A BRIEF CONSPECTUS OF AMERICAN COAL BALL STUDIES[1]

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IT is our purpose to present in the following pages a consideration of certain aspects of American coal ball studies. It is an expanding field of research in this country and one which promises to contribute information of considerable significance bearing on the evolution of the pteridophytes and early seed plants of the Palaeozoic.

No field of palaeobotanical research has been crowned with greater success than the investigations of the English coal balls during the past century. By contrast with those accomplishments, our studies in America are in their initial stages but, by virtue of the amount, the quality and the geologic range of material available, we are in a position to achieve comparable results.

In view of the fact that Prof. Birbal Sahni evinced considerable interest in these investigations, now progressing in a number of American laboratories, a discussion of our activities seemed especially appropriate to commemorate his interests and his contributions to Palaeozoic palaeobotany.

We will not attempt to present a comprehensive review of the American coal ball floras, nor of the work of those palaeobotanists now engaged in their study, but rather some general considerations concerning the source of the petrifactions, certain of the more important plants, and the prospects of continued investigations. We shall emphasize a particular coal ball locality recently discovered in the south-eastern part of the state of Kansas since it seems to be typical of what may be expected from the more favourable collecting grounds.

The collection of these petrifactions in the American coalfields has been augmented to a very considerable extent by the open-pit mining operations being carried on in certain parts of the central states. Included in this area are Indiana, Illinois, Missouri, Iowa and Kansas. Coal balls are known from states outside this area but to date the quantities of specimens obtained are very small. The vast bulk of our collections has come from southern Illinois, southern Indiana, Iowa and eastern Kansas. Not only is the geographical range rather extensive, but a number of different horizons are represented through the Pennsylvanian rocks (SCHOPF, 1941, p. 9).

Coal balls are obtained occasionally from deep mines but it is the practice where possible to dump or "back gob" them underground in abandoned passages. When they are inadvertently brought to the surface with the coal, they may be found on the nearby dump. If they have not weathered too long or been exposed to the heat of a burning dump, good specimens may be obtained.

Generally the open-pit or "strip" mine presents a more satisfactory hunting ground. Such mining operations are carried on where the coal lies within 50 or 60 ft. of the surface, the overlying soil and rock being removed by an electric shovel scooping up 30 or more cu. yd. at a time. This is followed by a smaller shovel which removes the coal, loading it on small railroad cars or trucks, the latter now being used in most mines. In the larger mines coal may be thus removed at the rate of 10 tons a minute. This bit of statistical information is added to give some concept of the magnitude of such operations for, from the standpoint of the palaeobotanist, it means that large areas of coal are being exposed and made available for investigation.

The occurrence of the petrifactions is sporadic in the extreme. In certain areas they are never known to occur while in others they are commonly encountered throughout the coal seam. This does not mean that they are uniformly dispersed through the coal but rather that masses of them may be expected fairly frequently. Their distribution is, however, as variable as the number of mines in which they occur.

The coal balls are always found in aggregations which vary in size from a few hundred pounds to many tons and the

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individual specimens range from a few centimetres to half a metre or more in diameter. The largest aggregation that has come to our attention is one discovered by Dr. James M. Schopf and Mr. R. M. Kosanke in the Big Creek No. 1 mine of the Wasson Coal Mining Corporation near Booneville, Indiana, in June 1948. A mass of at least 30 tons of coal balls was exposed (FIG. 2) and another aggregation of about half that size was found some 50 yd. farther along the seam. Stripping operations might continue, however, for weeks, months or even years without encountering another coal ball in this mine.

In the strip mines we collect these petrifactions in a number of different ways, depending primarily on how they happen to be available. One may walk along the surface of the exposed coal and locate them *in situ*. Often they appear as rounded masses lying slightly above the general level of the seam. If they are not abundant and there is likelihood of their being lost in the mining operations, they are then laboriously excavated although it is not an easy task. Where they occur in abundance they may be immediately discarded on the adjacent dump and are thus much more conveniently collected. In mines where the coal balls are very abundant they are used as road-building material and, if not badly weathered, may be gathered with a minimum of labour. Finally, they may be found on the dump on which the waste is deposited following processing of the coal.

