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SOME POINTS IN THE ANATOMY OF *ACROSTICHUM*  
*AUREUM*.

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[WITH PLATES III. AND IV. AND TEXT-FIGS. 27—40.]

A CERTAIN interest attaches to *Acrostichum aureum* inasmuch as it is the only Vascular Cryptogam now known whose habitat is the salt-swamp.

In view of the probability that many of our fossil Vascular Cryptogams were swamp-plants the investigation of this Fern seemed very desirable. Professor Oliver therefore suggested that I should examine material sent to him from Ceylon by Mr. A. K. Coomáraswámy.

*Acrostichum aureum* (= *Chrysodium vulgare*), so-called from the colour of its young leaves, is a handsome plant of bush-like growth forming a marked feature of the Mangrove Flora of Ceylon<sup>1</sup>. It has an erect stem with long up-standing pinnate fronds, the upper pinnæ of which are slightly smaller and fertile. From among the bases of the fronds numerous stout roots descend almost vertically in a tangled weft.

ADAPTATION TO CONDITIONS.

It is the roots which show the most interesting modification in connection with the peculiar mode of life. Each root is clothed with a soft brittle tissue which drops away in patches, leaving the central strand exposed—like a wire imperfectly covered with wool. This appearance is found on sectioning to be due to a great development of the middle cortex, which is furnished with huge lacunae (Pl. III., fig. 3). The cells lining the lacunar chambers are very irregular in shape, and connect up with one another by numerous short arms. The membrane between the arm of one cell and that of another is sclerised, and perforated with numerous scalariform or rounded pits (Pl. III., fig. 1).

<sup>1</sup> Tansley and Fritsch. "The Flora of the Ceylon Littoral,"  
NEW PHYTOLOGIST, Vol. IV., Nos. 1, 2 and 3.

In transverse section these dividing septa appear as round or oval pitted areas upon the more or less oval cells (Pl. III., figs. 2 and 4).

In longitudinal section the cells are somewhat elongated, and frequently present the appearance of a flask with laterally directed neck (Pl. III., fig. 5). It is only when the arms are presented to the observer end on, that their septa are seen as perforated discs, and as the walls of the chambers are usually but one cell thick, it is clear that they are found only on the cells of the radial wall in a tangential section (Pl. III., fig. 6) and on the tangential cells as seen in a radial section. The tangential and radial cells in these sections respectively, shew the arms in profile (Pl. III., fig. 6).

The connecting arms frequently expand at the cross wall, recalling the similar expansions seen in sieve-tubes and "trumpet hyphae."

Karsten<sup>1</sup> has described similar tissue in several Mangroves, notably in the roots of *Bruguiera gymnorhiza*. He figures disc-like connecting walls, which look almost precisely like those just described, but he does not mention any perforations. On the other hand the cells of *Bruguiera* possess thickening bands not found in *Acrostichum aureum*. Experiments on mangroves and on water plants have shown that such tissues are for the purpose of aeration, and we cannot doubt that here too the same function is performed.

The "air tissue" is found most abundantly on the proximal portion of the large roots. At the distal end it is almost absent, and the lateral roots form short sharp spines similar to those found on the aërial roots of *Dioscorea prchensilis*.<sup>2</sup>

The very close similarity of response met with in the mangroves, whose members are drawn from very widely separated orders of flowering plants, has always been a point of considerable interest, but this parallelism of development is brought out with much greater force, when we find the same response in the one member of this œcological association derived from the Vascular Cryptogams.

Under normal conditions, roots are very constant in their general anatomical features, and this is doubtless correlated with the constancy of the medium in which they grow, and of the functions which they have to perform. When one or both of these conditions is unusual, as in the present case, a very definite modification is met with, and this modification can with greater certainty

<sup>1</sup> G. Karsten. Ueber die Mangrove-Vegetation in Malayischen Archipel. Bibliotheca Botanica, Heft 22, 1891.

<sup>2</sup> Hill and Freeman. The Root-structure of *Dioscorea prchensilis*. Annals of Botany, 1903.

be referred to the altered circumstances than in the case of shoot structures, which come under the influence of far more complicated factors.

