois University at Macomb. Frankenberg completed his work with Donald A. Eggert, a former student of Delevoryas, studying petrified *Stigmaria* from North America (Frankenberg and Eggert, 1969). Slides and figured specimens of coal-ball plants described by Stewart and his students are located (with some exceptions)in the paleobotanical collections of the Botany Department in Morrill Hall at the University of Illinois.

Stewart's long-range plans were projected toward a systematic study of the coal-ball flora of the United States. As a result of his collecting activities with students, Stewart brought together the most extensive research collection of coal balls from the Illinois Basin, along with representative material from many of the coal-ball localities outside the basin area. Stewart explained:

> Extensive coal-ball collecting was prompted by my desire to get away from describing a coal-ball flora within a single coal ball and to have several specimens of a species as a basis for description, not just one specimen. This led naturally to mass collecting and the investigation of ontogenetic stages of the organisms we were studying. Without the help of Jim Schopf and especially Bob Kosanke and others at the Geological Survey, there would not have been the collections we have today. It was a report from Jack Simon (then with the Coal Section) that put us on to the coal balls from the Sahara mine.

Obviously, coal-ball flora studies are dependent on coal-ball collections from many areas and stratigraphic horizons that may not be avaiable for collecting in the future. A word of caution is appropriate regarding the relative permanence of coal-ball collections from many localities within the Illinois Basin and other areas. In a re-examination of the coal-ball collections at the Illinois Geological Survey and at the University of Illinois at Urbana, the two oldest collections in the Illinois Basin, many coal-ball specimens were found to have disintegrated beyond reconstruction because they had been stored without a protective coating. The length of time coal balls can be preserved seems to depend upon their relative pyrite content and the chemical treatments received by the specimen and may be less than 10 years for many coal balls regarded as being in a good state of preservation when originally cut. Coal balls very low in pyrite content have survived almost 50 years of storage in Noé's collection of coal balls from Indiana.

About an early collecting trip with Stewart, Hall related the following anecdote:

> We were poking around a tipple, at a coal mine that had been abandoned for a number of years, and the prospects really didn't look very good. Suddenly, Bill Stewart reached down and shouted with obvious excitement—"Here's one." So we pried this thing out, which looked suspiciously angular, turned it over, and there, neatly stamped on the lower surface was "Ill. Brick Co." Well, I suspect that neither of us had had much experience with collecting coal balls at that time.

Stewart recalled:

> The first coal-ball collecting trip was made with Jim Schopf and Bob Kosanke. We visited the New Delta mine which is only a couple of miles from the Sahara mine. The coal balls had the same flora [Herrin (No. 6) Coal]. We went to the area around Harrisburg and West Frankfort and ended up in Berryville.

Stewart was Chairman of the Botany Department from 1959 to 1963. In 1964 he wrote *An Upward Outlook in Plant Morphology*, which is the most lucid account of the Telome theory in the English language. In 1965 Stewart accepted the headship of the Botany Department, University of Alberta, Edmonton, Canada, where he has resumed his paleobotanical contributions, some of which are on coal-ball plants from the Illinois Basin (Ramanujam and Stewart, 1969). Stewart wrote:

> The potential for productive coal-ball studies is there and always will be. The basis for this judgment is the magnitude and quality of studies that have come from the University of Illinois laboratories over the past few years. I think it must be pretty apparent that to study coal balls, you have to go to the midwestern coal basins and there are a number of fine laboratories where such work can be done under the direction of competent supervisors.

Mass coal-ball collecting, literally by the ton, began early at the University of Illinois, and the emphasis on ontogeny of petrified Pennsylvanian plants had much of its origin in Stewart's morphological approach, which was expanded and developed by his students, particularly Delevoryas and, in turn, the latter's students. Generosity with the paleobotanical resources at his disposal was a characteristic of Stewart. Outstanding coal-ball specimens were loaned to his former students and to students and faculty at other universities (Fry, 1954; Eggert, 1959a; Phillips, 1961; and others). Andrews was similarly generous with research materials, particularly to Stewart's students.

Theodore Delevoryas quickly came to the attention of the paleobotanical community with a series of coal-ball studies, many carried out jointly with his classmate, Jeanne Morgan, on ferns, calamites, lycopods, pteridosperms, and cordaites from the Illinois Basin (Morgan and Delevoryas, 1952a, b, 1954; Delevoryas and Morgan, 1952, 1954a, b, c; Delevoryas, 1955b, 1956, 1957, 1958; Cohen and Delevoryas, 1959). A Delevoryas (1964b) review of ontogenetic studies of fossil plants conveys considerable insight into the ontogenetic facets of Carboniferous plants revealed by petrifaction studies. After other contributions on coal-ball plants from the basin, Delevoryas turned to Mesozoic plant studies, in particular the cycadeoids.

Donald Eggert, one of the first to study with Delevoryas, developed the concept of determinate growth into important contributions (1961, 1962) on the ontogeny of Carboniferous arborescent Lycopsida and Sphenopsida. After a post-doctoral year with Stewart in Urbana, Eggert established the first paleobotanical program at Southern Illinois University in Carbondale in 1961. Many of his subsequent contributions have been on Paleozoic ferns, particularly on coenopterid ferns (Eggert, 1964) and *Ankyropteris (Tedelea) glabra*, which has become one of the best known ferns as a result of his studies (Eggert, 1959b, 1963; Eggert and Taylor, 1966). Eggert later moved to the University of Illinois at Chicago Circle.

Thomas Taylor (1962, 1965, 1966, 1967a, b; Taylor and Leisman, 1963; Taylor and Delevoryas, 1964; Taylor and Eggert, 1969b) contributed extensively to our knowledge of Pennsylvanian ovules from the basin. He established the first paleobotany program and research laboratory in Paleozoic paleobotany at Chicago Circle.

Recollections of Some Important Discoveries

Some of the plants found in coal balls, although now known to be common in the Illinois Basin, aroused great interest when they were discovered. Each paleobotanist seems to have his own favorite discovery. Hall wrote:

> The shoot apex of Calamites was, like so much in paleobotany, a matter of chance and a good saw cut. In fact, it was several peels before I realized that we had a stem tip [Melchior and Hall, 1961]. I was, however, rather excited about the Anachoropteris-Tubicaulis specimen. The preservation seemed admirable. I spent a lot of time trying to get a feel for the 3-dimensional aspect of it, making a number of camera lucida drawings, and then putting them together in an isometric drawing. I thought more paleobotanists ought to use that technique [Hall, 1961].

Baxter wrote us:

> The most exciting discovery in paleobotany would have to be shared between Calamocarpon insignis and Elaterites triferens. I had been puzzling over the isolated large megasporangia, which ultimately were found attached to a Calamostachys-type cone, for over 15 years before it was finally possible to show that it was a nearly seed-like member of the Sphenopsida [Baxter, 1963]. The Elaterites triferens spores and cone were a high spot in that it was possible to observe the opening of the elaters on the spores after 250 million years of their being appressed to the spore in the cone specimen [Baxter and Leisman, 1967; Wilson, 1943, 1963].

Stewart wrote, "I think I got as excited about *Medullosa pandurata (M. noei)* as any project I have done. Finding micro- and mega-gametophytes in *Pachytesta* was also a spectacular thing" [Stewart, 1951a, b].

