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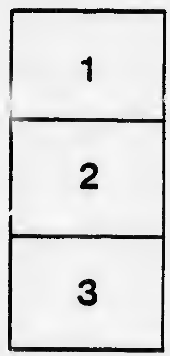
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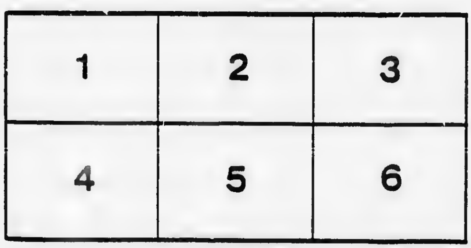
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ON

THE VEGETABLE STRUCTURES IN COAL.

By J. W. DAWSON, LL.D., F.G.S. &c.,
PRINCIPAL OF M'GILL COLLEGE, MONTREAL.

[*From the* Quarterly Journal *of the* Geological Society,
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On the Vegetable Structures *in* Coal. By J. W. Dawson, LL.D., F.G.S., &c., Principal of M'Gill College, Montreal.

(Plates XVII.—XX.)

Contents.

Introduction.—Accepting as established conclusions the vegetable origin of coal and the accumulation of its materials by growth *in situ*, rather than by driftage, there still remain some questions regarding its production, to which as yet no very satisfactory answers have been given. One of these relates to the precise genera and species of plants which have contributed the vegetable matter required; another to the causes (whether differences in the plants themselves or in the manner of their preservation) which have produced the different qualities of coaly matter observable in the different parts of the same bed, or in different beds in the same coal-field. In aid of the solution of these questions, and incidentally in illustration of the structure and affinities of the more important coal-plants, I desire to offer the results of a series of microscopical observations on the bituminous coals of Nova Scotia.

The observation of the beds associated with the coal, and of their contained fossils, has already furnished data which, inferentially at least, might dispose of these questions. A fundamental fact is the almost constant occurrence of *Stigmaria* in the underclays, first ascertained by Sir W. E. Logan, especially when taken in connexion with the further observations of Mr. Binney and Mr. Brown*, that *Stigmaria* is the root of *Sigillaria*. The sifting, by Sir Charles Lyell, of the comparative merits of the "estuary" and "peat" theories, and their final union, as together affording the required explanation of the observed facts,—the elaborate investigations of Goeppert in the coal-fields of Silesia,—those of Rogers, Newberry, and Lesquereux in those of the United States,—and the exploration of the wonderful coast-sections of the South Joggins and Sydney by Sir Wm. Logan, Sir C. Lyell, Mr. Brown, and the author—have all contributed facts and conclusions tending inevitably to certain results

* See also papers by the author, Quart. Journ. Geol. Soc. 1846 and 1853.

respecting the materials of coal, which, however, it appears to me, those geologists not immediately engaged in the study of the carboniferous system have been slow to perceive.

The direct investigation of the tissues preserved in the coal itself has also been pursued to some extent by Witham, Hutton, Goeppert, Brongniart, Bailey, Hooker, Quekett, Harkness, and others. Two difficulties, however, have impeded this investigation, and have in some degree prevented the attainment of reliable results. One of these is the intractable character of the material as a microscopic object, the other the want of sufficient information in regard to the structures of the plants known by impressions of their external forms in the beds of the coal-formation. Perplexed by the uncertain and contradictory statements arising from these difficulties, and impressed with the conviction that the coal itself might be made more fully to reveal its own origin, I have for some time been engaged in experiments and observations with this object, and believe that I can now offer definite and certain results in so far as relates to the particular coals examined, and, I have no doubt, with some slight medifications, to all the ordinary coals of the true coal-measures.

In ordinary bituminous coal we recognize by the unassisted eye laminæ of a compact and more or less lustrous appearance, separated by uneven films and layers of fibrous anthracite or of mineral charcoal. As these two kinds of material differ to some extent in origin and state of preservation, and in the methods of study applicable to them, I may arrange the subject under the following heads:—

1st. The structures preserved in the state of "mineral charcoal."

2nd. The structures preserved in the layers of compact coal.

I. *Structures preserved as "Mineral Charcoal."*

The substance known by the very appropriate name of "mineral charcoal" consists of fragments of prosenchymatous and vasiform tissues in a carbonized state, somewhat flattened by pressure, and more or less impregnated with bituminous and mineral matters derived from the surrounding mass. We cannot suppose that this substance has escaped complete bituminization on account of its original constitution; for we have abundant evidence that this change has passed upon similar material in various geological periods. A substance so intimately intermixed with the ordinary coal cannot be accounted for by the supposition of forest-conflagrations or the action of subterranean heat. The only satisfactory explanation of its occurrence is that afforded by the chemical changes experienced by woody matter in decay in the presence of air, in the manner so well illustrated by Liebig. In such circumstances, wood parts with its hydrogen and oxygen and a portion of its carbon, in the forms of water and carbonic acid; and, as the ultimate result, a skeleton of nearly pure charcoal, retaining the form and structure of the wood, remains. In the putrefaction of wood under water, or imbedded in aqueous deposits, a very different change occurs, in which the principal loss consists of carbon and oxygen; and the resulting coaly product contains proportionally more hydrogen than the original wood. This is the condition of the compact bituminous coal. This last may, by the action of heat, or by long exposure to air and water, lose its hydrogen in the form of hydro-carbons, and be converted into anthracite. In all the ordinary coals we have the products, more or less, of all these processes. The mineral charcoal results from subaërial decay, the compact coal from subaqueous putrefaction, more or less modified by heat and exposure to air. As Dr. Newberry has very well shown, in coals, like cannel-coal, which have been formed wholly under subaqueous conditions, the mineral charcoal is deficient*.

A consideration of the decay of vegetable matter in modern swamps and forests shows that all kinds of tissues are not under ordinary circumstances susceptible of the sort of carbonization which we find in the mineral charcoal. Succulent and lax parenchymatous tissues decay too rapidly and completely. The bark of trees very long resists decay, and, where any deposition is proceeding, is likely to be imbedded unchanged. It is the woody structure, and especially the harder and more durable wood, that, becoming carbonized and splitting along the medullary rays and lines of growth, affords such fragments as those which we find scattered over the surfaces of the coal†. These facts would lead us to infer that the mineral charcoal represents the woody débris of trees subjected to subaërial decay, and that the bark of these trees should appear as compact coal along with such woody or herbaceous matters as might be imbedded or submerged before decay had time to take place. We shall have an opportunity of testing the accuracy of these views when we consider the textures actually visible in the coal.