Although detailed chemical analyses are not in order here, a few words concerning the mineralization of these petrifactions, as well as the general state of preservation of the contained plants, may be of interest. Although there is every reason to believe that coal balls are representative samples of the plant debris that accumulated in the extensive Pennsylvanian swamps, the mineralization process was in no way selective with regard to either the kinds of plants that it preserved or the state of decay in which they existed at the time. One encounters plant remains preserved in all stages of decomposition. Where petrifaction took place soon after deposition of the plants the preservation may be perfect for the purposes of gross morphology, or even cellular contents such as nuclei may, on rare occasions, be intact (FIGS. 10, 11). At the other extreme, petrifaction may have taken place after the accumulated plant debris had been altered and closely approximated the relatively amorphous structure of coal. As an example of the latter we recently discovered large quantities of coal balls at an abandoned strip mine in Iowa which, upon being cut open, proved to consist of plant material that had decayed to such an extent that cellular details had been almost obliterated and had been consolidated to a near-coal stage.

The chief hazard to good preservation, assuming that the plant parts were intact at the time the process started, is the presence of iron sulphide. This mineral is not peculiar to American coal balls although specimens from many localities contain it to a greater or less degree. It is perhaps pertinent to add, however, that the finest specimens found in this country compare very favourably with the best of the English coal balls.

The iron sulphide may occur as either pyrite or marcasite. The latter is common in certain of the Iowa mines and due to its less stable nature specimens containing it may disintegrate very rapidly. In our own experience pyrite is the most commonly encountered form of the mineral. Not infrequently we find coal balls which are almost solid masses of iron sulphide, these being referred to by the miners as "sulphur balls".

Small amounts of pyrite are not detrimental but when it occurs in any appreciable quantity the specimens usually are not worth bringing into the laboratory. The mineral can be detected in the field by the yellowish colour and the greater specific gravity and it requires only a little experience in handling these fossils to determine their approximate quality.

The best coal balls contain plants that are petrified with calcium carbonate and they are recognized by their light weight and more or less chocolate-brown colour.

One of the more fortunate "problems" that American coal ball deposits present is that of mass treatment. Where good material is available it may be so in large quantities, perhaps many tons. The most profitable method of study, therefore, is one which will enable us to examine as much material as possible even at the expense of missing some of the smaller plants here and there. During the past few years we have encountered a number of localities from which tons of good material may be obtained. Much of this is from strip mines where a continuous supply is very uncertain. Due to the nature of the stripping operations a large mass of coal balls may be exposed and then covered over again as the stripping shovel works its way back along the seam. If the material appears to be especially promising as much as possible must be hauled away immediately, and in the case of the Indiana mine mentioned above those of us who had occasion to collect here took away some 3-4 tons. The problems of storing and the ultimate expense involved in cutting such large quantities of material are by no means small ones.

Other localities involve natural exposures such as hillside stream cuts revealing a coal seam bearing coal balls. Under such conditions there is no necessity of removing the petrifactions greatly in excess of the quantity that can be cut within a short time.

It is our procedure in the laboratory to cut each specimen once or twice, smooth and etch the surface, and examine it under a low power microscope. The specimen will then be either discarded or cut further depending upon how promising the initial cut may be. If a new or otherwise significant fossil is encountered, it will be cut out and given more study.

From any one locality there is often a preponderance of one species, or rather the organs or tissues of a single species. The coal balls from one locality that we have been studying rather intensively during the past two years consist very largely (70-80 per cent) of *Psaronius* roots ; in another the specimens yield mostly *Lepidodendron* remains, chiefly the periderm. Structures such as *Psaronius* roots are obvious in either a weathered or freshly broken surface and where a specimen appears to consist mostly of these organs it is left in the field.