This being so, it is not without interest in this connection, to consider the structure of the roots of fossil plants known to us.

The markedly lacunar character of the middle cortex of Calamite roots instantly occurs to one, and indeed the young root of *A. aureum* (Pl. IV., fig. 8) bears a surprising resemblance to the young Calamite root<sup>1</sup>. Still more striking is the immense development of middle cortex in Stigmarian roots, where the tissue was evidently of a very delicate nature, for it is rarely preserved except at the edges, where it joins the inner or outer cortex. It is highly probable that it was lacunar in character. A lacunar middle cortex has been described by Bower<sup>2</sup> in the axis of *Lepidostrobus Brownii*, and the prevalence of three distinct zones in most *Lepidodendra*, and to a less extent in living *Lycopsids*<sup>3</sup> is commented upon. The middle zone is always composed of delicate parenchymatous cells, arranged loosely, and frequently forming lacunae. The inner and outer cortical zones are generally each composed of a few layers of thick-walled or sclerenchymatous cells.

Turning now to the fossil Ferns and Gymnosperms we find here also plentiful instances of lacunar cortices. Among the Ferns proper the roots of *Psaronius* show a marked lacunar cortex which is also found in "Kaloxylon"—a root probably to be assigned to *Lyginodendron*, but at any rate belonging to a member of the *Pteridosperms*.

#### VASCULAR ANATOMY.

##### *Root.*

The roots, both large and small, are formed on a triarch plan, but the stouter roots have in addition three alternating protoxylem groups, quite different in character from the main groups. The xylem arms of the small triarch roots are very wide—almost as extended as the alternating phloem groups—and each blunt extremity is obviously composed of two protoxylems, reminding one of the structure of a *Sphenophyllum* stem. I can find nothing quite comparable in any described Fern.

<sup>1</sup> Williamson & Scott. "Further Observations, Etc." Part II., The Roots of Calamites, *Phil. Trans.*, Vol. 186, B. 1895.

<sup>2</sup> F. O. Bower. Structure of the axis of *Lepidostrobus Brownii*, *Annals of Botany*, 1893.

<sup>3</sup> The name "Lycopsida" is used throughout in the sense proposed by Professor Jeffrey to include all "Vascular Cryptogams other than Ferns."

The protoxylem groups of rootlets still enclosed in the parent tissues seem to be single (Pl. IV., fig. 8).

In the stout roots (Pl. III., fig. 3 and Pl. IV., fig. 7), as has been mentioned above, the three phloem groups are always bisected by a narrow, pointed, single protoxylem group, which alternates with the characteristic wide double protoxylem poles. As the phloem groups are shallow, this gives the large xylem body an almost circular appearance, although the triangular plan is quite discernible. The rounded contour of the xylem body, coupled with the comparative smallness of the phloem groups, and the presence of a great quantity of parenchyma in the xylem gives rise to a very stem-like appearance, recalling indeed the stem of *Gleichenia*.

The only Fern root I have seen figured in the readily available literature with which it can be even remotely compared, is that of *Angiopteris evecta*.<sup>1</sup> This has a polyarch structure and is altogether planned on generous lines. It approaches the root of *Acrostichum aureum* in the disposition of its abundant parenchyma. The stout roots of the latter plant, however, bear a far more striking resemblance to the petiole of *Lygodium japonicum*!<sup>2</sup>

We see then that in the character of the stele and of the cortex the roots of this Fern are exceptional and shew distinct resemblances to the stem-type. It will be remembered that Westermaier<sup>3</sup> has pointed out that the *pneumatophores* or air-storing roots of the mangroves proper have many stem characters. These organs are in fact intermediate in structure between true stems and roots. Thus the primary xylem is more or less centrifugal in development, and phloem may occur on the same radius. They are further provided with a pith and have no root-cap.