In examining the mineral charcoal, I have, after many trials, adopted the following process of preparation. Specimens were selected containing the tissues of only a single plant. Fragments or portions of stems of this character can be obtained by careful manipulation from most coals. They were placed in marked test-tubes, and treated with strong nitric acid, in which they were heated to the boiling-point, and kept in that condition so long as dense fumes of nitrous acid were disengaged, or until, on looking through the tube, the material could be seen to have a brown colour and a certain degree of transparency. In many cases, boiling in this manner for a short time is sufficient to render the fibres flexible, and as transparent as slices of recent wood when slightly charred. When ready for examination, the charcoal was allowed to settle, and repeatedly washed with pure water before removing it from the tube. It was then examined in water, with powers of from 50 to 300 diameters, drawings of the structures observed being made with a camera; and when it appeared desirable, specimens were put up in balsam for further examination. Some refractory specimens were found to re-

* American Journal of Science. See also Goeppert, "Abhandlung über Steinkohlen;" also a paper by the author, "On Fossils from Nova Scotia," Quart. Journ. Geol. Soc. 1846.

† See paper of 1846, previously cited.

quire alternate washing and boiling in hydrochloric and nitric acids before their structures could be made out; but in the preparation of more than two hundred specimens from various kinds of coal I have scarcely met with any that resisted all these processes*.

I may observe here that the object is not to decarbonize the coal and obtain what has been termed a siliceous skeleton. The change effected consists in the removal of bituminous matter, which is oxidized and dissolved by the acid, and of mineral matters, especially of the sulphuret of iron, which is one of the principal causes of the brittleness and opacity of the crude mineral charcoal. The prepared material is nearly pure carbon, burning without flame and leaving scarcely any ashes. It represents the cell-wall and its ligneous lining, or perhaps in some cases only the latter, in a state of perfect integrity, appearing under the highest powers quite smooth and continuous, and with all its minute markings in excellent preservation. The methods of incineration of the charcoal and of polishing its firmer portions I have found to be, in comparison with the nitric acid process, of little value. The first gives no adequate idea of the real character of the tissues. The second gives merely a rude outline of the more minute markings, and is chiefly valuable as affording cross-sections and a better view of the general arrangement of the tissues than can be obtained from the shreds of woody matter resulting from the process above described.

It is further necessary to state that, to compare specimens of coal with the structures of mineralized plants from the accompanying beds, it is not sufficient to have slices of the latter. It is necessary also to have specimens prepared by removing the mineral matter by an acid. Most of the coal-fossils showing structure are mineralized by the carbonates of lime and iron; and on removing these, the cell-walls will be found intact and sometimes apparently not even carbonized. Diluted hydrochloric acid suffices for this; and structures by no means to be found in the comparatively rude slices prepared by the lapidary can be distinguished in these isolated cells. Pyritous fossils, so intractable as slices, can always be resolved by the treatment with nitric acid, though in some cases they require a preliminary roasting, or, what is better, exposure to the weather until the pyrites begins to crumble.

A. *Tissues of Cryptogamous Plants in the state of Mineral Charcoal.*—Under this head I notice, in the first place, coarse scalariform tissues apparently identical with those of *Lepidodendron* and *Ulodendron,* in both of which genera the vascular axis consisted of a cylinder of scalariform vessels of great size, exceeding in this respect not only those of *Sigillaria,* but those of its Stigmaria-roots. Fig. 1 represents a portion of one of these vessels from the axis of a *Ulodendron,* probably *U. minus,* from the Picton main-seam. Fig. 2 is similar tissue from the rachis of *Lepidostrobus,* of the type of *L. variabilis,* from the Joggins. For the sake of comparison, I have drawn these to the same scale (300 diameters) as that of the vessel of *Stig-*

* This nitric acid process is, I believe, nearly the same with that recommended by Goeppert and Morris.

maria in Fig. 10, as well as of the other scalariform vessels represented in various figures. It will thus be seen that they are of great comparative size; and this, so far as my observation extends, is characteristic of these giant Lycopodiaceous plants. Tissues of this kind are by no means rare in the mineral charcoal, but are much less abundant than some other varieties. They are often difficult of recognition, owing to the wide tubes being crushed and appearing as masses of fibrils, which represent the broken transverse bars. In this state they constitute mineral charcoal of that powdery and incoherent character which does not distinctly show the fibrous structure.

A second and very remarkable form of Cryptogamous tissue appears in the minute "needles" that often lie in immense quantities in the planes of lamination of the coal, appearing to the naked eye like hairs or bristles. In the lower part of the Pictou main-seam, through several yards of thickness, nearly every plane of lamination presents these bodies more or less abundantly; and they also occur in the Sydney coal. For some time they baffled my attempts to ascertain their structure; but I have at length been able to resolve them into the two kinds of tissue represented in figs. 4 *a* to *f*. One of these is distinctly scalariform, though in some instances, owing to the obliquity of the bars, presenting the appearance represented in fig. 3. The other is a finely punctured woody tissue, sometimes with very fine spiral lines. Each needle-like filament is, in short, a bundle of scalariform vessels, enclosed in a sheath of woody fibres. This is precisely the structure of the vascular bundles of the petioles of ferns*, which may be obtained by maceration in water in the same condition with these fossils. That plants so abundant as the ferns should have left quantities of their débris in the coal is by no means surprising, though, with the exception of a few cases of the impressions of leaves mentioned by Goeppert, I am not aware that the fact has previously been ascertained. It is possible, however, that these vascular bundles may not have belonged to ferns alone. The long narrow leaves of *Sigillaria*† were strengthened by nerves no doubt composed of scalariform and woody tissue, and they must have fallen in great quantities in the coal-swamps. I have no certain means of making the distinction; but the forms of the scalariform vessels would induce me to suspect that those in figs. 4 *a*, *b*, may have belonged to Ferns, and those in figs. 4 *d*, *e*, to *Sigillariæ*. Further, the quantities of these fibres lying together and nearly parallel indicate that they may consist in part of the vessels of root-stocks or of bundles of stipes *in situ*.

B. *Tissues of Gymnospermous Plants in the state of Mineral Charcoal.*—Modern gymnospermous plants, whether Conifers or Cycads, differ both from Cryptogams and Angiosperms in the possession of discigerous wood-cells,—the discs occurring on the sides fronting the medullary rays, and consisting of depressed portions of

* Brongniart, Végétaux fossiles, fig. 36.

† *Cyperites* of Lindley and Hutton. See also *Sigillaria lepidodendrifolia*, Brongn.; and leaf of *S. scutellata*, in fig. 22.

the cell-wall enclosing thin spots or pores*. In true Conifers these peculiar wood-cells are associated with spiral vessels in the medullary sheath and leaves. In Cycads, so far as I have been able to ascertain, the associated vessels are of scalariform type. While similar in general structure, the discs or bordered pores of Conifers and Cycads admit of several varieties of form, and in different plants and in different circumstances may present very diverse appearances; and, since in the mineral charcoal these minute structures are those on which we must chiefly rely, it may save time in the first place to state the true nature of the gymnospermous bordered pore or disc, an example of which in all its parts, and as preserved in coal, is represented in fig. 5.

1. The central part of the structure consists of a thin portion of the cell-wall, usually called a "pore," which it actually is (owing to the disappearance of the original cell-wall) in much of the mineral charcoal. It may be circular, or more or less in the form of a slit; and in the latter case the pores on two adjoining cell-walls are often placed obliquely to each other, so that the two pores belonging to the opposite sides of the double cell-wall present a cruciform appearance. This is seen in some recent Conifers, as *Salisburia*, and in Cycads, as in *Cycas revoluta*†, and is not infrequent in mineral charcoal, in fossil Conifers, and, as I believe, also in *Sigillaria*.

