A Forest of the Coal Age

BY

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Geology
Leaflet 14

FIELD MUSEUM OF NATURAL HISTORY
CHICAGO, U. S. A.
1933

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STEPHEN C. SIMMS, DIRECTOR

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DETAIL OF THE CARBONIFEROUS FOREST RESTORATION IN FIELD MUSEUM

The large tree in the center background is a tree-like clubmoss, *Sigillaria*, partly hidden by the trunks of a *Lepidophloios* and a tree-fern with large leafscars on the stem and concealed above by fronds of this fern (*Psaronius*) and foliage of *Lepidodendron*. Ascending the *Lepidophloios* trunk is a seed-fern (*Lyginopteris*) with delicate forking fronds, one of which is shown bearing seed (*Lagenostoma*). The strap-shaped foliage in the upper left corner is that of the gymnosperm *Cordaites* and below on the left are two seed-ferns (*Neuropteris decipiens* above, *N. heterophylla* below) each presenting a seed-bearing frond. The small plant at the bottom center and right is *Sphenophyllum*. The large fallen trunk is a *Sigillaria* with a small herbaceous clubmoss, *Selaginellites*, spreading over its surface. The slender log on the ground is a *Lepidodendron* with rhombic leaf cushions. On this trunk is seen one of the large roaches of the period and beyond is one of the four-legged inhabitants of the swamp forests, a Carboniferous amphibian.

FIELD MUSEUM OF NATURAL HISTORY
DEPARTMENT OF GEOLOGY
CHICAGO, 1933

LEAFLET NUMBER 14

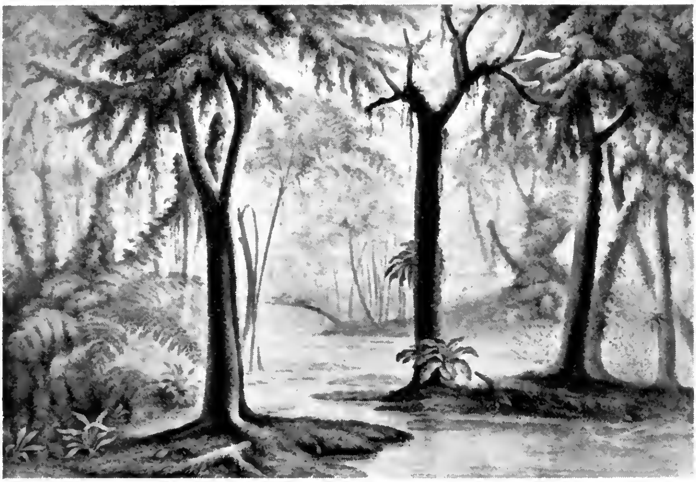

FIG. 1. Unger's landscape of Carboniferous time.

PREFACE

Various attempts have been made by paleontologists to picture the character of the Carboniferous flora. One of the first was that of Unger in the series of plates published in Vienna in 1847 under the title "Die Urwelt in ihren Verschiedenen Bildungsperioden." His landscape, reproduced above, will be recognized by many, for it has been widely copied in texts on geology. In the middle of the nineteenth century, however, the Carboniferous vegetation was still very imperfectly known. As paleobotanical science advanced other attempts were made on the basis of a better understanding of the plants

FIG. 2. Landscape of Carboniferous time. Restoration by Potonié.

FIG. 3. Carboniferous vegetation. Restoration by Potonié and Gothan.

composing the coal flora. The latest and most satisfactory of these are the paintings made under the direction of the famous paleobotanist Potonié. One published in 1898 in the form of a chart, issued under the auspices of the Prussian Geological Survey and School of Mines of Berlin, is reproduced here (Fig. 2). A still later representation of a Carboniferous landscape has since been sponsored jointly by Potonié and Gothan and has been republished within a year or two in revised form (Fig. 3).

An extensive landscape can be represented on paper or on canvas with great freedom with details unknown or imperfectly understood treated in a noncommittal manner. In a three-dimensional restoration, such as that in Field Museum, intended to be seen at close range, this large amount of freedom from troublesome questions does not exist. On the contrary it becomes necessary to commit oneself at every point and to determine, correctly or incorrectly, every particular in sight. The most that can be left to a painted background is a suggestion of general landscape features with the continuation and extension in space of that which is definitely shown, natural size, in the foreground.

The Museum "group" to which this leaflet refers is composed of an assemblage of three-dimensional reconstructions, contained within the space of 28 x 15 x 20 feet that it occupies. These reconstructions embody as far as possible the best available present-day knowledge of Carboniferous plants, as in the case of *Lyginopteris* and of Kidston's *Neuropteris heterophylla*. All essential details of the plants restored were obtained from fossil specimens existing in Field Museum collections or loaned by other institutions. In many cases the surface pattern of the tree trunks, form and surface markings of leaves, were produced directly from impressions of the fossils and then mechanically multiplied to the extent required. The technique developed in the laboratories for plant reproductions maintained in the Museum by Mr. Stanley

Field for the purpose of providing botanical exhibits, has made possible the execution of the restorations seen in this group. Throughout the progress of the work the writer, under whose direction this group has been produced, has enjoyed the inestimable advantage of the advice and cooperation of Professor A. C. Noé of the University of Chicago, Research Associate in Paleobotany in Field Museum, whose large and intimate acquaintance with the Carboniferous flora has made him an authority in this field. The Museum is indebted to Dr. R. S. Bassler of the United States National Museum and to Dr. A. S. Romer of the Walker Museum, the University of Chicago, for the loan of important material. No other special acknowledgments are considered necessary except as made in connection with text figures.

The appended list of popular works and the more readable and accessible technical ones on plants of the past will be found to contain ample references to the voluminous paleobotanical literature which exists on the subject of the ancient coal plants.

A FOREST OF THE COAL AGE

To most people coal is but a black mineral dug out of the earth, of interest only because it is useful to burn in the stove or furnace or under the boilers of ships and factories. To the geologist it is the remains of a vegetation that flourished ages ago, that may be studied by the paleobotanist, and even reconstructed in all its detail.

Ever since land plants gained possession of the surface of the earth, plant material has accumulated at various times in different places, and has been preserved from decay and gradually converted into peat or coal. Many coal beds have thus originated in relatively recent times, but none of these compares in importance or extent with those dating from that vastly remote age known as the Carboniferous, especially from its latter part, the so-called Pennsylvanian period, some 250,000,000 years ago, toward the end of the Paleozoic era.