Although space does not permit a comprehensive survey of all the recent American coal ball studies, a few contributions may be mentioned to indicate the trend of research in this field.

Contributing to our knowledge of the already diverse nature of articulate fructifications, Levittan and Barghoorn (1948) recently described a well-preserved sphenopsid cone (*Sphenostrobus Thompsonii*) from Iowa. Hoskins and Cross (1943) have described a fine specimen of the closely related genus *Bowmanites*, also from an Iowa coal ball, and the vegetative organs of *Sphenophyllum*, abundant in many American coal ball localities, have been described by Baxter (1948). Calamite stem remains thus far have been notably scarce in American coal balls but in recent collections from Illinois and Kansas we have encountered a number of them which will be described in the near future.

Pteridosperm remains, particularly of the polystelic Medullosas, have proven to be a very significant feature of the Pennsylvanian forests. Numerous new species based on well-preserved stems have been described which present a considerable range in anatomy from small distelic stems to the large *Medullosa Noei* with its Permian aspects. Particularly significant contributions have also been made in furthering our understanding of the unique Dolerothecas, presumably the male organs of the Medullosas (BAXTER, 1949 ; SCHOPF, 1939, 1948 ; STEIDTMANN, 1944 ; ANDREWS, 1945 ; ANDREWS & KERNEN, 1946).

Of the more promising lines of investigation that lie ahead, studies of the Coenopterid ferns may be expected to be highly significant. A number of genera have been reported, including *Stauropteris*, *Botryopteris*, *Etapteris* and *Ankyropteris*. Most of the descriptions to date have been based on rather fragmentary stem or frond remains and our need is for more complete specimens. This has been partially realized with the recent discovery by the writers of an especially fine specimen of *Botryopteris* consisting of a well-preserved stem with five fronds intact and nearly complete. It has contributed not only to our knowledge of *Botryopteris* but to the more general problem of the origin of leaves as well. Briefly, the leaf " trace " upon its departure from the stem is stelar in form and only later assumes the characteristic tridentate form. The retention of stelar anatomy is also found in certain of the primary and secondary pinna traces and combined with the fact that the " frond " is not laminated it presents some interesting and significant information on the early evolution of the leaf. A detailed account of this fossil has recently been published (MAMAY & ANDREWS, 1950).

We have chosen to devote the remainder of this paper to a consideration of a coal ball locality recently discovered in eastern Kansas, approximately 4 miles south of the town of Mineral. This has been selected because it is new in the annals of palaeobotany, is typical of the strip-mining localities, and it presents certain unique features.

Coal balls have been known from eastern Kansas for a few years and during the course of a general exploratory field trip in that region in October 1949 we investigated the pits of the Pittsburg and Midway Coal Mining Company. In one of the two pits currently operating large quantities of coal balls are being encountered. Many tons have been used as road-building material and most of our collecting has been done in the ditches along the main road leading to the pit. The coal balls are unique in that the weathered surfaces display in spectacular relief many of the plants contained within them; thus it is possible here to be much more selective in the field than is usually the case. They are also unique in that they contain a high percentage of large plant remains, such as *Psaronius* and *Lepidodendron* stems and, judging from preliminary studies, a rather diverse flora.

In the few dozens of coal balls from the Mineral locality that have been sawn and studied to date, a respectable number of notable plants are present which represent all the major groups of Carboniferous plants. There is apparently no single dominant plant group in this flora; the lycopods, calamites and cordaites are nearly equally represented, with others such as the psaronii, medullosas and coenopterids constituting a conspicuous portion of the flora. The following pages will be devoted to an enumeration of the generic groups recognized thus far, along with general remarks concerning the problems of major interest which are posed by each group and the possibilities for future research offered by each. Although the specific affinities of the plants discussed will be suggested in so far as our preliminary studies allow, we will not pretend to present final identifications; these and the problems suggested will be deferred for publication in future papers.

