RESEARCH ON THE CLASSIC JOGGINS PETRIFIED TREES

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A re-examination of the Carboniferous section of Joggins, Nova Scotia, does not support the prevailing theory that the petrified trees and coal deposits are ***in situ.*** *Ten evidences that support the allochthonous emplacement of the trees and rapid sedimentation include the absence of soil zones, unusual plant fossils within the hollow stumps, remarkable preservation of delicate fossils, diagonal trees, abundant presence of the marine tubeworm,* ***Spirorbis,*** *and polystrate trees. Seven observations that favor a similar interpretation for the* ***Stigmaria*** *"roots" associated with coal include the negative geotropism of the appendages, isolated sections of* ***Stigmaria*** *with radiating "rootlets," unusual orientations of* ***Stigmaria*** *and appendages, and the remarkable similarity of* ***Stigmaria*** *to the creeping stems of* ***Lycopodium.*** *A tentative model of allochthonous organic sedimentation is proposed.*

Introduction

Along the upper end of the Bay of Fundy, and on the outer east coast of Nova Scotia, a classic phenomenon of great interest is seen. Upright petrified stumps embedded in the cliffs have been exposed by marine erosion. It is a singular experience to walk along the beaches and see trees up to five meters tall and one meter in diameter standing out from the cliffs in what appear to be their original positions of growth. (Figure 1)

Figure 1. A beautiful petrified tree *(Sigillria)* originating in shale and extending up into sandstone. Joggins, Nova Scotia.

Coal is mined along the Bay of Fundy and in other Upper Carboniferous deposits of Nova Scotia. Petrified trees arise from the upper surfaces of some of the coal seams or are distributed in the strata between seams.

Charles Lyell visited[1] the cliffs near Joggins in 1842. A young Canadian scientist, William Dawson, accompanied him during a later visit, and went on to make a comprehensive study[2] of the Carboniferous of Nova Scotia. They followed the stratigraphy worked out by William E. Logan,[3] the first director of the Geological Survey of Canada. Richard Brown[4] recorded some of the unique features of the coal measures of the Sydney, Nova Scotia, area and helped settle the controversy concerning the relationship between some of the common fossils associated with coal, namely the *Stigmaria* roots and *Lepidodendron* trees.

Trees most commonly involved are the lycopod genera *Sigillaria, Lepidodendron,* and the coniferous *Cordaites;* the first two are often upright whereas the latter one is not. (Figure 2) The roots of the upright lycopods have been shown to change in morphology to become unquestioned and typical *Stigmaria* roots.[5] I also found one example near Sydney Mines that clearly demonstrated this relationship between the stigmariae and the lycopod trees.

Figure 2. Two *Cordaites* petrified logs in prostrate position. None were found upright. Joggins.

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Figure 3. Erect lycopod stumps were hollow and filled with sediments when buried, Joggins. Note that the sandstone bed passing along the top is not found inside the tree.

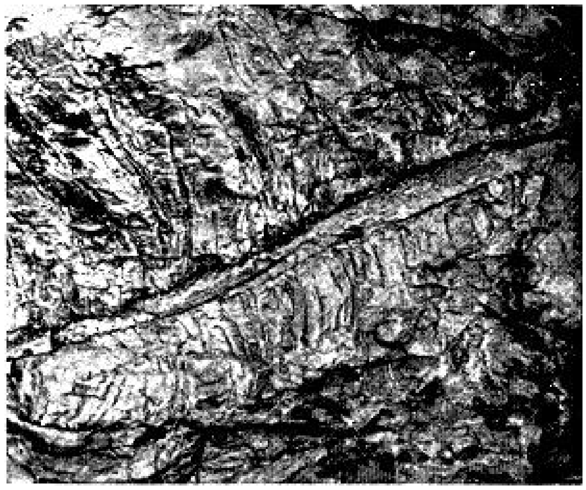

Figure 4. *Stigmaria* with radiating appendages. This *Stigmaria* was traceable a few feet to the right where it joined an erect tree. Point Aconi, Cape Breton Island, Nova Scotia.

The trunks of the two giant club-moss genera apparently were hollow or had soft pulp centers because all the vertical stumps were filled with sediments and only the outer wood or bark remained as a thin film of coal. (Figure 3) Horizontal trees of this type were almost always flattened.

Cordaites, a coniferous tree somewhat resembling the Parana Pine of the Southern Hemisphere, was not hollow. It had long spatulate or lanceolate leaves with parallel striations on the surface which caused early taxonomists to misplace it among the Monocotyledon.