The world's first great land flora was then reaching its culmination in the swampy rain forests that covered much or most of the land exposed in the northern hemisphere. In Europe and in northern Asia as in North America these forests existed for millions of years, giving rise to the vast accumulations of plant material that in the course of time have been compressed and changed into coal and now constitute the world's chief bituminous and anthracite deposits. In North America these Carboniferous forests extended from Nova Scotia more or less interruptedly through Rhode Island along the Appalachian coal field southward to northern Alabama and to Texas and westward through Nebraska along the present Rocky Mountain region even to Alaska. Throughout much of this great area the formation has become completely covered up in the course of subsequent geological events, and in places removed, but various large and distinct coal-bearing areas remain. The most widely known of

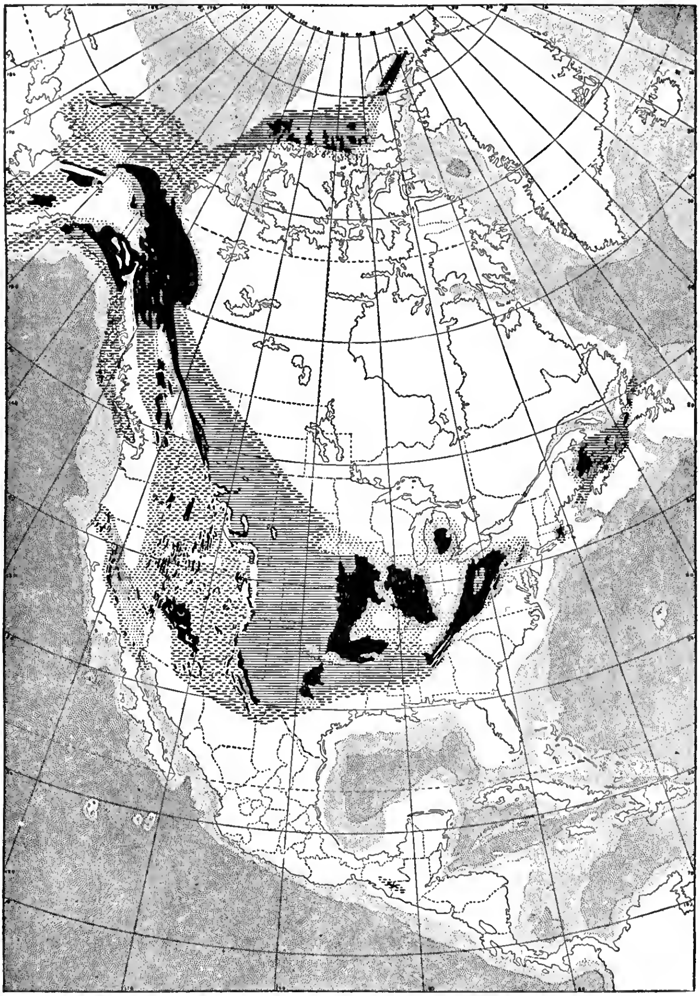

FIG. 4. Map showing the areas where the Pennsylvanian system appears at the surface in North America. The map also shows the areas where the Pennsylvanian system is thought to exist though buried (lined areas); the areas where it is thought once to have existed, but to have been removed (dotted areas); and by inference the relations of land and sea during the Pennsylvanian period. After Chamberlain and Salisbury.

these is the Appalachian, including the Pennsylvanian and West Virginian coal fields. Another, known as the Middle Central coal field, includes Illinois, Indiana, and part of Kentucky. A third, known as the Western field, comprises parts of Iowa, Nebraska, Kansas, Missouri, and Texas. In Europe the Carboniferous forests were somewhat less extensive but covered large parts of the British Isles, Belgium, parts of France, Germany, Poland, and Russia. In northern Asia, in Siberia, and especially in China, they were also extensive. Their remains testify to the general prevalence of the same kind of vegetation over an immense area under practically uniform conditions for an enormous length of time.

Essentially a flora of the northern continents, some of it in the course of time extended southward, crossing the equator and even reaching remote places in the southern hemisphere. Though this, at the time or soon afterwards, was overrun by a similar but much less luxuriant flora of its own, fossils of Carboniferous plants of the northern flora have been recovered as far south as Sumatra in the Old World and Peru and southern Brazil in the New.

It is certain that the face of the world at that distant period presented an appearance very different from that of the present day. There were no grass-covered prairies, no hillsides or mountain slopes with flowering plants in summer, no woods of broad-leaved flowering trees and shrubs such as constitute our modern forests in the temperate as in the tropical zone. None of these had yet made their appearance. The abundant and even rank vegetation which existed was made up of lower, flowerless orders, such as our horsetails, ferns, and club-mosses, now mostly insignificant plants but then forming a great and luxuriant flora. The badly drained land was dotted with bogs and swamps in which flourished stands of great horsetail rushes. Spreading endlessly, like giant canebrakes, over the marshy ground of a flat continent they disputed the possession of the land with forest-like formations of huge clubmosses and early gymnosperms that then attained the dimensions of forest trees. Ferns and fern-like seed plants formed the undergrowth and as climbers or clambering plants took the place of lianas. In these rain forests, which were constantly green, growth was continuous and probably rapid.

The trunks, even of the forest giants of the time, produced less of solid substance than might be expected from their size, for they consisted chiefly of a thin cylinder of wood filled with soft pith. All, however, eventually littered the ground with their debris and added to the accumulation of dead plant material.

Naturally, not all of the forest litter was preserved. A large part of it decomposed to form humus but the fact that so much was converted into coal indicates not only a very luxuriant growth during a period lasting millions of years, but also the prevalence of extremely favorable circumstances for its preservation, i.e., a minimum of decay. This points to the existence of swamp conditions, an abundance of rainfall and of standing water, and an acid or sour subsoil such as is generally associated with a lack of ready surface drainage. Such conditions are also indicated by peculiarities of the plants themselves, the structure and the horizontal and superficial disposition of their spreading root system, or perhaps, more strictly speaking, the rhizomes of the large trees, which, though interlacing with those of their neighbors, must have offered a relatively poor support for the tall trunks. So peculiar is the appearance of the system of roots that form the support of the trees of the clubmoss order, that it was once seriously argued that the branching roots, which are full of air spaces, must have acted as a raft and served to support a floating forest. One may, however, feel confident that most of the forest was well, though superficially, anchored in the mud.

Individual coal seams ordinarily range in thickness from a few inches to two feet or more, at times to as much as fifty feet. They are usually underlaid by clay and separated by intervening layers of sandstone or shale, for the growth of the vegetation in any one place was apt to be discontinuous, being interrupted from time to time by more or less extensive subsidence and submergence of the forest during which the deposition of sand or mud took place, covering up the accumulated debris. On renewed elevation the vegetation would again spread over the land. A mass of forest litter which has given rise to two feet of coal must have had from twenty to thirty times that thickness when it was laid down. One producing fifty feet of coal must have been prodigious, probably a quarter of a mile thick.

One theory of coal formation would explain all of the coal as due to the accumulation of drift deposited in river estuaries. This is the so-called "drift theory" which has been upheld as against that of the *in situ* formation of coal. Much evidence has been presented for both views and there can be little doubt that coal was formed in both ways, but by far the greater part of it where it grew. The present consensus of opinion seems to be that the coal forests were formed under conditions precisely such as exist in the estuaries of some great river system, and that their nearest present-day counterparts are to be sought in places such as the Dismal Swamp in Virginia, the brackish cypress swamps of southern Florida, the swampy rain forests at the mouth of the Amazon, or the Sundarbans in the delta of the Ganges and the Brahmaputra.