LEPIDODENDRALES

Fragments of all the organs attributable to the Lepidodendron trees (*Lepidodendron*, *Lepidophyllum*, *Lepidocarpon*, *Lepidostrobus* and *Stigmaria*) are present in many of the coal balls. Although two specimens of *Lepidostrobus* which have turned up are too badly crushed for detailed study, others of better quality may be expected in the course of further study. The "seeds" seem to be closely related to *Lepidocarpon magnificum* (ANDREWS & PANNELL, 1942).

Of particular interest are the stem specimens; these range in size from tiny branchlets only a few millimetres in diameter (FIG. 7), to large steles, 3 or 4 in. in diameter (FIG. 6). The smaller protostelic specimens usually have the cortex and leaf bases intact, while the large siphonostelic stems are usually decorticated; it is evident, however, that the latter represent branches or trunks of rather large size. In Fig. 7 the protostele is seen in the very first stage of medullation, while the stele shown in Fig. 5 presents a well-developed pith. The large stele in Fig. 6 shows the conspicuous primary body with a thick band of secondary wood. Judging from our initial studies these stems display a close affinity, if not conspecificity, with *Lepidodendron Johnsonii* (ARNOLD, 1940).

Several specimens have been found which display monopodial branching. Fig. 5 illustrates a young stem with two small branch steles departing through the cortex.

The problem of dynamics of growth which are presented by these stem fragments are of particular interest. There seems to be very little constancy in the relative amounts of primary wood in the large stems. Fig. 6 illustrates a stem with what appears to be a normal ratio of primary wood to the secondary. However, in two other specimens, about half again as large, the pith is proportionally much larger, and the width of the primary xylem is nearly three times as great as that of the smaller stem. Moreover, in the two larger specimens, the thickness of the secondary wood barely exceeds that of the primary, in spite of the large total diameters of the stems. It thus appears that primary growth of some specimens continued much longer than in others, with subsequent delays in the initiation of cambial activity. It would appear that either more than one species of *Lepidodendron* is represented or the size-and-form growth pattern of Bower is not followed.

ARTICULATALES

Calamites — The stem fragments of this genus constitute a second major element of the flora; they range in size to 10 or 15 cm.

in diameter. Although the large ones are somewhat crushed because of their hollow structure, the preservation is satisfactory. The secondary wood of many of the specimens is characterized by extremely broad rays (FIG. 14). An abundance of stem fragments offers adequate material for a comprehensive anatomical study of the species represented.

The fructification illustrated in Fig. 8 is very likely the fertile portion of a single sporangiophore of a calamite strobilus. Although additional material of this is needed, it represents, in all probability, a new species or genus. The abundance of stem remains is particularly significant in view of their scarcity in previously reported American coal ball floras.

Sphenophyllum — Stems of *Sphenophyllum* are abundant and well preserved (FIG. 17) ; it seems likely that in the material available fertile specimens may be expected which should add to our knowledge of their strobilar morphology.

MARATTIALES

Several specimens of *Psaronius* sp. ranging from approximately 5 cm. to nearly 15 cm. in diameter (including inner root zone) have been found. In some instances it was possible to recognize stems in the field by a casual inspection of the fractured surface of the coal ball.

Numerous *Psaronius* roots with their characteristic aerenchymatous cortex and small radial protostele (FIG. 17) are found in many of the Mineral coal balls. Other organs attributable to the group are petiolar fragments (*Stipitopteris* sp.), and apparently two species of the fructification genus *Scolecopteris* (one species has been positively identified as *S. latifolia* Graham ; the other seems to correspond closely to *S. minor* Hoskins). Our specimens of *S. latifolia* are of interest in that they add significant data to Graham's (1934) original description of the species. The pinnules upon which the synangia are borne have strongly inflexed margins (FIG. 9) ; the latter are not, however, entire, but deeply incised, forming long, narrow lobes. These are best seen in Fig. 13,' which illustrates several of the pinnules sectioned in a plane parallel to, and slightly below, that of the laminae proper ; here the margin appears not as continuous tissues, but as a series of separate and distinct segments. The significance of this distinctive foliar morphology will be fully discussed by one of us in a forthcoming paper.

