PHILOSOPHICAL TRANSACTIONS OF THE ROYAL SOCIETY B BIOLOGICAL SCIENCES

The Dictyoxylon Cortex of Lycopodiales as a Constituent of Coal

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VII. *The* Dictyoxylon *Cortex of Lycopodiales as a Constituent of Coal.*

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(Plates 19 and 20.)

1. The condition of preservation of plant remains in coal, especially in the bright bands, has hitherto made the identification of definite tissues a task of great difficulty. The structure has been so obliterated or obscured that in thin sections the material usually appears almost homogeneous. Such bands have a vitreous lustre and conchoidal fracture, and have been called by Dr. M. C. Stopes (1) *vitrain*. The process of vitrainisation, whatever its nature, is seldom complete, and structure may exist from mere traces up to a degree of preservation sufficient to give a striated appearance and silky lustre to the fracture, which Dr. Stopes has characterised as that of *clarain*.

2. The application to coal of the metallographic method of polishing, etching and examining by reflected light, made by Dr. H. Winter (2) and developed by the writer (3), has revealed the presence of structure where thin sections fail to show it. The technique is simple. The polishing follows the lines originally laid down by Sorby, and the etching fluid is a boiling saturated solution of chromic acid, containing a little sulphuric acid. The method is applicable to all kinds of coal, even anthracite. It has the advantage that sections in three determined planes at right angles may be made at one spot, which is difficult or impossible with thin sections, and yet essential to the interpretation of the structure of a plant fragment.

Identification of Secondary Xylem.

3. It has been found possible to identify secondary xylem and to determine the transverse, radial and tangential directions by means of the shape of the tracheides and the direction of seriation, or by the presence of medullary rays. It is even possible in some cases to determine the shape and disposition of the bordered pits. Most of the wood hitherto identified in coal has proved to be of the "dadoxylon" type. Plate 19, fig. 1 (No. 123), gives an example of the preservation of bordered pits in a radial section (in this case parallel to the bedding plane) in a bright lenticle, about $\frac{1}{2}$ to $\frac{1}{4}$ inch thick, from the Rams seam, Lancashire.

4. Dr. R. Thiessen considers that all the bright bands of coal are derived from "wood," and calls the material anthraxylon. There is no doubt that some such bands

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are derived from secondary xylem, but the evidence upon which many have been so described is insufficient. Radial seriation of the cells as seen in transverse section is not in itself conclusive, since this character is shared by periderm, in which also the cells are usually, though not invariably, much elongated. The detection of bordered pits or medullary rays is required for the diagnosis of xylem.

There is no doubt that many of the structures in coal which have been described as "woody tissue" are in reality periderm. Although the detection of medullary rays and bordered pits is rendered more certain by the new methods, yet the imperfect preservation of plant structures in coal makes it unsafe to rely upon the absence of these features for the diagnosis of periderm.

There are, however, certain of the Lycopodiales which have a complex periderm consisting of two kinds of cell so characteristically disposed as to present positive features to supplement the negative evidence. The present study deals with a case of this kind.

5. The band of bright coal (here called the "cortex band") which is the subject of this investigation, was first observed in a consignment of gas-coal delivered to the Swansea Gasworks in April, 1925, and said to come from the Grassmoor Colliery, near Chesterfield, Derbyshire. The appearance of the coal is so remarkable that in February, 1927, the writer and his assistant, Mr. W. J. Edwards, were independently able on different occasions to find it at the Grassmoor Colliery, and with the assistance of the Colliery Company to trace it to the Deep Soft (Heathcote) seam, though it has not yet been examined *in situ*.

General Macroscopic Appearance in Horizontal and Vertical Sections.

6. The band is a bright one, but in natural fractures, either "face" or "end," it has a striated appearance which gives it a silky lustre resembling that of "watered" or "moiree" silk. It must, therefore, be described as clarain and not as vitrain, according to the macroscopic features laid down by Dr. Stopes. (1) It differs from the commoner attrital clarain, consisting of débris of heterogeneous botanical origin, in the fact that the striæ are not entirely parallel to the bedding plane, and that the appearance varies according to the direction of the vertical section. Above and below the cortex band are bands of durain consisting of general plant débris (Thiessen's attritus) containing megaspores.

These features are well seen when the coal is polished upon cloth, so as to produce a certain amount of relief, and traces of cell-structure become visible under the microscope. The cell structure, however, is only developed fully by etching for about one minute.

The general macroscopic structure at low magnification (6 dias.) is shown in fig. 2 (No. 364), which is a photograph of a model of a cube of the coal, cut in three planes at right angles, at one point, O. The coal was cut in three determined planes, polished and etched, photographed, and the model constructed by pasting the photographs in correct position on a cube of wood. The plane BOC is the horizontal one, H, parallel to the bedding plane, the plane BOA is a vertical section, V_2, cutting the cells transversely, and COA is a vertical section, V_1, at right angles to V_2.

The coal is seen to consist of bright sheets or plates, alternating with duller ones, arranged approximately parallel to the bedding plane. This plate-like appearance is apparent in the horizontal section, H, BOC. In the vertical one, V_1, COA, the edges of the plates produce a nearly parallel striation, with rare anastomoses. The section, V_2, BOA, however, shows a very peculiar appearance which is characteristic of the band. The bright strands anastomose frequently, and enclose areas of the duller coal. It will be shown later that this appearance is to be interpreted as that of a broken net-work, the bright strands enclosing meshes of the duller tissue. These differences in the arrangement of the laminæ persist over the whole lenticle.

Microstructure of the Horizontal and Vertical Sections.

7. The microstructure of the laminæ was also found to be persistent in the three planes. A portion of the lenticle was selected where the laminæ were approximately parallel to each other and to the bedding plane. The structure is shown in fig. 3 (No. 139), which is a photograph of a model of a cube of the coal, magnified 200 dias. AOC is the horizontal section, H, COB a transverse vertical section, V_2, and AOB an axial vertical section, V_1. The bright laminæ consist of thick-walled cells, much elongated in a direction in the plane H, which is constant over a considerable space. The transverse section COB was cut vertically at right angles to this direction, and AOB parallel to it.

The transverse section (fig. 4) (No. 93) shows that the thick-walled cells are seriated in a direction parallel to that of the strands, and nearly horizontal. The cell walls in this direction form continuous straight lines, whereas those at right angles to it alternate. The horizontal section is therefore a radial one, since the direction of seriation is radial in either secondary xylem or periderm. The vertical axial section, AOB, is a tangential one.

In horizontal or radial section (fig. 5) (No. 270), the thick-walled cells are seen to be blunt-ended, and show evidence of their radial arrangement. No signs of bordered pits have been found in any of the sections cut. The thin-walled cells are not so uniform in character. They are sometimes much disorganised, as in fig. 4, but in other cases well preserved by being filled with a homogeneous matrix, which thin sections prove to be a translucent orange-yellow substance. In transverse section the thin-walled tissue is sometimes irregular, as in fig. 6 (No. 271), but often regular and in part seriated like the thick-walled cells.

The explanation of this variation is given by figs. 7 and 8. Fig. 7 (No. 300) shows a transverse section at low magnification (20 dias). A network of thick-walled strands is seen enclosing in its meshes thin-walled areas. One of these, at spot A in fig. 7, is shown at a magnification of 100 dias. in fig. 8 (No. 301). The thin-walled tissue is continuous with the thick-walled. The same radial files of thick-walled cells become thin-walled in the mesh, and somewhat tangentially elongated, and finally lose their seriation and become irregular.

This transition from regular seriated cells to irregular ones is accompanied by a change from the elongated to the parenchymatous form, as is shown by the radial section, fig. 9 (No. 304), and the approximately tangential one, fig. 10 (No. 306). Thus the elongated thick-walled regularly seriated cells of the strands become thin-walled in the meshes, gradually lose their elongated seriated character and become irregular parenchyma.

This transition from thick-walled prosenchymatous cells to thin-walled parenchyma is unlike any relation between secondary xylem and medullary ray tissue. On the other hand, it is very characteristic of the heterogeneous periderm of certain of the Lycopodiales, as Miss KISCH (7) has shown. Such periderms have a peculiar arrangement of the fibrous thick-walled plates or strands, which may take the form of a network or *dictyoxylon* cortex.

Appearance of the Coal in Thin Sections.

8. Thin sections of the "cortex band" were prepared by the methods of Dr. R. THIESSEN, to whom the writer is indebted for personal instruction in them. Fig. 11 (No. 157) shows a portion of a transverse section at a magnification of 450 dias. The thick-walled cells consist of a dark red substance, the lumens being reduced to slits or dots. The middle lamellæ are lighter in colour and particularly well marked in the radial walls of seriated cells.

The thin-walled cells are frequently preserved from crushing by infiltration by a light yellowish-orange material. The cell walls are of the same dark red colour as the thick ones, the middle lamellæ and "gussets" at the corners being sometimes visible. The walls show signs of decomposition, being reduced in thickness and occasionally fractured in some places, and thickened into small globules in others. This phenomenon has been observed in petrifactions by Miss KISCH (7).