Major Coal-Ball Localities

Most of the significant coal-ball localities (fig. 4) in the Illinois Basin have been discovered in active strip mines, and paleobotanists have become aware of them through the cooperation of the coal miners, operators, and the geological surveys. The Illinois Geological Survey has continued the search for coal balls, begun by Noé, during most of the past 50 years, and collections have been made by field parties from many new mining operations or areas. As a result, coal balls were collected from numerous mines and mining areas that are no longer open for paleobotanical collecting.

Two significant coal-ball horizons in the McLeansboro Group of the Illinois Basin are the Calhoun Coal Member in Richland County, Illinois, and the Parker Coal Member of the Patoka Formation near St. Wendel (now spelled St. Wendells), Indiana. The best known localities for each are in the beds and banks of creeks on farms where the thin coal seams were not commercially mined. Discovery of and/or stratigraphic determination for both coals are credited to J. Marvin Weller. Some of the Calhoun coal-ball localities are known as Berryville, Calhoun-North, or New Calhoun. Schopf wrote concerning two of these:

> It must have been about 1937 that Marvin Weller brought me a few small sample sacks of material he had collected in a creek bed in Richland County. The material consisted of weathered out and remarkably well-preserved examples of coal-ball type Psaronius roots. There was no trouble finding the big limy lens where the creek had nearly worn through. This became the Berryville locality.

The Calhoun-North locality was discovered by Harold R. Wanless, distinguished Pennsylvanian stratigrapher of the University of Illinois, and Donald L. Carroll, Educational Extension geologist of the Illinois Geological Survey, while on a field trip in the Calhoun vicinity (Schopf, 1938c). Schopf related that Carroll:

> ...came into my office with a story of a big mass of coal balls he had found a few miles from Berryville. Operators of a small limestone quarry above a thin coal bed had decided to get out some coal. They got an entry back a little way and ran into something hard. It must have been a lot of work getting it loose, but they had a winch outside and attached a cable and brought it out and dumped it on the ledge on top. It was about five feet long. There wasn't any other fossil material around the mine entrance, which was flooded with water from the quarry, so we broke this one block up into pieces small enough to load in the truck. This was my Calhoun-North locality. If they ever open up the quarry to expose the coal again, this should be marvelous collecting. Former strip mines had worked the Calhoun Coal a few miles to the south and Noé had earlier obtained some coal balls from that locality.
>
> But the thing that greatly impressed me about the aggregate we got at the Calhoun-North quarry was a number of peculiar lycopod cones, and a number of structures I could identify with Dolerotheca [Schopf, 1948a]. There also were at least a half dozen beautifully preserved stems of Psaronius, big specimens of Medullosa noei, Alethopteris leaves, lots of lycopsid cortex, and many roots. I am still not sure that it is the same coal bed as that at Berryville, but I suspect it is. I did the Mazocarpon paper first, incorporating in it some stratigraphic notes from a paper I presented in 1940 in Milwaukee [Schopf, 1941b].

The "stratigraphic notes" contained in Schopf's paper on *Mazocarpon oedipternum* (1941b) presented the first and still the most detailed consideration of the

stratigraphy of coal-ball horizons in the United States and Europe, and his concern (Schopf, 1950) about precision in stratigraphic reports of coal-ball sources has greatly influenced American paleobotanists. In his 1950 paper the silicified coal balls from the coal in the Shumway Cyclothem, the youngest coal-ball horizon yet discovered in the Illinois Basin, and the occurrence of coal balls in the Parker Coal at St. Wendel, Posey County, Indiana, were first reported. The latter occurrence was first discovered by John Lester, formerly of the Stratigraphy and Paleontology Division of the Illinois Geological Survey (Schopf, 1941b, p. 11).

Many of the coal-ball localities in the Illinois Basin became better known to paleobotanists in the late 1940s and early 1950s as a result of an extended collecting trip by Schopf in 1948, shortly after he joined the U. S. Geological Survey. Traveling in a Jeep, Schopf visited all the coal-ball localities known to him in the United States, and subsequent collections were made at many of these localities by Andrews, Baxter, Canright, Mamay, Stewart, and others. Schopf made arrangements to meet Kosanke near Boonville, Indiana, as he began the tour of the localities in the Illinois Basin. Schopf had never before seen coal balls from the Springfield Coal (V) in Indiana and he found the material outstanding. Schopf told Andrews about the coal balls, and Andrews and Baxter set out for the Wasson Mine locality near Boonville in a rented truck from St. Louis. Andrews wrote, "We were told by the mine superintendent that it was the first time that coal balls had been found there in some 25 years of mining." Baxter recalled the Boonville trip:

> This was a major coal-ball collecting trip for Henry and me. We loaded at least a ton and, on returning to St. Louis, Henry gave me about a third of the load as my share. It was out of my portion of these coal balls that the exceptional specimen of Ankyropteris glabra came, as well as the original material of Peltastrobus reedae [Baxter, 1951b, 1950; Leisman and Graves, 1964]. The Ankyropteris glabra was almost perfectly preserved throughout 29 cm total length and four nodes and internodes.

Further details of the Wasson Mine collection are given in Andrews (1951) and Andrews and Mamay (1952).

Schopf and Kosanke returned to the St. Wendel locality in Indiana, which was a difficult bank exposure to work, but they were reasonably successful in getting material. The St. Wendel locality had many roots from large living oaks covering masses of coal-ball material, which consisted mainly of the roots of previous occupants, *Psaronius* tree ferns. Hall enthusiastically recalled a coal ball from St. Wendel:

> I well remember that first coal ball I cut; it was 'CB 57' from St. Wendel, Indiana, and the reason I remember it so well is that it had the material of Heterangium americanum whose phloem I later described [Hall, 1952]. Later, Morgan and Delevoryas described Stewartiopteris from this same coal ball [Morgan and Delevoryas, 1952b].

The next stop for Schopf and Kosanke was the Berryville locality, where Andrews and Baxter joined them. Later, Stewart made extensive collections there and it was on one of those field trips with Stewart and Delevoryas that Arnold found a coal ball containing three *Calamostachys americana* cones (Arnold, 1958). The high quality of preservation of the coal balls from the Calhoun Coal at Berryville stimulated the use of dynamite, bulldozers, and portable jack hammers, for, as the collection of the numerous coal balls in the seam extended farther into the creek bank, the thickness of glacial overburden made a weekend pick and shovel excavation prohibitive. Andrews first conceived and effectively carried out a bulldozing operation at Berryville in 1959, and several tons of excellent material were

acquired for the *Botryopteris* study by Phillips (1961). Out of this collection came a specimen of *Botryopteris trisecta* that showed the osmunda-like habit of the plant. A specimen of *Catenopteris simplex* also was found (Phillips and Andrews, 1966).

Delevoryas and Henry W. Harris, a former army demolitionist who always collected with the paleobotanists from Urbana, later applied dynamite to the Berryville outcrop. Bulldozing was again effectively used at Berryville by Phillips and Stidd and later by Taylor and Eggert, who added the use of a jack hammer in the late 1960s.

Collections were also made by Schopf and Kosanke south of Danville, Illinois, on the Little Vermilion River. With Cady and Simon they also visited a new locality, the Pyramid Mine in the Herrin (No. 6) Coal in southern Illinois. Schopf wrote of this, "Nearly the whole bed had been permineralized and good plant material was abundant. I know the Illinois Survey got a couple truck loads and I collected about 600 pounds." As a result of these collections and others from outside the basin, Schopf brought together at the U. S. Geological Survey one of the most significant coal-ball collections in the United States.