COENOPTERIDALES

Thus far fragments of the five coenopterid genera *Botryopteris*, *Anachoropteris*, *Etapteris*, *Ankyropteris* and *Botrychioxylon* (?) have been observed in the Mineral coal balls. The coenopterids are generally accepted as a complex which gave rise to the ferns and pteridosperms, and, since all three groups are liberally represented in this locality, it seems likely that an intensive study of the coenopterids should add to our knowledge of inter-relationships within the group and to a better understanding of the transition elements leading to the ferns and pteridosperms.

The genus *Botryopteris* is the predominant representative. Numerous fragments of stems, petioles (FIG. 15) and foliar appendages of lesser orders are scattered throughout the coal balls.

The petiole genus *Anachoropteris*, with its characteristically involute vascular strand, is found in many of the Kansas coal balls.

Petioles of *Ankyropteris* (FIG. 16) are present in the flora, although not with the frequency of *Botryopteris* and *Anachoropteris*. This genus is of interest in that it is known to display axillary branching, the origin of which poses a fundamental morphological problem in itself.

Etapteris is represented by a single specimen thus far. Another interesting fossil possibly referable to *Botrychioxylon* has also been found. This stem, with a weak development of secondary xylem, and the presence of *Etapteris* in the flora, suggests the likelihood that further information concerning the *Botrychioxylon-Zygopteris-Etapteris* complex, which was investigated by Dr. Sahni (1932) in one of his notable works, may be sought in the Kansas coal balls.

PTERIDOSPERMAE

The pteridosperm complex is represented in the flora by stems, petioles, pinnules and microsporangiate fructifications referable to the genus *Medullosa*. Although only three stem fragments have been found thus far, the occurrence of numerous petiolar fragments and pinnules indicates that stems and fructifications may be expected. The stem specimen illustrated in Fig. 4 is sufficiently complete to indicate that its vascular system consisted of at least five steles. It is tentatively referred to *Medullosa Noei* Steidtmann. The microsporangiate fructifications discovered thus far (*Dolerotheca* sp.) number only four, and their preservation is not particularly satisfactory.

CORDAITALES

Cordaitean remains constitute a major element of the flora. The stems, leaves, microsporangiate strobili and seeds are conspicuous in every coal ball. The leaves are recognized by the numerous parallel veins with their characteristic accompanying sclerotic sheaths ; they are present in such abundance and so closely packed together as to lend a laminated appearance to the smoothed surface of many of the coal balls.

The microsporangiate fructifications (*Cordianthus* aff. *Schuleri* Darrah sp.) are characterized by their rosette-like appearance when seen in transverse section (FIG. 12). These are present in sufficient quantity to lend promise of ultimately finding complete fruiting axes.

The seeds appear to be conspecific with those described by Darrah (1940) under the binomial *Cordaicarpus spinatus*. Our specimens are notable from the standpoint of their extremely fine preservation. While seeds from other localities usually contain only the spiny sclerotic inner portion of the integument (sclerotesta), the cellular details of the fleshy sarcotesta can hardly be surpassed in the Mineral specimens.

This Kansas locality is distinctive from the standpoints of abundance of coal balls, good preservation of many of the plants, and an exceptionally diverse flora. There are, moreover, many other American localities which await detailed investigation and vast areas of the coalfields extending from Ohio to Texas remain to be prospected.

The Mineral locality may be expected to add appreciably to our knowledge of Carboniferous plants and it is hoped that it will also add a further stimulus to the continued study of American coal ball floras.

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EXPLANATION OF PLATES

Plate 1

1. Strip mining in southern Illinois; pit of the Pyramid mine near Pinckneyville. Large stripping shovel is shown in the left background; smaller shovel in the right background removes the coal.

Plate 2

2. A large aggregation of coal balls in a southern Indiana strip mine.
3. Piles of coal balls from a mine in eastern Kansas. These occurred in large patches in the coal and had been removed for use as road-building material.