2. The pore is placed in the centre of a depressed *disc* or *areole* in the cell-wall, which under the microscope appears as a circle, either, as in most recent Pines, much larger than the pore, or, as in some Cycads and some ancient Conifers, in *Sigillariæ*, and in *Calamodendra*, scarcely larger than the pore when the latter is circular.

3. When the discs are crowded, the intervening portions of the cell-wall, especially if thickened by ligneous deposits, appear as a *hexagonal network*, or as transverse bars enclosing the discs. This occurs in *Araucaria*, in many fossil Conifers, and in *Sigillaria* and *Calamodendron*.

It is important to observe that, in tissues in which the whole of this complex structure exists, it often appears only in part. Specimens of fossil wood of the same species may in different states of preservation, or prepared in different ways, exhibit to one observer hexagonal reticulation, to another circular discs or apparent pores, to another simple or cruciform slits, to another all these structures united. This has been a fertile cause of error in the microscopic examination of fossil plants. It is also worthy of notice, that when the pores are oval and transverse, and placed closely together, they form with their separating bars a kind of scalariform tissue not infrequent in Cycads and in fossil plants allied to them, and perhaps characteristic of these plants.

* The occurrence of such pores in *Wintereæ* and some other angiosperms is an exceptional fact; and the identity of structure of these with the true gymnospermous disc is not certain.

† Quekett, Lectures on Histology, vol. i. Goeppert, Monographie der Coniferen.

I shall now proceed to describe several forms of tissue that bear the above-mentioned characteristics of gymnospermous vegetation, and to consider the evidence that can be obtained as to the plants from which they have been derived.

1. One of the most common forms of coal-tissue, especially in the great Pictou main-seam, is that represented in figs. 8 *a* to *h* and *m* to *o*. It consists of slender wood-cells, with one or two rows of discs on the sides of the cell-walls fronting the medullary rays, which, when they can be distinguished, are short and consist of one or two rows of cells (figs. 8 *a*, *o*). These discs have either large round perforations with scarcely any areoles, or present transverse or decussating slits, or have the pores distinctly inscribed in a hexagonal or rectangular network. Examples of all these forms will be seen in the figures. Fig. 8 *m* shows the reticulations and pores, as seen in the same specimen under different lights. On some cells the discs are crowded, but on others they are thinly scattered (fig. 21). It must be observed, however, that the cells of the mineral charcoal are flattened by pressure; and consequently, when a specimen lies with the medullary rays parallel to the lamination of the coal, the pores are well seen; but when in the opposite direction, it is difficult to perceive them, and the tissue might be regarded as aporous.

Woody tissue of the kind above described is nearly always associated with the scalariform vessels seen in figs. 8 *i*, *k*, *l*, in such a manner as to show that both occurred in the same plant. This is an important observation (so far as I am aware, not hitherto made), and leading to the more precise determination of the plants from which the charcoal has been derived. It will be observed that these vessels are much more slender than those previously referred to, and that some of them present the appearance of elongated transverse pores with areoles.

Mineral charcoal of this type is usually tough, fibrous, and silky. It generally appears in rectangular pieces, but sometimes in stems much flattened. One of the latter, from the Pictou main-seam, is two inches broad and one line thick, and consists externally of mineral charcoal, with a plate of compact coal in the centre, and within this a thinner plate of mineral charcoal. It is, I have no doubt, a hollow cylinder of wood, much decayed both within and without, and flattened by pressure. Of eighty carefully selected specimens from the Pictou and Sydney coals, twenty-seven exhibited wood-cells of this type; and in more than half of that number these were associated with scalariform vessels.

The tissue just described has been observed by various microscopists, and is indeed one of the first to attract attention in most samples of coal, though in the methods usually pursued it is very imperfectly seen*.

* Witham, Fossil Vegetables. Reade, Philos. Journ. 1837. Hooker, Memoirs of Geol. Survey. Quekett, on Torbanehill Mineral, Microsc. Journal. Goeppert, Essay on Coal. Harkness, Ed. New Phil. Journal, New Series, vol. i. Dawson, Quart. Journ. Geol. Soc. 1846.

2. Another very abundant form of tissue, presenting to the naked eye the same characters with that last described, contains three, four, or five rows of pores disposed alternately. The cells themselves in this variety are larger, and the pores proportionally smaller. They are usually less distinctly areolated, and sometimes by transverse union pass into a kind of scalariform or reticulated tissue. They are associated, like the last, with scalariform vessels as represented in figs. 9 *a* to *f*. In the same eighty specimens referred to above, fifteen were of this variety; and, while the first was more abundant in the Picton coal, this was obtained chiefly from that of Sydney.

3. Other ducts or wood-cells, of still larger size, have numerous rows of pores spirally arranged. They are comparatively rare (see fig. 11)*.

4. In a number of specimens, slender scalariform vessels like those above described were found alone, without the porous tissues.

5. The comparatively coarse scalariform vessels of *Stigmaria* should be included here as belonging to *Sigillaria*. They occur not infrequently in the coal. One of them is represented in fig. 10, to show its relative size and appearance. This kind of charcoal is more lax and coarse in its texture than those previously mentioned under this head.

The tissues above-described constitute by far the larger part of the mineral charcoal, not only in the coals more particularly referred to, but in all others belonging to the true coal-formation that I have examined. We may now inquire to what families and genera they may have belonged; and this can be ascertained only by comparison with the structures known to occur in plants of the coal-formation. Materials showing at the same time unequivocal external form and internal structure are unfortunately rare, and sometimes liable to different botanical interpretations. I shall not enter into the controversies which have been raised on these points, but shall state as shortly as possible such observations of my own as appear to confirm or modify the results of previous inquirers. Of the views which have been maintained in respect to the mineral charcoal of a porous or discigerous structure, three, I think, deserve here especial mention. Goeppert appears to regard these structures as Araucarian, referring them mainly to the species *Araucarites carbonaceus*†. Hooker believes them to have belonged to *Cycads*‡. Harkness is inclined to attribute them to *Calamites*§. If for "Cycads" we read *Sigillariæ*, which I believe were the Cycads of the Carboniferous period, the union of all these views will represent the true state of the case.

The genus *Sigillaria*, in the wide sense in which the term is usually employed, no doubt represents a *family* of plants, though it is at present impossible accurately to distinguish the generic or even the specific forms. The correctness of Brongniart's reference of the

* Bailey has observed this structure in American anthracite, together with some of the others previously noticed.