Many pneumatophores have a peculiar development of the periderm for purposes of aeration. The phellogen forms layers of loose parenchymatous cells—"aerenchyma"—alternating with true cork layers. The phellogen arises in the cells of the outer cortex, thus being superficial in origin—another shoot-like character.

I have frequently noticed a very regular disposition of the cells of the outer cortex of the root of *A. aureum*, and have occasionally observed a distinct tangential wall in some of the large rounded cells of a continuous layer. This appearance suggested the possi-

<sup>1</sup> R. Shove. Ann. of Bot., 1900.

<sup>2</sup> Boodle. Anatomy of the Schizaeaceae. Annals of Botany, 1901.

<sup>3</sup> Westermaier. Zur Kenntnis der Pneumatophoren. Botanische Untersuchungen im Anschluss an eine Tropenreise, Freiburg, 1900.

bility of secondary cortex arising, for the production of special air-absorbing tissue.

Turning now to fossil roots, we find that they had very frequently characters which we regard as appertaining more strictly to shoots. The large Calamite roots have always a good pith and extensive cortex (see above). The anatomy of Stigmarian axes is of so indeterminate a type, that some divergence of opinion has arisen as to their morphological nature. It is best perhaps frankly to own them intermediate in character, like the rhizophores of their living allies, the *Selaginellas*.

The prevalence of centripetal development of the xylem in the shoots of Vascular Cryptogams removes one of the most constant differentiating features between the root and shoot as known in the Higher Plants. Nevertheless it seems to be only in the *Lycopsidea* that other characters combine to render morphological limitations obscure.

The peculiar nature of the periderm of fossil plants is frequently remarked upon. In root and shoot alike it arises from the cells of the outer cortex; while "‘periderm’ and ‘bark’ . . . . were very different in nature and function from the recent tissues which answer to them morphologically." It is doubtful whether any of the periderm cells became suberized, for the tissues exterior to it remained fresh, and it is conceivable that some of its delicate parenchymatous cells—such as those described for *Sigillaria spinosa*—may have had an aerating function.

#### *Stem.*

The chief conducting system of the stem forms a continuous cylinder, consisting of xylem elements in the centre, and clothed within and without with phloem, pericycle and endodermis in the manner characteristic of a solenostele. There are in addition a few slender accessory steles, lying in the ground tissue enclosed by the solenostele. The ground tissue immediately surrounding the solenostele, on the inside and on the outside, is differentiated into a broad band of sclerenchyma. There is a third sclerenchymatous sheath round the exterior of the stem. The solenostele is roughly triangular in transverse section, following the general contour of the stem (Text-fig. 27).

#### *Petiole.*

The petiole shows a far more complicated vascular system than we should expect from the comparatively simple arrangement in the stem.

<sup>1</sup> Scott. "Studies in Fossil Botany," p. 227.

Instead of the horseshoe leaf-trace, so frequently correlated with the solenostele, we meet with a bewildering number of small bundles, at the first glance giving almost the impression of being arranged in three concentric series. The position of the protoxylem elements in these bundles at once attracts attention (Text-fig. 36).

The bundles forming a row along the flattened upper (adaxial), side<sup>1</sup> of the petiole, have their protoxylem groups uppermost in the normal manner (Text-fig. 36). The protoxylem groups of the semi-circle of bundles arranged around the periphery of the convex under (abaxial) side are also directed towards the upper surface but within them is a smaller semicircle of bundles with inversely orientated protoxylem groups. This series, however, appears to be continuous at its ends with the outer series, and gives rise to the suspicion that they represent a lateral indentation of bundles arranged on the horseshoe plan.

The central internal system, and the upper row of bundles first alluded to, can similarly be explained as elaborations of the free ends of the horseshoe.

From an examination of the petiole alone, Mr. Gwynne-Vaughan, in a letter to Professor Oliver, has expressed his belief that the vascular system of the petiole of *Acrostichum aureum* can be "thus resolved." I fortunately had in the material at my disposal, a young plant from which a microtome-series of the base of one of its youngest fronds was obtained. It revealed the petiolar vascular system described above, but in its simplest terms (Text-fig. 34). The peripheral series of the lower side is composed of six bundles; within this is the inverted series consisting of only four bundles—two on each side and separated by a space. The central system is represented by one large bundle with several protoxylem groups. It is only slightly displaced from the middle of the row of bundles on the upper side.