Plate 3

(Unless otherwise indicated, all the specimens illustrated are from the Mineral, Kansas, locality.)

4. Transverse section of a *Medullosa* stem, showing portions of five steles. × 1·1.
5. Transverse section of a young stem of *Lepidodendron* sp., showing the departure of two branch steles. × 3.
6. Transverse section of the stele of a large *Lepidodendron* stem. Note the prominent siphonostelic primary body. × 1·3.
7. Transverse section of a small branchlet of *Lepidodendron* sp. Note the attached leaves and the small stele in the first stage of medullation. × 20.

Plate 4

8. Portion of a fructification of apparently calamitean affinity. Note the well-preserved spore masses. × 20.
9. Several pinnules bearing the fructification *Scolecopteris latifolia* Graham. Note the strongly inflexed pinnule margins. × 10.
10. Spores of an articulate cone, showing well-preserved nuclei. From Booneville, Indiana. × 700.
11. A single spore from Fig. 10. × 3000.

Plate 5

12. Cordaitean fructifications. The seed (*Cordaicarpus* sp.) is sectioned longitudinally and shows both the sarcotesta and sclerotesta. Fructifications of *Cordaianthus* sp. are also shown. × 5.
13. A group of pinnules of *Scolecopteris latifolia* Graham, sectioned in a plane parallel to, and slightly below, that of the laminae. Note that the pinnule margins appear as series of separate segments. × 10.
14. Transverse section of portion of a *Calamites* stem. Note the broad rays. × 4.
15. Two coenopterid petioles, shown in transverse section. *Botryopteris* sp. at the right, *Etapteris* sp. at the left. × 10.
16. Transverse section of a petiole of *Ankyropteris* sp. × 15.
17. At the right is shown a *Sphenophyllum* stem; at the left, a *Psaronius* root with the characteristic aerenchymatous cortex. × 13.

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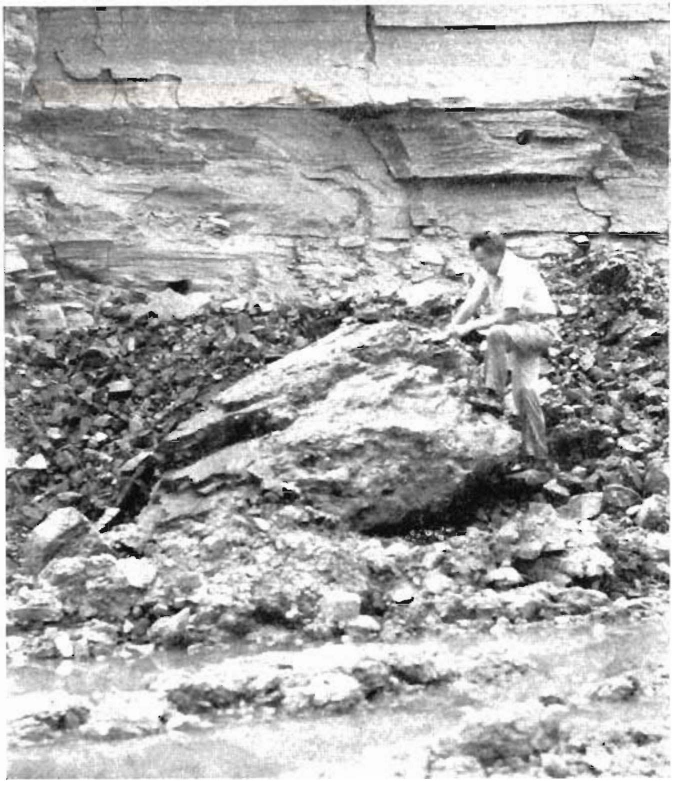