Since Schopf's 1948 visit, two important localities of coal balls have been found in the No. 6 Coal. The Sahara Coal Company No. 6 Mine near Carrier Mills, Illinois, has yielded the largest number of coal balls with well preserved plants. Subsequent studies of the plants have greatly expanded our knowledge of the No. 6 Coal flora, and it and the Calhoun Coal flora are the best known coal-ball floras in the Illinois Basin. Some coal balls were collected by M. E. Hopkins, Head of the Illinois Geological Survey's Coal Section, and R. A. Peppers, Survey paleobotanist, in the Peabody Eagle Mine No. 2 near Shawneetown, Illinois, during the excavation of the pit in the summer of 1967. Upon returning to the pit in the summer of 1968, they discovered vast quantities of coal balls, probably the largest mass occurrence of coal balls encountered in the Illinois Basin. Large collections were obtained from the area by the University of Illinois at Urbana, Western Illinois University at Macomb, Eastern Illinois University at Charleston, the Survey, and by Leisman from Kansas State Teachers College. The massive coal-ball zones had been anticipated prior to stripping operations when drill cores, studied by Kosanke, Simon, and Smith (1958), revealed coal balls replacing the coal in 9 of the total 10.2-foot thickness. The coal is normally about 3 feet thick in the area, but compaction is markedly less in the massive coal-ball deposits.

More recent discoveries of coal balls from coals in the Illinois part of the basin include one from the Banner Mine near Peoria, reported by Damberger of the Illinois Survey (*in* Smith et al., 1970), from the Colchester (No. 2) Coal, which rarely contains coal balls; one in the Summum (No. 4) Coal in pit 14 of the Peabody Northern Illinois Mine at South Wilmington; and several massive aggregates of coal-ball material discovered in the Friendsville Coal near Allendale by Roger Nance of the Survey.

One of the significant coal-ball localities in the Kentucky portion of the basin was visited in 1962 by J. A. Simon and W. H. Smith of the Illinois Geological Survey just west of Providence, Kentucky, where the Hart and Hart Coal Company operated. The coal-ball aggregates were exposed near an undisturbed hill surrounded by strip-mined land. The precise correlation of the "Baker" coal in which the coal balls were found is not known, but it is apparently between the Herrin (No. 6) and Danville (No. 7) Coals of Illinois. The flora contains abundant *Sphenophyllum* and a number of genera such as *Stelastellara* and *Schopfiastrum*, which were not previously known from the Illinois Basin.

Canright has reported many coal-ball localities in the Indiana portion of the basin (Canright, 1959). He wrote us:

> The most impressive coal-ball find was associated with the Parker Coal of Posey County (Andrews told me about the site). A huge calcified mass is embedded in a creek bed near St. Wendel—roots of Psaronius are most abundant and cellular details are beautifully preserved.

William S. Benninghoff, who was an undergraduate assistant in Darrah's lab at Harvard, earlier published a brief report of a coal-ball flora from Indiana's Springfield Coal Member (V) (Benninghoff, 1942). A general discussion of some of the plant genera in the coal balls from Indiana has been given by Judd and Nisbet (1969).

The availability of calcareous coal balls for research and teaching in the Illinois Basin is without parallel elsewhere in the United States, but a number of coal-ball localities at several stratigraphic positions in the Pennsylvanian in other states, principally Kansas, Iowa, and eastern Kentucky, have proved to be of equal importance as complementary records of the morphological evolution of the swamp plants, as are still older localities in western Europe.

Along with the marked increase in coal-ball studies during the past two decades, following Schopf's revisit to the basin, varying degrees of financial support for paleobotanical studies at universities have been received from the National Science Foundation, which was established in 1950. Grants for equipment, supplies, field trips, and graduate student stipends, either directly from the foundation or indirectly from graduate research boards or councils at the universities, allowed a number of institutions to establish paleobotanical research for the first time or to increase research programs.

Recent Contributions to Taxonomic Groups of Megafossils

Since the reviews of Andrews (1951) and of Andrews and Mamay (1955), paleobotany in the Illinois Basin and adjacent areas has contributed significantly to most of the taxonomic groups of plants in the Illinois Basin. Least emphasis has been on algae and the gymnospermous Cordaitales. The ontogenetic approach to coal-ball studies has been one of the important contributions by paleobotanists in the past two decades. The increased awareness of the diversity in most taxonomic groups has been a natural outgrowth of the increase in research from the Illinois Basin. The studies of the ferns, Coenopteridales and Marattiales, are among the most significant taxonomic achievements of the past 20 years. The contributions of, roughly, the past two decades are cited following, according to taxonomic group.

Early reports of fossil fungi penetrating vascular plant tissues in coal balls were made by Coulter and Land (1911) and Andrews and Lenz (1943). More recent contributions by Agashe and Tilak (1970), Batra, Segal, and Baxter (1964), Cridland (1962), and Dennis (1969a, 1970) have now established the presence of all three major groups of fungi in Pennsylvanian coal balls. Baxter (1960) and Davis and Leisman (1962) studied the *Sporocarpon*-like bodies from the American Pennsylvanian.

Highly significant ontogenetic studies in the morphology of arborescent lycopods were made by Andrews and Murdy (1958), Arnold (1960), Eggert (1961), Balbach (1962), Baxter (1965), Delevoryas (1967), and Ramanujam and Stewart

(1969). Cones and spores from compressions were described by Abbott (1963), Chaloner (1956, 1958), and Wood (1957), and from coal balls by Felix (1954), Balbach (1962, 1965, 1966a, and 1967), Leisman (1962a, b, 1970), Leisman and Spohn (1962), and Leisman and Stidd (1967).

Studies of vegetative parts of plants in compressions were carried out by Abbott (1968), while Evers (1951), Felix (1952), and Delevoryas (1957) reported on vegetative parts from coal balls. The underground portion of plants, *Stigmaria*, was described by Frankenberg and Eggert (1969) and Pfefferkorn (1972), and compression studies of stems and roots were made by Abbott (1968).

The herbaceous lycopod, *Selaginella* (*Paurodendron*, *Selaginellites*) has become one of the best known lower vascular plants from compressions and coal balls as a result of studies by Darrah (1938b), Fry (1954), Hoskins and Abbott (1956), Leisman (1961), Phillips and Leisman (1966), and Schlanker and Leisman (1969).

The vegetative remains of calamites, preserved largely as compressions, were studied by Abbott (1958), and fructifications of calamites were described by Hibbert and Eggert (1965), Abbott (1968), and Kosanke (1955), who also described the anatomy. Coal-ball studies of the vegetative anatomy of calamites were made by Andrews (1952), Anderson (1954), Andrews and Mahabale (1961), Andrews and Agashe (1965), Agashe (1964), Melchoir and Hall (1961), Eggert (1962), Good (1971), and Reed (1952). Cone anatomy, spores, and gametophytes attributed to the calamites were described by Arnold (1958), Baxter (1955, 1962, 1963, 1964, 1965), and Leisman and Bucher (1971), while the data linking calamites and equiseta were published by Baxter and Leisman (1967).

Sphenophyllum from compressions was reported by Abbott (1958), and its vegetative anatomy was described by Baxter (1948), Reed (1949), Phillips (1959), and Schabilion (1969). Despite the very few vegetative species of *Sphenophyllum* from petrifactions, several taxa have become known from past and recent studies on *Bowmanites* by Andrews and Mamay (1951) and Mamay (1959), on *Peltastrobus* by Baxter (1950) and Leisman and Graves (1964), on *Litostrobus* by Mamay (1954a), Reed (1956), Leisman (1964a), and Baxter (1967), and on *Sphenostrobus* by Levittan and Barghoorn (1948).