#### *Node.*

A series of transverse sections was made through the stem, and they probably included the insertion of the petiole just described.

As the node is approached from below, the first sign of the departure of the leaf-trace, is the bulging of the solenostele at one of its angles to form a horseshoe-like loop (Text-fig. 27). Very soon, however, the continuous horseshoe is broken up into bundles. This

<sup>1</sup> In Text-figs. 34 to 37 the upper (adaxial) side of the petiole is turned downwards to correspond with the position of the leaf-trace in Text-figs. 27 to 33.

Fig. 27.

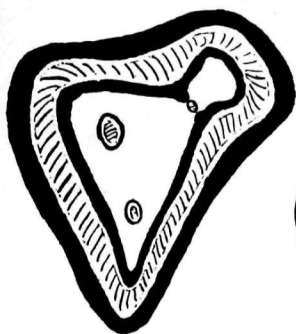


Fig. 28.



Fig. 29.

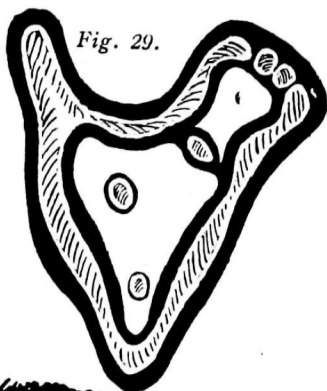


Fig. 30.



Fig. 31.



Fig. 32.



Fig. 33.



Black = sclerenchyma ; cross hatching = xylem ; white = ground tissue, except that immediately surrounding xylem, which represents phloem + pericycle + endodermis. [For explanation of Figs. see next page.]

- Fig. 27. Triangular solenostele of stem at beginning of departure of leaf-trace. Two accessory steles in ground tissue, and one across future leaf-gap.
- Fig. 28. Leaf trace becoming divided into bundles of *Series a*.
- Fig. 29. Ditto, further advanced. Root passing out on left.
- Figs. 30, 31. Further differentiation of bundles of *Series a*, and involution of the sides of trace to form *Series b*.
- Fig. 32. Fusion of penultimate portions of trace to form large bundle from which *Series c* will arise.
- Fig. 33. Commencement of differentiation of bundles of *Series c* from ends of trace.

is effected by sclerenchymatous elements, which, penetrating the vascular tissue from both sides, isolate portions of it, and thus give rise to the bundles of *Series a* (Text-figs. 28 and 29).

The sides of the original horseshoe now become infolded, and at the same time give off bundles forming the inverted *Series b* (Text figs. 30, 31, and 32).

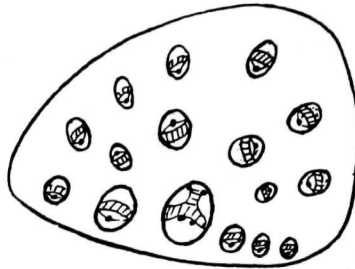


Fig. 34.

- Fig. 34. Base of young petiole. *Series a* consists of six bundles; *Series b* of four. The large bundle is the only representative of *Series c*, while the bundles on each side of it belong to *Series d*. N.B. Px. groups indicated by black dots as also in Figs 35 and 36.

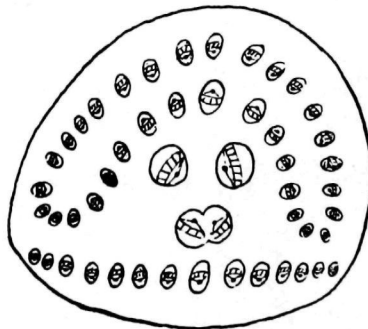


Fig. 35.

- Fig. 35. Older petiole, some distance from base. *Series a* composed of many bundles and forming a continuous curve with the inverted bundles of *Series b*. *Series c* composed of three bundles. *Series d* forms a row along the flattened upper surface. (See E of Fig. 37.)