It may be asked how such conditions could prevail over large areas in the interior of the continents. The presence of brackish water shells in association with coal seams indicates the invasion of the coal-forming areas by arms of the sea. These extended far into the interior of the present continental areas, receiving the excess water from the rivers and exercising a profound influence on the climate. In Illinois there is evidence, according to Professor Noé, of more than sixty such invasions by gulfs of the sea. Much has been written on the subject of the climatic conditions of the Carboniferous age, the great humidity prevailing, the generally murky atmosphere, the large amount of precipitation, and the large quantity of carbon dioxide in the air. It is generally accepted that the climate was warm and moist, without changes sufficiently marked to interfere with continuous growth or large enough to impress on the structure of the vegetation any perceptible indication of a seasonal periodicity.

FIG. 5. An impression in Pennsylvanian sandstone of the surface of the trunk of one of the *Sigillarias* or ribbed-stem clubmoss trees of Carboniferous forests. Above each of the five leaf cushions included in this fossil impression is seen the leafscar proper with its two distinct smaller scars, those of the vascular bundles that entered the leaf.

For our knowledge of the botanical character of the Carboniferous flora we are dependent on its fossil remains, especially the casts and impressions preserved in the layers of shale or sandstone that separate and cover the coal beds. The plant remains in the coal itself have for the most part been so greatly modified and compressed that individual parts are not readily distinguishable. The fossil remains are very numerous. They abound on the mine dumps in all coal areas. Unfortunately they are always fragmentary, but, thanks to the painstaking work of many paleobotanists in many parts of the world, there is available at present a large body of knowledge concerning the plants of that time. One is thus able to obtain a very definite idea of the character of many of the species which formed part of the Carboniferous vegetation and, on the whole, to arrive at a very fair conception of the general constitution of the flora which covered the earth

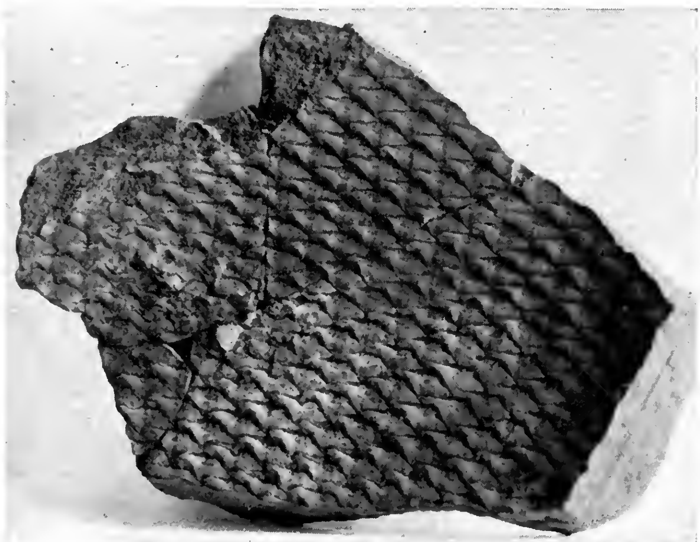

FIG. 6. *Lepidophloios acadianos* Dawson. A sandstone impression of another order of clubmoss trees of the Carboniferous forest. The scale-like leaf cushions are broader than long and closely crowded.

at a time when feeble-limbed amphibious vertebrates were first emerging from the waters of the swamp.

This detailed knowledge of the ancient flora makes it possible to restore with a considerable degree of confidence a typical assemblage of plants of Carboniferous time. This is what has been done in the preparation of the group which forms a part of the historical geology exhibits in Ernest R. Graham Hall in Field Museum. 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

FIG. 7. A split sandstone nodule from Mazon Creek, Illinois, with an included fossil leaf (*Neuropteris decipiens*), a fragment of a frond of the large seed-fern shown in the group.

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 exhibit in Field Museum shows a scene in a dense swamp forest at the margin of a stretch of shallow water which may be an arm of an inland lake, the quiet backwater of a large watercourse, or a lagoon at the estuary of a slow-flowing river, a locality where stagnation prevails rather than movement—a landscape which may be considered typical of the conditions under which the flora of the period reached its climax. Of an upland flora of the Carboniferous age nothing is known. If it existed, it was probably much less luxuriant and consisted of species adapted to a drier environment or able to endure it, such as those elements of the flora that survived into the next period. The Pennsylvanian flora of which there are fossil remains, was of a kind that flourished only in the presence of abundant moisture.

The margins of the watercourses, the shallow lakes and estuaries, were bordered with dense formations of calamites, huge horsetails resembling in character the present-day scouring rushes (*Equisetum*), but then tree-like forms with wood and bark. They approached bamboos in height and probably in rapidity of growth and rivaled or exceeded the giants among present-day bamboos in diameter. The term *calamites* (from calamus, a reed) was originally applied only to the remains of stems, the cylindrical casts of the hollow, ribbed interior from which the pith had disappeared, or flattened impressions showing the jointed exterior surface. Many kinds have been distinguished and described according to the external characters of the stem. Some have numerous branches at all or at most of their nodes, others at certain regular intervals only, others again appear to have had few or no branches. Some had foliage branches of one order only directly on the main stem, others branched repeatedly and profusely, producing a bushy or graceful tree-like top. The leaves were always borne in whorls. Two distinct types of foliage were common. One consisted of filiform, jointed leaves in dense whorls at the nodes of the slender ultimate branches (*Asterophyllites*), the other of flattened leaves in whorls of a stellate shape (*Annularia*). The latter are particularly abundant at Mazon Creek and are to be seen on the calamites in the group. Like their smaller modern relatives, the horsetails and scouring rushes, the calamites had extensive underground rootstocks. They were reproduced by spores formed in cones or catkin-like spikes, usually situated at the tips of the foliage-bearing branches.

FIG. 8. A fragment of a branch of a calamite in a Carboniferous sandstone nodule, showing the type of calamite foliage (*Annularia radiata*) most common at Mazon Creek, Illinois, and represented in the group.

The great horsetail rushes were greatly exceeded in size by the trees that formed the bulk of the vegetation. Foremost among these were the club-

FIG. 9. A fossilized fragment of the armor of leaf cushions that invested the trunks of scaly-stemmed clubmosses of the Carboniferous age (*Lepidodendron clypeatum* Lesquereux).

mosses of many species that attained the size of large forest trees. They sometimes reached six feet in diameter and a hundred feet in height. With their columnar trunks fluted or ornamented as if by a sculptured pattern, with their unbranched or sparsely branched tops terminating in a single tuft or in a canopy of equally and repeatedly forking branches bearing grass-like foliage, and with their horizontally extended and regularly forking roots, these big clubmosses must have set their somber stamp on the entire landscape. Those in the background of the group in the Museum may be seen with their rootlets exposed at the edge of the water.

