Educational Series 11

FOSSIL PEAT FROM THE ILLINOIS BASIN

A Guide To The Study Of Coal Balls Of Pennsylvanian Age

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Illinois State Geological Survey

STATE OF ILLINOIS
DEPARTMENT OF REGISTRATION AND EDUCATION

COVER - A photograph (natural size) of a cellulose acetate peel showing the fossil peat preserved in a coal ball collected from the Herrin (No. 6) Coal Member near Carrier Mills, Illinois. Figure 2 describes its contents.

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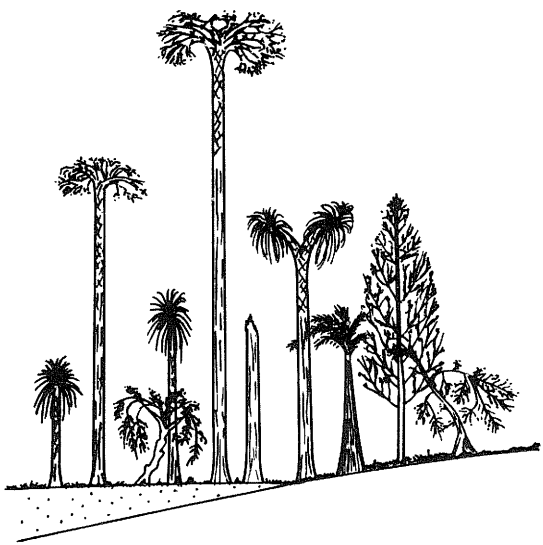

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INTRODUCTION

Millions of years ago, in the interval of geologic time called the Pennsylvanian, the present-day coal seams of the Midwest were layers of peat—beds of water-soaked and somewhat rotted plant debris accumulated in thickly forested swamps. Deep burial by layers of sediments during a vast span of time changed almost all the peat into coal. A little of it, however, impregnated with minerals from water that had oozed through it, was preserved in stone. The lumps and masses of this fossil peat that occur in the coal seams have long been known as coal balls.

As figure 1 illustrates, coal balls are not necessarily ball-shaped. Nor do they contain only peat—some rarer ones hold marine animal fossils. This guide, however, discusses only the coal balls that contain fossil peat, the type most common in the Illinois region.

Coal balls are found from time to time when mining operations and stream erosion uncover them in coal beds. They have often been overlooked. A coal ball fresh from the seam is a rather undistinguished object—a rounded to irregularly shaped, dull brown rock crusted with coal. A casual examination of such a coal ball may not reveal that it contains a mass of tightly packed plant debris. It is certainly not obvious that some of the plant materials are intact organs and tissues with their actual cell walls still preserved several hundred million years after their death and burial.

To see the smaller features in a coal ball, one must look at the thin sections and etched slices cut from it, particularly the translucent peels of plant tissue lifted whole from slices of the coal ball. The photograph of the coal-ball peel in figure 2 illustrates the excellent preservation of the plant remains found in some coal balls and the beauty of fossil peat and peel preparations.

Deposits of fossil peat of Pennsylvanian age are found in Europe as well as in the United States. Coal balls were first reported in England in

Fig. 1 - Coal balls found at the Peabody Coal Company's Northern Illinois Mine near Wilmington, which was closed in 1974. Standing in front of the pile is Melbourne A. McKee, the coal chemist who was the first to discover coal balls in the Summum Coal Member.

1855—"coal ball" is, in fact, the British name for the material. American studies began much later. No one in the United States recognized our fossil peat deposits for what they were until 1922, when specimens from a coal mine in Illinois were identified. Before that, coal balls had been reported by American geologists simply as rock masses in the coal seams, and, although several scientists had actually studied plants from fossil peat, none had identified the material or associated it with the European coal balls.

For many years after their discovery, midwestern coal balls were known to only a few scientists. Now, however, there is more occasion to study fossil peat. More coal-ball deposits are being found as coal mining increases, and more people are studying fossils and other aspects of geology, either privately or in school. To help such students learn about this native fossil material, we have written this guide. It discusses the geology of the coal-ball deposits and the kinds of studies made of coal balls. It describes the methods used to prepare and preserve the fossil peat for study and illustrates some of the common plant parts found in it.

The instructions presented in this guide reflect techniques developed over a number of years by many paleobotanists who use variations of such procedures. Teachers and students will no doubt develop modifications of the techniques to suit their particular needs.

For their special help, we thank David L. Reinertsen, Myrna M. Killey, and W. Dale Farris of the Illinois State Geological Survey, and James M. Mahaffy and Lisa M. Pratt, Botany Department, and Alice Prickett, School of Life Sciences, of the University of Illinois.

GEOLOGY OF THE FOSSIL PEAT DEPOSITS

The Illinois Basin

The coal beds in the Illinois region that contain fossil peat lie in a large structural depression in the earth's crust that geologists have named the Illinois Basin. The Illinois Basin is an oval area of the crust more than 400 miles long and 200 miles wide that sank very gradually for about a quarter of a billion years. The sinking basin formed a persistent depression in which layers of mud and sand, deposited by seas and rivers, accumulated. Although the basin area was not a very deep depression at any time, its continued sinking during such a long period allowed layer upon layer of water-carried sediment to collect in it. The deepest remaining accumulation of these sediments (which have long since hardened into bedrock) is almost 3 miles thick. The Illinois Basin structure underlies most of Illinois and the adjacent parts of southwestern Indiana and western Kentucky. In figure 3, the dotted line drawn to show the limits of the coal-bearing Pennsylvanian rocks is also a general outline of the Illinois Basin that contains them.

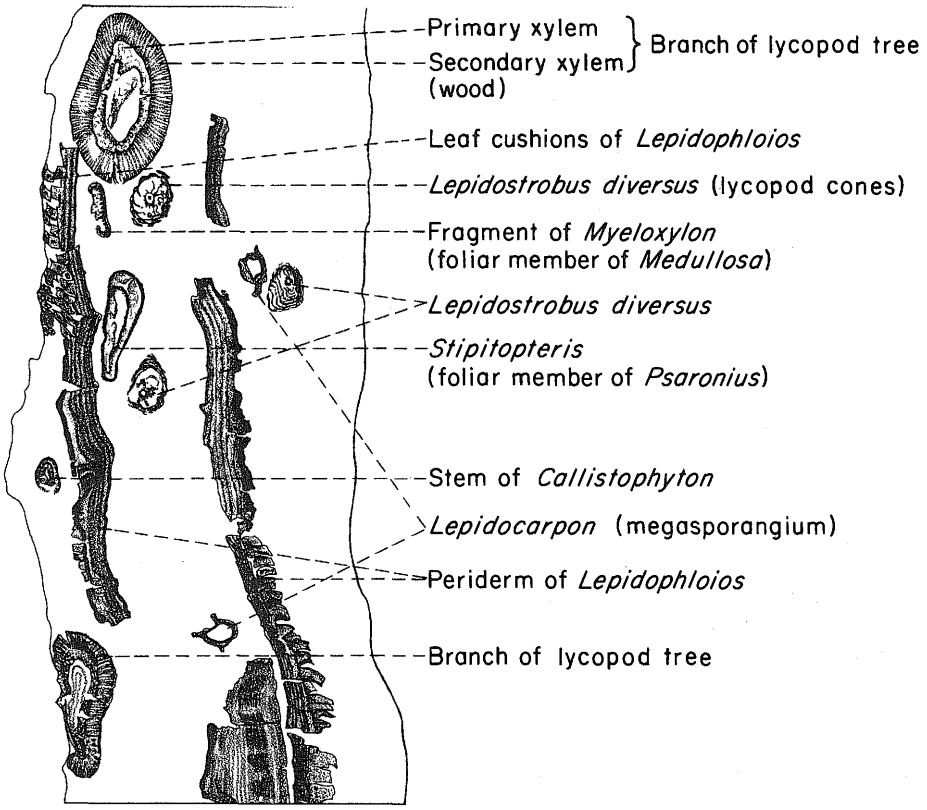
The Illinois Basin area began to collect sediments at the beginning of the Paleozoic Era, about 600 million years ago, when the earth's crust in the region gradually sagged, allowing shallow seas to cover the eroded Precambrian igneous and metamorphic rocks. Throughout the Paleozoic, the basin region subsided intermittently, slowly, and at different rates. It was often covered by shallow seas, and during these times rivers flowing into the seas brought mud and sand that they had eroded from the land. These sediments became beds of shale and sandstone after they were buried by later deposits. Shell sands and chalky muds that formed in the seas became limestone beds.

Near the end of the Paleozoic Era, during the geologic time interval of the Pennsylvanian Period, the basin region was still sinking, but in such a way that it was alternately covered by shallow seas and by great swamps lying just above sea level. The Pennsylvanian Period lasted about 40 million years (between about 320 and 280 million years ago). During that time the root systems and the fallen debris of lush swamp forests accumulated as layers of peat whenever the region was above sea level. Later the peat became coal. Figure 4 is a cross section of the Illinois part of the Illinois Basin. It shows the depression in the Precambrian rocks filled by layers of Paleozoic sedimentary rocks, with the Pennsylvanian deposits on top. The drawing does not show the relatively thin surficial layers deposited atop the older rocks by winds, streams, and glaciers during the past million years or so.

How the Coal Balls Formed

In the Illinois Basin, each coal seam is part of a set of sedimentary rock layers that were formed by a certain series—or cycle—of geologic

Fig. 2 - A cellulose acetate peel section of a slice of permineralized peat taken from the Herrin (No. 6) Coal Member. Collected from the No. 6 Mine of the Sahara Coal Company, which is near Carrier Mills. Some of the larger plant fragments are identified on the drawing on the opposite page.

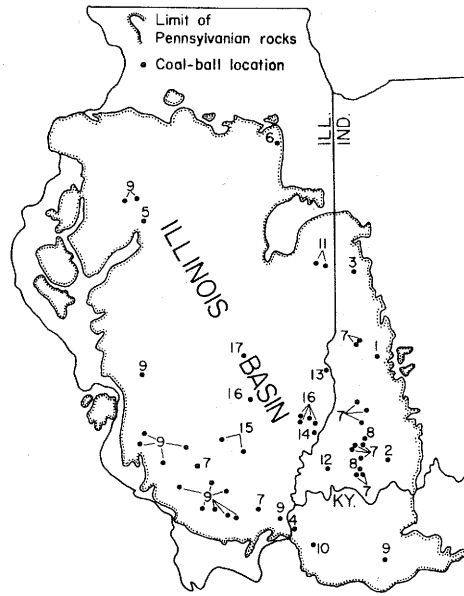


events. These cycles occurred repeatedly during the Pennsylvanian Period. A cycle began when the subsidence of the basin slowed or stopped. At that point, rivers emptying mud and sand into the sea that occupied the basin were able to fill in large parts of it and create a lowland where a freshwater swamp could develop. During the next stage of the cycle, a lush forest grew in the swamp, and the root systems and fallen debris of plants accumulated, finally becoming a layer of peat. Still later, subsidence of the basin caused the sea to flood the swamp, killing its forests and burying its peat bed with river and marine muds and sands. The next cycle began when the subsidence stopped or slowed and the accumulating sediments built up another lowland where a new freshwater swamp could flourish.

As this cycle of events, with variations, was repeated many times during the Pennsylvanian Period, sediment deposits hundreds of feet thick accumulated. The set of layers that accumulated in each cycle of freshwater and marine deposition is referred to as a cyclothem. The heat and high pressures that were a consequence of deep burial eventually changed each peat layer into a coal layer, or seam. The layers of river mud, marine mud, and sand became beds of shale, limestone, and sandstone, respectively.

Often not quite all of the peat in a layer became coal. In some places, before the peat layer was compressed much, water carrying dissolved minerals seeped through it and impregnated masses of the plant debris. When the minerals crystallized, the plant tissues were embedded in nodules of rock—transformed into coal balls. This preserving process is called permineralization. The peat is said to be permineralized because the plant material itself is preserved by being impregnated and surrounded with minerals.

In the Illinois Basin, the mineral preserving the peat was generally calcite (calcium carbonate), but pyrite (iron sulfide) is abundant in some coal balls and present in all. Usually, the greater the pyrite content, the poorer the preservation of the plants. Some coal balls from upper Pennsylvanian and much younger coals are silicified (impregnated with various forms of silica minerals) but such coal balls are rare in the Illinois Basin and are not considered further in this guide. The chemical composition of coal balls is highly varied, but, of those containing plants with well preserved cellular detail, calcareous (calcite-bearing) coal balls are the most often studied, being the easiest to prepare.