The portions of the horseshoe just below the involuted sides



now fuse, forming a three-armed structure, the lateral arms of which give off bundles to form the *Series d* of the upper side; the middle arm forms the large bundle with many protoxylems, which will give rise to the central *Series c*. (Text-figs. 33 and 34).

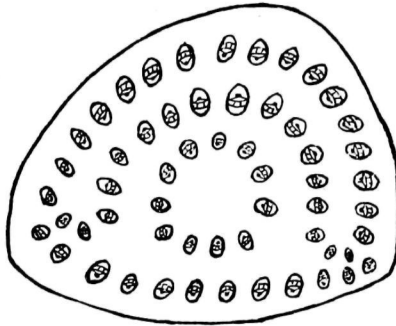


Fig. 36.

Fig. 36. Base of very old petiole. *Series a, b* and *c* much as in Fig. 35, but *Series c* composed of a ring of bundles. (See F of Fig. 37.)

The presumption therefore of the essential horseshoe character of the complicated leaf-trace seen in the mature petiole, is entirely justified by the detailed examination of its origin at the node. The method of the elaboration of the horseshoe into its final form can thus be very clearly made out (Text-fig. 37). It consists essentially of the involution of the sides of the horseshoe, and fusion of the lateral portions near the free ends, while at the same time the whole structure becomes divided up into bundles. The process may be divided roughly into four stages (i.) differentiation of the middle portion of the horseshoe into *Series a* (Fig 37, A & B); (ii.) infolding of the sides of the horseshoe and differentiation from them of *Series b* (Fig. 37, C & D); (iii.) fusion of opposite sides of the horseshoe just above the free ends, and differentiation from these ends of *Series d* (Fig. 37, E); (iv.) formation of *Series c* from fused portion (Fig. 37, F).

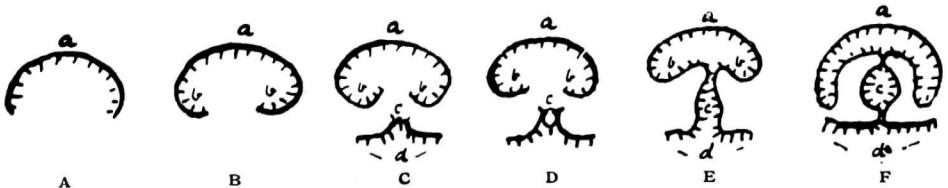


Fig. 37.

Fig. 37. Purely diagrammatic representation of stages in formation of complicated leaf trace. It is represented as a continuous curve, while the short projecting teeth indicate the position of the protoxylem groups. Notice that they are on the inside of the curve.

A & B. Curve of *Series a*. (Figs. 27-29.)

C & D. Involution of sides of curve to form *b*. (Figs. 30-33.)

E & F. Differentiation of *Series c* and *Series d* from ends of horseshoe shaped trace. (Figs. 34-36.)

The whole matter is somewhat obscured by the over-lapping of the above stages, which nevertheless are fairly well defined. The trace loses its connection with the stem-stele during stage (iii.)

*Accessory Steles.*

At each node one of the internal accessory steles mentioned above, approaches the gap formed by the out-going leaf-trace, and later closes this gap by fusion with the free ends of the solenosteles. In longitudinal section they appear as short irregular strands which branch and fuse, but always end blindly (Text-fig. 38).



Fig. 38.

Fig. 38. Longitudinal section of stem. It shows the irregular form of the short blind internal accessory steles.

*Leaf Blade.*

The lamina of the leaf is more highly differentiated than is usual among Ferns, and shows many features obviously correlated with the exceptional habitat of this species (Pl. IV., Fig. 9).

It is markedly bifacial, the upper half being characterized by a large-celled hypoderm, and beneath this two layers of elongated closely-set palisade cells. The lower half, which occupies about two-thirds of the total thickness, consists chiefly of loosely-arranged spongy mesophyll cells with plentiful lacunae. The hypoderm on this side is frequently interrupted by the stomatal air chambers. The stomata themselves are flush with the surface, and not raised from it, as in some of the other species of *Acrostichum* examined.