The two principal types of these characteristically Carboniferous trees are *Lepidodendron* and *Sigillaria*. The former take their name from the armor of rhombic leaf cushions (Figs. 9, 10) that covered the trunks and indicate the spiral arrangement of the leaves. The latter are so-

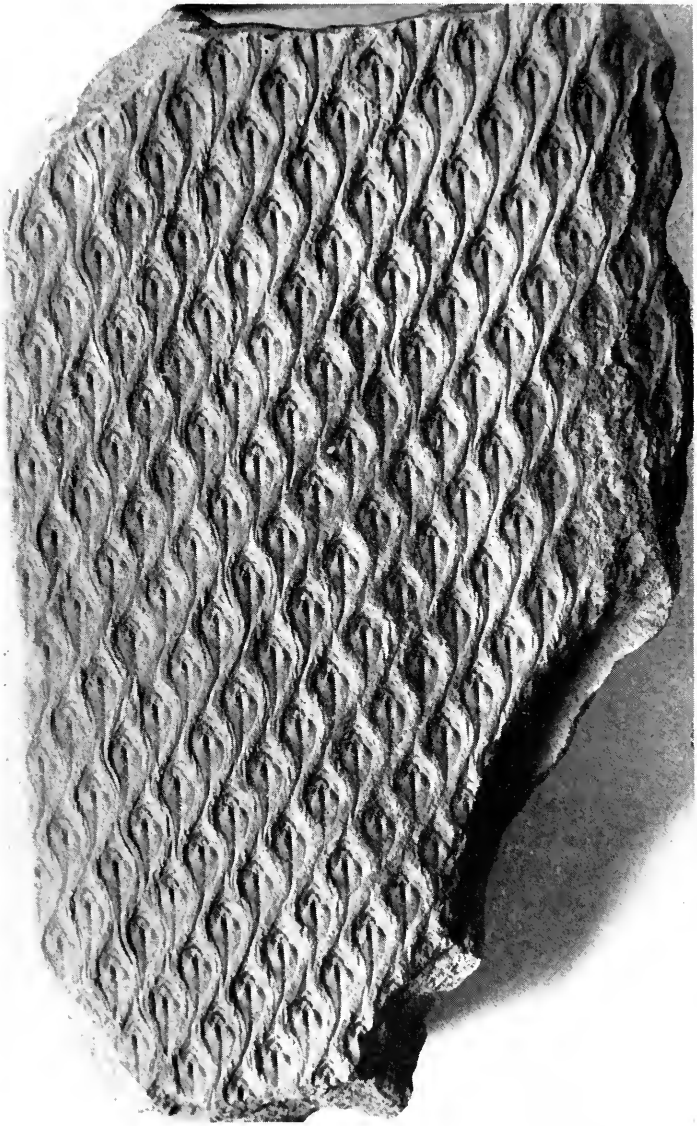

FIG. 10. An impression in sandstone of the Pennsylvanian period of the surface pattern on the trunk of an ancient clubmoss (*Lepidodendron obovatum* Sternberg). Mazon Creek, Illinois.

FIG. 11. A slab of Carboniferous limestone from Mazon Creek, Illinois, showing fossil fern fragments and a large fossil clubmoss cone (*Lepidostrobus ovatifolius* Lesquereux).

called because of the seal-like impressions of their persistent leafscars, generally in vertical rows on the ribbed or smooth stem (Figs. 5, 12). There were other forms intermediate between these, and still others distinguished by various kinds of characteristic sculpturing on the surface of their stems, such as the forking *Lepidophloios* (Fig. 6), near the center of the group. High on the trunk and large branches of this are clumps of short, leafy shoots, terminating in a spore-bearing cone. Such masses of cones were probably produced periodically, were shed and replaced by a new crop of shoots. The *Sigillarias* also produced their cones on the trunk, differing in this respect from the freely branching *Lepidodendrons* that bore their foliage and cones (Fig. 11) at the tips of slender terminal branches. Clubmoss cones must have appeared in great profusion and produced their pollen-like spores in enormous quantities, for masses of spores constitute an important element of the plant material that was converted into coal. Indeed, certain coals seem to be made up entirely of spores.

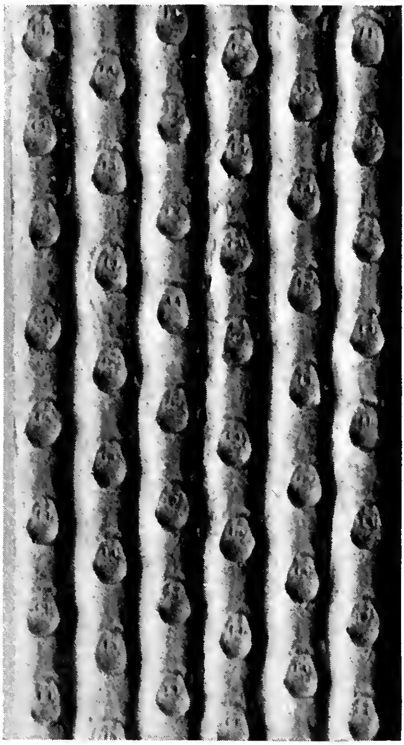

FIG. 12. *Sigillaria saulli.* A cast from an impression of the stem of another ribbed-stem Pennsylvanian clubmoss. The leafscars are closer set than in Fig. 5. The small scars of the pairs of vascular bundles that entered each leaf are plainly visible.

CARBONIFEROUS SWAMP FOREST GROUP

A restoration of plant and animal life of the Carboniferous period especially as this is represented in the fossil remains of the Upper Pennsylvanian in the Middle Central coal field at Mazon Creek, Illinois. The forest formation of giant clubmosses, ferns and fern-

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like plants on the left is repeated in the distance. On the right is seen a solid formation of the large Paleozoic horsetails known as calamites. The group occupies a space 28 by 15 by 20 feet, and forms a part of the historical geology exhibits in Ernest R. Graham Hall.

The *Sigillarias* with their single or few terminal tufts of long, slender leaves must have had a general appearance suggestive of the so-called grass trees of Australia.

Most of the Paleozoic clubmosses became extinct at the end of the Carboniferous age but some of the smaller ones persisted much longer. The group is represented today by the ground pines and *Selaginellas,* the former mostly of the temperate zone, the latter in the tropics.

The other great group of tall forest trees of the period were early gymnosperms, called *Cordaites* in honor of the paleontologist Corda. They have long since disappeared but belonged to a line which probably gave origin to such conifers as *Araucaria* and *Agathis,* the Australian kauri tree, essentially Tertiary trees still in existence today in the southern hemisphere. The *Cordaites* were truly large-leaved (Fig. 13). The species of this order included in the group has a sparsely branching trunk and broadly

FIG. 13. A slab of Pennsylvanian limestone with fossil leaves of several species of the Carboniferous gymnosperm *Cordaites.* That in the rectangular area at the apex is of *Cordaites borassifolius,* which was reconstructed for the group.

strap-shaped, leathery leaves closely massed on the branches, as in some trees of the lily family, such as *Dracaena* or *Cordyline*. The *Cordaites* bore true seeds, which were not produced in cones but on small shoots in the leaf axils much as in the Ginkgo, a surviving, chiefly Mesozoic relative of the *Cordaites* line.