One of the major contributions from the Illinois Basin and adjacent areas is the elucidation and description of the smaller ferns assigned historically to the Coenopteridales and other genera. *Ankyropteris (Tedelea) glabra* is one of the best known as a result of the studies by Baxter (1951b), Andrews (1956), Eggert (1959b, 1963), and Eggert and Taylor (1966). *Botryopteris* is probably the best known genus from the research by Mamay and Andrews (1950), Delevoryas and Morgan (1954c), Murdy and Andrews (1957), Phillips (1961), Phillips and Andrews (1965), and Phillips and Rosso (1970). Organic connection between *Anachoropteris* and *Tubicaulis* was established by Hall (1961), and important contributions were made on both *Anachoropteris* (Delevoryas and Morgan, 1954a; Phillips and Andrews, 1965) and *Tubicaulis* (Mamay, 1952; Delevoryas and Morgan, 1952; Eggert, 1959a).

New genera of coenopterid ferns were described as *Apotropteris* (Morgan and Delevoryas, 1954), *Biscalitheca* (Mamay, 1957; Abbott, 1961; Cridland, 1966; Phillips and Andrews, 1968), *Catenopteris* (Phillips and Andrews, 1966), *Eopteridangium* (Andrews and Agashe, 1963) and *Sermaya* (Eggert and Delevoryas, 1967). The first American occurrence of *Rhabdoxylon* was reported by Dennis (1968b). Research on the vegetative anatomy of zygopterid ferns was carried out by Andrews

(1942a), Baxter (1952), and Dennis (1969b). Abbott (1954) wrote a monograph on the fern genus *Oligocarpia*.

The morphology of marattiaceous ferns is largely but not exclusively derived from Pennsylvanian fossils of Illinois. Beginning with Lesquereux's (1879, 1880a) original description of *Caulopteris giffordi*, the petrified (silicified and calcified) genus *Psaronius* was studied by Hoskins (1934), Gillette (1937), Moon (1939), Reed (1949), Baxter (1953), Morgan (1959), Stidd and Phillips (1968), and Stidd (1971). Foliar members were described by Lenz (1942), Morgan and Delevoryas (1952a, b), and Stidd (1971). *Scolecopteris* fructifications were described by Ewart (1961) and Mamay (1950), who also studied other fructification genera of marattiaceous ferns.

Pteridosperms that occur in the Illinois Basin are known from the coal-ball studies on *Medullosa* by Arnold and Steidtmann (1937), Steidtmann (1937, 1944), Schopf (1939), Andrews (1945), Baxter (1949), Stewart (1951a), Stewart and Delevoryas (1952, 1956), Delevoryas (1955a), Norton (1966), and Dennis (1968a); on *Sutcliffia* by Phillips and Andrews (1963); on *Callistophyton* by Delevoryas and Morgan (1954b) and Delevoryas (1956); on *Heterangium* by Andrews (1945) and Hall (1952); and on *Microspermopteris* by Baxter (1949).

The study of ovules from coal balls added considerable information on known genera: *Conostoma* (Neely, 1951; Taylor and Leisman, 1963; Taylor, 1967b; Rothwell and Eggert, 1970; Rothwell, 1971); *Hexapterospermum* (Taylor, 1966; Matten and Hopkins, 1967); *Pachytesta* (Stewart, 1951b, 1954, and 1958; Taylor and Delevoryas, 1964; Taylor, 1965; Taylor and Eggert, 1969b); *Physostoma* (Leisman, 1964b); *Stephanospermum* (Hall, 1954; Taylor, 1962; Leisman and Roth, 1963); and *Taxospermum* (Neely, 1951). Newly described genera include *Albertlongia* (Taylor, 1967b), *Callospermarion* (Eggert and Delevoryas, 1960; Stidd and Hall, 1970b), *Coronostoma* (Neely, 1951), and *Tyliosperma* (Mamay, 1954b).

Significant discoveries of pollen-bearing structures that were made in compression genera include *Aulacotheca* (Eggert and Kryder, 1969), *Crossotheca* (Andrews and Mamay, 1948) and the new genus, *Schopfitheca* (Delevoryas, 1964a). *Dolerotheca* was described by Schopf (1948a) and by Baxter (1949). Five new petrified genera were described recently: *Callandrium* (Stidd and Hall, 1970a), *Halletheca* (Taylor, 1971), *Idanothekion* (Millay and Eggert, 1970), *Lasiostrobus* (Taylor, 1969, 1970), and *Rhetinotheca* (Leisman and Peters, 1970).

The Cordaitales from coal balls in the Illinois Basin are known only from the studies of Cohen and Delevoryas (1959) and Judd and Nisbet (1969). Anatomical studies of Cordaitales from outside the basin were published by Andrews (1942a), Andrews and Felix (1952), Baxter and Roth (1954), Brush and Barghoorn (1962), Cridland (1964), Darrah (1940), Fry (1956), Harms and Leisman (1961), Leisman (1961), Pierce and Hall (1953), Reed (1946), Reed and Sandoe (1951), Roth (1956), Traverse (1950), and Wilson and Johnson (1940).

Palynology

The early history of the development of palynology—the study of spores and pollen—can be found in publications by Wodehouse (1935), Erdtman (1943), Faegri and Iversen (1964), and others. Few of the earliest contributors who worked outside the Illinois Basin, however, are mentioned here. Witham (1833) is thought to have been the first to observe fossil plant spores, but he did not recognize their true nature. Von Post (1916), who worked with material from Swedish bogs, presented the first modern percentage analysis for pollen. Prestwich (1840), who

acknowledged the aid of Morris in plant descriptions, was the first to illustrate isolated fossil megaspores, and Binnie and Kidston (1886) described the Carboniferous spores of Scotland. Thiessen and Staud (1923) and Thiessen and Wilson (1924), who used thin sections of coal from the Appalachian region, are credited with being the first to use spores in the identification and correlation of coal seams. Raistrick (Raistrick and Simpson, 1933; Raistrick, 1934) macerated coals and used the isolated spores to correlate coal seams in England.

Some of the earliest studies in fossil plant spores and pollen in the United States were carried out in the Illinois Basin. Thiessen (White and Thiessen, 1913; Thiessen, 1920), in order to demonstrate some of the botanical constituents in coal, was probably the first to illustrate spores macerated from Illinois coal. Most of his publications, however, concerned his system of petrographic classification of coal.

Illinois State Geological Survey

Louis C. McCabe of the Illinois Geological Survey is generally credited with being the first to publish (1932) a paper entirely devoted to a study of macerated coal samples from the Illinois Basin. He described and illustrated some characteristic spores, cuticles, and woody structures macerated from the 13 coal members he studied. McCabe recognized the geological and stratigraphic significance of differences in spore assemblages from one coal to another. The botanical and lithological constituents of the Herrin (No. 6 Coal) were the subjects of McCabe's dissertation (1933).

O.J. Henbest, who was a field assistant to David White during White's later work in the Illinois Basin, wrote a note (1933a) that was a general discussion of spores and other botanical constituents in macerated residues and thin sections in the No. 6 Coal. His unpublished master's thesis on the floras of certain carbonaceous shales of Illinois dealt largely with lycopods and lycopod cones from the Francis Creek Shale (Henbest, 1933b). In another paper (1936) he compared size and ornamentation of some modern and fossil lycopod spores.