The yellowish material which fills the cells is probably ulmic, not resinous, and appears to permeate the whole mass, since no empty lumens are present. Fig. 12 (No. 210) (Plate 20) shows the appearance of the section at a lower magnification ($17\frac{1}{2}$ dias). The spot marked E was that at which fig. 11 (No. 157) was obtained. It should be noted that the thick-walled strands, which are bright by reflected light, appear dark when photographed by transmitted light.

Interpretation of the Macrostructure.

9. Alternations of thick-walled with thin-walled so-called "resin-filled" cells have been figured by THIESSEN (4) and described by him as common in Palæozoic coals, and as being "woody tissue showing bands similar to those of annual growth rings."

Prof. G. HICKLING (5) gives a very fine coloured plate of a lenticle from the Yard Coal, Wallsend Colliery, which is very similar to the one now under consideration. He describes it as part of the *Myeloxylon* cortex of a *Medullosa*. This cortex is, however, of the "*Sparganum*" type, consisting of parallel plates of sclerenchyma, which do not anastomose as in the *Dictyoxylon* type found in *Lyginopteris*. All such cortex of pteridosperms is, however, excluded from consideration by the fact that, both in HICKLING's specimen and in ours, the thick-walled tissue is seriated and is periderm, whereas in the pteridosperms it is primary unseriated cortex.

The arrangement of the fibrous strands in the "cortex band" clearly points to a distorted and fractured *Dictyoxylon* periderm. A cortex of the "*Sparganum*" type, consisting of parallel radial plates, could be folded by compression, but would not show the anastomosis presented by our specimen. In fig. 13 (No. 163) we see two nearly perfect meshes, and approximations to this condition are not rare (fig. 7) (No. 300). A common appearance, however, is that of concentric arcs as in fig. 12 (No. 210).

To interpret the macroscopic appearance we require to know the effect of pressure upon such a structure as a *Dictyoxylon* cortex. This is less readily observed in petrifactions than in coal, since the tissue has been protected from the effects of pressure by the mineral matrix.

A *Dictyoxylon* cortex, though presenting the appearance of a network in section, is in reality a mass of rather regularly disposed elongated compartments (called by RENAULT "cellules"), of which the thickened fibrous strands are the "walls" and the meshes containing the thin-walled tissue the "lumens." Its structure is homologous with that of a true cellular tissue, such as secondary xylem, in which the cells are also elongated and regularly disposed. The effect of pressure upon such a mass can frequently be observed in coal. The walls are flexed and finally fractured, the thick junctions of the cells appearing as isolated fragments, of the peculiar shape known to petrologists by MÜGGE's term *Bogen-struktur* (arc structure). A model of such structure is seen in fig. 14 (No. 140), cut in three planes at right angles. It is from a piece of coal derived from secondary xylem in which the lumens have remained empty.

In axial sections the elongated cellular appearance is not greatly disturbed, but in transverse section (COA) the cells are seen to be fragmented and, while retaining evidence of their regular arrangement, the junctions are "telescoped" into each other, so as to produce a series of concentric arcs. A few of these fragments, cut somewhat obliquely, are shown, greatly enlarged, in fig. 15 (No. 395). The bright fragments are the junctions of the cell walls, the dark parts are the remains of the lumens. The stellate shape, bounded by arcs, and prolonged where the cells are cut obliquely, is characteristic of the junctions of a broken cellular mass.

Comparison with fig. 16 (No. 393), which is part of a transverse section of the "cortex band," shows the similarity in shape and disposition of the fibrous strands in the "cortex band." The concentric areas arise from the fracture of the "cellules" of the cortex, and the anastomoses of the strands correspond in shape and arrangement to the junctions of the xylem cells. We have, in fact, a *Dictyoxylon Bogen-struktur*. The macrostructure of the "cortex band" is therefore that of a fragmented *Dictyoxylon* cortex, and the microstructure that of a heterogeneous periderm.

Identification of the Cortex.

10. Heterogeneous periderms have been described in the case of several Lycopodiales, both Sigillariæ and Lepidodendra, in which the periderm is often enormously developed. They are chiefly known from the description, by RENAULT and his collaborators (6), of silicified material from Autun, in France, and have been described in *Sigillaria spinulosa* (Germar), *S. Lepidodendrifolia*, *S. obliqua* (Brogn.), *S. venosa* (Brogn.), *Stigmaria Brardi*, *Lepidodendron rhodumnense*, and *L. esnostense*.

Of these, *S. spinulosa* is recognised as the leiodermarian form of *S. Brardi*, and *S. Lepidodendrifolia* and *S. venosa* are very closely allied to it (Kidston (8)). A few specimens of *S. spinulosa* of RENAULT'S preparation are in the Williamson Collection at the British Museum (W. 665, transverse section, and W. 668, tangential).

By the courtesy of Prof. COSTANTIN, the writer was enabled to study RENAULT'S specimens at the Muséum National d'Histoire Naturelle at Paris, and to have them photographed by Mons. A. CINTRACT. This was necessary, since RENAULT'S illustrations, made in 1875, were hand-drawn.

In *Lep. esnostense* (and *Stigmaria Brardi*) the strands of thick-walled periderm anastomose at such long intervals that they do not present a *Dictyoxylon* appearance in transverse section, but that of parallel radial bands. In tangential section they have, however, the appearance of an elongated net-work. In transverse section, moreover, the periderm is jointed, so as to form a series of *concentric* tangential rings. *Stigmaria Brardi* has only a very thin layer of periderm.

In *Lep. rhodumnense* we have, in transverse section (fig. 17) (No. 352), a *Dictyoxylon* cortex in the exterior parts, but the strands are regularly thickened at the anastomoses, so as to give an appearance of concentric rings even more marked than in *Lep. esnostense*. Towards the interior of the cortex the periderm becomes simple. The appearance of the transverse section of *Lep. rhodumnense* thus differs greatly from that of our "cortex band."

11. There remains, of known forms, only *Sigillaria spinulosa* (Germar), *S. Brardi* (Brogn.) or its near allies. The structure of *S. Brardi* agrees very closely with that of the "cortex band," both macroscopically and microscopically. Macroscopically, it consists of radial plates of periderm which anastomose frequently, and present the appearance of a network of radially elongated meshes in transverse section (fig. 18) (No. 345), and of much elongated meshes in tangential section (fig. 19) (No. 346). In radial section, the arrangement is more plate-like.

The three sections are assembled into a model in fig. 20 (No. 397). As, however, the photographs are in this case taken by transmitted light, the values are the reverse of those obtained by reflected light. This figure should be compared with fig. 2 (No. 364), which is a model of a piece of the "cortex band" at the same magnification (20 dias.).

The thick-walled periderm forms "cellules," enclosing meshes of thin-walled tissue, which in the silicified specimens is usually much disorganised. Microscopically, the periderm consists of greatly elongated thick-walled cells, of rectangular transverse section, arranged in radially seriated files. The strands enclose meshes of thin-walled tissue, the character of which is not very well shown in RENAULT'S original drawings, which appear to have been restored in places.

Miss M. KISCH has made a detailed study of the periderm of Lycopodiales (7). She has shown that the whole of the heterogeneous cortex was originally periderm. The parenchyma of the meshes is formed from the ordinary radial files, the cells being left thin and becoming tangentially elongated. Though initially prosenchymatous, they become divided by horizontal and vertical septa. This gradual change may be seen in places in fig. 18, a photograph of one of RENAULT'S preparations, and very clearly in our preparations of the coal, fig. 8 (No. 301). In the coal, indeed, the thin-walled cells are often better preserved than in the silicified petrifactions. The gradual transition, which might lead to the supposition that in the coal we are dealing with different states of preservation of the same tissue, is thus explained.

In some places the thin-walled tissue in the coal is disorganised, and its preservation in other places appears to be due to the cells being filled with a bright coaly material, which in thin section is translucent and of a yellowish-orange colour. The chemical nature of this filling has not yet been determined, but it is probably ulmic, not resinous.

A study of RENAULT'S preparations shows a feature which has been overlooked. Although the thin-walled cells of the meshes have generally disappeared entirely, those which remain are usually filled with a yellowish material. This is not very marked in the exterior portion of the cortex, but is observable in that from the deeper portions.

In radial section, the rather thinner-walled fibres, which are still part of the periderm strands, are usually of a bright yellow colour. The parenchyma of the meshes has a strong yellow filling throughout, sometimes with a darker centre. No such colour is observable in the places where the tissue has perished, nor in the adjacent xylem.

It is difficult to say if this filling was present in the living plant or is a product of the decomposition of the tissue. In the latter case it must have been produced and solidified very early, since it has preserved the cells in the coal from being crushed.