† Beinert and Goeppert, Abhandlung, &c. ‡ Memoirs of Geological Survey.
§ Edin. N. Phil. Journal, New Series, vol. i.

family to Gymnosperms allied to Cycads I cannot for a moment doubt; but they presented among themselves a wide range of organization, on the one hand presenting apparent affinities to Conifers, and on the other to Cryptogamous plants. According to Brongniart*, the essential structure of *Sigillariæ* includes a woody axis surrounding the pith and consisting of two series of scalariform or porous† vessels, with medullary rays and transverse bundles of vessels proceeding from the inner cylinder through the medullary rays and the thick cellular bark to the leaves. I have two examples from the Joggins, illustrating at once this structure and the tissues found in the coal. The first is an erect stump, not presenting external markings, but standing on a Stigmaria-underclay and having a central axis retaining structure. Fig. 6 shows a longitudinal section of a part of the axis, of the natural size. The pith (*a*) exists in the form of transverse coaly plates, showing that it had a structure like that of the *Sternbergiæ*, some of which at least have been ascertained to be the pith of Conifers‡. Immediately surrounding the pith is a narrow cylinder of scalariform vessels, fig. 6 *b* and fig. 7 *f*. From this pass bands of similar tissue diagonally outward (fig. 6 *c*) through the outer cylinder, which consists of the discigerous tissue, represented in different aspects in figs. 7 *a*, *b*, *c*, *e*. The minute markings of the same tissues as seen when prepared by an acid are represented in fig. 7 *d*. In this plant we have woody tissue which might readily be confounded with that of Conifers; but it is associated, not with the spiral vessels of these plants, but with scalariform vessels, which, if alone, might be mistaken for those of Lycopodiaceæ or Cycadeæ; and the general arrangement of the tissues is that of the Sigillarioid plants. A glance is sufficient to shew the similarity of both the discigerous and scalariform tissues to those of the mineral charcoal above described. Another example is furnished by the mineral charcoal filling the lower part of a large erect stump, ribbed in the manner of *Sigillariæ*,—the same which afforded the bones of *Dendrerpeton Acadianum*. These bones and certain foreign vegetable matters lay on a bed of mineral charcoal, all of one description and representing the decayed wood which occupied the base of the stump. The structure of this wood, as it appears in slices, is represented in fig. 13 *a*. It is given in this form in my paper on the Joggins§; and at that time I supposed it to be a variety of interrupted scalariform tissue. When subjected to the action of nitric acid, it displays the beautiful porous and areolated structures shown in figs. 13 *b*, *d*, and in fig. 5. Fig. 13 *d* shows the same cell as seen at different focal distances. The medullary rays are seen in fig. 13 *c*, and in fig. 13 *e* scalariform tissue found in the same masses of charcoal. The disc-structure of this fossil closely resembles that of *Salisburia*

* Tableau des Genres.

† I regard the "vaisseaux réticules" of Brongniart as of this character; and Dawes has ascertained the presence of porous wood-cells in *S. reniformis* (Quart. Journ. Geol. Soc. vol. vii.).

‡ Williamson, in Manchester Proceedings; Dawson, in Proc. Americ. Association, 1856.

§ Quart. Journ. Geol. Soc. 1853.

adiantifolia or *Araucarites Beinertianus*; but it is still more like that of *Cycas revoluta*, in which we also find the scalariform vessels, while in Conifers we have spiral vessels instead.

Without citing further examples, these may suffice to show that the great ribbed Sigillarioid trees of the erect forests of the Joggins are identical in the structure of their woody axes with much of the mineral charcoal of the coal. They also show that the wood of some of these Sigillarioid trees approached very nearly to that of Conifers, from which, however, they differed in the possession of a cylinder or bundles of scalariform tissue, and in the great thickness of their cellular bark as compared with that of their woody axes. The difference in this last particular has, however, been much exaggerated. Such facts as I have been able to obtain give for the average relative diameters of the axis and of the whole stem the proportion of one to four or five; so that a *Sigillaria* of the very ordinary diameter of two feet would have an axis 5 to 6 inches in diameter, and might afford much mineral charcoal*.

The structures observed in the genus *Calamitea* (Cotta) or *Calamodendron* (Brongn.), to which some at least of the *Calamites* belong, are very similar to those above described, and include both discigerous and scalariform tissues†. In figs. 11 and 12 *a* to *h* I have represented the structures of a plant having the external markings of *Calamites*, preserved as pyritous mineral charcoal in the Sydney main-seam. They are similar to those described by Cotta, Unger, Dawes, and Goeppert, and cannot be distinguished from much of the discigerous mineral charcoal. They can scarcely be distinguished from those of *Sigillaria*, to which, as Brongniart maintains, they were probably closely allied, differing principally in their verticillate leaves and thinner cellular bark‡. It is unfortunate that we do not know how far such structures prevailed among the *Calamites*; but here, as in the case of *Sigillariæ*, we probably have a gymnospermous family presenting several degrees of complexity of structure, but in all cases having woody structures which have furnished important contributions to the beds of coal. The only doubt resting on this conclusion is the possibility that similarity of external form may cause us to associate plants of cryptogamous affinities with those which, on the evidence of structure, we have good ground to believe will, when their fructification is known, be found to occupy a higher place§.

* Hooker, in Mem. Geol. Survey, states that the axis of a *Sigillaria* five feet in diameter might be only two inches in thickness. According to my observations, the pith-cylinder alone of such a trunk, independently of the woody matter surrounding it, should be of that thickness.

† Dawes, Quart. Journ. Geol. Soc. 1849. Goeppert, 'Transition Flora'. Harkness, *loc. cit.*

‡ The *roots* of *Calamites* were not unlike the *rootlets* of *Stigmaria*, and occur with them in the underclays. See paper on the Joggins section, Quart. Journ. Geol. Soc. 1853.

§ My observations merely show that plants having the surface-markings of *Calamites* have the structure described. Goeppert also has obtained similar results ('Transition Flora'). I do not by any means maintain that all the plants included in the genera *Calamodendron*, *Calamitea*, and *Calamites* show such structures; on the contrary, I am convinced that much confusion exists in these

The tissues of *Conifers* are comparatively well known; but they so closely resemble, when in the state of mineral charcoal, those of *Sigillaria* and *Calamodendron* that I cannot with certainty affirm their presence. Fig. 14 represents a discigerous structure which I have not found associated with scalariform vessels; and this kind of negative evidence affords at least a possibility that some of the fragments of mineral charcoal showing only discigerous cells are Coniferous. Several years ago I stated my belief that this is the character of much of the mineral charcoal* of the Pictou coal; but I was not at that time aware of the existence in the coal of other discigerous tissues so like those of Conifers; and my specimens were slices polished in the usual way, and not showing in perfection the minute markings. Figs. 20 *a* and *b* represent two of the best of these specimens, which no doubt may be Coniferous†.