The shade of the upper canopy of branches was not too dense to prevent the existence in the Carboniferous forest of a luxuriant vegetation of lesser size and the fossil remains include an extraordinary quantity and variety of stems and foliage of fern-like aspect. This element formed so large a part of the Carboniferous vegetation that the age has been called the Age of Ferns. It is now known that these fern-like fossils are derived from at least two superficially similar but very distinct kinds of plants, true spore-bearing ferns, many on the order of present-day tree-ferns, and a large variety of seed-bearing plants with cycad-like seeds but with fern-like foliage that at first led to their confusion with the ferns. The usual and convenient form of classification of fern-like fossils and its terminology current among geologists is based on the appearance of the fronds alone, and fails to make the important botanical distinction. In most cases it is in fact not yet known whether certain well-known fronds or parts of fronds are those of a fern or of one of these seed-bearing plants. In other cases, now sufficiently numerous, it has been possible for paleontologists to associate definitely the fern-like foliage with stems, fruit, and even with special pollen-bearing fronds, so that all essential characters of certain seed-ferns (Cycadofilices or Pteridosperms) are well understood. Parts formerly described as widely separate species are thus now known to belong to the same plant.

The most famous case of this kind is the seed-bearing *Lyginopteris*, a climber or semi-climber shown supported by the trunk of one of the larger trees near the center of the group (Plate I), where it is easily recognized by its

FIG. 14. Fragments of foliage of the seed-fern *Lyginopteris*. These fronds were long known as *Sphenopteris hoeninghausi* before their connection with the other parts of this plant was even suspected.

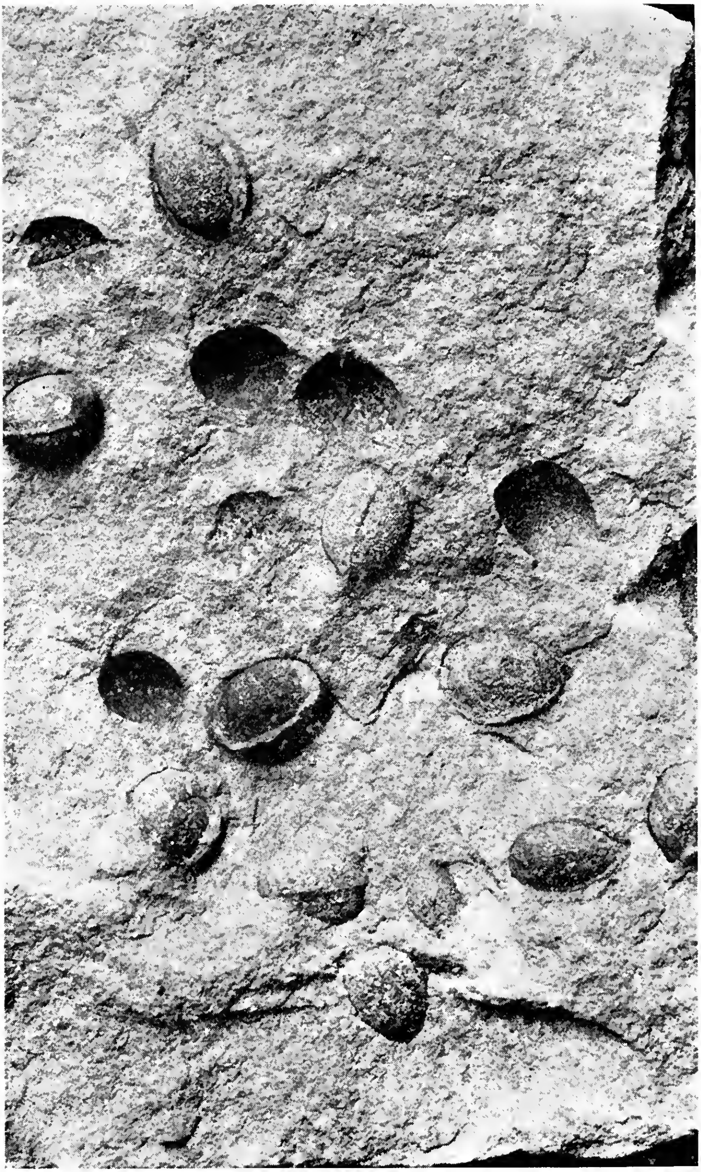

FIG. 15. A block of sandstone from Mazon Creek, Illinois, with imbedded fossil seeds of the large seed-fern shown in the group.

proproots, its delicate fern-like foliage (Fig. 14) the slender forked rachis of its fronds and its special fruiting frond among its upper leaves. The seeds of this with their calyx-like envelope have long been known as *Lagenostoma*. The forking of the main rachis of the frond appears to be a constant characteristic of these seed-bearing plants. It is conspicuous in one of the heavier, large-leaved species with large seeds to the left in the group, a restoration of one of the most abundant of Carboniferous fossils of the state of Illinois (Fig. 7). Another peculiar feature which the forked leaves have in common is the presence on the lower part of the leaf stalk, of large, simple leaflets very different in outline from the rest of the foliage. This is particularly noticeable in the bracken-like seed-fern in the immediate foreground of the group and is especially well seen on the still coiled young leaves. Many of these plants had stems like the tree-ferns. The fossil stems sometimes reach two feet in diameter.

The true botanical status of the characteristically Carboniferous climber, *Mariopteris*, with stiff, twice-forked fern leaves (Fig. 16), ascending the small *Lepidodendron* tree on the right (Plate I), is not determined.

FIG. 16. A part of the frond of the climbing fern or seed-fern *Mariopteris* seen near the large dragon fly in the group.

Stems of tree-ferns are conspicuous and frequent among Carboniferous fossils. Several types are known, two of which are represented in the group. No Paleozoic fern can be included in any family of living ferns, but one of those shown in the group does not differ greatly in general appearance from its modern relatives found today in the southern hemisphere. Its leaves and the leafscars on the stem are in straight rows, but stems of tree-ferns with the leafscars in the now usual spiral arrangement were also found fossil in the coal measures. The other is distinctly peculiar in appearance due to the disposition

FIG. 17. A portion of the stem of a tree-fern (*Psaronius*). The rock is Carboniferous sandstone. The large leafscars are seen to be placed in straight rows. Compare with the tree-fern trunk in the restoration.

of its leaves in only two vertical rows, which produces a fan-shaped top as in some banana plants or in the traveler's tree of Madagascar. It is called *Megaphyton*, "large plant," not a very well-chosen name for such a distinctive fern.

On the ground are small clumps of a very common and characteristic plant of the Carboniferous swamp vegetation, *Sphenophyllum*, a term referring to the wedge-shaped leaf. It is further characterized by numerous, slender, little-branched, jointed stems, whorls of delicate, notched or slit leaves and long, fruiting, catkin-shaped spikes, which resemble closely the spore-bearing spikes of the large calamites. Because of its sometimes finely divided leaves, suggesting those of some modern water plants, *Sphenophyllum* was formerly thought to have been an aquatic. It has also been considered a climber, because of its long stems, too slender to stand erect alone, but it was probably neither. It has been represented in the group as of the general habit of a straggling herb such as the well-known bedstraw *Galium*, to which it is of course not in the least related. *Sphenophyllum* is now entirely extinct. With the calamites, to which it is undoubtedly related, it is sometimes classed as one of the Articulates, or jointed-stem plants. It may represent an early stock from which the calamites had originated.