12. It may be concluded from this investigation that the "cortex band" of the Deep Soft seam at Grassmoor consists entirely of fragments of the complex periderm of *Sigillaria Brardi*, or a lycopodiaceous tree closely allied to it. In the deepest parts of the cortex, according to RENAULT, the periderm becomes simple. Such bands occur in the Deep Soft seam, and similar ones are very common in coal.

This bright band of coal is, indeed, a fossil, or assemblage of fossils of one kind, apparently preserved by organic matter derived from the decomposition of plant tissue, in much the same way as in petrifactions by inorganic material. It has not yet been determined whether the periderm of the carboniferous lycopods was suberised, but if so the preservation of the structure would be explained. It is hoped to make a detailed chemical examination of the material.

13. *Sigillaria Brardi* is somewhat rare in Britain, but impressions have been found in the Upper, Middle and Lower Coal measures. No British structural material has been reported, unless this band of coal can be so called. Sigillarian impressions are very common in the Deep Soft seam at Grassmoor, though *S. Brardi* has not so far been identified there. The Deep Soft seam lies about the centre of the lower part of the Middle Coal measures. *S. Brardi* has been found at Longton, in Staffordshire, not far from Grassmoor, near the top of the Middle Coal measures (Kidston (8)).

Acknowledgments.

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The writer is also indebted to Prof. A. C. Seward, Dr. D. H. Scott, and Dr. Marie C. Stopes for their friendly interest and advice, and to the Grassmoor Colliery Company for assistance in obtaining the specimens.

REFERENCES.

(1) Stopes, M. C. (1919). 'Roy. Soc. Proc.,' B, vol. 90, p. 470 (1919).

(2) Winter, H. (1913). 'Glückauf,' p. 1406 (1913).
Winter, H. (1923). 'Fuel in Science and Practice,' vol. 2, p. 78 (1923).

(3) Seyler, C. A. (1923). 'Fuel in Science and Practice,' vol. 2, p. 217 (1923).
Seyler, C. A. (1925). 'Fuel in Science and Practice,' vol. 4, p. 56 (1925).

(4) Thiessen, R. (1920). 'Bull, 117' (1920), Dept. of the Interior, Bureau of Mines, U.S.A., Plate CI, A, Plate CXIV, A.

(5) Hickling, G. (1917). 'Trans. Inst. Mining Eng.,' vol. 53, Plate I.

(6) Renault, B. (1875), and Grand 'Eury, C. 'Mém. de l'Acad. Sci.,' vol. 22 (1875).
Renault, B. (1893–1896). 'Bassin Houiller et Permien d'Autun et d'Epinac,' Fasicule IV, Flore Fossile, Pt. 2, Atlas (1893), Texte (1896). (Ministère des Travaux Publics, Paris.)
Renault, B., and Roche, A. (1897). 'Bull. Soc. Hist. Nat. d'Autun,' vol. 10, pt. 1.

(7) Kisch, M. (1913). 'Annals of Botany,' vol. 27, p. 281 (1913).

(8) Kidston, R. (1894-1897). 'Proc. Roy. Phys. Soc. Edinburgh,' vol. 13, p. 23.

DESCRIPTION OF PLATES.

Note.—The numbers after the figures are the reference numbers to the writer's collection of photographs, a copy of which is deposited with the Fuel Research Board. The original photographs are here slightly reduced, so that the actual magnifications are 92 per cent. of those stated below.

Plate 19.

Fig. 1 (No. 123).—Part of a bright band of coal from the Rams seam, Lancashire, × 300 dias., showing secondary xylem of *Dadoxylon* type in horizontal (radial) section. The elongated tracheides are seen, with multiseriate round alternate bordered pits. Etched 2 minutes with boiling chromic acid.

Fig. 2 (No. 364).—Model of part of Grassmoor "cortex band" at magnification of 20 dias. (A thin piece of durain partly overlies the "cortex band" on the left.) Polished and etched $\frac{1}{2}$ minute.

Fig. 3 (No. 139).—Model of part of Grassmoor "cortex band," at magnification of 200 dias. This represents an actual cube of the coal, about 1/100-inch cube, magnified 200 times, cut in three planes at right angles at one spot O, AOC being the radial section, AOB tangential and COB transverse. Polished and etched $1\frac{1}{2}$ minutes.

Fig. 4 (No. 93).—Vertical section V_2 cut at right angles to the direction of the fibres at the spot O, × 200 dias. The thick-walled cells are cut transversely and are seriated in a direction parallel to the strands or plates, *i.e.*, in this case horizontally.

Fig. 5 (No. 270).—Part of the radial section, × 200 dias., showing the character of the thick-walled cells, their elongation and blunt ends.

Fig. 6 (No. 271).—Part of the thin-walled area to show non-seriated parenchymatous cells seen in radial section.

Fig. 7 (No. 300).—Part of transverse section, × 20 dias. At spot A is a small mesh, and below it a larger one. At the bottom is the junction of four meshes formed by the anastomosis of two strands.

Fig. 8 (No. 301).—The spot A on Fig. 7, × 100 dias. The radial files of thick-walled periderm pass into thin-walled cells, tangentially elongated, and finally lose their seriation.

Fig. 9 (No. 304).—Part of radial section (horizontal), × 50 dias. The thin-walled cells of a mesh, with thick-walled tissue on either side.

Fig. 10 (No. 306).—Part of tangential section (V_1), × 100 dias. Thin-walled tissue, with thick-walled below it.

Fig. 11 (No. 157).—Part of thin transverse section, × 450, from spot E on fig. 12.

Plate 20.

Fig. 12 (No. 210).—Part of thin transverse section, × $17\frac{1}{2}$ dias.

Fig. 13 (No. 163).—Grassmoor cortex band, transverse section, polished only. Two nearly perfect "cellules" seen in transverse section, × 24 dias. The thick-walled fibrous strands of periderm enclose the thin-walled tissue in meshes, being fractured and somewhat displaced at the bottom. (Note that the direction of the bedding-plane or horizon is here placed vertically for purposes of better illustration of the form of the meshes.)

Fig. 14 (No. 140).—Model of piece of coal derived from secondary xylem (Grassmoor Colliery). COA is the transverse section, COB and AOB are axial, but oblique to the radial and tangential planes. COA shows the appearance of fractured seriated cells in transverse section (*Bogen-struktur*). × 200 dias. (approximately).

FIG. 15 (No. 395).—Cell junctions, from COA, fig. 14, enlarged to about 600 dias. to show the shape in rather oblique transverse section, and appearance of concentric arcs.

FIG. 16 (No. 393).—Part of transverse section of "cortex band" × 8 dias. to show similarity of fractured junctions of *Dictyoxylon* "cellules" to *Bogen-struktur*.

FIG. 17 (No. 352).—*L. rhodumnense*, × 20 dias. Transverse section of cortex (Renault Collection, Box 77, C17).

FIG. 18 (No. 345).—*Sigillaria spinulosa*, × 20 dias. Transverse section of exterior of cortex. (Renault Collection, Box 96, C16).

FIG. 19 (No. 346).—*S. spinulosa*, × 20 dias. Tangential section of cortex (Renault Collection, Box 96, C13).

FIG. 20 (No. 396).—*S. spinulosa*, photograph of model constructed from RENAULT'S preparations of silicified specimens. The photographs were mounted in correct position on a cube, but RENAULT'S sections were not cut at one spot. The model should be compared with fig. 2, which is on the same scale (20 dias.). The dark parts of fig. 20 correspond to the bright parts of fig. 2.