My examinations of the mineral charcoal open up the further question, whether we really know the precise line of separation between *Coniferæ* and *Sigillariæ*. I am even inclined to suspect that some of the described species of Conifers of the coal may be the woody axes of large *Sigillariæ*, or at least of trees approaching quite as nearly to these plants as to modern Conifers. Some species of *Palæoxylon* (Brongn.) and of *Pissadendron* (Endlicher), and the *Protopitys Buchiana* (Goeppert), are liable to this suspicion; and so are the species of *Dadoxylon* with large Sternbergia-piths,—though Prof. Williamson appears to have ascertained that in one of these last the medullary sheath is spiral, not scalariform, and though those which I have examined appear destitute of scalariform tissue and diverging vascular bands. In further illustration of these singular Conifers as connected with the coal-structures, I give in figs. 15 and 16 the structures of the wood of two *Sternbergiæ*, which I have been able to resolve by the nitric acid process since the publication of my paper on these fossils. These plants had no trace of scalariform vessels; and it is not uninstructive, with reference to the possible affinities of *Sigillariæ* and *Coniferæ*, to compare their structures with those of figs. 6, 7, and 8. The pith of the stem represented by fig. 15 was 2 inches in diameter and finely wrinkled; that represented in fig. 16 had a pith half an inch in diameter and very coarsely wrinkled.

Some of the tissues in the coal might have belonged to such trunks as those of *Colpoxylon* and *Medullosa*, which have been referred to Cycads; but the evidence for the existence of Cycads in the coal-

genera; I have, however, every reason to believe that the structure described by me is that of the ordinary typical *Calamites*, so plentiful in the coal-formation of Nova Scotia. I should suppose, from the description in Quart. Journ. Geol. Soc. vol. vii., that Mr. Dawes's specimens are similar to mine; on the other hand, the plant communicated by Prof. Williamson to Sir C. Lyell ('Manual of Geology,' chap. xxiv.), unless it be an accidental union of two distinct stems, must, if the drawing and description be correct, differ materially from anything that I have seen.—J. W. D., May 1859.

* "On Fossil Plants from Nova Scotia," Quart. Journ. Geol. Soc. 1846.

† The single erect Conifer observed in the Joggins section, while showing that true Conifers grew in the coal-swamps, may also be taken as evidence that they were rare.

period, as distinct from *Sigillariæ*, is so slight that we need scarcely take these into the account. *Diploxylon* and *Meleopithys* of Corda probably belong to the family of the *Sigillariæ*, and, I presume, could not be distinguished in the state of mineral charcoal from other genera of that family*.

c. *Tissues of Uncertain Origin.*—Under this head I place the very remarkable ducts represented in fig. 17. They are spiral vessels, even larger than the great scalariform vessels of *Lepidodendron*, and are scattered over one of the planes of lamination of a specimen of Sydney coal, in the manner of the bundles of vessels of ferns already mentioned, which they even exceed in size. They are perfectly cylindrical in form, and appear to have been arranged separately in some lax tissue which has been quite disintegrated by decay. They may perhaps have belonged to some endogenous plant, and may be compared with the great spiral vessels of the *Banana*.

II. *Structures preserved in the Layers of Compact Coal.*

The compact coal, constituting a far larger proportion of the mass than the "mineral charcoal" does, consists either of lustrous conchoidal *Cherry-* or *Pitch-coal*,—of less lustrous *Slate-coal*, with flat fracture,—or of coarse coal containing much earthy matter. All of these are arranged in thin, interrupted laminæ†. They consist of vegetable matter which has not been altered by subaërial decay, but which has undergone the bituminous putrefaction, and has thereby been resolved into a nearly homogeneous mass, which still, however, retains traces of structure and of the forms of the individual flattened plants composing it. As these last are sometimes more distinct than the minute structures, and are necessary for their comprehension, I shall, under the following heads, notice both as I have observed them in the coals in question.

1. The laminæ of pitch- or cherry-coal, when carefully traced over the surfaces of accumulation, are found to present the outline of flattened trunks. This is also true, to a certain extent, of the finer varieties of slate-coal; but the coarse coal appears to consist of extensive laminæ of disintegrated vegetable matter mixed with mud.

2. When the coal (especially the more shaly varieties) is held obliquely under a strong light, in the manner recommended by Goeppert, the surfaces of the laminæ present the forms of many well-

* I have little confidence in the establishment of genera or species on the minute structures of fragments of wood; but I believe that this evidence is sufficient to distinguish from each other the vascular cryptogams and gymnosperms of the coal-period, and that in the latter, if careful to avoid being misled by different states of preservation of the same tissue, we may distinguish in this way *Sigillariæ*, *Calamiteæ*, and *Coniferæ*. Having gained this point, which I have tried to reach by the observations recorded in the text, we may safely go on to subordinate distinctions. This I have not attempted, but it is a promising field of investigation.—J. W. D., May 1859.

† The quantity of volatile matter is not material to our present inquiry, since the differences of structure depending on the vegetable matter remain even in anthracite.

known coal-plants, as *Sigillaria*, *Stigmaria*, *Poacites* or *Nœggerathia*, *Lepidodendron*, *Ulodendron*, and rough bark, perhaps of Conifers.

3. When the coal is traced upward into the roof-shales, we often find the laminæ of compact coal represented by flattened coaly trunks and leaves, now rendered distinct by being separated by clay.

4. In these flattened trunks it is the outer cortical layer that alone constitutes the coal. This is very manifest when the upper and under bark are separated by a film of clay or of mineral charcoal, occupying the place of the wood. In this condition the bark of a large *Sigillaria* gives only one or two lines in thickness of coal; *Stigmaria*, *Lepidodendron*, and *Ulodendron* give still less. In the shales these flattened trunks are often so crushed together that it is difficult to separate them. In the coal they are, so to speak, fused into a homogeneous mass.

5. The phenomena of erect forests explain, to some extent, the manner in which layers of compact coal and mineral charcoal may result from the accumulation of trunks of trees *in situ*. In the sections at the South Joggins, the usual state of preservation of erect *Sigillariæ* is that of casts in sandstone, enclosed by a thin layer of bark converted into compact, caking, bituminous coal, while the remains of the woody matter may be found in the bottom of the cast in the state of mineral charcoal. In other cases the bark has fallen in, and all that remains to indicate the place of a tree is a little pile of mineral charcoal, with strips of bark converted into compact coal. Lastly, a series of such remains of stumps, with flattened bark of prostrate trunks, may constitute a rudimentary bed of coal, many of which exist in the Joggins section. In short, a single trunk of *Sigillaria* in an erect forest presents an epitome of a coal-seam. Its roots represent the Stigmaria-underclay; its bark the compact coal; its woody axis the mineral charcoal; its fallen leaves, with remains of herbaceous plants growing in its shade, mixed with a little earthy matter, the layers of coarse coal. The condition of the durable outer bark of erect trees concurs with the chemical theory of coal, in showing the especial suitableness of this kind of tissue for the production of the purer compact coals. It is also probable that the comparative impermeability of bark to mineral infiltration is of importance in this respect, enabling this material to remain unaffected by causes which have filled those layers consisting of herbaceous materials and decayed wood, with earthy matter, pyrites, &c.