Such xerophilous features obtain in all the plants of the Mangrove swamps<sup>1</sup>—and are no doubt connected with the percentage of salt in the water,—but the adaptation is certainly more impressive here, in the leaf of a Pteridophyte which usually has a far simpler organization. The other species examined show a uniform mesophyll and no hypoderm, while the stomates project from the surface, raised on a little dome of cells.

*Other Species of Acrostichum.*

For purposes of comparison several other species of *Acrostichum* have been examined. With the exception of *A. crinitum*, which is an erect-growing plant, these had all creeping rhizomes. All the species cut, however, without exception, showed a dictyostelic structure with a leaf-trace composed of two to five strands arranged in a simple loop (Text figs. 39 and 40).

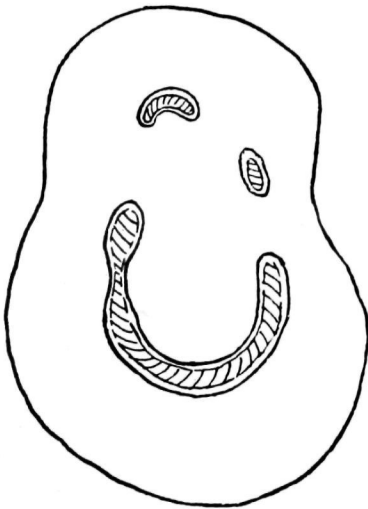


Fig. 39.

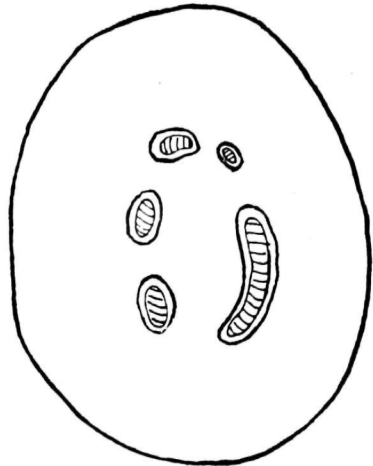


Fig. 40.

Figs. 39 & 40. Generalized diagrams of anatomy of stems of other species of *Acrostichum*. The three bundles of the leaf trace passing off.

*A. quercifolium* is the simplest. Its leaf receives two small strands which pass up the petiole unaltered.

*A. tomentosum*, *hybridum*, *conforme* and *crinitum* are very similar in behaviour. Usually about three strands pass off to the leaf, and these frequently soon divide to form five.

The dictyostely of these species is very obviously related to solenostely, and evidently results from the over-lapping of the leaf-gaps.

<sup>1</sup> Areschoug. Untersuchungen der Mangrove-Pflanzen. Bibl. Bot. Heft. 56, 1902.

*A. lomarioides* shows a somewhat different state of affairs. Its vascular system consists of an irregular circle of bundles, whose existence obviously bears no relation to the leaf gaps.

#### CONCLUSION.

We see then that in the facts brought forward here, there are two distinct centres of interest.

With regard to its vascular anatomy *Acrostichum aureum* presents us, perhaps, with the most complicated petiolar system, coupled with a solenostelic stem structure, which has yet been described. Nevertheless, the horseshoe curve upon which the continuous or broken leaf trace of the Polypodiaceæ is constructed can easily be distinguished.

This anatomical structure cannot be readily referred to the habit of the plant, for although the dictyostelic species first examined were all prostrate creeping forms, the erect growing species *A. crinitum*, which was obtained with some difficulty, proved to be dictyostelic also, and in all respects quite similar to the others. *A. aureum*, however, certainly differs from *A. crinitum*, in its infinitely more robust and bush-like growth, as in the possession of a solenostele, and massive, complicated leaf-trace.

The consideration of the structure of this plant in relation to its mode of life, has shown as we should have expected, that it is the roots which are most modified.