PHILOSOPHICAL TRANSACTIONS OF THE ROYAL SOCIETY B BIOLOGICAL SCIENCES

FIG. 1
PLATE 123

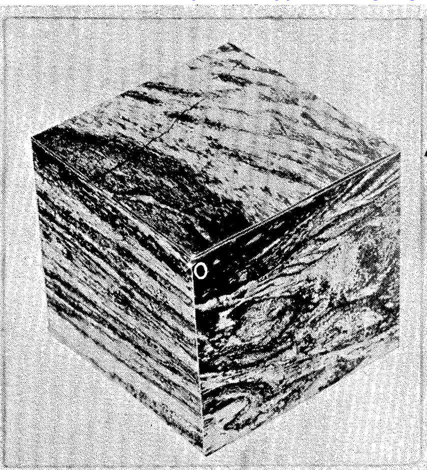

FIG. 2
PLATE 364

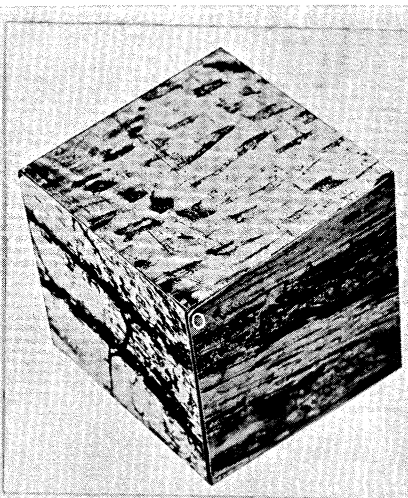

FIG. 3
PLATE 139

FIG. 4
PLATE 93

FIG. 5
PLATE 270

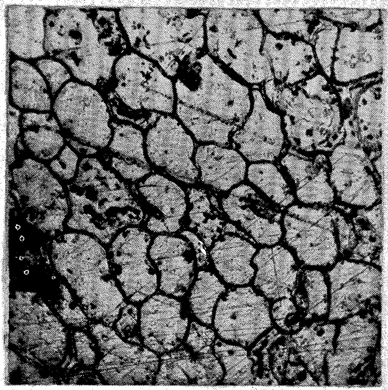

FIG. 6
PLATE 271

FIG. 7
PLATE 300

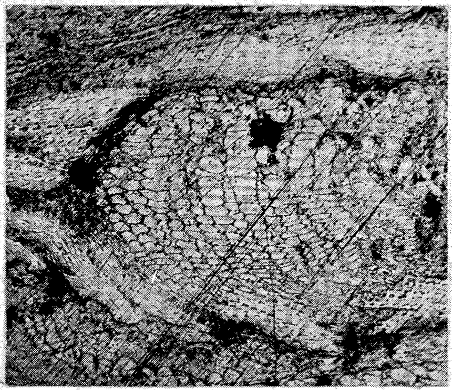

FIG. 8
PLATE 301

FIG. 9
PLATE 304

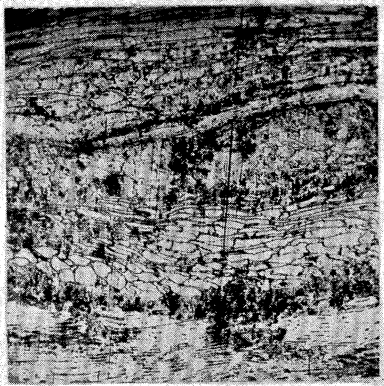

FIG. 10
PLATE 306

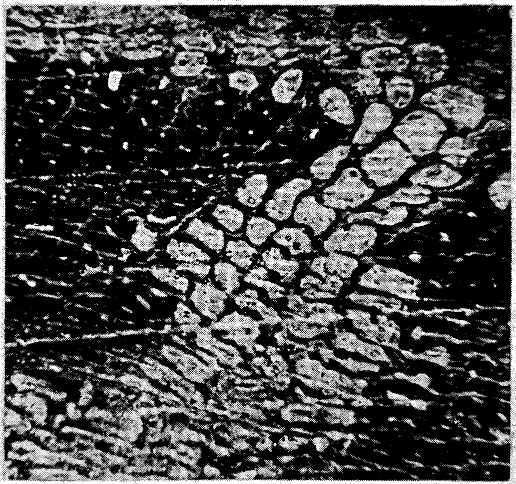

FIG. 11
PLATE 157

PHILOSOPHICAL TRANSACTIONS OF THE ROYAL SOCIETY B BIOLOGICAL SCIENCES

FIG. 12
PLATE 210

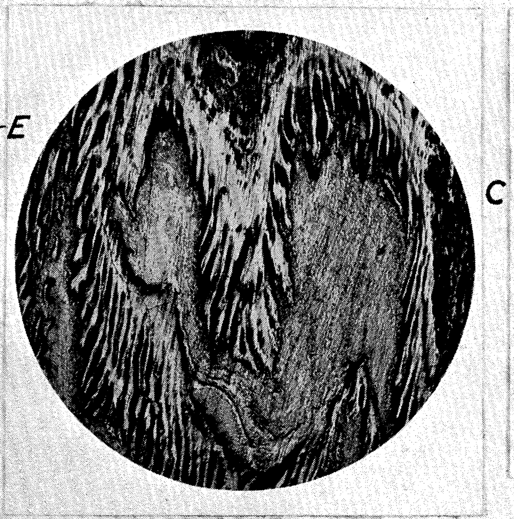

FIG. 13
PLATE 163