FIG. 18. A fragment of *Sphenophyllum* in a split sandstone nodule from Mazon Creek, Illinois.

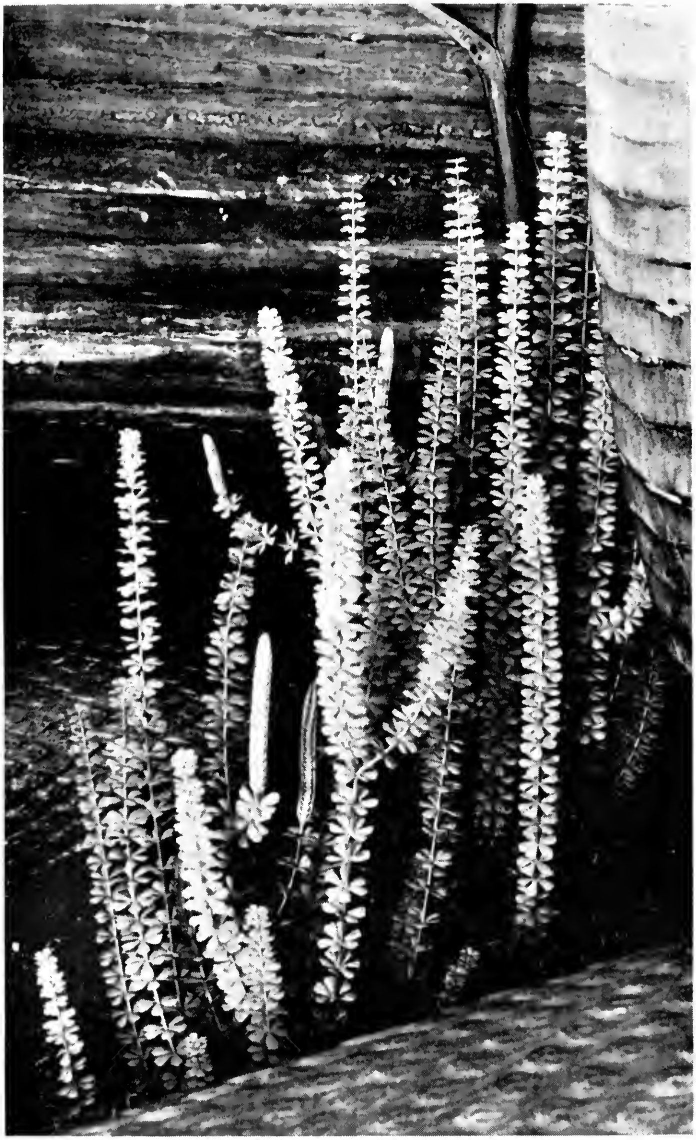

FIG. 19. A clump of *Sphenophyllum* showing the slender, jointed stems, whorled leaves, and the catkin-like strobile.

In swamp forests where the larger vegetation is so dense as that shown in this group, a noticeable poverty of small herbaceous plants usually prevails and beyond the *Sphenophyllum* little has been indicated. There is, however, evidence of the presence in the Carboniferous flora of smaller clubmosses resembling the ground pines and *Selaginellas* of today, of small ferns, mosses, and liverworts that all together must have constituted the ground cover in places favorable for their development. Fungi parasitic on old tree trunks and on the fallen stems have been found and they, as well as bacteria, undoubtedly brought about the disintegration of some portion of the enormous mass of the vegetation litter of the forests.

Most of the characteristic flora of the Carboniferous age became extinct with the elevation of the continental land masses and the onset of arid conditions in the northern hemisphere in the next period, the Permian, which closes the Paleozoic age. The explanation of the extinction of this first great land flora of the world lies in the manner and conditions of fertilization of spore-bearing plants. The giant clubmosses and most of their contemporaries were unable to maintain their numbers or to propagate their kind except in the presence of abundant moisture.

Not the least interesting feature of the Carboniferous forest is its animal life. Insects were very numerous, though they were then only at the beginning of their long course of evolution, which has led to the myriads of species of the present time. They were still in large part primitive and much less varied in form and in habits than they have subsequently become. Most modern groups were entirely unrepresented, not yet having appeared, but, together with the simplest forms embodying all primitive characters of winged insects, and transitional forms intermediate between these primitive insects and various groups existing today, a few well-defined types, such as mantids, stone flies and roaches had already appeared.

Compared with most recent insects the primitive ones were large and rather clumsy, with two pairs of straight, equal wings and in front of these a pair of wing-like expansions on the first segment of the thorax. The abdomen was regularly segmented, often with a pair of lateral expansions on every segment and with simple terminal appendages. The head bore compound eyes as well as simple ones, simple, jointed antennae and chewing mouth parts. The legs were simply jointed for crawling. On the whole the insects were apparently adapted more for short flits and glides than for flight. With the end of the period these primitive forms disappeared.

Among the hordes of other insects of the period were forms pointing clearly to dragon flies, locusts, termites, and bugs. Some of the early dragon flies reached an enormous size and attained dimensions that never since have been equaled in the insect world. One of the giant Paleozoic

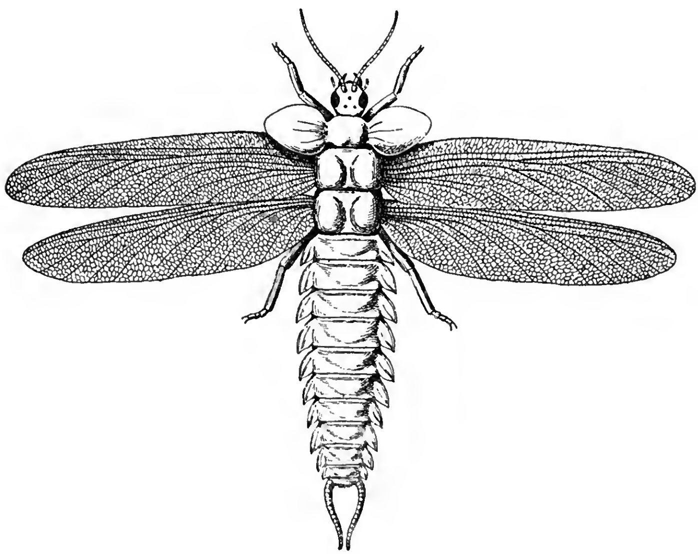

FIG. 20. Primitive winged insect of the Carboniferous age (*Stenodictya lobata* Brongniart) from Handlirsch (order Palaeodictyoptera).

"dragon flies" had a spread of wings of almost thirty inches.

The roaches were especially well established and almost incredibly numerous, with hundreds of species. Among these were some of large size. All the unmistakable peculiarities which characterize their tribe today had already been fixed in their ancestors of the Carboniferous forests. In point of ancient and well-established lineage few present-day inhabitants of the earth can vie with the cockroach.