6. The microscopic structure of the purer varieties of compact coal accords with that of the bark of *Sigillaria*. The compact coals are capable of affording very little true structure. Their cell-walls have been pressed close together; and pseudo-cellular structures have arisen from molecular action and the segregation of bituminous matter*. Most of the structures which have been figured by micro-

* Some lignites and fossil woods from the Saskatchewan, recently placed in my hands by Sir Wm. Logan, very well illustrate the *mechanical* change experienced both by wood and cortical cells in the process of conversion into compact

scopists are of this last character, or at the utmost are cell-structures masked by concretionary action, pressure, and decay. Hutton, however, appears to have ascertained a truly cellular tissue in this kind of coal. Goeppert also has figured parenchymatous and perhaps bast-tissues obtained from its incineration. By acting on it with nitric acid, I have found that the structures remaining both in the lustrous compact coals and in the bark of *Sigillariæ* are parenchymatous cells and fibrous cells, probably bast-fibres. These tissues are usually badly preserved; but in some cases I have found them as perfect as in fig. 18, which represents cellular tissue from the coal of Lingan, Cape Breton.

7. I by no means desire to maintain that all portions of the coal-seams not in the state of mineral charcoal consist of cortical tissues. Quantities of herbaceous plants, leaves, &c. are also present, especially in the coarser coals; and some small seams appear to consist entirely of such material,—for instance, of the leaves of *Nœggerathia* or *Poacites*. These materials, however, constitute relatively but a small part of the larger and more valuable seams. I have represented in fig. 19 fragments of the only tissue preserved in the Poacites-coal, which appears to be the epidermis of these leaves, showing traces of a fine cellular tissue and round perforations, perhaps remains of stomata. I would also observe that, though in the roof-shales and other associated beds it is usually only the cortical layer of trees that appears as compact bituminous coal, yet I have found specimens which show that in the coal-seams themselves true woody tissues have sometimes been imbedded unchanged, and converted into structureless coal, forming, like the Coniferous trees converted into jet in more modern formations, thin bands of very pure bituminous material. The proportion of woody matter in this state differs in different coals, and is probably greatest in those which show the least mineral charcoal; but the alteration which it has undergone renders it almost impossible to distinguish it from the flattened bark, which in all ordinary cases is much more abundant.

III. *General Conclusions.*

1. With respect to the plants which have contributed the vegetable matter of the coal, these are principally the *Sigillariæ* and *Calamiteæ*, but especially the former. With these, however, are intermixed remains of most of the other plants of the period, contributing, though in an inferior degree, to the accumulation of the mass. This conclusion is confirmed by facts derived from the associated beds,—as, for instance, the prevalence of *Stigmaria* in the

coal. The lignite has the texture of jet, but retains sufficient traces of structure to show that it consists of Coniferous wood; and in specimens in which the presence of mineral matter allows this structure to be better seen, the density of the material is seen to be occasioned, not by the dissolution of the texture into a paste, but by the complete flattening of the cells. This condition occurs also in the ancient bituminous coal, and accounts for all those appearances really structural seen in slices of it, and for the differences in these observable in horizontal and vertical slices.

underclays, and of *Sigillariæ* and *Calamites* in the roof-shales and erect forests.

2. The woody matter of the axes of *Sigillariæ* and *Calamiteæ* and of Coniferous trunks, as well as the scalariform tissues of the axes of the *Lepidodendreæ* and *Ulodendreæ*, and the woody and vascular bundles of Ferns, appear principally in the state of mineral charcoal. The outer cortical envelope of these plants, together with such portions of their wood and of herbaceous plants and foliage as were submerged without subaërial decay, occur as compact coal of various degrees of purity, the cortical matter, owing to its greater resistance to aqueous infiltration, affording the purest coal. The relative amounts of all these substances found in the states of mineral charcoal and compact coal depend principally upon the greater or less prevalence of subaërial decay, occasioned by greater or less dryness of the swampy flats on which the coal accumulated.

3. The structure of the coal accords with the view that its materials were accumulated by growth, without any driftage of materials. The *Sigillariæ* and *Calamiteæ*, tall and branchless, and clothed only with rigid linear leaves, formed dense groves and jungles, in which the stumps and fallen trunks of dead trees became resolved by decay into shells of bark and loose fragments of rotten wood, which currents would necessarily have swept away, but which the most gentle inundations or even heavy rains could scatter in layers over the surface, where they gradually became imbedded in a mass of roots, fallen leaves, and herbaceous plants.

4. The rate of accumulation of coal was very slow. The climate of the period, in the northern temperate zone, was of such a character that the true Conifers show rings of growth not larger nor much less distinct than those of many of their modern congeners*. The *Sigillariæ* and *Calamites* were not, as often supposed, composed wholly, or even principally, of lax and soft tissues, or necessarily short-lived. The former had, it is true, a very thick cellular inner bark; but their dense woody axes, their thick and nearly imperishable outer bark, and their scanty and rigid foliage would indicate no very rapid growth or decay. In the case of *Sigillariæ*, the variations in the leaf-scars in different parts of the trunk, the intercalation of new ridges at the surface representing that of new woody wedges in the axis, the transverse marks left by the successive stages of upward growth—all indicate that at least several years must have been required for the growth of stems of moderate size. As the best means of illustrating these features of the growth of *Sigillaria*, I have given, in fig. 22, a restoration of a plant of this genus, with figures illustrative of its mode of growth, from specimens in my own possession†. The enormous roots of these trees, and the conditions of the coal-swamps, must have exempted them from the danger of being overthrown by violence. They probably fell, in successive generations, from natural decay; and, making every

* Paper on Fossils from Nova Scotia. Quart. Journ. Geol. Soc. 1847.

† See also various figures illustrating these points, in Brongniart's 'Végétaux Fossiles.'

allowance for other materials, we may safely assert that every foot of thickness of pure bituminous coal implies the quiet growth and fall of at least fifty generations of *Sigillariæ*, and therefore an undisturbed condition of forest-growth enduring through many centuries. Further, there is evidence that an immense amount of loose parenchymatous tissue, and even of wood, perished by decay; and we do not know to what extent even the most durable tissues may have disappeared in this way; so that in many coal-seams we may have only a very small part of the vegetable matter produced.

5. Lastly, the results stated in this paper refer to coal-beds of the middle coal-measures. A few facts which I have observed lead me to believe that, in the thin seams of the lower coal-measures, remains of *Nœggerathia* and *Lepidodendron* are more abundant than in those of the middle coal-measures*. In the upper coal-measures similar modifications may be expected. These differences have been to a certain extent ascertained by Goeppert for some of the coal-beds of Silesia, and by Lesquereux for those of Ohio †; but the subject is deserving of further investigation, more especially by the means proposed in this paper, and which I hope, should time and opportunity permit, to apply to the seventy-six successive coal-beds of the South Joggins.

EXPLANATION OF PLATES XVII., XVIII., XIX., XX.