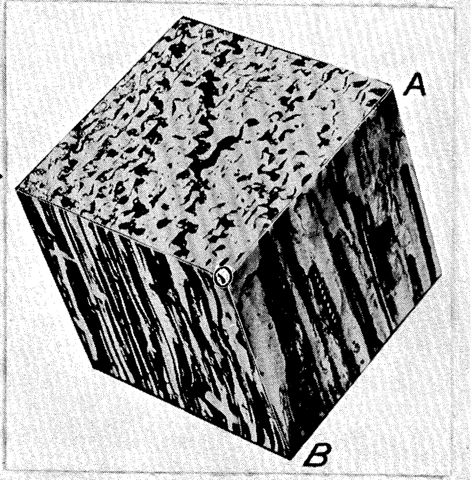

FIG. 14
PLATE 140

FIG. 15
PLATE 395

FIG. 16
PLATE 393

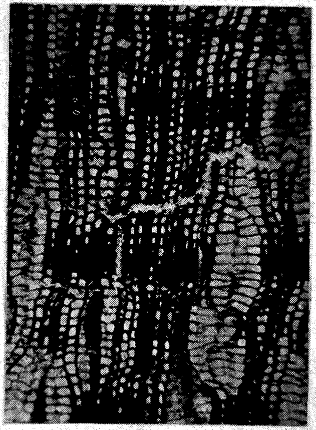

FIG. 17
PLATE 352

FIG. 18
PLATE 345

PHILOSOPHICAL TRANSACTIONS OF THE ROYAL SOCIETY B BIOLOGICAL SCIENCES

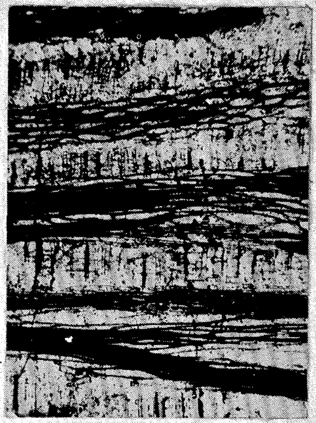

FIG. 19
PLATE 346

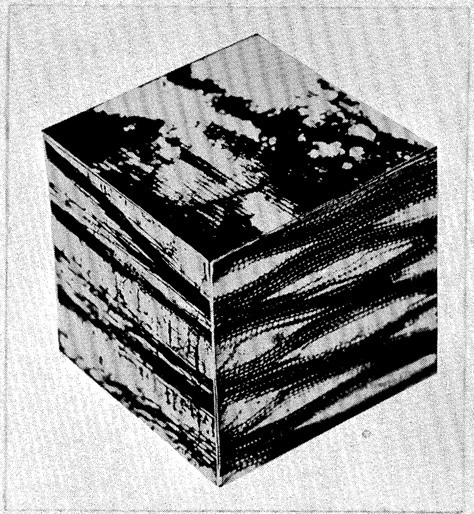

FIG. 20
PLATE 396

FIG. 1
PLATE 123

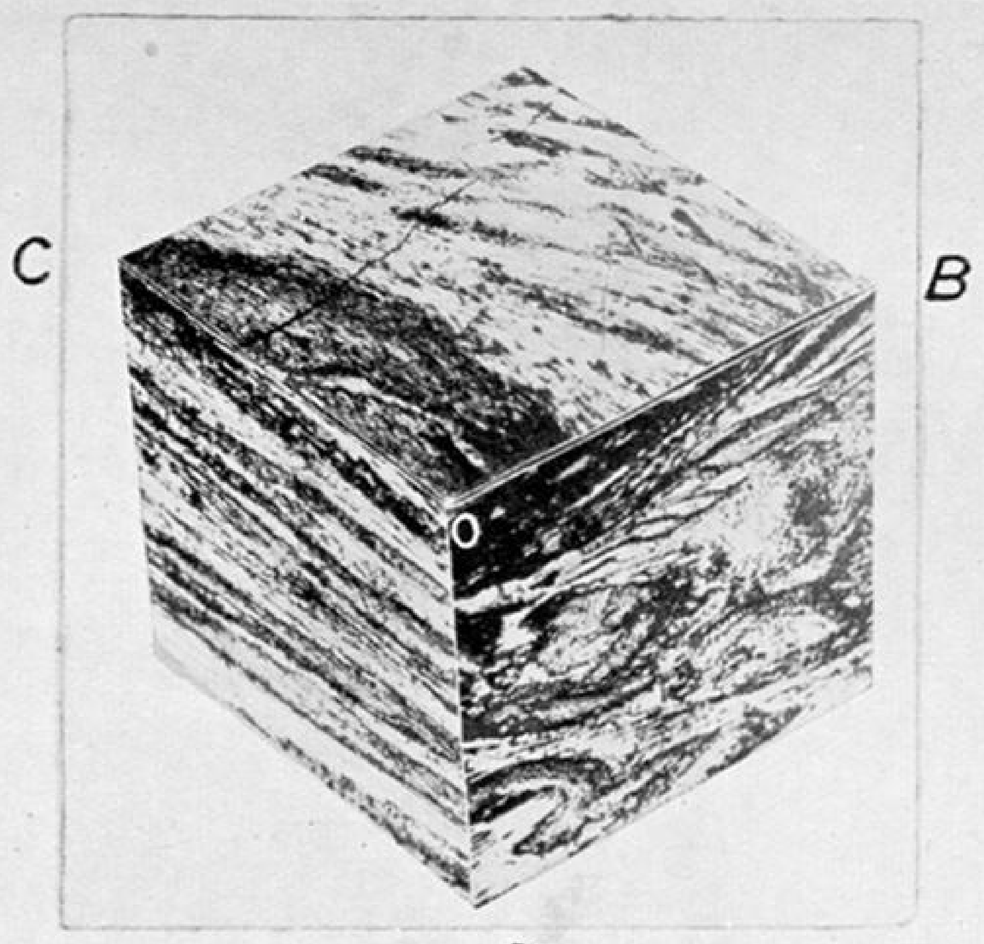

FIG. 2
PLATE 364
A

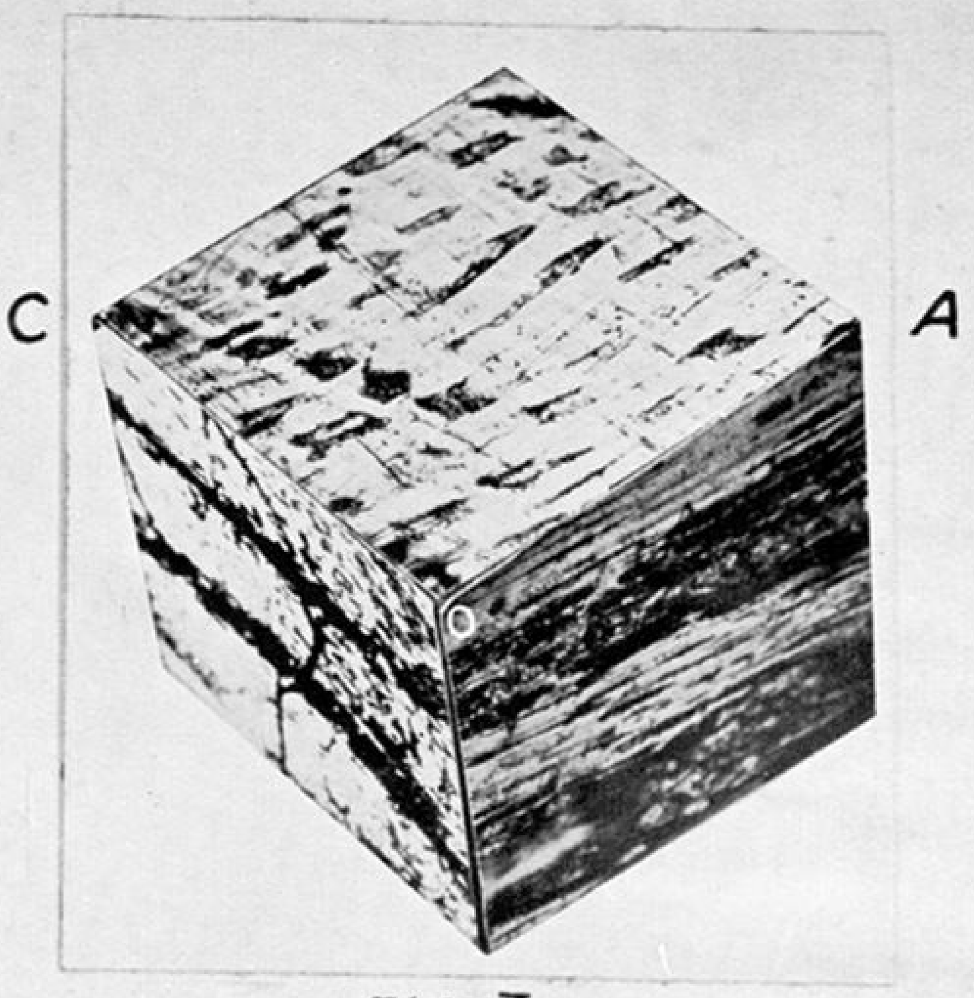

FIG. 3
PLATE 139
B

FIG. 4
PLATE 93

FIG. 5
PLATE 270

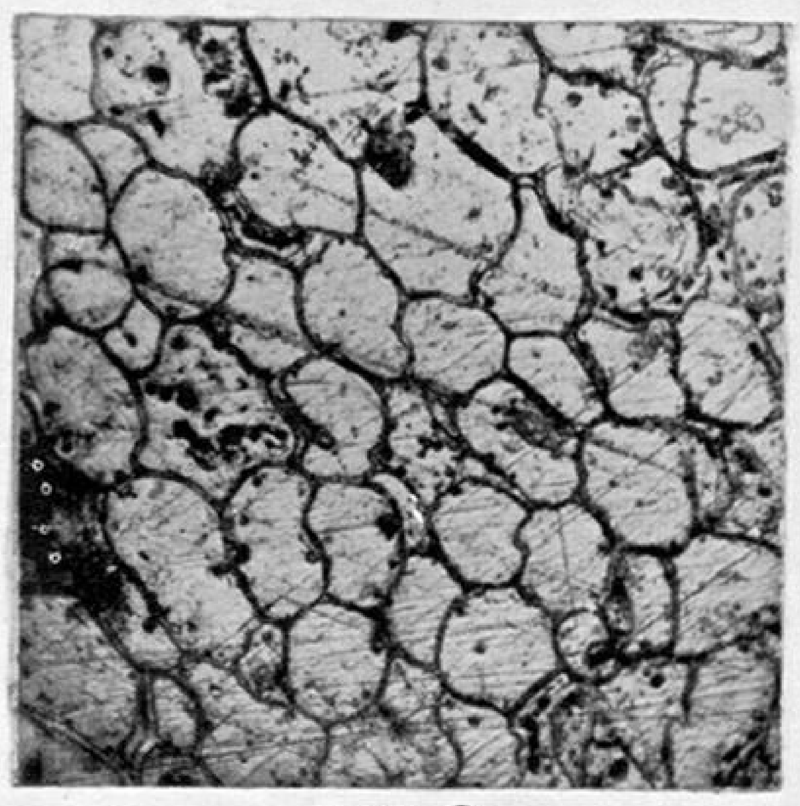

FIG. 6
PLATE 271

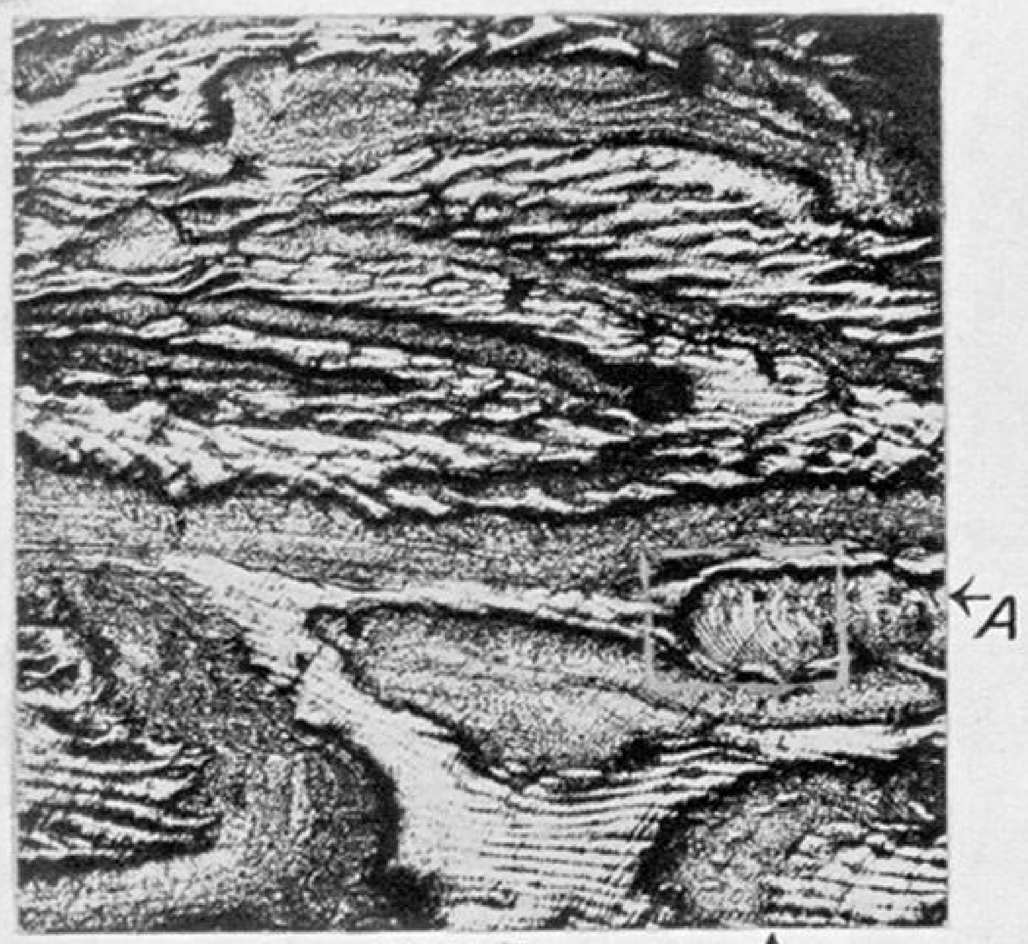

FIG. 7
PLATE 300
↑
A

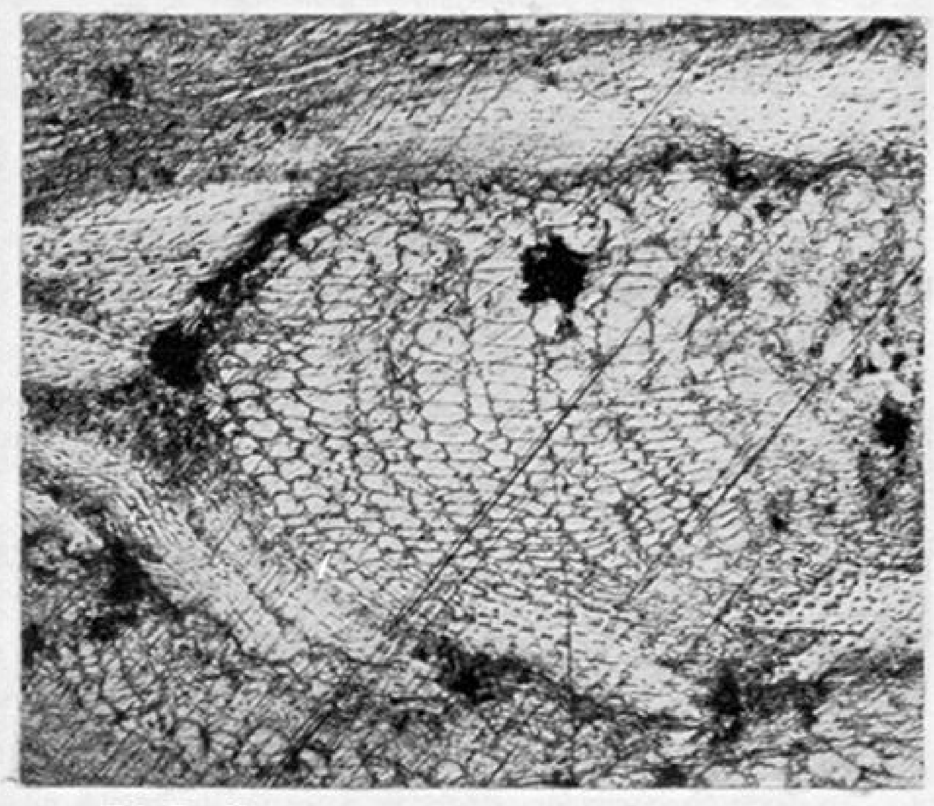