Coal Members

17 Unnamed coal member of Shumway Cyclothem
16 Calhoun Coal
15 Opdyke Coal
14 Friendsville Coal
13 Unnamed coal
12 Parker Coal
11 Danville (No. 7) Coal
10 "Baker" Coal
9 Herrin (No. 6) Coal (No. 11 of Kentucky)
8 Unnamed coal immediately above Springfield (No. 5) Coal
7 Springfield (No. 5) Coal
6 Summum (No. 4) Coal
5 Colchester (No. 2) Coal
4 De Koven Coal
3 Unnamed coal in Staunton Formation
2 Buffaloville Coal
1 Lower Block Coal

Fig. 3 - Locations in the Illinois Basin at which coal balls have been reported.

In general, plant remains in coal balls that were buried rapidly and underwent little decay and compression before they were permineralized are well preserved. Photographs of coal-ball plants in scientific papers and the specimens in displays and teaching collections could lead to the belief that most coal balls have marvelously well preserved and diverse contents. Almost the opposite is true. The plant remains in most coal balls show some degree of collapse, erosion, and decay, and the quality of preservation varies from place to place, even in a single coal seam. Nonetheless, perhaps 75 percent of the plant remains in coal balls can be identified as to genus or type of tissue or organ.

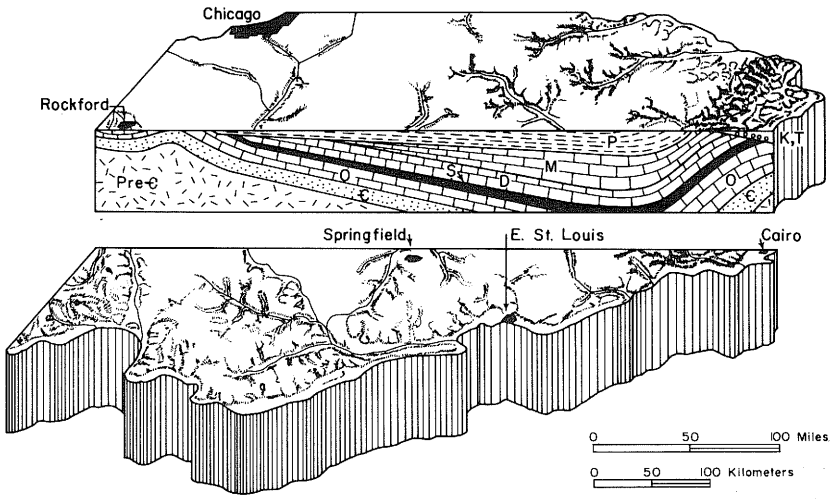


Fig. 4 - Stylized north-south cross section shows the structure of the Illinois Basin. In order to show detail, the thickness of the sedimentary rocks has been greatly exaggerated and the younger, unconsolidated surface deposits have been eliminated. The oldest rocks are Precambrian (Pre€) granites. They form a depression that is filled with layers of sedimentary rocks of various ages: Cambrian (€), Ordovician (O), Silurian (S), Devonian (D), Mississippian (M), Pennsylvanian (P), Cretaceous (K), and Tertiary (T). The scale is approximate.

Not all coal balls contain such a variety of fossils as figure 2 displays. Parts of the most abundant trees occur in coal ball after coal ball—chunks of lycopod bark, stigmarian rootlets, *Psaronius* roots, and mats of plant debris. Because of the sameness and poor preservation of their plant contents, most of the coal balls collected for scientific purposes are probably discarded after being cut and examined. Only significant and exceptionally well preserved specimens are kept for research and teaching.

More than 75 different coals of Pennsylvanian age have been identified in the Illinois Basin, but fossil peat has been reported from only about one-fifth of them. Coal balls are abundant in only relatively small deposits and are generally uncovered by coal mining, although stream erosion has exposed coal balls in a few natural outcrops. Figure 3 shows where coal balls have been found in the Illinois Basin and the names of the coals that contained them. More deposits of fossil peat are known in the Illinois Basin than elsewhere in the United States, although coal balls have been found in coals of Pennsylvanian age from Oklahoma to Pennsylvania and from Iowa to Texas. Coal balls of similar age have also been reported in Britain, in the Donetz Basin of the U.S.S.R., and in other parts of Europe.

THE PLANTS IN FOSSIL PEAT

The peat fossilized in coal balls or transformed into coal is all that remains of the luxuriant tropical forests of the Illinois Basin. Roots, stems, foliage, spores, and pollen of the ancient plants were preserved in

the peat. Most of these plants were the tree forms of vascular plants of five major groups—lycopods, ferns, pteridosperms (seed ferns), cordaites, and sphenopsids (fig. 5). Many of the trees grew to enormous size, some of them towering more than 100 feet high. Many smaller plants also grew in the coal swamps, principally ferns, a variety of small sphenopsids, and some pteridosperms. Only one genus of vascular plants from that period is still living today, *Selaginella*, a very small lycopod.

In contrast to the tree forms preserved in many peats and coals of later geologic periods, the dominant trees of most Pennsylvanian coal-ball floras in the Illinois Basin were lower vascular plants that bore no seeds. Lycopods, represented by the tree forms *Lepidodendron* and *Lepidophloios*, were the giants of the swamp. They were woody plants, but much of their structural support and most of their trunks were composed of cortex and bark; these tissues, along with the extensive root systems, became major constituents of most of the early and middle Pennsylvanian coals. Between middle and late Pennsylvanian time, major environmental changes occurred, and *Psaronius* tree ferns became the dominant plants of many coal swamps. Although *Psaronius* grew to heights of up to 25 feet, it was nonetheless a herbaceous plant and obtained most of its support from a massive root mantle that contributed heavily to the peat.

All the swamp-forest trees and some of the smaller plants had air chambers (lacunae) in their root systems. Such lacunae are characteristic of nearly all vascular plants that live in aquatic or semi-aquatic habitats, and their presence indicates the fossil plants must have lived in that kind of environment.

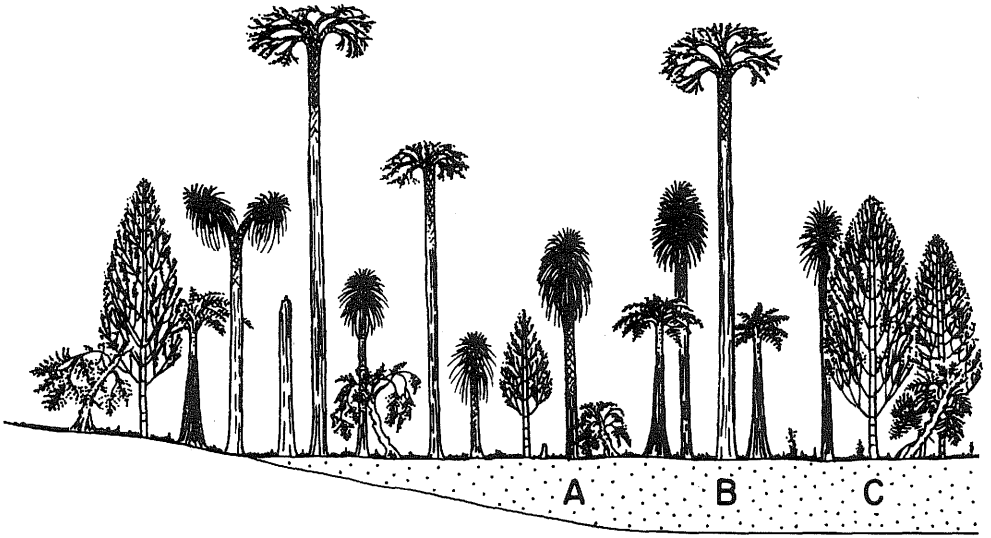


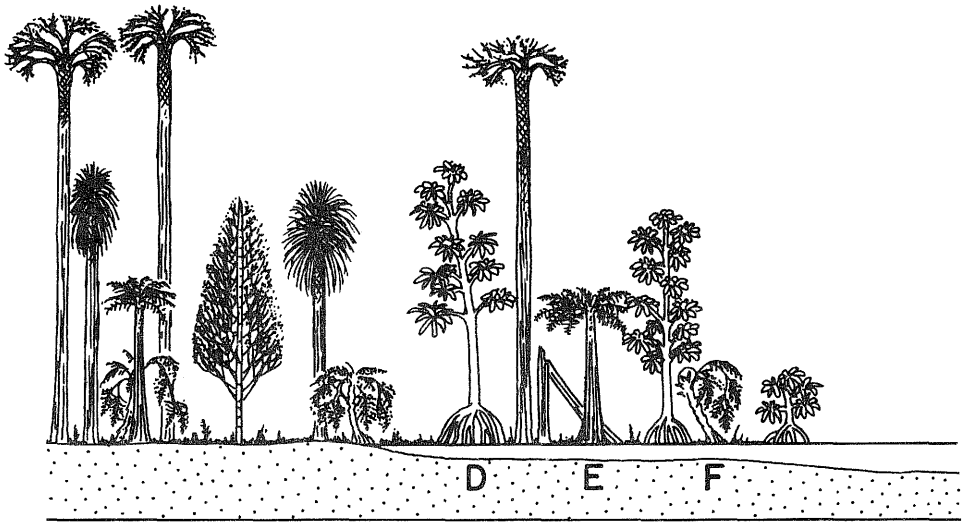
Fig. 5 - Reconstruction of typical trees of the coal swamps that prevailed during the Penn-
dendron), which reached heights of up to 115 feet (35 meters); other trees are drawn
nius); F. seed fern (*Medullosa*). The habitats of the trees ranged from inland swamps
which was preserved in coal balls.

In and among the plant debris and intact tissues of the vascular plants in coal balls, the filaments (hyphae) of fungi have been preserved. Representatives of the three major groups of fungi have been reported, but few mycological studies have been made. Surprisingly, no bryophytes (liverworts and mosses) or algae have thus far been recognized in coal balls.

The literature dealing with the anatomically preserved plants in coal balls is found in many separate articles in professional journals and is not collected in comprehensive books. A rather complete bibliography appears in Illinois State Geological Survey Circular 480, *Development of Paleobotany in the Illinois Basin*, by T. L. Phillips, H. W. Pfefferkorn, and R. A. Peppers (1973). The Circular also provides a history of coal-ball discoveries and introduces the people who studied them in the Illinois region. The Survey's Educational Series 6, *Pennsylvanian Plant Fossils of Illinois* (now available only in libraries), is a good reference for beginning students and contains pictures of the plant fossils most commonly found in Illinois. The bibliography at the back of our guide lists publications that introduce the study of paleobotany and discuss different kinds of fossil plants.

STUDIES OF FOSSIL PEAT

Sustained studies of permineralized peat began in the Illinois Basin more than half a century ago when the paleobotanist A. C. Noé recognized



sylvanian Period. A-B. Successive growth stages of lycopods (*Lepidophloios* or *Lepido*- in proportion here; C. sphenopsids (*Calamites*); D. cordaites; E. tree fern (*Psaro*- to coastal swamps. The trees are shown rooted in peat (stippled pattern), some of

coal balls in Illinois and began to study the plants they contained. Noé's work and that of the paleobotanists who came after him are part of the interesting history of coal-ball plant studies in the Midwest that is explored at length in the *Development of Paleobotany in the Illinois Basin.*

From the beginning, studies of coal-ball plants and fossil peat have been particularly exciting and challenging to paleobotanists. There are several reasons. First, the material can be used to answer questions about coal and both fossil and living plants. In addition, the fossil peat is sufficiently abundant and the plants in some coal balls are so excellently preserved that geologists and paleobotanists have been inspired to study the material in many different ways and to make frequent use of each other's work. Let us consider these points a little further.

For convenience, we can consider the questions about coal balls, like the questions that animate all scientific research, to be of two kinds—questions that are issues of *basic* research and those that are issues of *applied* research. Basic research—scientific investigation carried out chiefly to gain an understanding of the subject of study—answers such questions about fossil peat as, What kinds of plants grew in the swamps where the coals formed? What did the plants look like? What kinds of environments did they live in? How did they evolve as time passed? How are they related to modern plants?