Cady (1933) discussed and illustrated macerated megaspores, small spores, resin, and cell structures in Illinois coal and showed how they appear in thin sections.

Schopf not only made many contributions to our knowledge of Pennsylvanian plant megafossils of Illinois, but he was also an early and active worker in the study of plant spores. Schopf (1936b, 1938d) investigated in detail the spores of the No. 6 Coal, which is generally the thickest and economically most important coal in Illinois. He discussed (1938d) maceration techniques, botanical considerations (including some of the most lucid biological descriptions of spores to be found), and taxonomy of fossil spores. Most of the study was devoted to a systematic description of the megaspores and prepollen found in coal.

The Annotated Synopsis of Paleozoic Fossil Spores and the Definition of Generic Groups, by Schopf, Wilson, and Bentall (1944) became a classic in American palynology because it provided a basis for a system of classification of fossil spores. The publication increased interest in spore studies among paleobotanists, and the system of classification it presented was used for many years, especially in the United States. Many of the generic definitions were incorporated by the classification devised by Potonié and Kremp (1954, 1955, 1956) and their followers, which is now widely used. The genesis of the 1944 paper was explained by Schopf:

> I first became acquainted with Dick Wilson about 1936. I had become much concerned with the various classifications based on spores and I learned that he was too. I think [the publication by] "Wilson and Coe" [1940] had just appeared. It seemed logical that we get together on the classification. I had learned of Bentall's work in Tennessee and it seemed to me a good idea to bring him in too. He did most of the drawings for the publication by Schopf, Wilson, and Bentall (1944) and he also made other constructive suggestions after I had written a first draft version.

Two students who did their graduate work under H. R. Wanless at the University of Illinois completed their theses in palynology. Brokaw (1942) correlated the Springfield (No. 5) and Harrisburg (No. 5) Coals by the use of spores. Eddings (1947) described the small spores of the Chapel (No. 8) Coal (formerly called the Trivoli Coal) and showed both the lateral extent of the coal and the thickness of the interval between the No. 6 and No. 8 Coals.

Robert M. Kosanke joined the Illinois Geological Survey in late 1942, working under Cady in the Coal Section. He later replaced Schopf as Survey paleobotanist when Schopf moved to the Bureau of Mines in 1943. Kosanke, like Schopf, contributed to all branches of paleobotany in the Illinois Basin, but his major contributions were in the areas of palynology, research, and teaching. Asked how he got started in these areas, Kosanke wrote: "My interest in geology-paleontology-paleobotany originated with a science requirement, general geology, at Coe College, taught by Leonard R. Wilson. I started graduate work at Cincinnati with J. H. Hoskins in 1940." It was when Hoskins went on leave early in World War II that Kosanke joined the Illinois Survey.

Kosanke later continued his graduate studies at the University of Illinois, completing his degree in 1952 under Stewart. He received a part-time appointment to the University botany staff in 1958 and taught a course in palynology. He had gained early palynological experience from undergraduate research with Wilson on interglacial peat deposits in Iowa (Wilson and Kosanke, 1940) and from a study of microfossils from Pennsylvanian coal from Iowa, his senior thesis (Wilson and Kosanke, 1944). Kosanke wrote us, "...I was delighted to have the opportunity to teach palynology in the graduate college at Illinois. Even when I started teaching palynology in 1958 there were few schools in the United States offering such a course." One of Kosanke's early students in that course was Russel A. Peppers, who replaced him at the Survey shortly after Kosanke joined the U. S. Geological Survey in Denver in 1963.

Peppers recalls how he was introduced to palynology by Kosanke:

> William Merril, advisor for my master's thesis at the University of Illinois, suggested that I collect some carbonaceous material from the Muddy Sandstone Member (Cretaceous) to see if it would yield spores or pollen. I was making a general stratigraphic study of the Muddy in parts of the Powder River Basin, Wyoming. I brought a few samples to Kosanke, and he showed me how to macerate them and prepare the material. Although the sample did not yield a large variety of spores, I became interested in palynology and completed my doctoral thesis under Kosanke.

Kosanke (1945a, 1947, and 1950), while with the Illinois Geological Survey, was one of the first in the United States to establish a framework of correlation of coals in an entire basin and through a thick sequence of strata. In his 1950 publication, which is now a basic reference for Pennsylvanian spores in the United

States, more than 100 new species of spores were described. Concerning his thinking at the beginning of the 1950 study, Kosanke wrote us:

> I felt I had demonstrated (1943) the value of coal correlations using spores and pollen so that my own thoughts on the matter at the start of the Illinois project were simply to establish the range zones and consequent results....Plant succession, whether modern or from the fossil record, records change, and change is interesting to examine. I believe such changes are easier to follow in palynology than in studies of megascopic remains.

At a symposium on oil exploration in 1964, Kosanke illustrated some spores and discussed how spore data from Paleozoic strata could be applied to oil exploration.

Kosanke came in contact with many paleobotanists on collecting trips in the Illinois Basin and other areas, among them Schopf, Andrews, Arnold, Just, Hoskins, Stewart, Baxter, Mamay, and Delevoryas. Although Kosanke did not study coal-ball plants extensively, upon noticing that the plant material in them had not been replaced, he (Kosanke, 1945b) devised a way to stain plant remains in calcareous coal balls.

Palynological maceration techniques usually result in the separation of the megaspores and miospores that form the bases for most palynological research. Thus, megaspores become the subject of specialized study. The most comprehensive description of Mississippian and Pennsylvanian megaspores in the United States is Marcia R. Winslow's publication (1959) on the Illinois megaspores.

Peppers (1964) compared the variations in abundance and variety of spores from various lithologic units in several cylothems in the Illinois Basin. In 1970 he studied in detail the spore assemblages from numerous samples of coals from the Carbondale and upper Spoon Formations of the Illinois Basin. Although coal correlation was the primary purpose of the study, variations in spore assemblages in several coals were found to be related to some extent to structural features, which were thought to have produced differences in surface elevation at the time of coal deposition.

Comparative studies of spores from compressions have been made by Pfefferkorn, Peppers, and Phillips (1971).

Indiana University and Indiana Geological Survey

Experiences leading to the first palynology course at Indiana University were described by Canright:

> The summer of 1958 Gulf Oil asked me to go to Caracas to help set up a palynology lab for the subsidiary, Mene Grande Oil Company. There I worked on the Eocene palynomorphs of the Maracaibo Basin, as well as a Lower Cretaceous core from Ghana....in 1959, I established a palynology course at Indiana University at the graduate level.

Canright became Chairman of the Botany Department of Arizona State University at Tempe in 1964, and the collections made by him and his students from the Illinois Basin from 1954 to 1964 were acquired for the paleobotanical collections in the Botany Department at Indiana University, where David C. Dilcher is paleobotanist and Donald R. Whitehead is palynologist.

G. K. Guennel, while paleobotanist with the Indiana Geological Survey, contributed two important papers on the palynology of Indiana coals. The first

dealt with the use of spores in the differentiation of coals in the Alleghenian Series and the second was concerned with coals in the Pottsvillian Series (Guennel, 1952, 1958). Guennel (1954) also discussed the megaspore species *Triletes triangularis*, which is found in abundance in one of the Block Coal Members of Indiana. The paleobotany, including spores, and chemical composition of the Indiana paper coal and its depositional environment have been studied by Neavel and Guennel (1960). The Indiana coal also provided material for a study of the origin and function of the thickened portion of the exine of *Torispora* and the relation of this genus to the sporangium *Bicolaria* (Guennel and Neavel, 1961). The depositional environment of the Colchester Coal (IIIa) of Indiana was interpreted by Neavel (*in* Zangerl and Richardson, 1963) from his petrographic analyses and from Guennel's spore analyses of various intervals through the coal. After Guennel went to Marathon Oil Company, H. W. Lee took over palynological studies at the Indiana Survey for a short time. He published a paper on a coal maceration method in 1964.