FIG. 8
PLATE 301

FIG. 9
PLATE 304

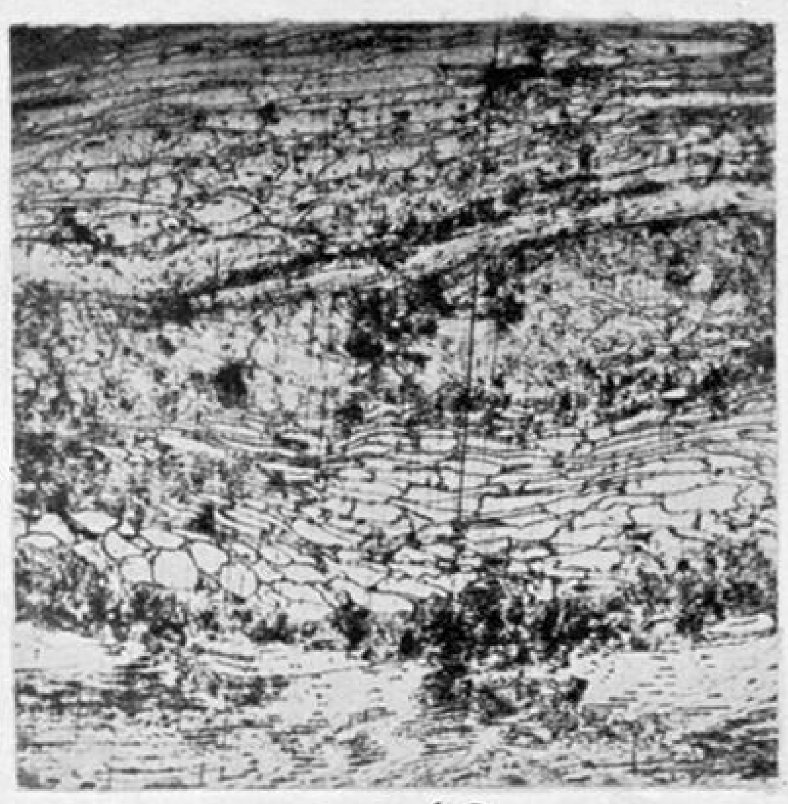

FIG. 10
PLATE 306

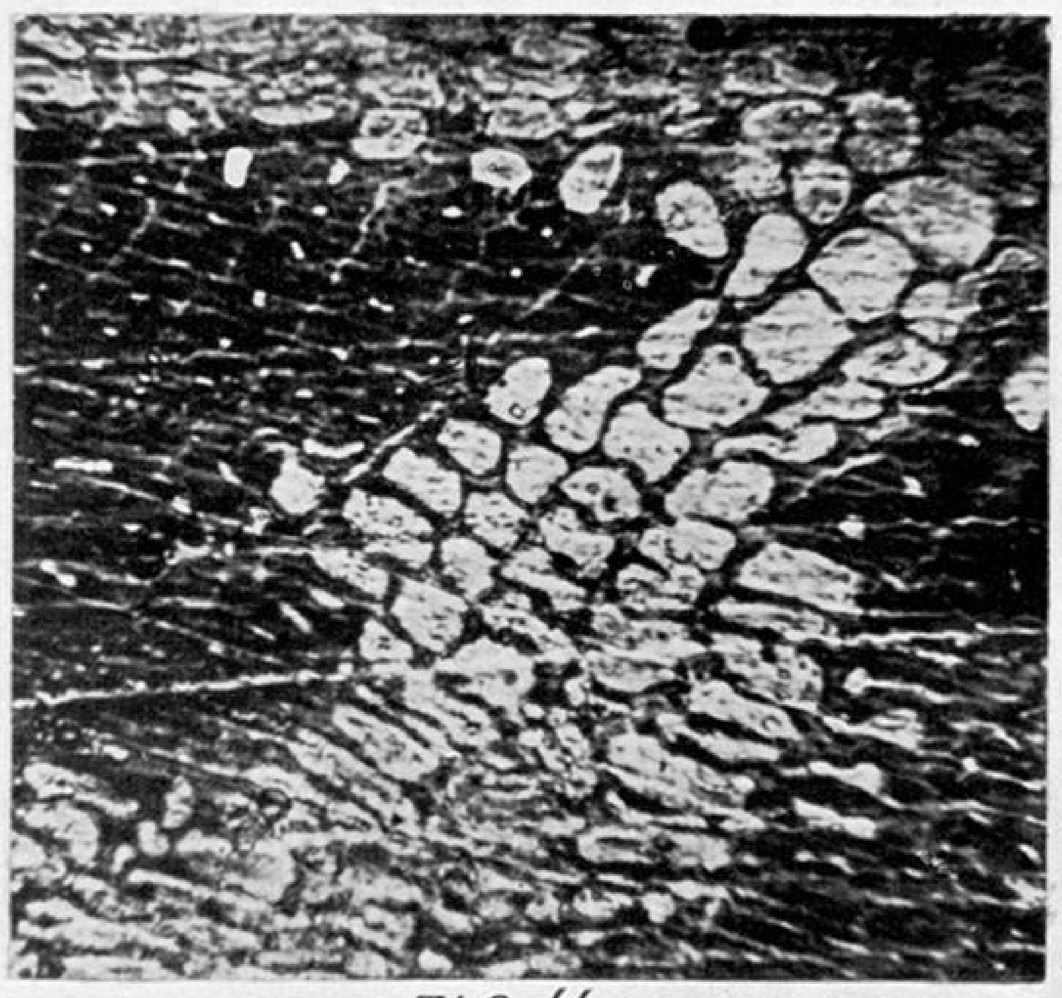

FIG. 11
PLATE 157

PLATE 19.

FIG. 1 (No. 123).—Part of a bright band of coal from the Rams seam, Lancashire, × 300 dias., showing secondary xylem of *Dadoxylon* type in horizontal (radial) section. The elongated tracheides are seen, with multiseriate round alternate bordered pits. Etched 2 minutes with boiling chromic acid.

FIG. 2 (No. 364).—Model of part of Grassmoor " cortex band " at magnification of 20 dias. (A thin piece of durain partly overlies the " cortex band " on the left.) Polished and etched $\frac{1}{2}$ minute.