Applied research is scientific work undertaken to serve some specific and foreseen economic or social need. In fossil peat studies, applied research is involved with answering such questions as, What kinds of plants and plant parts contributed to the various deposits of coal? How are the economic qualities of coals related to the kinds of peat from which they formed? How can knowledge of the kinds of plants that form coals help us predict the characteristics of coals and find the kinds of coal we need? What plants identify the different coal beds well enough for accurate mapping of coal reserves?

Very often a research project has both basic and applied objectives. The distinction between applied and basic research is made only because each type has different short-term goals. The distinction does not argue that one kind of research is better than the other or, in the long run, more useful.

Internal Anatomy and External Morphology

Paleobotanists who study the plants in coal balls find the material is particularly well suited to studies of plant anatomy (structure) and morphology (form) because the structure and forms of the plant organs found in the peat can actually be reconstructed. In practice, the worker saws a coal ball into slices that intersect plant parts and takes peels from the surfaces of the slices. By placing the peels in order, properly spaced, he

can create a three-dimensional, sectioned view of the plant part under study. At this point, a restoration of the part—a drawing or model—can be made.

Coal balls may also be split and broken along natural layers formed by the plant material. Surfaces of the plants thus revealed display detail similar to that found in compression-impression fossils. Such detail is helpful in making plant restorations and comparisons with other forms of plant preservation.

Making restorations, or models, of plant fossils is an excellent way to visualize and communicate what has been learned about the form and structure of the plants. Most fossils of the common vascular plants of the Pennsylvanian coal swamp floras are fragments found separately. For that reason restorations are used to assemble all the known vegetative and reproductive structures of plants and to illustrate their life cycles, growth and development, and, possibly, evolution.

Finding out how a plant or a plant organ changes in size and structure as it grows is a major purpose of paleobotanical studies and is one of the areas that have received much attention in the past 20 years. As extinct plants obviously cannot be observed growing, it may be hard to decide whether some fossils are different growth stages of a single species or are parts from different species. Enough is now known about the development of plants of the Pennsylvanian Period to provide a sound basis for comparing their growth patterns with those of other fossil plants and living plants.

Plant Taxonomy

In paleobotany and other sciences, taxonomic studies are the foundation for scientific work. They establish the criteria for identifying and classifying specimens and provide the precise names and descriptive vocabulary that scientists need to communicate their findings accurately and systematically.

In general, the taxonomy of anatomically well preserved fossil plants parallels that of living plants, but there are marked differences. A whole living plant and its parts are scientifically identified by one genus name and one species name. *Acer saccharum*, for example, is the scientific genus and species name of a sugar maple tree, and the same name is used for a pollen grain, stem, or leaf from it. In contrast, each part (or organ) of a fossil plant may have been given a genus and species name.

For example, the stem of a certain kind of lycopod tree has been given the generic name *Lepidophloios*, its root is called *Stigmaria*, the cone is *Lepidostrobus* or *Lepidocarpon*, and the leaves are *Lepidophylloides*. Two species of the cone genus are *Lepidostrobus diversus* and *Lepidostrobus*

oldhamius. All these names for one plant commemorate discoveries made in the past century and a half. Fortunately, not all fossil plants have such an extensive list of generic names.

The adoption of "organ genus" taxonomy for fossil plants came about because paleobotanists seldom find fossils of whole plants. For practical reasons, they have chosen to name each plant part when it is found rather than wait, perhaps for years, until a whole plant is discovered or assembled. Although a paleobotanist may not always know to what whole plant a fossil plant part belongs, he can at least assign it to a *family*, a closely related group of one or more genera. In 1975 the organ genus was formally deleted as a category distinct from genus, but it will still be found in references published before that time.

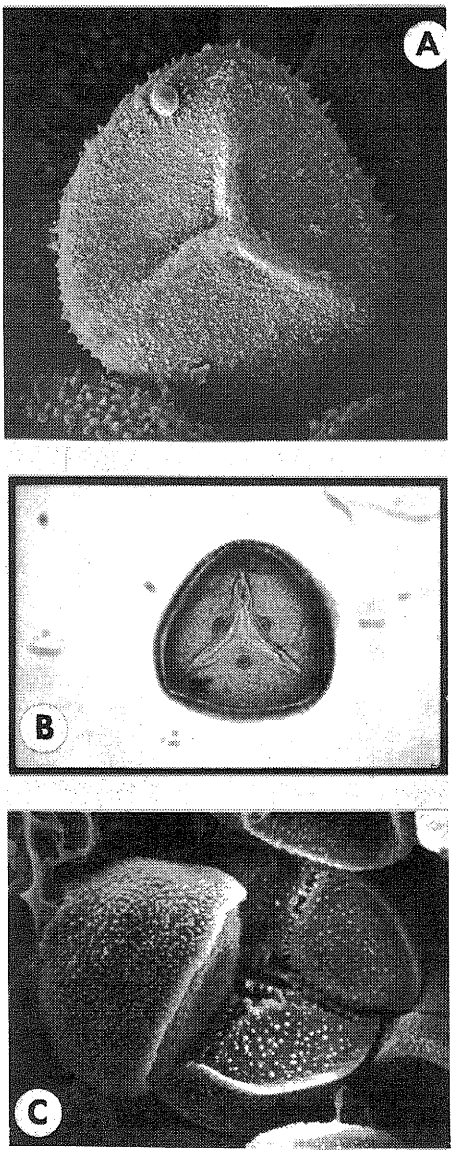
When a whole plant is being reconstructed from separate parts, a matter of great patience and detective work, several names assigned by other workers generally must be reconciled. The International Code of Botanical Nomenclature provides rules for determining what the valid binomial (genus and species) name is for a whole plant that has multiple-named parts. However, in their informal references to such whole plants (often for lack of a single established name), paleobotanists commonly use the generic name of the plant's stem. In the example above, paleobotanists would probably refer to the *Lepidophloios* tree.

The prospect of dealing with so many names may appall the novice, but there are only about 100 organ genera of coal-ball plants of the Pennsylvanian Period. Most of the generic names have been given to ovules and spore-bearing or pollen-bearing structures—all collectively referred to as "fructifications." (These fructifications are not related to the fruits of flowering plants, which did not appear until some 200 million years after the coal-ball plants.)

Because most coal-ball plant remains are fragmentary and occur as isolated organs, monographic (single subject) studies customarily concentrate on organs—ovules, cones, stems, and so on—rather than on a whole plant species or genus, as would be the case in a study of living plants. Most such paleobotanical studies seek to discover evolutionary relations among different specimens of a plant organ.

Plant Evolution

The plants in coal balls provide a unique opportunity for studying the plant evolution that took place during the Pennsylvanian Period, a time interval of about 40 million years. Because coal balls occur in many different Pennsylvanian coal seams of the United States and Europe that represent more than 30 different intervals of geologic time, they can be studied to determine what changes occurred in plants during the Pennsylvanian Period. Detailed studies of the evolution of coal-ball plants are just be-



ginning, but an enormous amount of descriptive data has been amassed by paleobotanists who have studied European coal-ball plants for more than a hundred years and those from the United States since the turn of the century.

Palynology

The study of the pollen and spores of living and fossil plants is called *palynology*. In the coal swamps of Pennsylvanian time, pollen and spores from plants fell into peat beds and were preserved. These microscopic fossils are round or bean-shaped sacs, most of which have ornamented surfaces. Two kinds are shown in figure 6. Paleobotanists have found that some of these fossils, by their abundance, associations with each other, and geologic range in time, are useful "index assemblages" that identify the coals in which they are found.

Most spores and pollen found in coal and coal balls were separated from their parent plants and are mixed with the plant debris of the localities where they settled. In some coal balls, however, plant reproductive organs are found that still contain their spores or pollen. Such discoveries make it possible not only to match a parent plant with its spore or pollen but also to recognize the natural variations in size and form that exist in pollen or spores of a single

Fig. 6 - Spores from coal balls as they are seen under great magnification. (Courtesy of Joan M. Crisman, Florida State Museum, University of Florida at Gainesville.)
A. *Crassispora kosankei*, a microspore from a cone of *Sigillaria* (*Mazocarpon oedipternum* forma *microphorium*). The triradiate mark is visible on its proximal surface, the surface that was in contact with the three other spores in its tetrad. Scanning electron micrograph. × 1000.
B. Proximal view of *Crassispora kosankei* made with a light microscope. Three internal papillae and the trilete suture are visible. ×500.
C. Equatorial and proximal views of three members of a spore tetrad of *Lycospora* from a *Lepidostrobus* cone. From the Lower Block Coal of Indiana. The spores are about 300 million years old. Scanning electron micrograph. ×1400.

species. Once a palynologist knows the normal variations that may occur in any one species, he can make more precise identifications of isolated pollen or spores.

The study of spores and pollen involves many of the same approaches used to study other parts of fossil plants. However, palynology, especially coal palynology, requires separate mention because it is such a well developed branch of paleobotany. It has been of great help in correlating, or achieving more precise correlation of, the various coal beds across the Illinois Basin. Palynology is the most useful branch of paleobotany for stratigraphic correlation. (In stratigraphic correlation, an individual rock layer, or unit, is traced from place to place by matching such characteristics as fossil content, rock composition, or position between other recognizable units.) As coal-ball plant studies identify more of the parent sources of spores and pollen, better correlations of coal seams will be made, not only across the continent but between North America and Europe.

Preparation of Floras

The word "flora" refers not only to the assemblage of plants found in a particular place but also to a scientific publication that systematically catalogs and describes the plants found in a certain area or deposit. Floras are particularly useful reports because they bring together in one work comprehensive research results that include information published separately in many places at different times. Floras have not been compiled for the plants in American coal balls, but useful floras have been prepared for the plants in the well known and longer studied coal balls of Britain, the Netherlands, Belgium, and Germany.

When floras of the Illinois Basin coal balls are made, they will probably include information about spores and pollen, along with statistical analyses of the abundance, associations, and time distribution of the vegetation. Bringing such information together will help to establish the stratigraphic ranges of various plants, their relative abundance, and the kinds of plants that lived together. Why certain plant associations occurred when they did and what environments prevailed in the Pennsylvanian coal swamps are natural extensions of such studies.

Analyses of Permineralized Peat

Where coal balls are abundant, they are likely to occur in layers (or zones) in a coal bed (fig. 7) and are the best evidence we have of the original plant constituents of the peat that became coal. Coal-ball zones may be separated by layers of coal. Locally, coal balls make up the entire thickness of the seam. Where single layers or just a few layers of coal balls occur they are generally near the top of the coal bed (fig. 8).

Analyses of a coal-ball deposit measure the quantities of the various kinds of plants present, the kinds and quantities of the organs and tissues

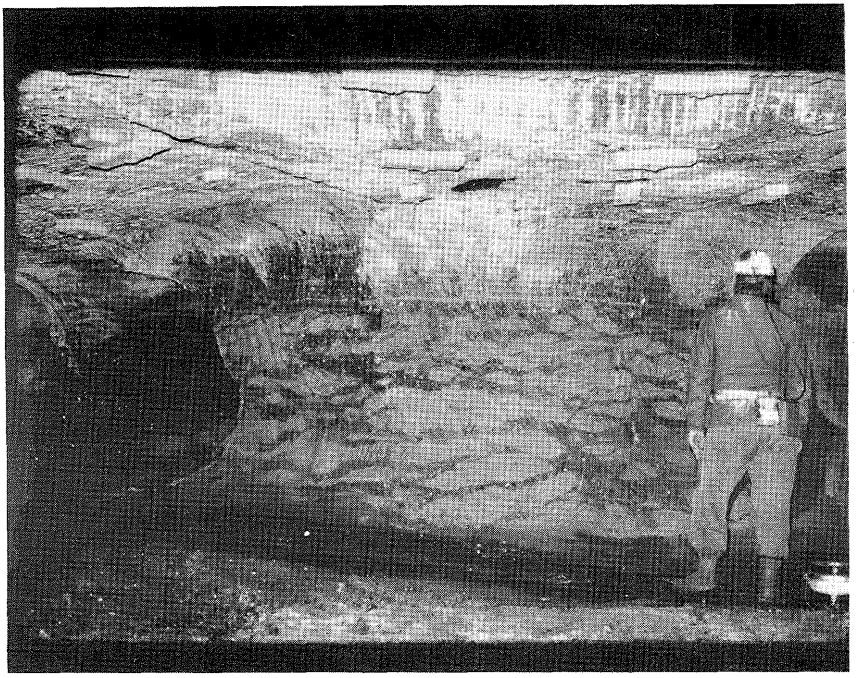


Fig. 7 - Multiple zones of coal balls (light gray lenticular pattern) exposed in side of support pillar in Herrin (No. 6) Coal Member in underground mine No. 24 of the Old Ben Coal Corporation near Benton, Illinois. The coal balls at this location occupy most of the coal seam thickness but are separated by coal partings.