The small types of insects so common today were relatively few if not entirely lacking. The evolution and specialization of the insects, in contrast to that of other groups of animals, have been accompanied by a general diminution in size. Ever since their advent in a great burst of forms in the Carboniferous age, the insects have been the chief contestants of the land vertebrates for the possession of the earth. It is an interesting coincidence that these two fundamentally different groups, that have since progressed in almost diametrically opposite directions, made their appearance simultaneously in the Carboniferous forest.

An impression in the rocks of the Upper Devonian, the preceding period, is interpreted as a footprint of a four-legged animal, and a Greenland find of large numbers of skeletons has recently been reported. Otherwise the

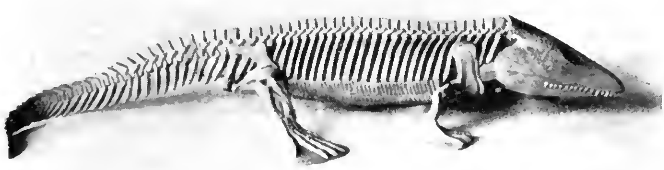

FIG. 21. Restoration of the skeleton of *Diplovertebron* Watson, one of the early amphibia (Stegocephalia) of the Carboniferous age. From a model prepared under the direction of W. K. Gregory.

FIG. 22. *Diplovertebron,* one of the early tetrapods as restored in Field Museum on the basis of the skeleton in Fig. 21.

earliest known tetrapod remains are from the Lower Carboniferous rocks of Europe. They are mostly of salamander-like forms, decidedly amphibian, though with abundant indication of their aquatic origin. Their nearest relatives are to be sought among the lungfishes and lobe-finned ganoids of the preceding period, with whom they probably share a common ancestry. In Upper Carboniferous time they became more numerous and many species are known from Europe as well as from North America. The American ones are derived from a single coal mine in Ohio. They range in size and shape from tiny newts to mud puppy and eel-like forms eight or nine feet in length. Many of them perhaps seldom or never emerged from the water of the lakes and pools in the forest. Most of them, judging by their structure, were amphibious rather than purely terrestrial in their habits, retaining the elongated body form adapted to swimming, with at least the ventral portion of the armor of the original aquatic stock from which they sprang. This protection for the lower surface of the body was no doubt valuable on land, for the newly acquired legs appear in many cases still too weak to support much weight and some of these earliest four-legged adventurers in the woods must have moved over the ground with the aid of fish-like twists and wrigglings of the body.

This first group of amphibia, known as Stegocephalia, persisted throughout the next period and for some time after the close of the Paleozoic era. As is usual in the course of evolution of vertebrates, they increased in size until they became very large and unwieldy and finally disappeared. One of the last of their kind had a skull four feet in length. The early terrestrial vertebrate stock gave rise to the reptiles, and by way of these in the course of time to all the higher vertebrates.

Of the present-day practical importance of the ancient coal beds there can be no question. They are today our main source of readily available energy for power and light. To realize how exceedingly important they are, it is only necessary to note on the map how largely the centers of the world's present industrial activity parallel in location the remains of forests of the Carboniferous age.

To those who have had the patience to read the preceding brief account of the swamp forests of the past, it will be of interest to pursue a step farther the natural history of the ancient plant material.

It is well known that coal consists chiefly of carbon. The presence of coal in the rocks, even to the graphite in the pre-Cambrian or the diamond is always attributed to plant remains, for the carbon of coal is derived directly from organic carbon compounds such as starch, sugar and cellulose that with water formed the bulk and substance of the vegetation in ancient times as well as now.

It is perhaps less often realized that the carbon of the plants is not obtained from the soil by way of their roots but from the air by way of their leaves and that consequently the original source of the vast amount of carbon locked up in the great coal fields was the carbon dioxide that formed part of the atmosphere in Carboniferous time.

Plants are the only natural agency known capable of abstracting carbon from the air. They employ it in the construction of their own tissues and store it up for future use. The mechanism by which this is accomplished is the plant cell with its green coloring matter. The energy utilized by plants in breaking down the stable carbon dioxide, separating its two elements, carbon and oxygen, is that portion of the sunlight passed by the green filter.

It is the energy from sunlight used in the formation of the carbon compounds of plants and stored by them in potential form, that constitutes the importance of coal. Coal has been called "bottled sunshine," which sounds fanciful but is substantially correct, for it is the stored energy of the sunlight of a past geological age that is liberated as heat in burning coal when the carbon abstracted from the air of several million years ago is returned to the atmosphere of today.

It has been said that the characteristic peculiarity of modern civilization consists of the rapid expenditure of this stored energy of the past. The statement might be paraphrased into terms of natural history to read that the ultimate descendants of the Carboniferous tetrapods have now reached the point of utilizing the long-buried remains of their ancestral forests. On the other hand, throughout the ages the cockroach remains unchanged, a living fossil, its prospects of survival still unsurpassed.

The geography and climate of the Carboniferous age have been the subject of much speculation. It is difficult to explain, without assuming a shifting of the poles, how the now temperate zone or parts of the circumpolar region of the northern hemisphere could have had a uniformly warm climate, while in the next period extensive glaciation took place in corresponding latitudes in the southern hemisphere. It is equally difficult to explain on the basis of the present geography of the continents how the special and different flora of the southern hemisphere, the Gondwana flora, coming up from the south at the close of Carboniferous time, could have spread simultaneously over places as remote from each other as

Australia, India, Africa, and South America. It is, therefore, usual to assume the existence at the time of a large land mass (Gondwana land) serving as a link between the continents to the south.

In this connection great interest attaches to the theory recently brought forward to the effect that the continents as we know them today were not always fixed in their present position but were once part of a great single land mass which later split up into portions that have gradually drifted apart. This is Wegener's celebrated "theory of continental drift." A theory so radically opposed to the usual conception of the stability of the continents has naturally not met with a uniformly favorable reception but no other explains so well the course of events in the plant world of the time. The map on page 34 shows the general distribution of the two coal floras, the northern and the southern, and that on page 35 the approximate position of the present-day continents as parts of Wegener's "continental block" of Carboniferous time.

With the poles located as indicated on this map, the northern coal forests come to occupy a position along the equator, accounting for the uniform climate and other peculiarities and the Gondwana flora of the various southern continents in a compact area showing evidences of glaciation in late Carboniferous or Permian time.