FIG. 3 (No. 139).—Model of part of Grassmoor " cortex band," at magnification of 200 dias. This represents an actual cube of the coal, about 1/100-inch cube, magnified 200 times, cut in three planes at right angles at one spot O, AOC being the radial section, AOB tangential and COB transverse. Polished and etched $1\frac{1}{2}$ minutes.

FIG. 4 (No. 93).—Vertical section V_2 cut at right angles to the direction of the fibres at the spot O, × 200 dias. The thick-walled cells are cut transversely and are seriated in a direction parallel to the strands or plates, *i.e.*, in this case horizontally.

FIG. 5 (No. 270).—Part of the radial section, × 200 dias., showing the character of the thick-walled cells, their elongation and blunt ends.

FIG. 6 (No. 271).—Part of the thin-walled area to show non-seriated parenchymatous cells seen in radial section.

FIG. 7 (No. 300).—Part of transverse section, × 20 dias. At spot A is a small mesh, and below it a larger one. At the bottom is the junction of four meshes formed by the anastomosis of two strands.

FIG. 8 (No. 301).—The spot A on Fig. 7, × 100 dias. The radial files of thick-walled periderm pass into thin-walled cells, tangentially elongated, and finally lose their seriation.

FIG. 9 (No. 304).—Part of radial section (horizontal), × 50 dias. The thin-walled cells of a mesh, with thick-walled tissue on either side.

FIG. 10 (No. 306).—Part of tangential section (V_1), × 100 dias. Thin-walled tissue, with thick-walled below it.

FIG. 11 (No. 157).—Part of thin transverse section, × 450, from spot E on fig. 12.