This modification is seen in the very abundant development of lacunar cortex and further in a somewhat stem-like vascular anatomy. Both these features are characteristic of the roots of the mangroves, and *A. aureum* therefore shows very strikingly how similar may be the response to common conditions, even in plants separated very widely from a systematic point of view. We have seen that the characteristics dwelt upon here, are, in addition features very common in fossil roots, particularly in those of Lycopside affinity. We have here then a vascular Cryptogam, which, growing at the present day under swamp conditions, shows special characters which are common also in the roots of fossil plants. As far as it goes, this is in support of the theory that many of our fossils were swamp plants. Dr. Scott remarks in his "Studies" that the lacunar character of Calamite roots points to life in water or wet mud. From the great development of vascular tissue, the latter seems more probable.

I cannot avoid the conclusion that very probably the upper portions of the roots of *Acrostichum aureum* are exposed, and may

function somewhat as the "prop"-roots of other mangroves. As a mere speculation, it seems to me even more probable that the Stigmarian axes of the ancient Lycopods were prop-roots, for they were known in many cases to "strike sharply down at an angle of 50° or 60° and only begin to take a horizontal course at some distance from the main trunk."<sup>1</sup> Their anatomy lends support to the view by analogy with that of the prop-roots of flowering plants.

When we consider the part that these members have to play, it is not surprising that the anatomical structure is intermediate between that of a root and a shoot, for the mechanical requirements of both must be met. On the girder system a medullated axis is recognized as most suitable to support a weight, while a central solid core best withstands the strains resulting from the forces to which a root is subjected.

Prop-roots in tidal swamps must be liable to stresses from the shifting nature of the surrounding medium, and in accordance, on the one hand, with the amount of weight which the structure is called upon to bear, and, on the other hand, with the amount of strain induced, a preponderance of shoot or root-characters may be expected.

In this connection it may perhaps be permitted to hazard an almost unsupported suggestion.

The root characters common to our fern, to the mangroves, and to fossil plants particularly of Lycopsidan affinity, have been sufficiently insisted upon; also the fact that these characters obtain largely in the living members of the latter phylum.

It seems then that an imperfect differentiation of root and shoot is characteristic of the Lycopside and may be correlated with the comparative insignificance of their leaves. Lycopside undoubtedly bulked largely in the coal measure vegetation, and evidence seems to be stronger as to the petrification of these plants *in situ* than in the case of members of other groups. We may perhaps take this as far as it goes as indicating suitability to swamp conditions.

The lacunar character of the plants, the imperfect differentiation of root and shoot, and the small leaves are all consistent with, and perhaps partly due to a swamp life, with its plentiful water supply and peculiar mechanical conditions. It may be that their descendants were never quite able to throw off the shackles of their ancestry, and to this day retain many of the characteristics of their forbears, together with a moisture-loving habit.

<sup>1</sup> Scott, "Studies in Fossil Botany," p. 220.

It is frequently contended that a moister climate obtained during the carboniferous epoch, and however this may be with regard to general atmospheric conditions,<sup>1</sup> it is clear that a damp heavy air would exist in the swamp itself.

If future knowledge should prove that such really were the conditions under which the greater number of the ancient Lycopods flourished, and evidence accumulate in favour of the view that such plants were essentially ill-adapted to the driest terrestrial conditions,<sup>2</sup> we should be furnished with a clue to the cause of the decadence of this group and the total extinction of its arborescent forms.

It has been pointed out to me that mountain ranges are the best means of wide distribution, and from such situations these plants would, on our hypothesis, necessarily tend to be excluded.

The lines of thought suggested by the examination of *Acrostichum aureum* have led me rather far into the realms of pure speculation, and for this I must beg to be excused.

My warmest thanks are due to Professor Oliver and to Mr. Tansley for their very kind and helpful interest in the progress of the work.

<sup>1</sup> Seward, "Fossil Plants as Tests of Climate."—Sedgwick Prize Essay, 1892.

<sup>2</sup> Monarch roots must be less effective as absorbent organs than those furnished with more than one protoxylem group.