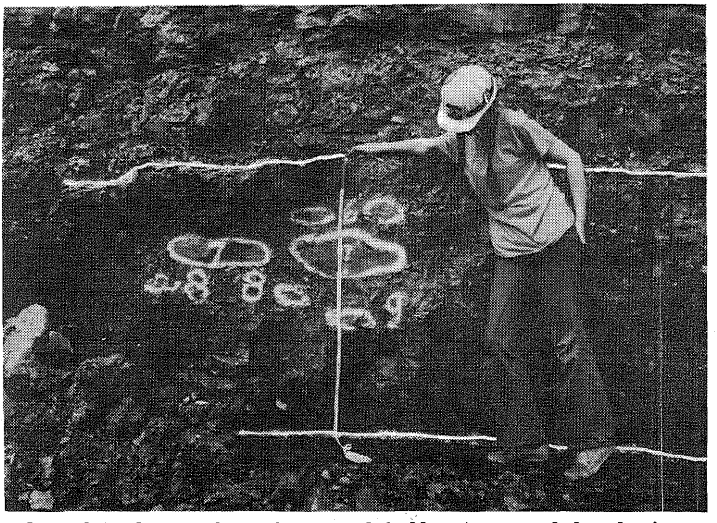


Fig. 8 - A cleared coal-seam face shows coal balls at several levels in upper half of Summum (No. 4) Coal Member. White paint marks top and bottom of coal seam and outlines the coal balls. (Pit 14, Peabody Coal Company Northern Illinois Mine, near South Wilmington, Illinois.)

that occur, and the physical relationships of these elements to each other. The ways in which plant associations, plant tissues, and peat chemistry relate to the coal that is formed are revealed by such analyses. They also enable paleobotanists to describe the environment of the coal swamp and evaluate the effects that environment had on plant growth and coal development.

Analyses of fossil peat deposits of coal basins such as the Illinois Basin yield enough information to support two observations. First, the plant remains in a single coal bed may show that different assemblages of plants grew in a given swamp at different times, indicating that the environment of the swamp changed. Second, there are both minor and major changes in the coal-swamp floras throughout the Pennsylvanian Period that indicate long-term and short-term environmental changes in the basin area and resultant evolutionary changes in the plants.

In many respects, Pennsylvanian peat studies parallel those of modern, or Holocene, peats. A thinly cut section of a modern peat, a mangrove root peat, is pictured in figure 9. The similarities between the structure of the modern peat and that of the ancient peat preserved in coal balls, shown by the peels on plates 1, 2, and 3, are apparent. However, unlike botanists who can look at the growing plants that are contributing to modern peats, paleobotanists studying ancient peats can observe only the plant fragments that were buried together in very limited areas where min-

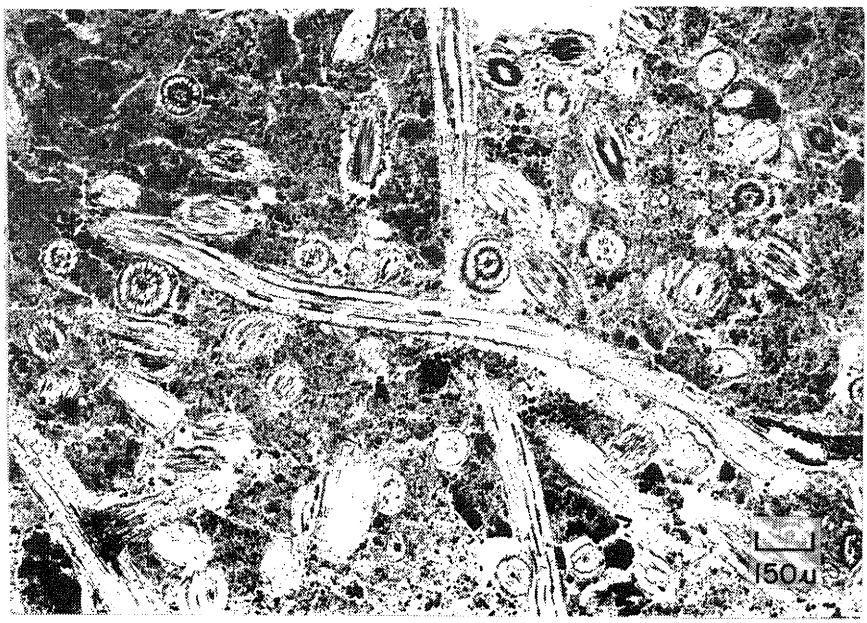


Fig. 9 - A thinly cut section of *Rhizophora mangle*, a mangrove root peat from the saline mangrove swamps of southern Florida. (Photograph by Arthur D. Cohen, University of South Carolina.)

eral matter preserved them. To complicate matters further, the remains of plants that lived at one time are typically penetrated by the root systems of other plants that lived later, and the remains of a series of forests are sometimes preserved in the multiple peat zones of a single coal seam (fig. 7). Studies of modern peat-forming environments can help us understand some aspects of ancient peat swamps that were forested with now-extinct types of trees.

Formation of Coal Balls

How coal balls were formed is a highly technical and somewhat speculative subject that cannot be dealt with here in detail.

We do, however, know enough about coal-ball occurrences, their chemical compositions, and their physical characteristics to recognize that the permineralization of the peat can be brought about by mineral-laden ground waters, marine inundations with their associated sediments, or by combinations of these agents.

PREPARING COAL BALLS FOR STUDY

Some of the larger features of the plants preserved as permineralized peat can be seen and studied on weathered, broken, or cut surfaces of coal balls. However, detailed cellular structures of these fossils are seen best in special preparations that are made to be studied with microscopes. One such preparation is called a thin section.

The tissues of living plants are easily cut into thin slices (thin sections) with a razor blade or microtome and can be stained and permanently mounted on glass slides for microscope study. For almost a century (1845-1928) the only way known to obtain such translucent slices of fossil-plant tissue involved cutting a very thin slice of the rock in which the plant was preserved and grinding the slice until it was thin enough to let light come through it so that cell structures would be revealed when it was placed under the microscope. Thin sections of this type are still used to prepare some plant fossils in which cell walls are only partially or poorly preserved. If the cell lumens (voids) of a fossil are filled with opaque minerals, such as pyrite, the surfaces of slices cut from it are polished and examined with reflected light. However, the laborious thin-section method of preparing coal balls has been largely replaced by the "peel" technique introduced by John Walton in 1928.

Walton's technique involved cutting a slice from a coal ball, grinding the cut surface flat, and immersing it briefly in weak acid. The acid dissolved a little of the calcite surrounding the plant tissues exposed in the cut surface and left a 30- to 40-micron thickness of the tissues stand-

ing in relief. Next, a fluid that dried to a tough, transparent film was poured on the etched surface. The fluid permeated the exposed plant tissues (principally cell walls in some altered form) and, when it dried, embedded them in a flexible film that could be peeled from the surface of the coal ball. This transparent "peel" preserved the plant structures as translucent sections of cell walls. Until 1956, the best peel material used was a liquid called parlodion. Since then, coal-ball peels have been made by embedding the plant material in the surface of a cellulose acetate sheet that has been cut to cover the slice surface and liquefied with acetone. This technique and other methods of preparing coal-ball material for study are explained in the following pages.

The peel technique is a relatively fast and simple procedure that wastes little of the coal-ball material. A peel, unlike a thin section mounted on a glass slide, covers the whole surface of a coal-ball slice and is relatively tough, permanent, and easy to store. In addition, parts of the peel can be cut out and mounted on slides for examination with higher power microscopes. Plates 1, 2, and 3 are photographs of coal-ball peels taken through a microscope. They show plant parts commonly found in midwestern coal balls.

Making Coal-Ball Peels

1. *Sawing a Coal Ball*—Slice the coal ball (fig. 10), much as you do a loaf of bread, into slabs one-half to 1 inch thick. Examine each slice

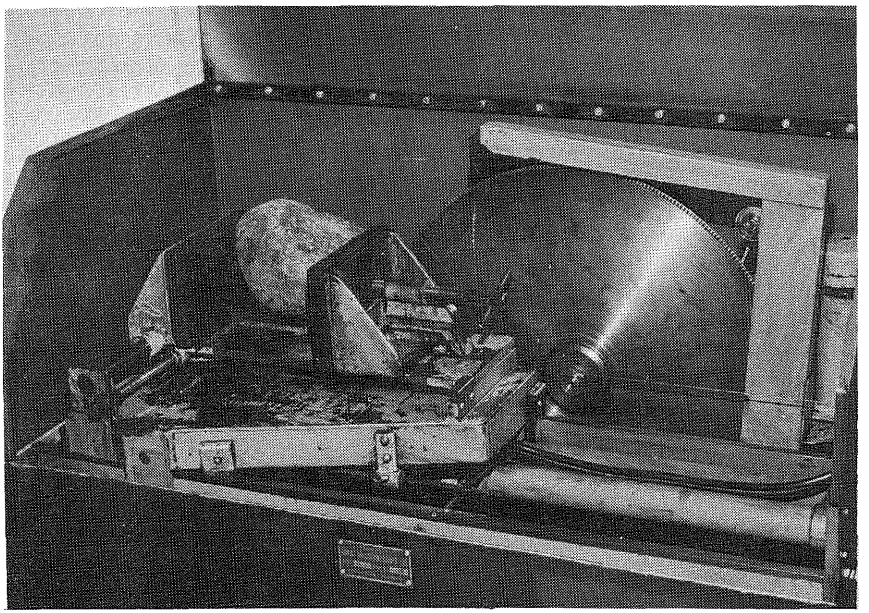


Fig. 10 - A side-loading lapidary saw. A coal ball is held in the vise on a sliding carriage. The notched rim of the saw blade contains industrial diamonds that cut off the portion of the coal ball that extends beyond the jaws of the vise.

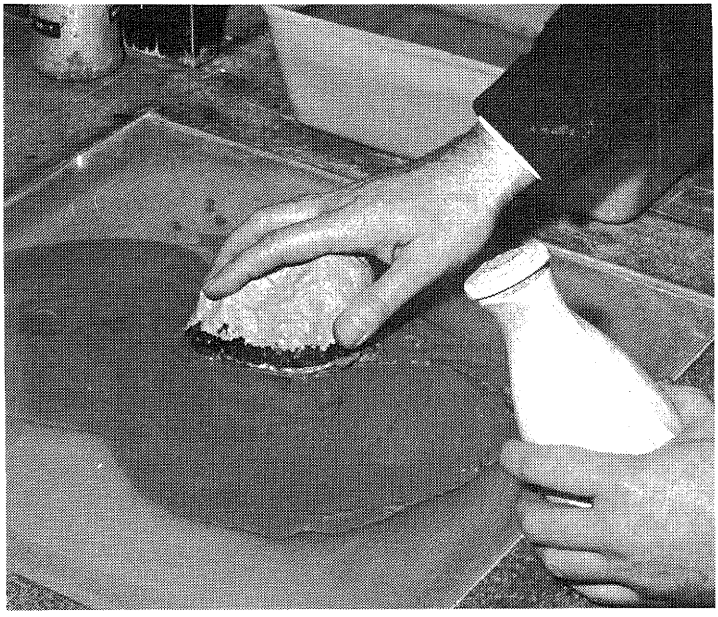


Fig. 11 - Smoothing a coal-ball slice with a wet paste of silicon carbide powder on a heavy glass plate. The unsmoothed, natural surface of the slice is coated with latex paint to protect it from acid and water. The paint also can be used to code slices for identification.

before you cut the next. If you see an interesting plant organ, change the angle or thickness of the cuts, if necessary, to obtain sections along or across the organ's center line. Most coal balls are encrusted with a thin layer of coal, and, unless plants are exposed or you have an intuition about orienting the coal ball a certain way, its shape and size determine the position in which it is placed in the saw for the first cuts.