FIG. 12
PLATE 210

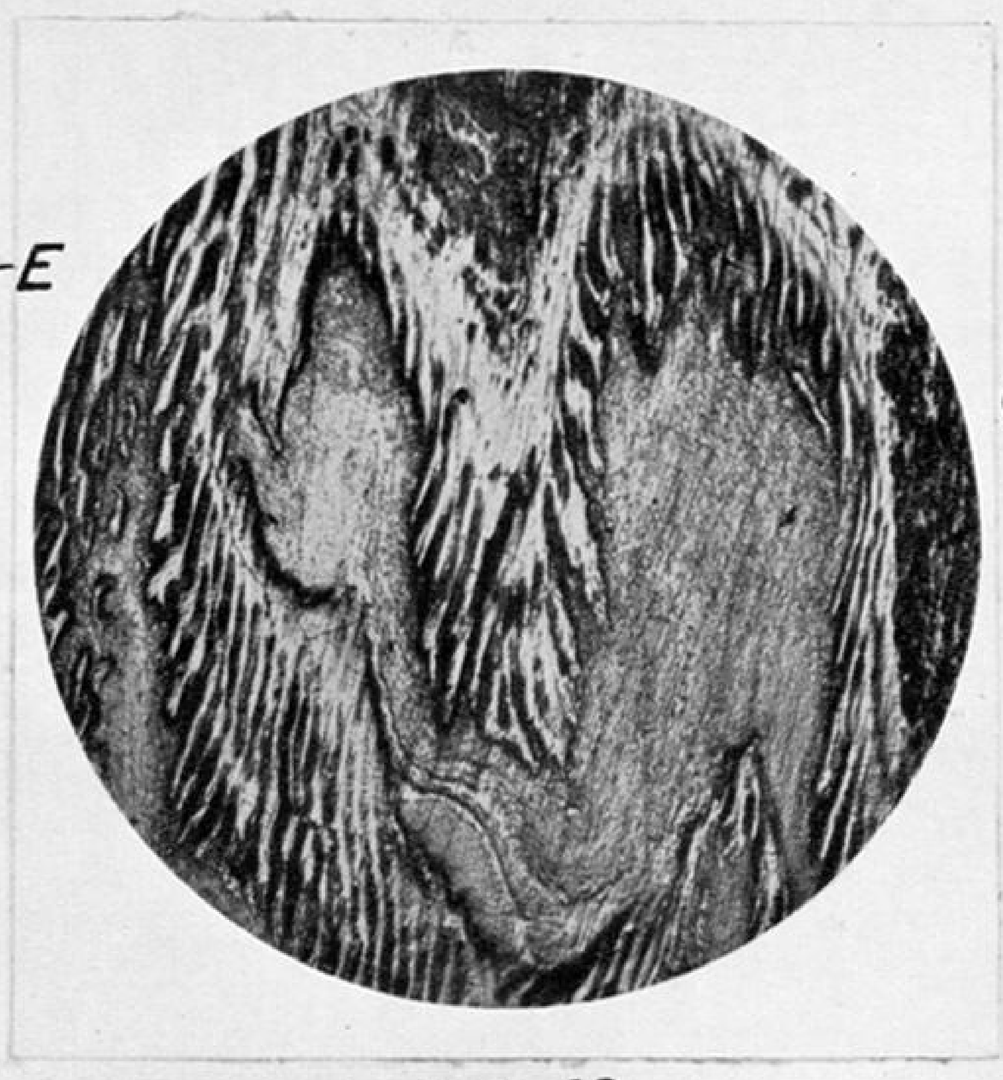

FIG. 13
PLATE 163

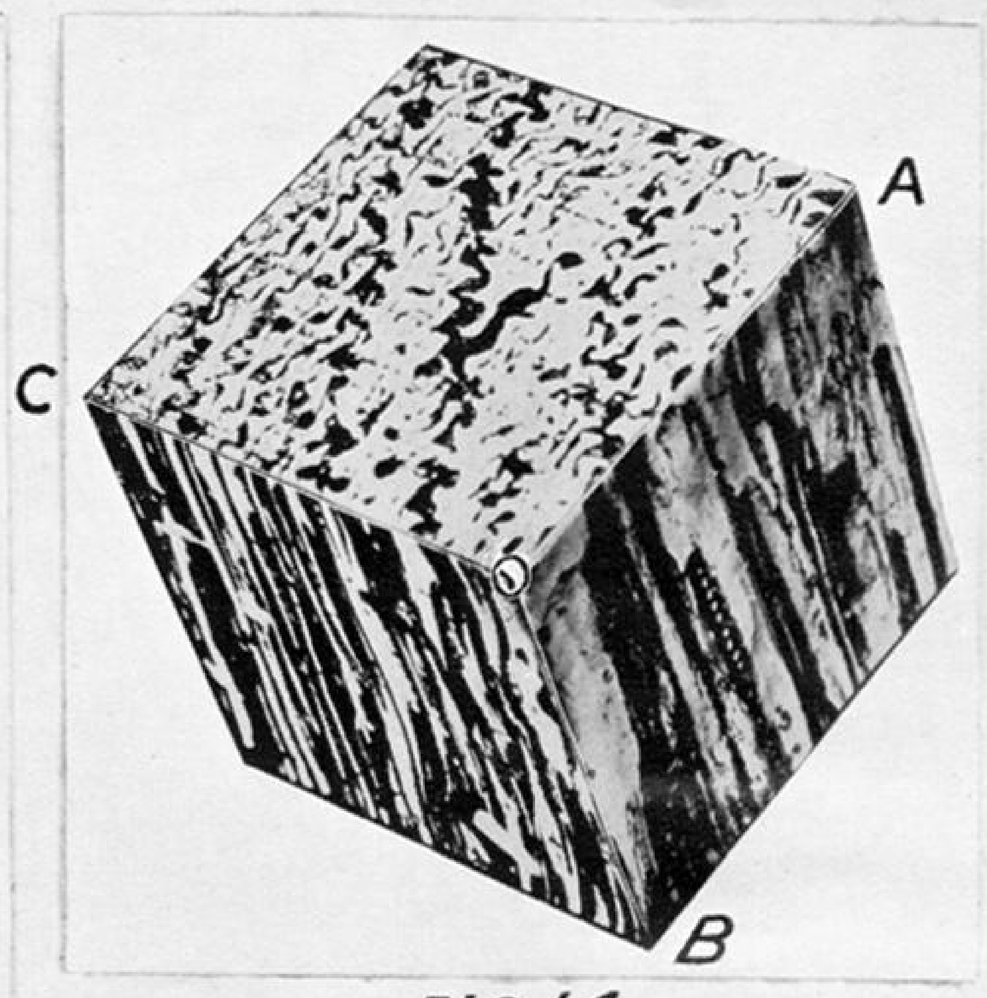

FIG. 14
PLATE 140

FIG. 15
PLATE 395

FIG. 16
PLATE 393

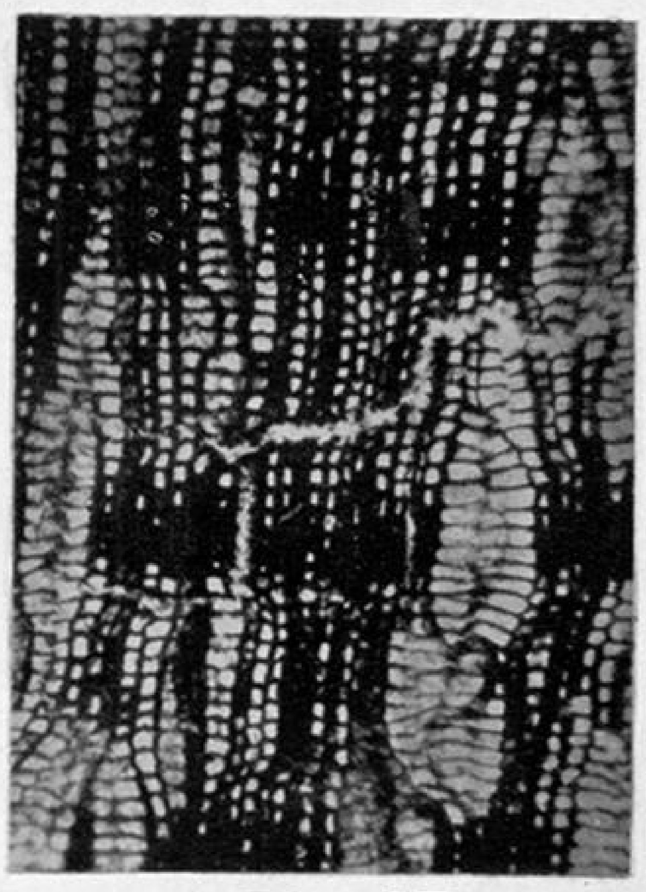

FIG. 17
PLATE 352

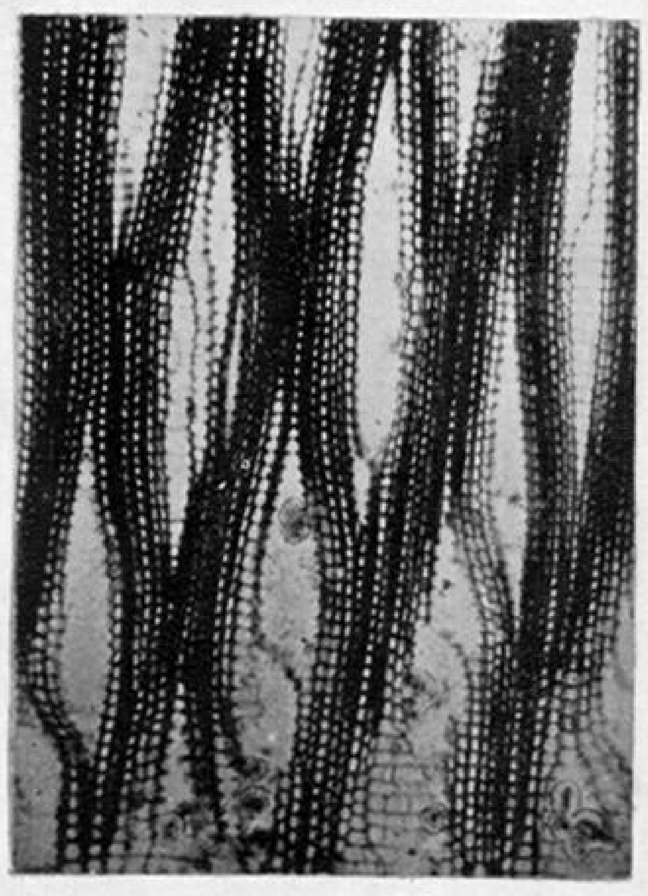

FIG. 18
PLATE 345

FIG. 19
PLATE 346

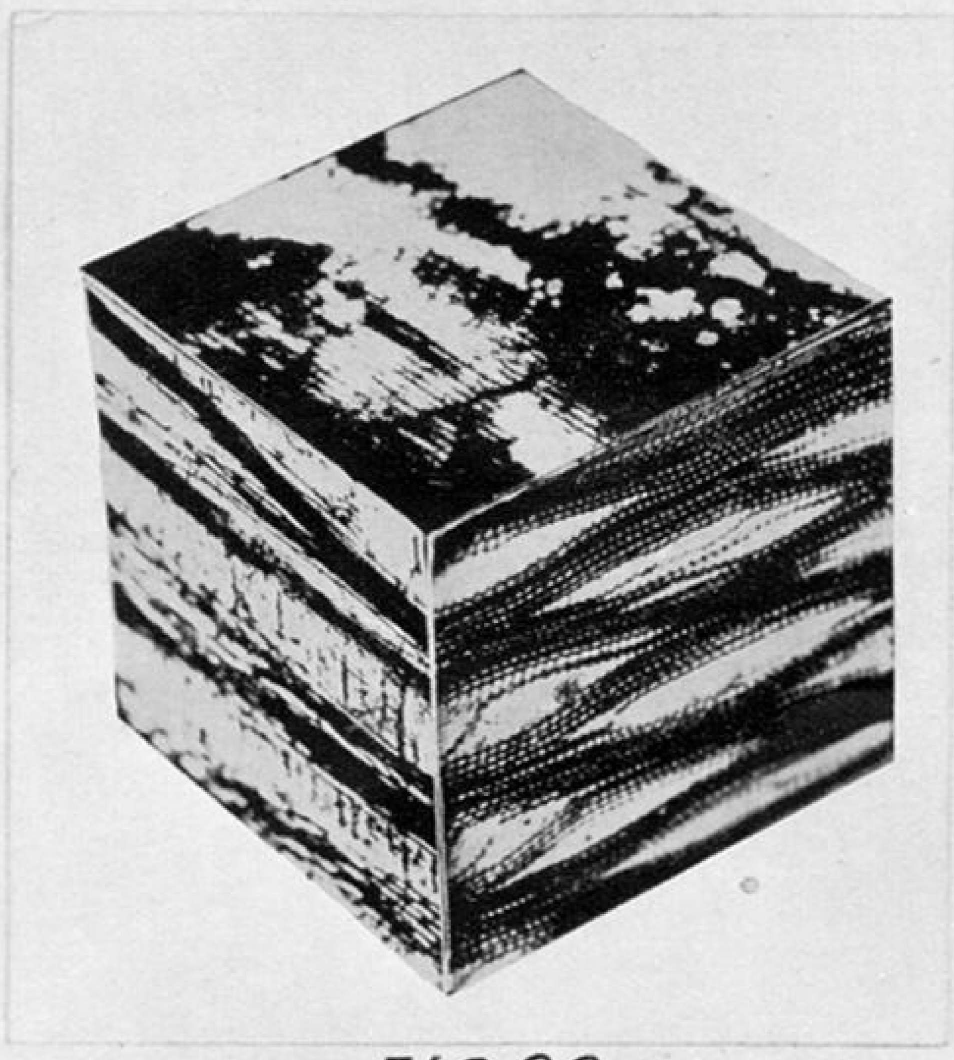

FIG. 20
PLATE 396

PLATE 20.

FIG. 12 (No. 210).—Part of thin transverse section, $\times 17\frac{1}{2}$ dias.

FIG. 13 (No. 163).—Grassmoor cortex band, transverse section, polished only. Two nearly perfect "cellules" seen in transverse section, $\times$ 24 dias. The thick-walled fibrous strands of periderm enclose the thin-walled tissue in meshes, being fractured and somewhat displaced at the bottom. (Note that the direction of the bedding-plane or horizon is here placed vertically for purposes of better illustration of the form of the meshes.)

FIG. 14 (No. 140).—Model of piece of coal derived from secondary xylem (Grassmoor Colliery). COA is the transverse section, COB and AOB are axial, but oblique to the radial and tangential planes. COA shows the appearance of fractured seriated cells in transverse section (*Bogen-struktur*). $\times$ 200 dias. (approximately).

FIG. 15 (No. 395).—Cell junctions, from COA, fig. 14, enlarged to about 600 dias. to show the shape in rather oblique transverse section, and appearance of concentric arcs.

FIG. 16 (No. 393).—Part of transverse section of "cortex band" $\times$ 8 dias. to show similarity of fractured junctions of *Dictyoxylon* "cellules" to *Bogen-struktur*.

FIG. 17 (No. 352).—*L. rhodumnense*, $\times$ 20 dias. Transverse section of cortex (Renault Collection, Box 77, C17).

FIG. 18 (No. 345).—*Sigillaria spinulosa*, $\times$ 20 dias. Transverse section of exterior of cortex. (Renault Collection, Box 96, C16).

FIG. 19 (No. 346).—*S. spinulosa*, $\times$ 20 dias. Tangential section of cortex (Renault Collection, Box 96, C13).

FIG. 20 (No. 396).—*S. spinulosa*, photograph of model constructed from RENAULT'S preparations of silicified specimens. The photographs were mounted in correct position on a cube, but RENAULT'S sections were not cut at one spot. The model should be compared with fig. 2, which is on the same scale (20 dias.). The dark parts of fig. 20 correspond to the bright parts of fig. 2.