University Studies

Gray and Taylor (1967a) described and illustrated some morphological variations in *Ahrensisporites symetricus* from a coal in the Mansfield Formation in Putnam County, Indiana. The same authors (1967b) compared the spore assemblages from the Schultztown Coal of western Kentucky with that of the Colchester (No. 2) Coal of Illinois. Lewis R. Gray, who received his doctorate at the University of Illinois and is now at the Amundsen-Mayfair Branch of Chicago City College, was Kosanke's last graduate student at Illinois. Taylor's interest in palynology developed early, and he and Eggert at Chicago Circle embarked on the light and electron microscopy study of the spores and pollen from coal-ball fructifications (Taylor, 1968, 1970; Taylor and Eggert, 1969a; and Taylor and Millay, 1969).

The scanning electron microscope is a new, significant tool for microfossil studies, and it has permitted the resolution and effective illustration of morphological differences in spores of quite similar coal-ball plants from different stratigraphic positions (Phillips and Rosso, 1970). Spores and pollen from identifiable fructifications and attached foliage or axes can be identified with isolated spores from coal and other sedimentary rocks to provide a basis for establishing natural affinities of isolated spores, their variation within a single sporangium, and various stages of maturation, as was done by Hall and Stidd (1971).

Contribution of Coal Petrography to Paleobotany

Coal petrography is the description and classification of the components of coal, and its study in the Illinois Basin began in the 1920s. The emphasis of early research in coal petrography was directed toward discovering the paleobotanical composition of coal to find clues to how coal was formed. To achieve this goal, both chemical (maceration) and physical methods (thin sections, polished sections) were developed for studying the organic components of coal. However, the paleobotanical information contributed by petrographic studies is rather limited in comparison with the detailed information to be obtained from palynology and the study of coal balls. Only in rare cases can techniques of petrographic study be used to classify plant specimens.

Before 1920, Reinhardt Thiessen developed at the U. S. Bureau of Mines a system of terminology based primarily on data derived from thin sections of coal. Thiessen's work was paleobotanically oriented and was undoubtedly influenced by his close association with David White. Thiessen did not publish the essentials of his methods. When Schopf joined the U. S. Bureau of Mines staff in 1943, he was determined "to find out how Thiessen's system of coal petrography actually works." After much research he did publish (1956) a coherent account of the system.

Since the late 1920s and early 1930s, most of the work in coal petrography has been related to evaluating coal for various commercial uses. The terminology of modern coal petrography is based on nomenclature originally developed by Stopes (1919) from megascopic examination of coal. This system was soon adapted to describing the coal elements revealed with a microscope. It is now commonly known as the Stopes-Heerlen system because it was revised and presented at the Second International Carboniferous Congress at Heerlen in 1935. Although the system is fundamentally based on "macerals" (constituents of coal considered analogous to minerals in rocks), the plant origin of the macerals has been generally recognized. The *International Handbook of Coal Petrography* (1963), prepared by the International Committee for Coal Petrology, defines terms for coal constituents commonly used in coal petrography. Cady (1942) introduced the name "phyteral" for organic plant forms or fossils in coal to distinguish them from the organic material of which the fossils may be composed (macerals). Much of the work using the Stopes-Heerlen system has been done with reflected light (metallurgical techniques), although thin sections have also been used.

Cady (1939, *in* Lowry, 1945, 1960), Parks and O'Donnell (1956), Marshall (1955), Schopf (1956), Harrison (1961), and others have discussed and compared the Thiessen and Stopes-Heerlen systems of terminology. The relations of the two systems to the paleobotanical composition of coal are readily recognized, although some uncertainties have developed in their use where relations to paleobotany have not been established. Thiessen (1913) briefly recounted the early history of the study of microscopic coal constituents. Much of the subsequent history of coal petrology, including contributions by Midwestern workers, is reported in Marshall (1955). How the field of coal petrography has expanded was indicated by Berry, Cameron, and Nandi (1967), who discussed the developments in coal petrography in North America, and by Mackowskr (1967), who wrote of the recent progress in the field.

Although many papers concerned with petrography of coals in the Illinois Basin have been published, most of them are only indirectly related to paleobotany. In addition to the summaries in Thiessen (1913) and Marshall (1955), reports on coal petrography are listed in Willman et al. (1968), Nevers and Walker (1962), and in the lists of publications of the Illinois, Indiana, and Kentucky Geological Surveys.

Probably the earliest micropetrographic study of Illinois Basin coals was reported by Thiessen in 1913. In that classic contribution, *The Origin of Coal*, White and Thiessen (1913, pls. 1-4, 43-54) provided exceptionally fine illustrations of plant compressions on the bedding planes of bituminous coals from Illinois and recognizable botanical components in sections of the Rock Island (No. 1) Coal Member (which they called "Exeter Coal") and Shelbyville Coal Member of Illinois, as well as of isolated spores and cuticles. The study, which was initiated to determine the relations between plant composition and coal types and their properties, mentions some of the plants in the Rock Island and Shelbyville Coals.

Thiessen (1920, 1930), in describing his system of coal classification, illustrated several thin sections of Illinois coal and several spores that had been macerated from coals, among which were the Shelbyville and Herrin (No. 6) Coals of Illinois. Several coals were distinguishable by the dominance of certain spore taxa.

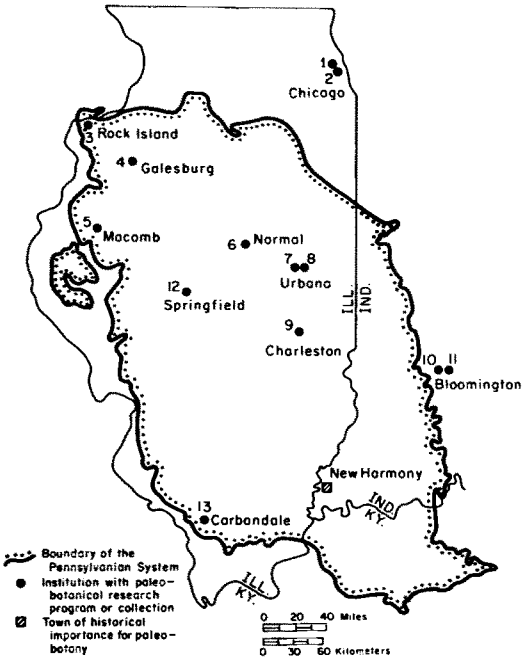
Vertical changes in paleobotanical composition of coals revealed in thin sections were considered by Ball (1932) as a possible tool in correlation of Illinois coals. He remarked on the difficulty of identifying spores from various planes in thin sections and thought that a classification of spores was needed before spores could be used to any extent in correlation.