Figure 10 shows a coal ball in a vise on a sliding carriage that feeds it into a diamond-edged saw. The rim of the steel saw blade runs in cutting oil, which serves both to cool the blade and wash away the rock powder from the cut. After the slice has been cut, thoroughly clean the cutting oil from it with hot water, detergent, and a scrub brush. The sooner this is done the better, especially if the coal-ball slice is porous or cracked, to keep the oil from penetrating the slice. Examine the wet slice under a dissecting microscope. The saw marks and irregular edges where the coal ball broke during cutting will not interfere with this initial examination.

2. *Rough-trimming the Slice*—Carefully chip, file, grind, or nip off rough edges that would keep the cut surface of the slice from lying flat, in full contact with the lap wheel or glass plate, during the smoothing process. If the slice has two cut sides, peels can be taken from both. Simply prepare both sides according to directions.

3. *Smoothing the Cut Surface*—To smooth a cut surface, grind the specimen on a lap wheel or a thick glass plate (fig. 11) smeared with a paste

of water and Carborundum powder (the trade name for silicon carbide). Number 400-grit Carborundum powder is used when the surface is smoothed on a glass plate. A coarser grit is commonly used on a lap wheel, but a fine grit must be used in the final preparation of the surface.

Use a circular or figure-eight grinding stroke to obtain the smoothest possible surface. When the surface is smooth to the touch, rinse the specimen thoroughly to clean off all the grit. A soft-bristled brush helps to remove grit.

4. *Etching the Smoothed Surface*—Hold the coal-ball slice by the edges—smooth surface down (fig. 12). Keeping your fingers off the smoothed surface, submerge it in 5 percent hydrochloric acid (HCl) so that it reacts with the acid for about 15 seconds. The 5 percent acid will not harm your hands. Rinse the acid off the slice with a gentle stream of tap water.

Etching time varies from about 12 to 20 seconds for coal balls from different localities in Illinois and adjoining states. Fifteen to 18 seconds is satisfactory for most American coal balls. The best etching time for slices from any particular coal ball or coal-ball deposit can be worked out by trial and error. Etching time may be varied slightly, depending on what the peel is to be used for. Examine the peels taken from the etched surface and repeat the process until a good peel is obtained. A "good" peel is one

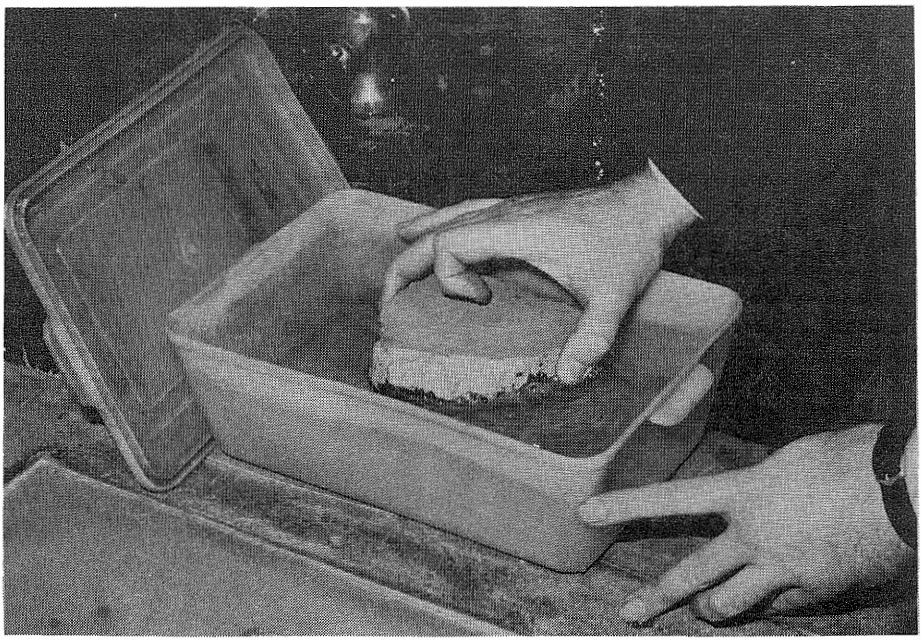


Fig. 12 - Etching a coal-ball slice in 5 percent hydrochloric acid. The untreated surface of the slice is coated with latex paint. The froth of bubbles at the edge of the slice is carbon dioxide released by the reaction of the calcite in the slice with the acid.

that shows clearly what you need to see or photograph. Compare your peel with the photographs on the plates at the end of this guide.

After the slice has been rinsed, put it in a "gravel pit"—a box or tray of pea-sized gravel—to dry. Prop the slice at a slight angle on the edge of the gravel pit, etched side up. (If both sides are being prepared, keep as much of the lower side off the gravel as possible.)

CAUTION: *Do not touch the flat, etched surface. Very fragile plant material stands only 30 to 40 microns above the etched surface of the rock. The slightest touch will wipe it off.*

The gravel in the gravel pit should be about $1\frac{1}{2}$ inches deep and consist of clean, smooth pebbles approximately a quarter of an inch in diameter. The loose gravel provides a tidy, convenient surface on which slices can be rested and leveled. Many substitutes may be used, but do not use sand, which can easily get onto etched surfaces and into peels.

Although 5 percent HCl will not harm your hands, it will sting cuts and abrasions and damage jewelry and clothing. Keep the acid containers covered when they are not in use. Acid vapor from uncovered containers will rust many items in a laboratory area.

5. *Drying the Etched and Rinsed Slice*—Let the slice air-dry in the gravel pit. If you wish to hasten drying, fan the slice or flow acetone or ethyl alcohol over its surface several times.

CAUTION: *The etched surfaces of the slice must be completely dry before you proceed to the next step.*

The surface tension of water tends to hold moisture on the slice surface, and 30 minutes or more may be required for air-drying. The other methods reduce drying time to a few minutes. If the slice is not completely dry when the peel is made, an opaque, milky stain will form at the edge of the peel.

After the surface is etched and dried, the brown plant tissue stands out in marked contrast to the white calcite matrix. Figure 13 is a scanning electron micrograph of etched coal-ball material. At this point, the cellular structures of the plants can be examined under a dissecting microscope. The slice must be carefully handled to prevent scuffing the extremely fragile material on the etched surface.

6. *Applying the Cellulose Acetate Sheet*—Two items are required for application of the cellulose acetate to the coal-ball surface (fig. 14): (1) a plastic wash bottle of acetone N.F., and (2) a sheet of cellulose acetate 0.003-inch thick that is cut to extend a half to one inch beyond the edges of the specimen's etched surface.

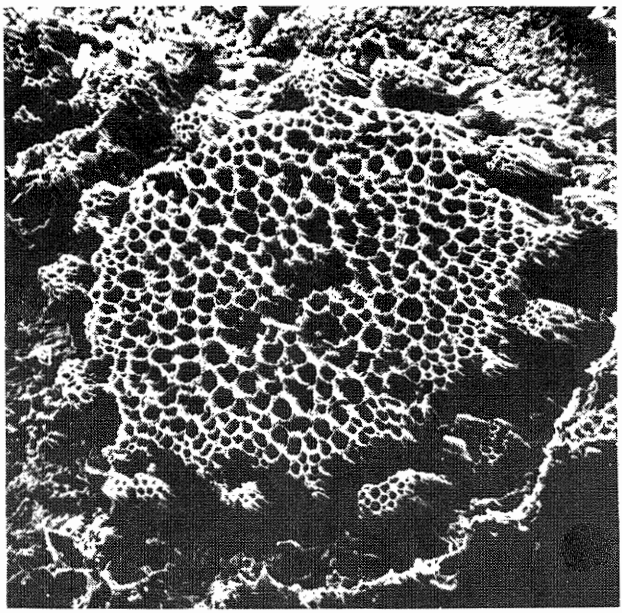


Fig. 13 - Scanning electron micrograph of the tracheids (tube-like cells that conduct water) of the xylem of a lycopod. ×36. The etched plant tissue is like that exposed when a coal ball is etched for peeling but is in higher relief.

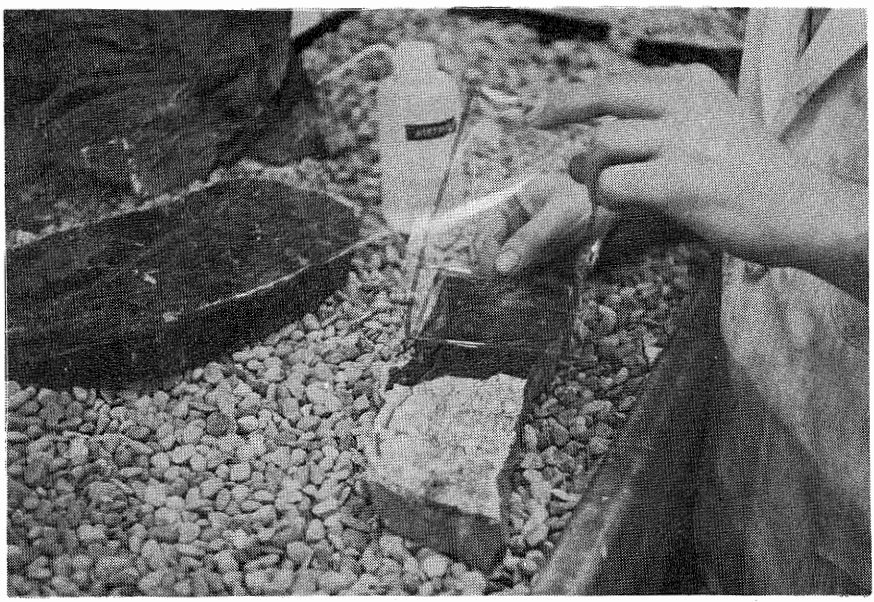


Fig. 14 - Placing a sheet of cellulose acetate on a coal-ball slice that has been etched with acid. The dark surface area is wet with acetone; the light area is dry. The sides of the slice are protected with latex paint.

CAUTION: *High concentrations of acetone fumes can be explosive and toxic. Perform the following steps in a WELL VENTILATED AREA AND AWAY FROM FLAMES AND SPARKS. Avoid unnecessary contact of acetone with your skin. Cellulose acetate is flammable, and fumes from its burning are noxious.*

Level the slice in the gravel pit by eye. Squirt acetone onto about half of the slice surface so that it is completely wet. Do not, however, flood the slice with acetone. Because the slice will not be perfectly level, acetone tends to accumulate along one side. From that side, holding the top and bottom of the pre-cut cellulose acetate sheet to bend it slightly and guide it, *LIGHTLY AND DEFTLY ROLL THE SHEET ONTO THE SLICE*. As it unrolls, the sheet will push the excess acetone across the slice. Figure 14 illustrates this process. If the acetone evaporates before the whole sheet is rolled on, stop and quickly squirt a little more acetone onto the dry area and continue rolling.

Be sure to let the sheet roll on. Do not drop the sheet onto the slice, do not press it on, and do not lay it on flat. If you do, numerous air bubbles will be trapped between the slice and the sheet. Once the sheet touches the acetone-wet surface, do *not* tug at it, try to adjust it, or pat it down.

The proper amount of acetone, just enough to permit embedding the plant tissue in the sheet, is best judged by trial and error. Too much acetone completely breaks the acetate's crystalline structure and causes wrinkling of the upper surface of the peel. The upper side of the cellulose acetate sheet should remain smooth. In any case, parts of even the worst peels will be useful for study.

7. *Drying and Removing the Peel*—Once the acetate sheet is on the slice, wait at least 15 minutes to remove it, preferably longer. Peels removed in 15 minutes tend to curl. In order to prevent curling, wait an hour or longer to give the acetone ample time to evaporate and the sheet's structure time to stiffen.

Remove the peel simply by lifting it at one side and gently pulling it up and off the slice. If the peel sticks, use a razor blade to shave it off the slice.

8. *Taking Another Peel from the Same Surface*—To peel the slice again, grind its peeled surface smooth, repeating the procedures described in steps 3 through 7. As many as 500 such peels may be made from a 1-inch thickness of rock.