Fig. 1. Scalariform vessel of *Ulodendron*; mineral charcoal; 300 diameters.
2. „ „ *Lepidodendron*; mineral charcoal; 300 diam.
3 & 4. Scalariform vessels and punctured wood-cells from vascular bundles of petioles of Ferns, &c.; mineral charcoal; 300 diam.
5. Gymnospermous bordered pores of *Sigillaria*? mineral charcoal; 1200 diam.
6. Axis of *Sigillaria*; longitudinal section; natural size.
7. Structures in the same, 300 diam. *a*, *b*, *c*, *d*, *f*, longitudinal sections; *e*, transverse section.
8 & 9. Discigerous and scalariform gymnospermous tissues; mineral charcoal; 300 diam.
10. Scalariform vessel of *Stigmaria*; 300 diam.
11 & 12. Structures of *Calamodendron* (? *Calamites*); mineral charcoal; 300 diam.
13. Structures of axis of erect *Sigillaria*; mineral charcoal; 300 diam.
14. Discigerous cells; mineral charcoal; 300 diam.
15 & 16. Coniferous tissue enclosing *Sternbergiæ*; 300 diam.
17. Spiral duct; mineral charcoal; about 20 diam.
18. Parenchymatous cells, from compact coal.
19. Epidermis of leaves of *Nœggerathia*, from coal.
20. Discigerous wood mineralized by carbonate of iron; Pictou Coal. *a*, longitudinal; *b*, transverse. 300 diam.
21. Discigerous and plain wood-cells; mineral charcoal; 300 diam.
22. Illustrations of mode of growth of *Sigillaria*. *a*, restoration of a ribbed *Sigillaria*; *b*, restored sections of trunk, showing outer rind, cellular bark with vascular bundles, woody axis, scalariform axis, pith with transverse septa; *c*, portion of leaf of *S. scutellata*; *d*, intercalation of rib, ligneous surface; *e*, irregular scars, showing intermission of upward growth, cortical surface.

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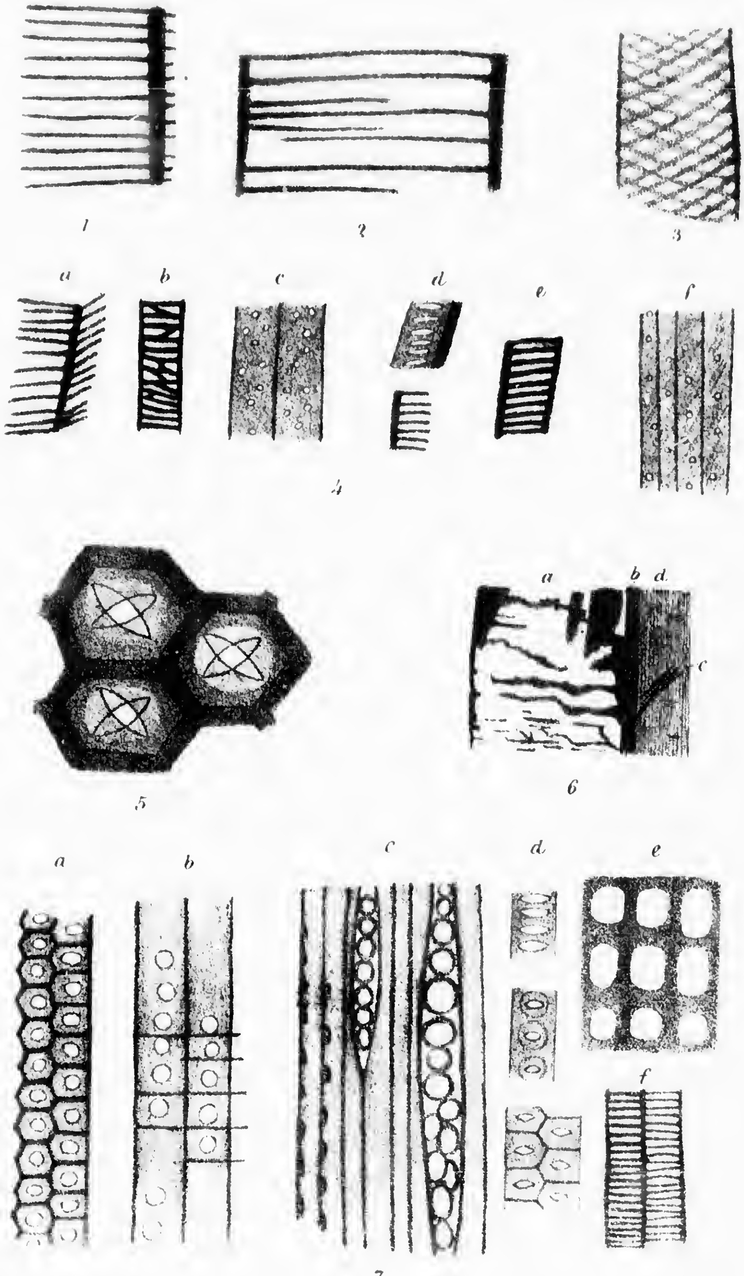
* I may refer to my late paper on Devonian Plants from Canada for an example of a still older coal made up principally of remains of Lycopodiaceous plants of the genus *Psilophyton*. (Quart. Journ. Geol. Soc. No. 60, p. 477.)

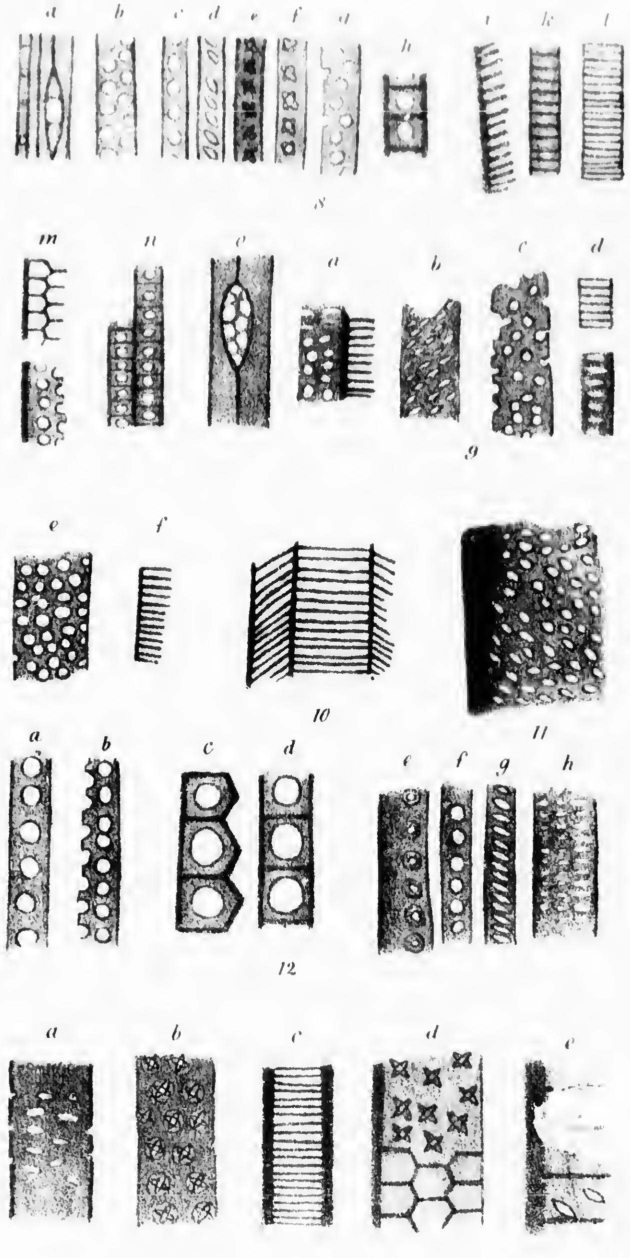
† Report of Survey of Ohio, 1858.