Two Possible Viewpoints

In the early days of geological investigation and observation, keen students of the earth such as Nicolaus Steno and John Woodward largely accepted the Genesis Flood as a reality and interpreted the structure of the earths surface and the organic evidences found within as the result of this event. When coal was definitely established to be plant debris, the mode of its emplacement in the sediments was generally assumed to be the result of drift on the waters of the Noachian Deluge.

A new view was voiced in the writings of Hutton and Playfair, and crystallized under Lyell. Under these and other opponents of catastrophism, the autochthonous* concept of coal formation became dominant and has remained dominant except for some weakening of the view under the impact of Henry Fayol's clear and forceful presentations for drifting which he produced near the end of the nineteenth century.[6]

Among the factors which served as strong arguments for *in situ* accumulations of plant remains were the reports and studies[7] of erect trees and spreading roots and rootlets (*Stigmaria* and appendages) apparently found in place in the ancient soils. Despite serious anomalies connected with the uniformitarian interpretation of the vertical trees, the spreading roots and rootlets, and the surrounding sediments, the trees and stigmariae, probably more than any other factors, cemented the thinking for autochthonous coal formation. (Figure 4) This view of coal origin necessitates abundance of time for geological processes to function at uniform rates. Thus this belief was a major contributor to the establishment of the geologic time scale. Few other formations appeared to have as many and as convincing evidences of *in situ* conditions as did the Carboniferous.

Dawson considered each level of trees to represent a ground surface or soil level. Taking also the *Stigmaria* root zones and the coal seams to be soil levels, he recorded 85 such horizons and felt this to be the minimum number of soil levels revealed along several miles of sea cliffs in the Joggins region.[8]

The growth of forests and the establishment of soils for at least 85 levels, required the rhythmic rise and fall of the land for the burial of each level. Incomplete cyclothems are continuous through more than 14,000 vertical feet in the Joggins area.[9] The difficult requirement for the land surface in the same locality to be suitable for the exacting conditions of bog formation following many of the emergences from the sea was considered justified by the evidence.

*The term "autochthonous" refers to coal formation from indigenous plant remains which grew in the place where coal is found (i.e. in situ). The term "allochthonous," refers to coal formation from plant remains which have been transported by some force from place of original growth to present location.

Figure 5. This petrified stump is filled with coarse sandstone but surrounded by shale except at the top. Hammer at base gives scale. Point Aconi, Cape Breton Island.

Ten Evidences for Allochthonous Origin

Although the autochthonous origin of the coal, trees, and *Stigmaria* roots at Joggins has been assumed since Dawson's research, substantiation of this view appears difficult. Evidences in favor of an allochthonous origin and rapid sedimentation are enumerated below:

1. The coniferous *Cordaites*, although mingled with erect lycopod trees, has not been found erect. (Figure 2) If the trees are in growth position the solid, more durable trees, rather than the hollow fragile ones, would be expected to remain standing in the midst of invading seas and depositing conditions.[10]

2. Just under 70% of the hollow vertical tree trunks contain sediments unlike or having different bedding than the surrounding matrix. Often the type of sediment lying just above the broken-off stump top also fills its hollow cavity. A few examples had internal sediments unrelatable to any overlying or surrounding strata. (Figure 5) It could be postulated that the original matrix was completely removed and replaced by another, or the stumps were moved to a new location after infilling, but neither of these possibilities is comparable with the *in situ* theory.

3. A distinctive soil level is usually missing. (Figures 1, 3, 5, 6, 20) Only a small number of the vertical trees arise from coal. The majority originate in shale or sandstone which exhibit no change in texture or organic content. Several trees in the same stratum may arise from different levels—none of which qualify as ancient soil zones.

Petrified stumps arising from a coal surface almost never send roots into the coal, but spread their roots out onto or just above the coal. A modern peat bog exposed in cross-section near Sydney Mines by eroding seas has had at least two living forests growing on its surface in post-Pleistocene times. These forests were killed and the stumps buried by accumulating peat. The tops of the stumps of the most recent forest protrude above the present peat bog surface.

Figure 6. Overlapping erect trees only a few feet apart. Glace Bay, Cape Breton Island.

Such a situation seems not to have been attained in the coal seams and petrified trees. Stumps of trees that grew in or on peat, now coalified, should be easy to recognize if the trunks extended into the sediments above the coal.

4. The presence of overlapping erect trees seems to preclude the amount of time needed for their normal growth in their present positions. (Figure 6) The major portion of the lower trunk would have protruded above ground during the entire life of the upper tree if both are in growth position. The hollow interiors of both were filled when sandy mud buried them. The trees are three meters apart and the nearly horizontal bedding, easily traceable between them, negates the suggestion that they grew simultaneously on an even surface.