9. *Protecting the Surface of the Slice with a Peel*—When the slice is to be stored, leave a peel stuck on the surface. It will to some extent seal the slice off from air and moisture and effectively display the plant material in the slice.

10. *Mounting and Storing Whole Peels*—For storage and examination, a peel may be stapled or taped (shiny side up) on stiff white paper or cardboard after its rough edges have been trimmed. Peels mounted in this way can be stacked or placed in envelopes or binders. The finished peel is a permanent, inert, but *flammable* preparation.

Examining Peels with a Microscope

The peel preparation can be examined directly under a dissecting or stereo microscope. A white background or mount under the peel makes it easier to observe with reflected light. Always mount and examine the peel with the shiny side up, as it was on the coal-ball slice.

A coal ball and its peel will usually contain several different kinds of plant structures, although it may be difficult at first to see individual parts because the material is so closely packed together. Roots, stems, and leaves of several kinds of plants are commonly found in the same peel because various parts of different plants fell into the swamp together and the roots of other plants often grew through and among them. Figure F on plate 2 shows leaves infiltrated by rootlets.

Parts of the peel that require greater resolution of detail may be cut out and mounted on a microscope slide for examination with a compound microscope. Such slides can also be photographed through a microscope.

Mounting Peel Sections on Glass Slides

1. *Cutting the Peel*—A standard (25 mm by 75 mm) glass microscope slide and a 22-mm square cover slip are used for mounting peel sections. With scissors cut out the section of the peel that is to be mounted. The cut-out section should be a little smaller than the cover slip but no less than about 18 mm square. Use forceps to handle the cut peel during the mounting operation.

2. *Cleaning the Peel Section for Photography*—Unless the peel is to be photographed, this step can be omitted because calcite patterns on the peel, which this treatment removes, do not hamper visual examinations.

Submerge the peel section, rough side up, in a 10 percent solution of HCl to remove any calcite that may be on its rough surface. Soak about 10 minutes or until bubbles stop forming on the peel. The bubbles are filled with carbon dioxide released by the reaction between the calcite and the acid. The rough surface of the peel should be turned up so that the bubbles escape and the acid stays in contact with the surface of the peel. The peel section can be left in the acid for several hours without being damaged.

Next, remove the peel section from the acid and put it into a container of tap water for at least a few minutes to wash the acid off. After it is

washed, blot the peel dry with a paper towel. Place it between dry paper towels, put a weight on top to keep the peel flat, and leave it to dry on a warming table for 24 hours at 42° C. If no warming table is available, leave the peel on an unheated flat surface for at least 48 hours.

3. *Mounting the Peel Section*—Submerge the cut-out peel in xylene for 10 to 15 seconds to remove from it all traces of moisture. Do not leave the peel in xylene for more than a couple of minutes because the xylene will harden the peel and make it difficult to mount.

Put a drop or two of HSR (Harleco Synthetic Resin in xylene) on the center of the glass slide on which the peel is to be mounted. Remove the peel from the xylene and blot off the liquid, but leave it just damp. Put the damp peel on the slide *with its smooth side up*, lowering it gently into the drop of HSR to spread out the mounting medium.

Place one drop (more for larger peels) of HSR on the smooth upper surface of the mounted peel. With a pair of forceps, place the edge of the cover glass on the glass slide and gently lower it onto the peel (fig. 15), again spreading out the mounting medium.

The amount of HSR needed will vary with the size of the peel that is being mounted. For a cover slip of normal size (22 mm square) one drop of HSR under the peel and one over it are sufficient. The cover glass should not be much larger than the peel; the larger the cover glass, the longer it takes for the HSR to harden completely.

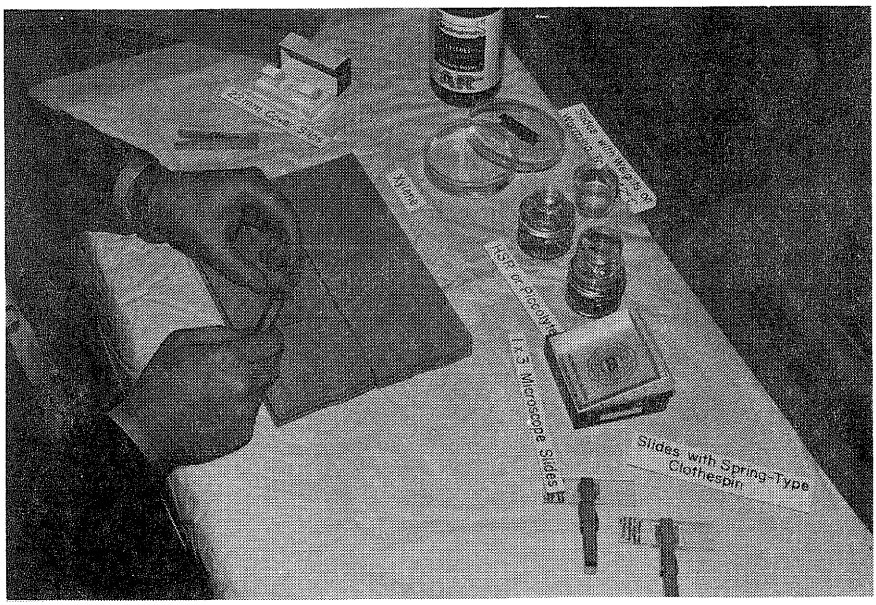


Fig. 15 - Materials used in preparing a microscope slide and in curing mounted peel sections. In the picture, a cover slip is being placed on the slide with the aid of forceps.

4. *Curing the Slide*—Cure the slide on a warming table (about 42° C) or in a warm, vented oven (110° F) from several days to a week. If an oven or warming table is not available, use Piccolyte in a 50 percent xylene solution as a mounting medium and allow at least a week for it to air-dry. To make sure the mount is flat, place a metal weight (smaller on its base than the cover glass) on the slide while it is being heat-fixed. Lead blocks about 1 inch long with ends one-half inch square (less than 18 mm) are ideal weights. If such weights are not available, a spring clothespin may be used to clip the "sandwich" together for 24 hours, but the pin should be removed before subsequent curing. After it is cured, the slide is ready for examination and photography.

Recovering Spores and Other Microfossils from Coal Balls

Some coal-ball slices preserve sporangia containing spores or pollen. A mass of spores or pollen is usually orange-brown and is quite distinctive even when still tightly packed within the sporangial wall. These reproductive bodies and other microfossil elements can be freed from a calcitic coal ball by acid maceration and mounted on slides for study under light microscopes that have 400× to 1000× high-dry and oil-immersion objectives. Higher magnification and greater resolution usually require use of a scanning electron microscope and processing techniques different from those given below.

If spore masses cannot be found in the coal-ball slice, a few separate spores will usually be found after parts of the slice are macerated. Even the microfossil debris of cell walls, cuticles, and tissue fragments will provide an instructive look at the microfossil components of peat.

There are several ways to remove a sporangium, or mass of spores, from a coal ball. The material can be excavated with a dental drill, a stout dissecting needle, or by other appropriate tools and then macerated in a 10 percent hydrochloric acid solution. Alternatively, the paraffin-well technique may be employed (fig. 16), following the directions given below.

1. *Making the Mold for the Paraffin-Well Technique*—If a peel is still on the coal-ball slice, cut a window in it to expose only the area that is to be treated with acid. The rest of the peel can be left in place.

With modeling clay, make a plug about three-fourths of an inch high and large enough in circumference to cover the area to be treated with acid. Press the plug onto the area to be treated. Make the plug taper, with the top larger than the bottom, so that it will be easy to pull out of the paraffin well.

Next, build a wall of modeling clay around the plug, leaving about an inch of space between the plug and the wall. Make the wall slightly lower than the top of the plug.

When the clay plug and wall have been made, pour melted paraffin into the space between them to a depth of about half an inch. After the paraffin solidifies, remove the plug and wall. A paraffin well similar to the one in figure 16 should result.

2. *Macerating the Coal Ball*—Pour a 10 percent solution of hydrochloric acid into the paraffin well from a wash bottle, transfer pipette, or eye dropper. The length of time required to separate the microfossils from the calcite matrix of the coal ball is best judged by periodically removing a little of the acid from the well and examining its contents on a temporary slide that has a cover slip. The maceration process can be repeated if a 10-minute exposure to the acid does not produce enough material. If coal-ball material is simply excavated from the coal ball or chipped from a rough side, macerate the fine chips in a test tube or bottle.

When you judge there is sufficient material for your purpose, pipette all the acid from the well to a glass centrifuge tube, test tube, or a small, wide-mouthed glass container.

3. *Separating the Microfossils from the Acid Solution*—If a centrifuge is not available to separate the microfossils from the acid solution, allow them to settle to the bottom and let the liquid concentrate by evaporation.

If a centrifuge is available, remove the acid from the solution by repeatedly adding water to it, centrifuging it, and decanting (pouring off) the clear liquid above the concentrated fossil material.

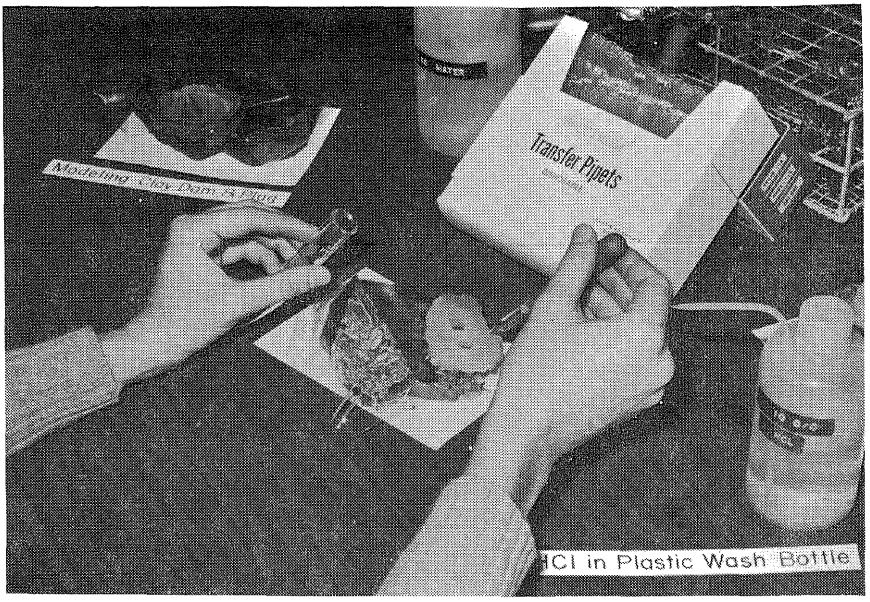


Fig. 16 - The paraffin-well maceration technique. Hydrochloric acid containing microfossils is pipetted from one of the paraffin wells to a glass centrifuge tube.

In decanting, the clear fluid from the test tube must be emptied in a single deft motion so that the microfossils remain in the tube. Until you are well practiced, decant into a beaker to avoid losing the microfossils.

4. *Dehydrating the Microfossils*—Remove the water from the washed and centrifuged microfossils by soaking them in a series of dehydrating solutions—50 percent alcohol, 95 percent alcohol (twice), absolute alcohol, 50 percent alcohol with 50 percent xylene, and then pure xylene. Each step in the series involves leaving the material in the dehydrating liquid a few minutes and then centrifuging and decanting. The dehydration process can be modified, but the water must be removed from the microfossil material so that the material can be mounted in a resinous medium.

5. *Mounting the Concentrated Microfossils on a Glass Slide*—Pipette a small drop of the concentrated microfossils (in xylene) onto a glass slide. Add a drop or two of HSR to the drop on the slide and place a 22 by 30 or 22 by 40 mm cover glass over it so that the microfossils are slowly spread out to allow the best possible observation. The xylene droplet of microfossils may be spread out over a wider area of the slide prior to adding HSR and the cover glass, or the xylene droplet may be mixed with HSR before the mounting medium is placed on the slide. To cure the slide, follow the procedures given on page 26.

If a centrifuge is not available, a droplet of the microfossils that have been concentrated simply by settling and evaporation can be placed directly in a larger droplet of CMCP-9 or CMCP-10 mounting medium and left about 15 minutes to permit some evaporation and dispersion of water. Place a cover glass on the slide and allow the material to air-dry. *Do not place on a warming table.* Such slides are less permanent than heat-fixed HSR-mounted slides but equally useful for most observations.