B. E. DAHLGREN

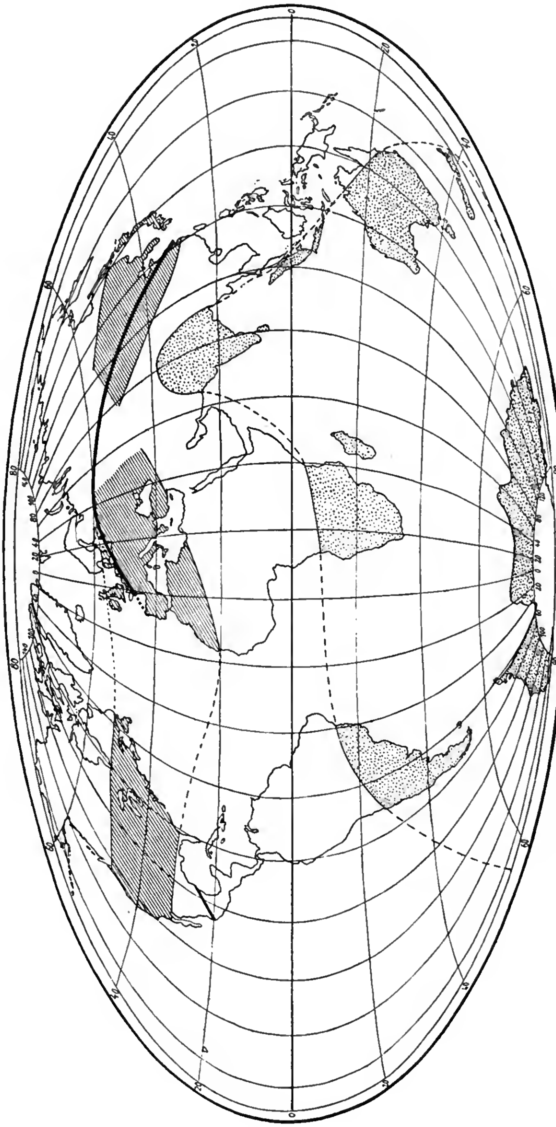

FIG. 23. Distribution of the Carboniferous flora in the northern hemisphere and of the closely related Permian Gondwana or Glossopteris flora in the southern, indicated on a map of the continents in their present position. From Zimmermann.

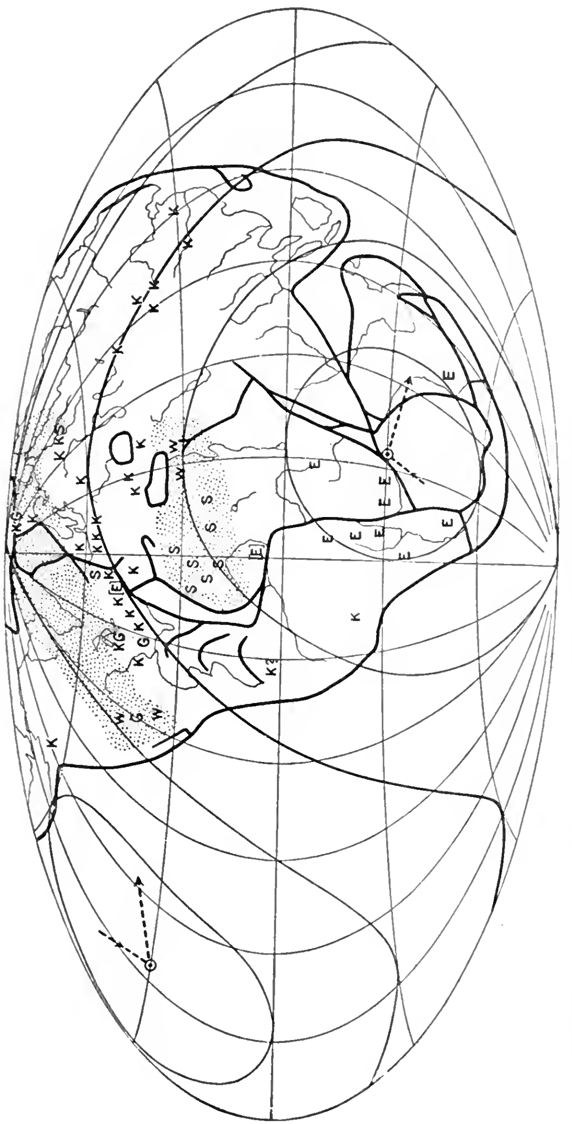

FIG. 24. Map of the world in Carboniferous time, the continents forming a single large mass. The positions of the poles are indicated by the dotted circles and the direction of their movements by arrows. K = Carboniferous deposits, E = traces of glaciation, S = sand, W = desert, G = gypsum deposit. After Köppen-Wegener, from Zimmermann.

TABLE OF GEOLOGICAL PERIODS

Name and age in years of eras	Geological periods	Predominant forms of life
Cenozoic	Pleistocene—Recent Pliocene, Miocene Oligocene, Eocene	Flowering plants, mammals
60,000,000 Mesozoic	Cretaceous Comanchian Jurassic Triassic	Reptiles, early birds Gymnosperms, cycads and other seed plants
200,000.000	Permian	Gondwana flora
	Pennsylvanian	Carboniferous swamp forests
	Mississippian	Early amphibia, insects
Paleozoic	Devonian	Early land flora
	Silurian	Fishes
	Ordovician	Higher invertebrates
	Cambrian	Algae, probably primitive land plants
550,000,000 Proterozoic		Lower invertebrates Algae
1,200,000,000 Archean or Archeozoic 1,850,000,000		Dawn of life Unicellular organisms
2,000,000,000		Formation of earliest rocks

PLANTS AND ANIMALS REPRESENTED IN THE CARBONIFEROUS FOREST GROUP

PLANTS

Clubmosses—Lycopods

Lepidodendron clypeatum Lesquereux
Lepidodendron obovatum Sternberg
Lepidodendron modulatum Lx.
Lepidostrobus ovatifolius Lx.
Sigillaria rugosa Brongniart
Sigillaria saulli Bgt.
Sigillaria scutellata Bgt.
Sigillaria lacoei Lx.
Sigillaria laevigata Bgt.
Sigillaria trunk
Stigmaria ficoides Sternb.
Lepidophloios laricinus Sternb.
Selaginellites

Seed-ferns—Cycadofilices

Neuropteris heterophylla Bgt.
Neuropteris decipiens Bgt.
  Medullosa stem
  Cyclopteris leaves
  Trigonocarpus seeds
Lyginopteris oldhamnia Williamson
  Sphenopteris hoeninghausi leaves
  Lagenostoma ovoides seeds

Ferns—Pteridophytes

Caulopteris giffordi Lx.
  Psaronius stem
  Pecopteris leaves
Megaphyton frondosum Artis
  Psaronius distichus stem
Mariopteris muricata (Schlotheim) Zeiller

Jointed-stem Plants—Articulates

Sphenophyllum emarginatum (Bgt.) Koenig
Calamites
  Annularia radiata (Bgt.) Sternb.

Gymnosperms

Cordaites borassifolius (Sternb.) Unger

INSECTS

Primitive Insects—Palaeodictyoptera

Stenodictya lobata Bgt.

Early Dragon Flies—Protoodonata

Meganeura monyi Bgt.

Protoorthoptera

Gerarus danielsi Handlirsch

Roaches—Blattoidea

Archeoblattina beecheri Sellards

VERTEBRATES

Primitive Amphibia—Stegocephalia

Diplovertebron punctatum Fritsch
Ceraterpeton galvani Huxley
Eogyrinus attheyi. In background

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PRINTED IN THE UNITED STATES OF AMERICA
BY FIELD MUSEUM PRESS