5. A variety of organic remains are found in the sediments within the stumps, including forms unexpected for trees *in situ*. Leaves, needles, fruits, twigs, and branches would fall into hollow upright stumps; but the presence of sections of *Stigmaria* roots and *Calamites* stems is less understandable without recourse to an allochthonous theory of origin. (Figure 7) Three examples of *Stigmaria* and one of *Calamites* inside hollow stumps were found by the author in the North Sydney area, and Brown[11] makes reference to one.

Figure 7. *Stigmaria* with radiating appendages positioned in the sediments inside an erect tree. Sydney Mines. Cape Breton Island

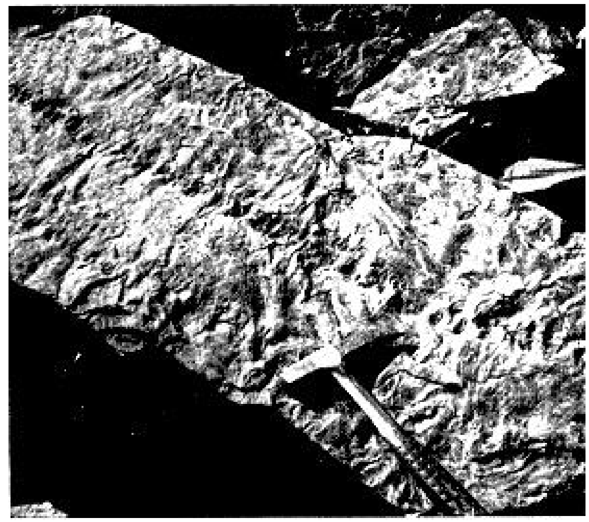

Figure 8. Tracks on sandstone. Joggins.

Figure 9. Diagonal tree in sandstone near Alder Point, Cape Breton Island.

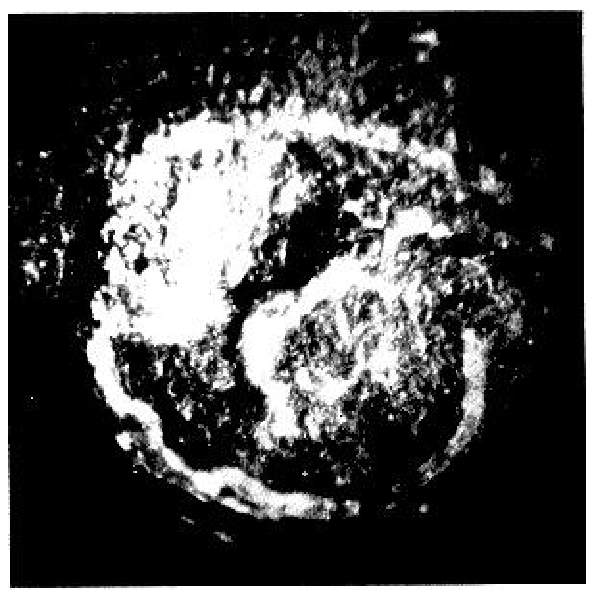

Figure 10. Cross section through the small tubeworm, *Spirorbis,* in organic sediments at Joggins.

Bones of several species of amphibians or reptiles have been found inside the vertical stumps.[12] The carcass or bones of an amphibian or reptile within a hollow stump before erosional removal of the stump, would travel with the stump and be buried in sediments when the stump was buried. Swimming animals might seek out floating rafts of trees and plant debris during a flood. Animal tracks, also seen in the Joggins sediments, fail to provide useful insights because they could be produced under a variety of situations and conditions.[13] (Figure 8)

6. Remarkably beautiful preservations of delicate organic structures are found. Foliage which accumulates on a modern ground surface seldom remains intact for more than one or two seasons. Just below the surface, vegetable matter has lost much of its original form and identity by decay.