PRESERVING COAL BALLS

A coal ball that has been preserved for more than a quarter of a billion years in a coal seam may disintegrate quickly after being exposed to air and water. How long a coal ball (or its slices) will remain intact and useful after it has been collected varies greatly and depends on its mineral composition and the physical and chemical processes to which it has been subjected since it was uncovered. For instance, coal balls with moderate to high pyrite contents may weather quickly upon exposure and disintegrate at their outcrops in a matter of months. In contrast, coal balls of this type usually remain intact for many years if placed in dry storage, markedly deteriorating only after they are sectioned and subjected to the steps of the peel technique. Many of the coal-ball slices containing abundant lycopods, and even more of those with *Cordaites* assemblages, tend to expand, warp, and split apart in months. They continue to deteriorate if stored for several years unless efforts are made to preserve them. Other coal-ball slices, particularly those containing an abundance of *Psaronius* or those having a low pyrite content, have survived 50 years of storage without substantial damage.

The following practices will help preserve coal-ball slices:

1. If slices are being peeled day after day, coat their rough, unusable sides with latex paint (see figs. 11 and 12). A partly painted coal ball absorbs less acid and water than an unpainted one.

2. If slices contain pyrite, partly embed them in plastic to keep air and water from as much of the pyrite as possible. Slices with a somewhat greenish cast contain considerable pyrite.

3. If slices are to be stored for several weeks or months, leave a peel on the surfaces that are peeled.

4. If slices are to be stored for years, coat all the surfaces once or twice with marine spar varnish or a comparable transparent sealer so that the fossils in the slice and any labels on it are visible. The sealer should be a type that can be ground off when the slice is to be peeled again.

5. Above all, minimize their exposure to moisture in every possible way. Do not allow coal-ball slices to soak long in water, either to remove oil or to perform any step of the peel technique. Store them in a dry place.

Repairing and Embedding Coal-Ball Slices

Coal-ball slices that have been broken may be reassembled and embedded in plastic. Simple breaks in slices can be mended with water putty. However, if the slice is disintegrating, it should be embedded in a liquid plastic. Small slices of coal balls that require identical lengths of time in acid also can be mounted together in one plastic block. They are then well protected and can be peeled more efficiently.

Whether coal ball slices are to be repaired with water putty or embedded in plastic, their peel faces must be firmly glued with rubber cement to a heavy piece of glass. Temporarily gluing all the pieces to the same plane surface insures that when the repairs are completed the peel faces will be exactly even and can be prepared and peeled together.

1. *Gluing the Pieces to a Glass Plate*—Grind the peel faces of the slices smooth. Spread rubber cement over the entire peel face of each coal-ball piece and onto the area of the glass plate on which it will lie. Press the peel faces firmly against the glass plate.

2. *Making Repairs with Water Putty*—Mix the dry water putty with water to form a heavy paste before you glue the broken coal-ball pieces to the glass. Place the pieces close together on the glass plate and moisten with water the fracture faces that are to be joined together. Insert the water putty between the fracture faces and press the faces together (the

fresh rubber cement on the glass will allow slight lateral movement). Scrape off any extruded putty. Allow to dry for 24 to 48 hours. Twist the specimen off the glass plate and rub off the rubber cement with a paper towel. Water putty can also be used to repair whole coal balls before they are cut and to reassemble sliced coal balls for recutting, if they have been cut at angles that miss the more informative sections of the plant organs.

3. *Embedding Pieces in Plastic*— To reassemble a broken slice and embed it in plastic, glue the pieces onto the glass plate as close together as possible. If different small coal-ball slices are embedded together, leave at least a quarter of an inch for plastic between the pieces to strengthen the mounting. The embedding plastic shrinks a little as it cures, and this shrinkage can split the mounting where the plastic is too thin. The glass plate should extend several inches beyond the mounted specimens on all sides and be large enough to sit across the top of the mold, suspending the coal-ball pieces in the plastic until the plastic hardens.

To make a mold for the plastic, find or make a cardboard box large enough to allow half an inch of space between the bottom and sides of the box and the specimens mounted on the glass plate. Line the box with a single piece of aluminum foil that is free of holes (see fig. 17).

Mix the liquid plastic with its catalyst and pour a little of it into the mold. Cautiously, lower the glass-mounted coal-ball pieces into the

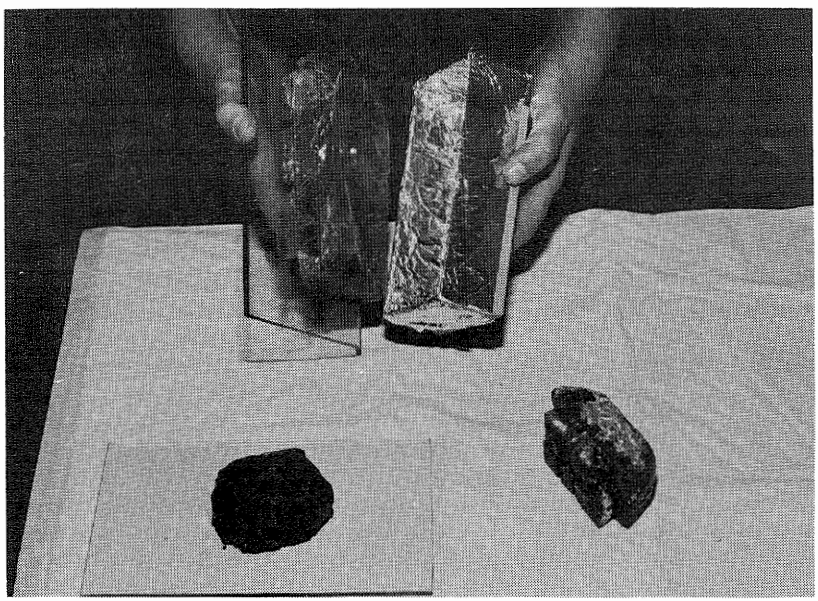


Fig. 17 - Coal balls embedded in plastic. At top center, an embedded slice (left) as it appears when removed from a mold (right), a box lined with aluminum foil. At lower left is a slice glued to a glass plate. At lower right are five small slices embedded in one block of plastic.

plastic to see how high the plastic rises on them when the glass plate is lying on top of the mold. Add more plastic to bring it up to the desired level around the coal-ball pieces.

Embed as little of the coal-ball pieces as is necessary to obtain a strong mount, because when the coal-ball surface is flush with the plastic the peel sticks to the plastic. Fragile specimens must be embedded more deeply than stronger ones. It may be possible to leave as much as an inch of the stronger specimens protruding from the plastic and as little as a quarter of an inch of the fragile ones.

Once the mold is filled and the coal-ball pieces are suspended in place, do not disturb the preparation until the plastic hardens, a period of about 48 hours. You can then remove the glass plate and plastic block from the mold and carefully twist the embedded pieces from the plate. Remove any aluminum foil that sticks to the plastic and trim or break off all the sharp plastic edges. (Diagonal-cutting pliers work well.) Rub the rubber cement off the exposed faces of the coal-ball pieces. They are now ready for the peeling operation.

SOURCES OF MATERIALS

Finding Coal Balls

Coal balls have been reported from 50 or more localities in the Illinois Basin (fig. 3). Although more than half the localities are in the Herrin (No. 6) Coal Member and the Springfield (No. 5) Coal Member—two coals that have been extensively mined—15 other coals have yielded coal balls. The best known coal-ball floras are those from the Herrin Coal Member, particularly from southern Illinois, and those from the Calhoun Coal Member. Anyone who seriously wants to find coal balls should study the reports of paleobotanists to learn where coal balls have already been found and how they occur. The *Development of Paleobotany in the Illinois Basin* lists many of these reports. Some of them are now available only from libraries at universities, large museums, and other research institutions.

After you have decided on a locality to explore, be sure to get permission to enter the property and to take out specimens.

Paleobotanists working with Illinois coal balls are always eager to learn the location of newly exposed and unrecorded coal-ball deposits. If you find coal balls in a place you suspect no paleobotanists have visited, please inform the Educational Extension Section of the Illinois State Geological Survey of the precise location of the deposit. You will be notified of the status of your discovery and put in contact with the paleobotanist who investigates it if an investigation is made.

Materials Needed

The materials used in coal-ball preparation and repair described in our guide are listed below with the names of some suppliers. Other companies sell such supplies. The companies listed are those from which the Botany Department of the University of Illinois purchases supplies at present, but the list is not an endorsement of those particular companies. You should get information from other suppliers about products available and prices charged.

Materials	Sources
Clear cellulose acetate, standard grade, 0.003-inch thick	Transilwrap Company 2615 N. Pauline St. Chicago, Il 60614 (material available in rolls or 20 by 50-inch sheets)
No. 400 grit Carborundum	Large hardware stores, lapidary suppliers, or The Carborundum Company P.O. Box 337 Niagara Falls, NY 14302
Acetone N.F., hydrochloric acid (acid muriatic), xylene, ethyl alcohol	Chemical suppliers and other retail stores
Piccolyte in xylol 50% solution, or HSR (Harleco Synthetic Resin in xylene); Turtox CMCP-9 or CMCP-10 mounting medium	Macmillan Science Company (formerly Turtox or General Biological Supply House, Inc.) 8200 South Hoyne Ave. Chicago, IL 60620
Durham's Water Putty	Hardware stores
Crystal Cast HS4101, embedding and casting plastic	Crystal Craft Division High Strength Plastic Corp. 1401 West Jackson Blvd. Chicago, IL 60607
Almag cutting oil	Texaco products distributors

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EXPLANATION OF PLATE 1

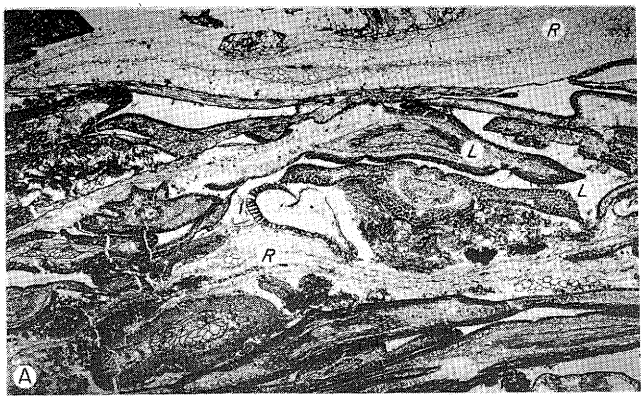
PHOTOMICROGRAPHS OF PEELS SHOWING PENNSYLVANIAN PLANT ORGANS COMMON IN ILLINOIS COAL BALLS—LYCOPOD TREES

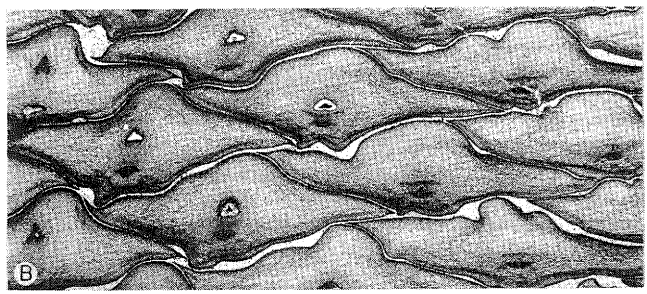
A. Rootlets (coarse-celled, lighter colored bodies, some labeled *R*) infiltrating a mat of leaves (darker structures, some labeled *L*). The rootlets are named *Stigmaria* and the leaves *Lepidophylloides*. Both are parts of the lycopod tree named *Lepidodendron* or *Lepidophloios*. Cross sections of leaves and longitudinal sections of rootlets. × 11. (At this magnification structures shown are 11 times their natural size.)

B. Cross sections of leaf cushions on the outer surface of the trunk of a lycopod tree, *Lepidophloios kansanus*. Leaves were attached to the leaf cushions. Each cushion has a ligule (in the white triangular-shaped areas in the centers) above the vascular bundle (the lip-shaped, black structures). × 4.

C. Cross sections of rootlets (*Stigmaria*) from the lycopod tree named *Sigillaria*. Each rootlet has—from the outside in—an outer layer, an inner hollow space (lacuna, *U*), and a sheath of connective tissue (*C*) supporting a xylem strand and joining it to the outer layer. Note that the rootlets in figures A and C are both assigned to the same organ genus, *Stigmaria*, even though they are now known to come from different genera. × 11.