J. W. D. del. W. West lith.

W. West imp.

VEGETABLE TISSUES IN COAL



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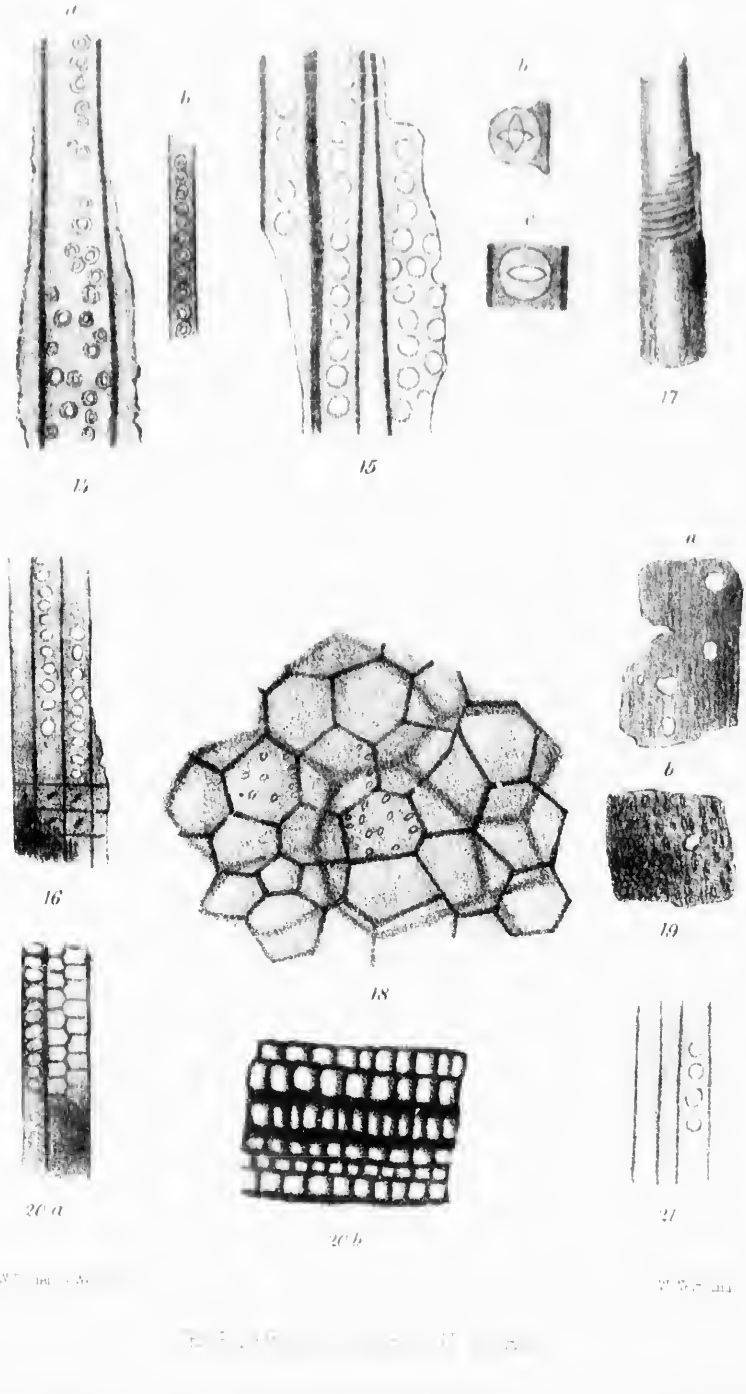
VEGETABLE TISSUES IN COAL



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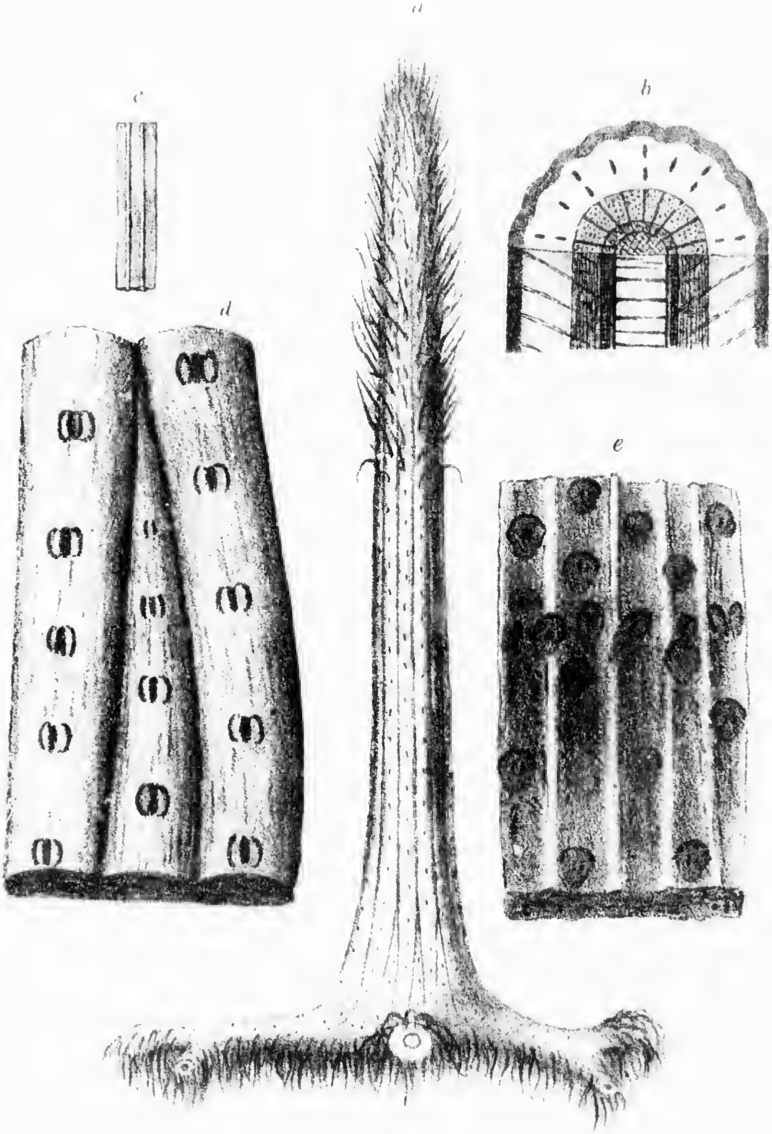

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SIGILLARIA