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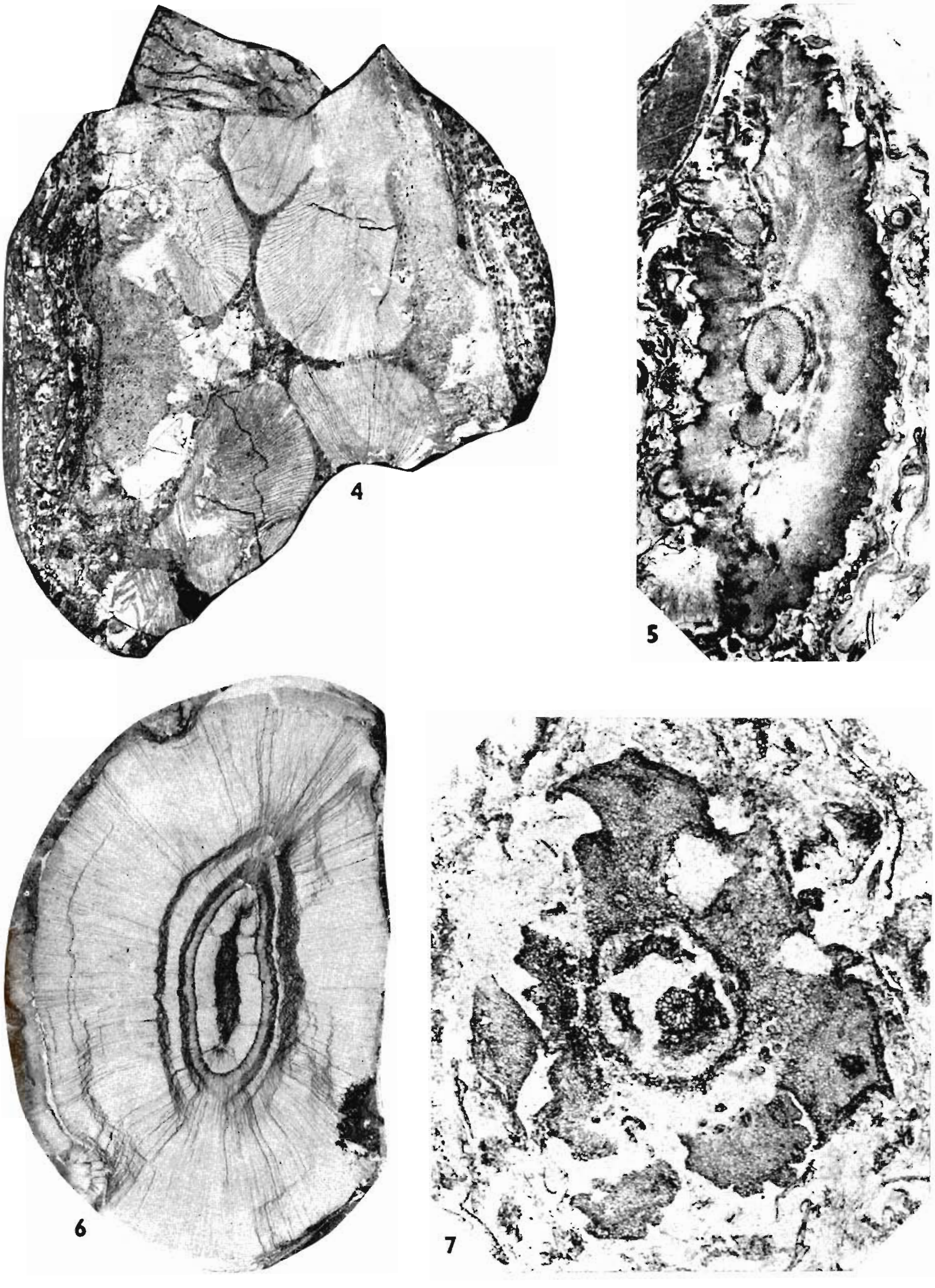
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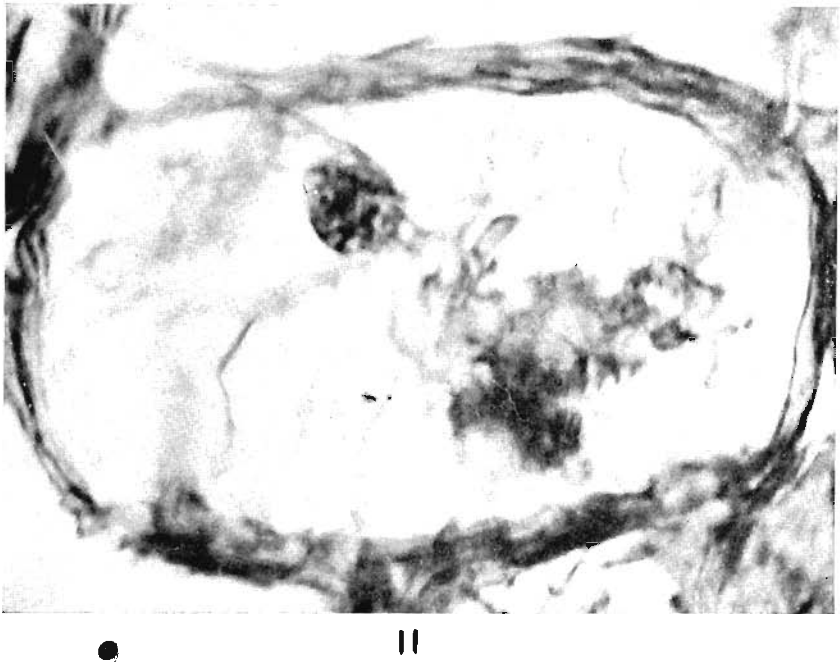