D. Cross section of a stem of a lycopod tree branch, *Lepidodendron sclerotic*um. From left to right: primary xylem (*X*), wood layer (*W*), supportive cortex (*Y*), periderm, or bark (*P*), and leaf cushions (*L*). × 4.





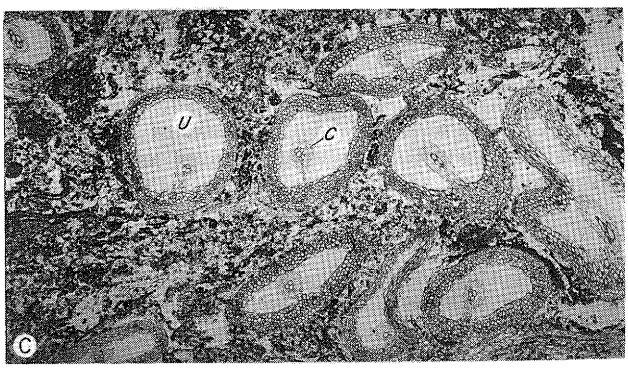
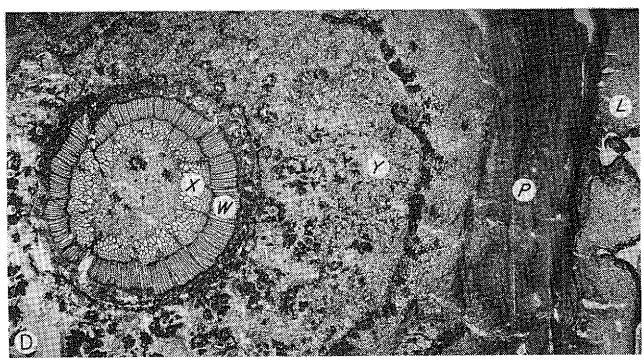


Plate I



EXPLANATION OF PLATE 2

PHOTOMICROGRAPHS OF PEELS SHOWING PENNSYLVANIAN PLANT ORGANS COMMON IN ILLINOIS COAL BALLS—LYCOPODS, *SELAGINELLA*, TREE FERNS, AND *CORDAITES*

A. Cross section of a megasporangium (*M*) and sporophyll named *Lepidocarpon*, from the lycopod tree *Lepidophloios*, and an ovule (*O*) from the seed fern *Taxospermum*. Megasporangia were borne by many lycopod trees. The *Taxospermum* ovule is one of the most common small seeds in coal balls. No embryos have been found preserved in any ovules in coal balls. × 4.

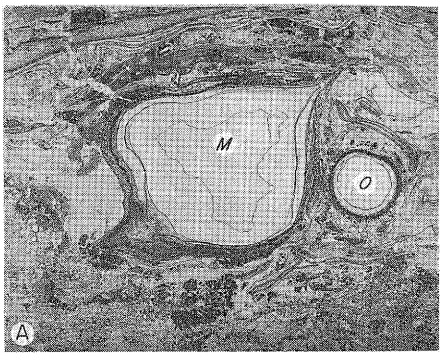
B. Cross section of a lycopod twig (center structure) sheathed with its leaf cushions and leaves (*L*), also in cross section. The leaves are spirally arranged around the cylindrical twig. × 11.

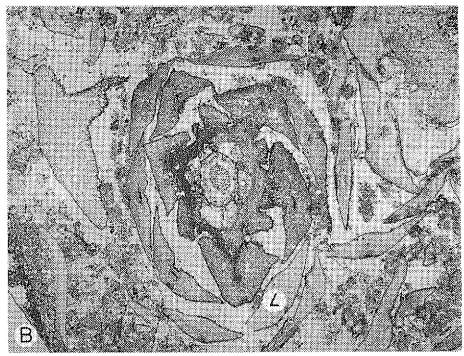
C. Cross section of a *Selaginella* stem with a star-shaped xylem (center) surrounded by the cortex with lobes, some of which correspond to leaf bases or leaves (*L*). *Selaginella* is the only genus of vascular plants in the Pennsylvanian coal swamps known to have survived to the present day. × 20.

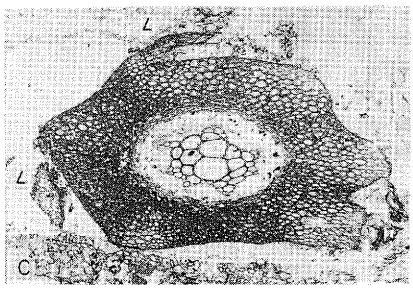
D. Paradermal section (parallel to the surface) of a pinnule of *Scolecopteris* (belonging to the tree fern *Psaronius*) showing cross sections of groups of 3 and 4 sporangia. × 20.

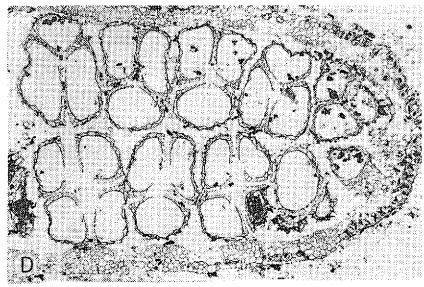
E. Cross section of a root of the tree fern *Psaronius*. The star-shaped body with the large tube ends radiating from its center is the xylem (lower left). A rootlet (*R*) is connected to the xylem and has grown through the cortex. The larger spaces in the cortex are air chambers. × 11.

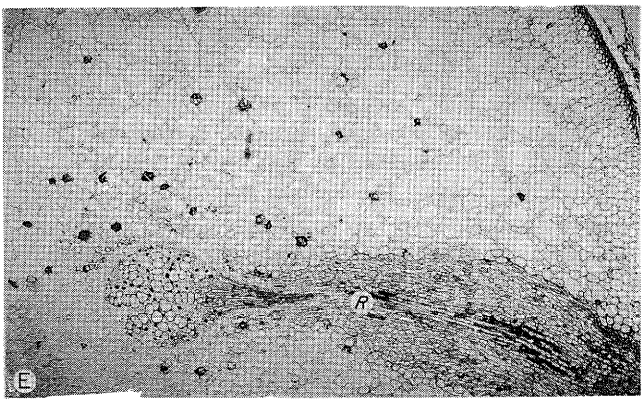
F. Cross sections of *Cordaites* leaves fallen into layers and infiltrated by stigmarian rootlets. Each leaf has a single row of round, regularly spaced vascular bundles. × 11.











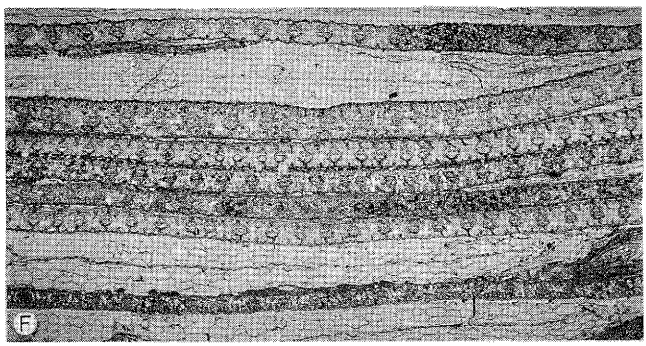


Plate 2

EXPLANATION OF PLATE 3

PHOTOMICROGRAPHS OF PEELS SHOWING PENNSYLVANIAN PLANT ORGANS COMMONLY FOUND IN ILLINOIS COAL BALLS—SEED FERNS, *SPHENOPHYLLUM*, AND *CALAMITES*

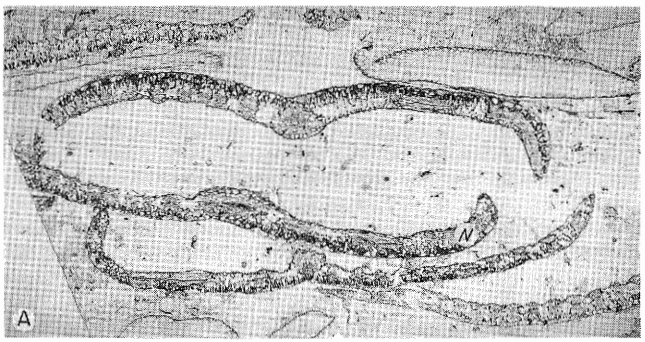
A. Cross sections of laminate *Alethopteris* pinnules (*N*), which are "leaflets" from the fronds of the seed fern *Medullosa*. The "leaf" parts of *Medullosa* fronds are given the names *Alethopteris* and *Myeloxylon*. Seed ferns are also called pteridosperms. × 11.

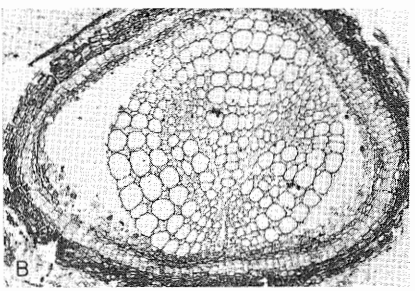
B. Cross section of a *Sphenophyllum* stem with a triangular primary xylem strand surrounded by wood and an outermost layer of periderm (bark). × 20.

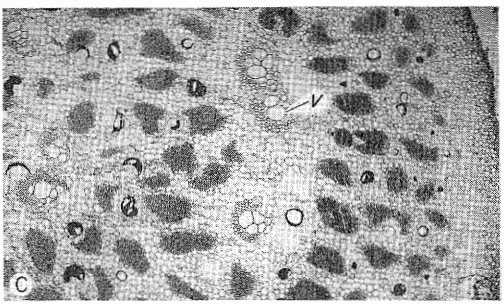
C. Cross section of part of a frond rachis, *Myeloxylon*, from the seed fern *Medullosa*. Scattered through the ground tissue are vascular bundles (clusters of large tubes, *V*) and dark clusters of thick-walled supporting cells. The large tubes with black rims or contents are resin canals. × 11.

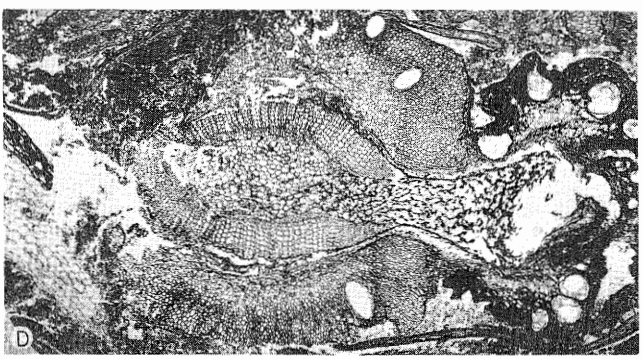
D. Cross section of the stem and an immature branch of the small seed fern *Callistophyton*. The center of the stem (central part of the photo) and the branch (right side) are connected by common tissues at this level. The large white spots around the branch and at the right side of the stem are secretory cavities. × 11.

E. Cross section of a small *Calamites* stem showing its hollow center and bands of wood radiating out from the carinal canals (the ring of large, white, circular openings). The outer layer—the cortex—is complete and wrinkled on the right side. The epidermis is the outermost layer of cells around the cortex. *Calamites* resembled and were probably the ancestors or very close relatives of the modern horsetails or scouring rushes (*Equisetum*). × 11.









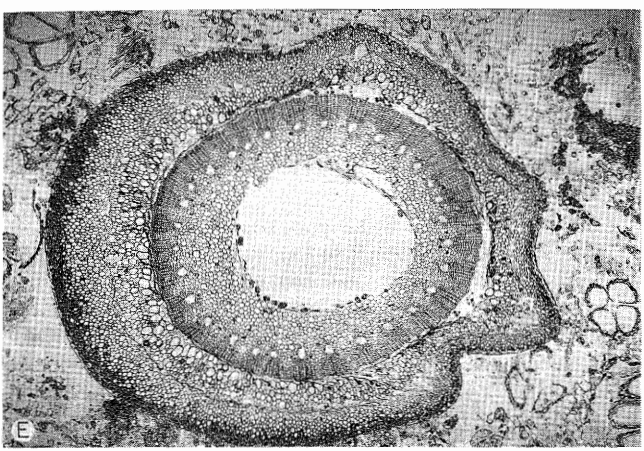


Plate 3

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