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#### EXPLANATION OF PLATES.

##### PLATE III.—THE ROOT.

- Fig. 1. Portion of middle lacunar cortex of root as seen in transverse section (Fig. 3) enlarged. The *vertical* arms of its irregular cells seen on end—most show a pitted area. ( $\times 100$ ).
- Fig. 2. Single cell of tissue shown in Fig. 1 under greater magnification, *p.a.*, pitted area. ( $\times 400$ ).
- Fig. 3. Transverse section of stout root. *o.c.*, outer cortex; *m.c.*, middle lacunar cortex; *i.c.*, inner sclerenchymatous cortex; *end.* and *per.*, endodermis and pericycle; *d.px.*, double protoxylem group of stele; *s.px.*, single protoxylem group. ( $\times 17$ ).
- Fig. 4. Single cell of tissue shown in Fig. 1. *p.a.*, pitted area (cf. Fig. 2). ( $\times 400$ ).
- Fig. 5. Portions of three cells of tangential wall of lacunar chamber of middle cortex as seen in tangential longitudinal section (cf. Fig. 6). *p.a.*, lateral view of pitted area between arms of neighbouring cells. ( $\times 400$ ).
- Fig. 6. Portion of middle lacunar cortex of root as seen in tangential longitudinal section. *rad. w.*, cells of radial walls of lacunar chambers seen on end, many show pitted areas; *tan. w.*, cells of tangential wall viewed from the side. ( $\times 100$ ).

## PLATE IV.—THE ROOT (Figs. 7 &amp; 8). THE LEAF BLADE (Fig. 9).

Fig. 7. Transverse section of stele from root similar to that shown in Fig. 3. The drawing is bounded by endodermis and pericycle; *d.px.*, double protoxylem groups, of which there are three; *s.px.*, single protoxylem group, of which there are also three, alternating with the three double groups; *ph.*, phloem groups, composed almost entirely of sieve tubes. The centre is occupied by the large xylem body consisting of tracheides and very plentiful parenchyma. ( $\times 170$ ).

Fig. 8. Transverse section of rootlet as it passes through the cortex of the parent root; *o.c.*, outer cortex; *m.c.* middle cortex; *i.c.*, inner cortex. Compare the relations of the three cortical zones in much older root (Fig. 3). Note that the middle cortex here consists of cells with living contents. ( $\times 100$ ).

Fig. 9. Transverse section of the lamina of the leaf; *hyp.*, hypodermis; *p.m.*, palisade mesophyll; *s.m.*, spongy, mesophyll; *st.*, stoma. ( $\times 170$ ).

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## THE OSMOTIC STRENGTH OF CELL SAP IN PLANTS GROWING UNDER DIFFERENT CONDITIONS.

BY ERIC DRABBLE AND HILDA LAKE.

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COMPARATIVELY few observations on the osmotic strength of cell sap in plants growing under different physical conditions seem to have been made. The most familiar is probably Mr. Francis Darwin's determination for the Dandelion, given in his "Practical Physiology of Plants." The method employed by him consisted in cutting the inflorescence-stalk longitudinally and placing strips of the stalk in pure water. This resulted in curvature of the strips in an outward direction—*i.e.*, the cells occupying the inner face of the strip expanded more than those occupying the outer face, owing largely to the mechanical arrangement of the tissues in these regions. The curled strips were then placed in solutions of potassium nitrate of known strengths, and the solution in which the strip retained the same degree of curvature was taken as isotonic with the cell sap. This method gives very accurate determinations of the strength of the sap, but is only applicable in relatively few cases. A method involving observation of the plasmolysis of the cells can however be very generally applied. By this means a number of plants have been examined with regard to the strength of their cell sap. A series of solutions of sodium chloride was made of the following concentrations in gram molecules—.10, .11, .12, etc., up to .30. Portions of the plant the strength of whose cell sap was to be determined were placed in pure water. Strips of the epidermis of the leaf were placed in a drop of the solution on a slide, and gently covered with

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