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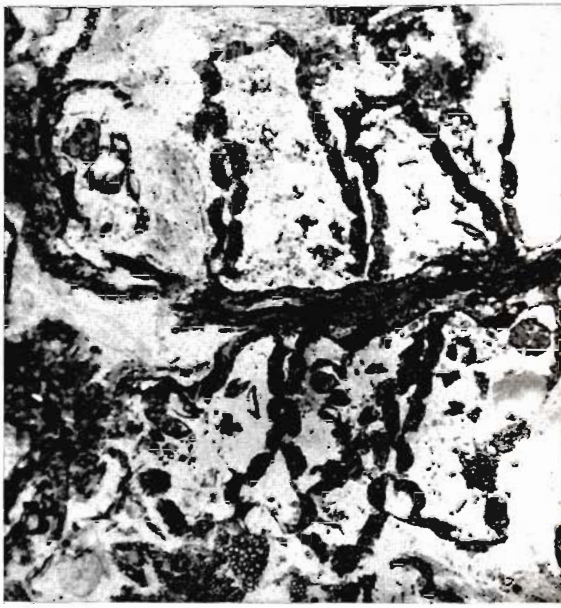

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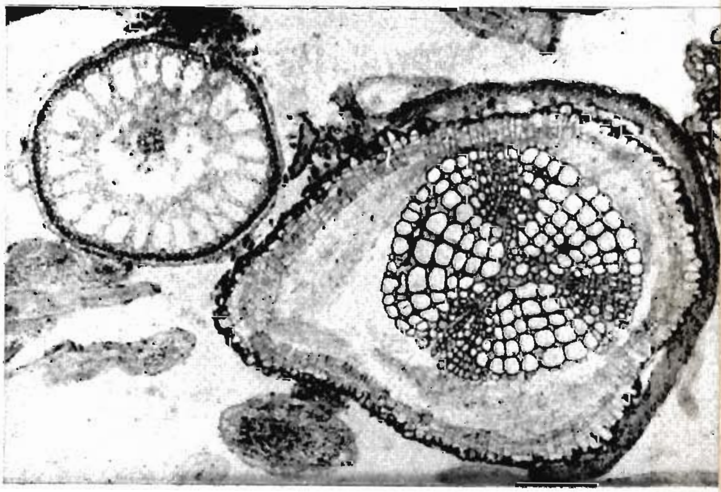

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