Fieldner et al. (1932) and L. C. McCabe (1932, 1933, 1934) described and illustrated some of the paleobotanical constituents of the No. 6 Coal in Illinois. McCabe noted that vitrain might show the anatomy of plants, the presence of branches, growth stages, and different stages of preservation. W. S. McCabe (1936) etched polished surfaces of the No. 6 Coal with a mixture of sulfuric and chromic acid to reveal more clearly the resins, spores, cuticles, and cell structures in vitrain. As mentioned in the section on palynological studies, O. J. Henbest (1933a) compared botanical constituents in macerated coal residues with the constituents observed in thin sections. In a discussion of the botanical components in Illinois coal, G. H. Cady (1933) illustrated thin sections showing spores, resin, cuticular tissue, and xylem cell structures and compared them with macerated material.

In addition to his palynological investigations, Kosanke was interested in broader aspects of coal composition. In 1951 he used thin sections and polished sections to investigate a boghead coal from the upper part of the Tarter Coal Member (Abbott Formation) of northern Illinois, which is equivalent to the Willis Coal Member of southern Illinois. He compared the algal colonies in the Tarter Coal with those found in boghead coals of Pennsylvania and Kentucky. Kosanke (1952) presented the chemical analyses of various botanical constituents, including megaspores, cuticles, and resin rodlets of several coals from Illinois and elsewhere. Resin rodlets from several Illinois coals were thought by Kosanke and Harrison (1957) to be produced by the pteridosperm *Medullosa*.

Anticipated Directions in Pennsylvanian Paleobotany

The Illinois Basin is now roughly outlined by institutions with active teaching and/or research programs in paleobotany, for the most part the larger universities and the geological surveys (fig. 5). The number of paleobotanists at universities and colleges represents a major expansion in paleobotany in the last two decades in the United States. More geology, biology, and general liberal arts students are being exposed to paleobotany as an interesting and active field of study. Paleobotanists, although still a small group compared to the numerous workers in other areas of paleontology, are increasing in number. They are exploring new areas of study and renewing interest in older areas. This intensified research is seen in the rapid increase of published pages during the last 25 years. The pioneers of paleobotany in the Illinois Basin have passed along important discoveries, a broad understanding of Pennsylvanian plants, and basic frameworks in all branches for more precise and extensive paleobotanical contributions. As more information becomes available, there is a growing need for synthesis and efficient retrieval of paleobotanical data. Synthesis, particularly, is needed in palynology.



1 - Field Museum of Natural History (formerly Chicago Natural History Museum)
2 - University of Illinois at Chicago Circle
3 - Augustana College
4 - Knox College
5 - Western Illinois University
6 - Illinois State University
7 - Illinois State Geological Survey
8 - University of Illinois
9 - Eastern Illinois University
10 - Indiana Geological Survey
11 - Indiana University
12 - Illinois State Museum
13 - Southern Illinois University

Fig. 5 - Institutions in the Illinois Basin that have paleobotanical research programs or collections.

The study of plants from coal balls from 14 coals within the Illinois Basin provides a paleobotanical framework on which evolutionary studies of species and genera can be carried out. Such studies may be complemented by work on coal balls from stratigraphic horizons in other areas of the United States (for example, Kansas, Iowa, Oklahoma, eastern Kentucky) and in Europe. Because coal balls from North America and Europe are complementary, it is possible to follow anatomically certain common genera through more than 20 sampling zones, spanning virtually the entire Pennsylvanian or Upper Carboniferous (Silesian) Period.

Future studies probably will examine the evolutionary basis for morphological concepts in appropriate taxonomic groups. Mycological studies of coal-ball floras and comparisons of the foliage in coal-ball plants with the compression floras promise to yield significant data. Coal-ball studies at present are concerned with determining the connections between plant parts and establishing whole plant restorations, further ontogenetic studies, monographs of genera, descriptions of floras, and comparative flora studies. The many sizable coal-ball collections that have been made during the past two decades furnish excellent opportunities for broadening the scope of studies of coal-ball plants.

One such study is being made by Leisman, who wrote, "My major project involving the Illinois Basin is an ecological or floristic comparison between Kansas coal-ball horizons (Weir-Pittsburg, Mineral, Fleming, and Bevier) and the Herrin (No. 6) Coal as revealed at Sahara [Coal Company Mine]." Concerning coal-ball floras, Darrah wrote:

> I should like to see a critical flora prepared for not only the coal plants of Illinois but of the whole United States. Inasmuch as most of the work quite naturally has been botanical and morphological we have no real synthesis as to the floral associations and ecological attributes which most certainly can be derived from the voluminous evidence already at hand. In the second place, I should like to see someone tackle the fern fructifications. I believe there is a diversity here which will ultimately give us a chance to unravel the impression-compression fern-like foliage that abounds in the Pennsylvanian.

As to the future developments of paleobotany in coal-ball studies, Baxter suggested:

> ...I would expect most of the important new discoveries to relate to the smaller "herbaceous" flora, which I think has been largely overlooked up to now. I also think the cordaitean assemblage of seeds, leaves, stems, and roots is much more complex than now realized and holds a lot of promise for some major new discoveries.

Hall indicated, "One project that I think might be done with coal balls is to examine their pollen content, a palynological study of coal balls. There's still plenty of room for electron microscope studies on coal-ball plants, both TEM and SEM." Stewart stated, "I am all for getting palynologists to take a look at their material from a biological point of view, to try to relate spores and pollen to the structure and organisms that produce them."

Stratigraphy will continue to be important in the study of compression-impression floras. However, compression floras must be found in more than the 25 stratigraphic units now known in order to improve the biostratigraphic subdivisions. The compression floras known from the upper part of the Pennsylvanian (McLeansboro Group) are low in diversity and mainly contain forms with long stratigraphic ranges. The paleoecological implications of compressions also offer a promising area of study, as does systematic study of outstanding floras from a single locality or bed.

Palynology continues to be an important tool in the identification and correlation of coal and other rocks in the Illinois Basin. As spore data accumulate, palynology will prove more reliable in correlating strata between different basins. More detailed studies are needed to refine the criteria for differentiating individual seams and interpreting their stratigraphic relations. Examination of some of the thinner and less widely distributed coals that have not received much attention should be included. Additional palynological studies of the thin coals in the Chesterian Series, which Kosanke initiated, will probably be made.

Paleoecological factors that influence the composition of the coal flora will no doubt be emphasized. One approach is the study of spore assemblages and petrographic constituents of samples taken at frequent intervals throughout individual coal seams, which has been done in several areas outside Illinois. Although detailed petrographic analyses of coal columns have been made at the Illinois Geological Survey, spore analyses of correspondingly close intervals of a coal seam have not yet been published.

The paleoecology of plant life will become clearer as the affinities of more dispersed spores become known. The vertical sequences of coal balls in coal also provide evidence of the plants that inhabited the swamps, and such sequences could shed considerable light on changes in the peat swamp environment. The fact that the coal balls of plant fossils are essentially in situ makes them invaluable for such work.

The synthesis of spore data from all the branches of paleobotany would be helpful in relating isolated spores and pollen to their parent plant types. Such a synthesis could explain the variations in spore morphology encountered in palynological studies. It could also delineate stratigraphic ranges of plants where only palynological data are available. Studies of the spore assemblages from a variety of rocks other than coal also could shed light on the Mississippian and Pennsylvanian floras.

We agree with the sentiment expressed in James Schopf's closing comment to us, "There is no dearth of potentially productive material to work on!"

DEVONIAN PALEOBOTANY

Tasmanites was reported from the Devonian of Illinois by Savage (1920) and Schopf, Wilson, and Bentall (1944). The spore-like bodies had already been described from the Pleistocene as reworked Devonian microfossils. No outcrops of Devonian rocks containing abundant spores of other genera have been found in Illinois, but two studies on Devonian terrestrial spores found in Illinois diamond-drill cores have been published. In 1963, Guennel reported on a Devonian spore assemblage that had been deposited in cavities in a Silurian reef in southern Illinois. The palynology and petrography of core samples of a very thin Middle Devonian coal from central Illinois were the subject of a short report by Peppers and Damberger (1969).

No Devonian plant megafossils have been found in the Illinois Basin other than petrified axes in the New Albany Shale Group, which is partly Upper Devonian and partly Kinderhookian (lower Mississippian) in age (Hoskins and Cross, 1952). Most of the Devonian plant localities occur outside the Illinois Basin and the discoveries are not treated here.

MISSISSIPPIAN PALEOBOTANY

Very few studies of plants of Mississippian age have been made from the Illinois Basin, although prospects for both palynological and megafossil studies seem rather good. Many significant gaps remain in our understanding of evolutionary events and plant groups between the Devonian and Pennsylvanian Periods.

Hoffmeister, Staplin, and Malloy (1955) described spores from outcrop and core samples of the Hardinsburg Formation (Mississippian) of Illinois and Kentucky. The palynology of Chesterian and a few lower Pennsylvanian coals in the Illinois Basin was presented by Kosanke at the 1959 International Botanical Congress, but only an abstract of the study has been published. Seven of the coals Winslow (1959) used in her report on Illinois megaspores are Mississippian in age.

Algal nodules, apparently of green algae of the Codiaceae, were reported by Bieber (1965) from the lower and middle parts of the St. Louis Limestone in Putnam County, Indiana.

After Worthen's (1860) very early report of Mississippian plants in the Illinois Basin and subsequent descriptions of the material that Lesquereux studied (Lesquereux, 1866, 1870; Janssen, 1940a, b), very little interest developed in Mississippian plants, although numerous reports of compression-impression vascular plants were made by geologists working in southern Illinois. More than 30 localities are now known, and recent studies on Chesterian Series (upper Mississippian) plants have appeared (Lacey and Eggert, 1964; Jennings, 1970). Petrifactions from the Waltersburg Formation were reported and illustrated in a preliminary study by Jennings (1970). *Lepidodendron volkmannianum* was recently reported and illustrated from the basal St. Louis Formation in Meade County, Kentucky (Browne and Bryant, 1970); this species was previously reported from the Chesterian Tar Springs Formation in Kentucky (Noé, 1923b) and Illinois (Lacey and Eggert, 1964). Jennings (1972) described a new lycopod genus, *Valmeyerodendron*, from compressions from the Salem Limestone in Monroe County, Illinois.

Lawrence C. Matten, paleobotanist at Southern Illinois University, has taken the "Noé approach" of informing and interesting amateur collectors in the search for plants of Mississippian age in southern Illinois (Matten, 1971). Matten was a stu-

dent of Harlan P. Banks at Cornell University and has shifted his research interest from Devonian plants to younger ones available in southern Illinois and adjacent areas.

CRETACEOUS PALEOBOTANY

Well preserved Cretaceous plants, including petrified wood and leaf cuticles, have been illustrated by Matten (1971). Of his research in Cretaceous studies Matten wrote,

> My work on the Cretaceous plants of southern Illinois started with several field trips about three years ago. Dave Dilcher indicated that E. W. Berry had found angiosperms in the clays of southern Illinois. A careful search of the publications of the State Geological Survey turned up a number of localities where Upper Cretaceous (Gulfian Series) and Tertiary clays occur. I was actually hoping to find a locality or two to take my paleobotany class to instead of having to journey down to Tennessee. Well, we found a number of productive localities for leaves, lignitized wood, and silicified wood. I am also hoping to isolate pollen and spores from the clays. The flora is extensive, diverse, and is preserved in a number of ways, allowing for a complete paleobotanical study. The fact that there was no one working on this material and the huge collection of petrified woods led me to start working on it.

Robert H. Tschudy, palynologist with the U. S. Geological Survey, Denver, also has been working with material from the Mississippi Embayment. In 1970 he described two new pollen genera in Cretaceous and Paleocene strata, one sample of which is from the McNairy Formation in Massac County, Illinois.

PLEISTOCENE PALEOBOTANY

The first surge of interest in Pleistocene paleobotany came in the last century with the recognition that wood, seeds, and spores could be found in glacial deposits. Winchell (1876) and Penhallow (1892) described finds of twigs, cones, and woods, and Baker (1912) mentioned plant megafossils in connection with mollusks in lake deposits. When a tunnel was built in the last century to supply Chicago with water from Lake Michigan, unusual round bodies of microscopic size were found in the till at the excavation site. These bodies turned up for a considerable time in the water supply of the city. Finally, Johnson and Thomas (1884) and Dawson (1885) interpreted them properly as reworked Devonian spore-like bodies (*Tasmanites*) in Pleistocene tills.

Fungi, preserved in woods, were described from the Manito Bog by Tehon (1938) and from gravels at Ashmore, Illinois, by Galbreath (1947), who also described gymnosperms and angiosperms from that locality.

The first analytical studies of pollen from the Pleistocene in the Illinois Basin were made in the 1930s from more than 15 localities (Voss, 1933, 1934, 1937, 1939; Artist, 1936; Fuller, 1939). More recent studies have been made by Griffin (1952), Kaeiser and Harris (1958), and Smith and Kapp (1964) that indicated the migration of trees in post-Wisconsinan time in the northern half of Illinois. The studies were criticized by Eberhard Grüger (1970): "These investigations do not meet modern standards, because either no non-arboreal pollen was counted, the pollen sum was too small, or the sample levels were too widely spaced."

Grüger recently worked on Pleistocene palynology in Illinois (Grüger, 1970, 1972), with the assistance of the Illinois Geological Survey. He investigated three cores from lake sediments that had been deposited during the Illinoian glaciation. Five zones can be recognized, and they show the change to warm interglacial climate, the influence of the Wisconsinan glaciation, and fluctuations in post-glacial times. In a more detailed study, Grüger (1972) interpreted, from pollen analysis of sediment at 11 different localities, the vegetational changes that took place in Illinois during Wisconsinan time.

SUMMARY

Paleobotanical studies in the Illinois Basin began with the establishment of state geological surveys, and their early directors, such as David Dale Owen and A. H. Worthen, encouraged such work. The development of universities and museums in the area further expanded and diversified the fossil plant studies from the Devonian, Mississippian, Pennsylvanian, Cretaceous, and Pleistocene sedimentary deposits.

Among the pioneers of paleobotany in the Illinois Basin, Leo Lesquereux, David White, and A. C. Noé made particularly influential contributions.

The economic importance of coal deposits of Pennsylvanian age stimulated the first studies of compressions-impressions, coal petrography, coal balls, and palynology. Stratigraphic studies also have stimulated paleobotany by providing a framework for much paleobotanical research, and the resultant data have aided stratigraphy. Paleobotanical studies of the Pennsylvanian in particular have had a major impact on all branches of paleobotany.

Palynology has been effectively used in correlation of the Pennsylvanian coals and for interpretation of the Pleistocene climate.

The growth of paleobotany has accelerated in recent years. Two-thirds of the publications on paleobotany have been written since 1950, and, while most of the paleobotanists who developed the new branches of fossil plant studies are still active, many new workers have entered paleobotany. Its expansion to increasing numbers of universities and other institutions is indicative of further growth.

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