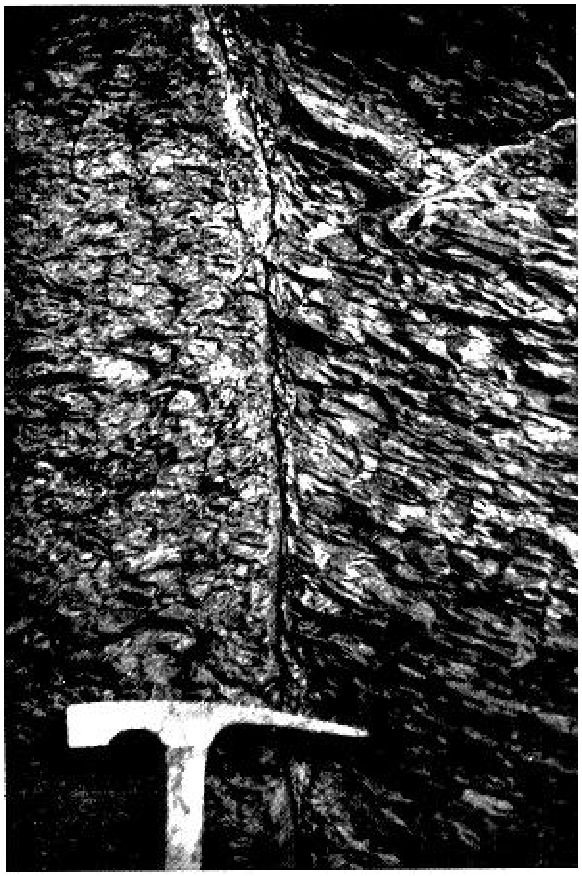

Figure 11. Longitudinal section through standing tree in shale. Shale on left inside tree; shale on right banked up against outside of tree. Sydney Mines.

Especially problematic would be such fragile structures well preserved below the roots of vertical trees in growth positions. The trees mentioned under item 4 above, exhibited this feature well.

7. Diagonal petrified trees, tipped 45 or more degrees are occasionally seen in the cliffs. (Figure 9) The roots are at right angles to the stumps and not parallel to the bedding. Such trees speak of rapid burial or transport *in toto* along with the sediments.[14]

8. A marine tubeworm *Spirorbis* (Figure 10) is frequently attached in abundance to vegetable matter in the coal and to the prostrate and erect trees, both inside and outside the hollow stems. The postulated limnic habitat for Carboniferous *Spirorbis* is highly questionable and goes against almost every facet of evidence available.[15] The presence of this annelid almost forces the conclusion that the trees were exposed to deep marine intrusions or floated in saline water.

9. Sediments often bank up against the vertical stumps and have a saucer-like bedding within

Figure 12. Minor unconformities in bedding near Joggins.

the hollow interiors. (Figure 11) This settling of sediments along with well-preserved fossils suggests rapidity of depositing processes.

10. The vertical lycopod stumps often penetrate two or more strata, one of which rarely may be a coal seam. Polystrate trees, 11.5 meters or more tall,[16] would necessitate rapid fallout of sediments at least that deep in that location to prevent decay of the upper parts of the stumps.

Most of the sandstones are cross-bedded, contain ball and pillow structures, show local unconformities, cut and fill phenomena, or are ripple marked; all features of rapid water flow or movement. (Figure 12) Sand itself is not transported without a substantial current.

Shales, on the other hand, do not show clearly current and flow evidences. The fine nature of the sediments of which shale is composed probably would not settle out except in water that was relatively quiet or deep enough to allow materials to sink below surface agitation.

In addition to these two sediment types and the gradations between them, there are occasional strata of conglomerate especially in the lower part of the Carboniferous. These are composed of pebbles and flat cakes of shale that appear to have been ripped up from a partly dried but unindurated shale bed on which the conglomerates were laid.

The cyclothems of Nova Scotia are mostly incomplete. Throughout much of the over 14,000 feet of Carboniferous strata, sandstone and shale alternate and the thickness of the individual beds vary greatly. (Figure 13) Although plant remains are scattered through most of this depth, coal as such is missing from much of the sequence.

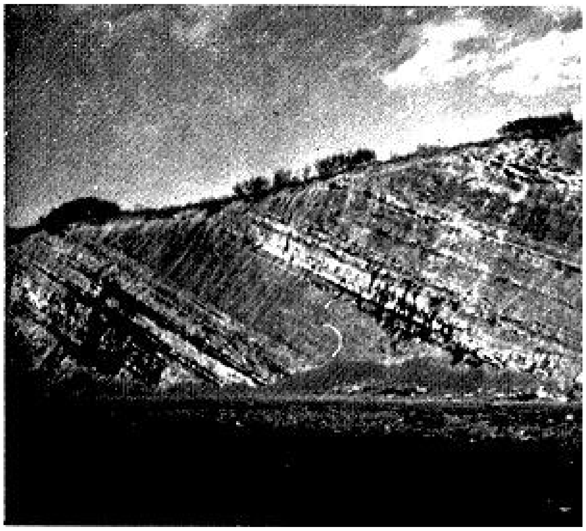

Figure 13. Cliffs near Joggins showing rhythmic sedimentation.

I know of no count of the total number of cyclothems in this Carboniferous deposit but the number must be in the hundreds. Hundreds of emergences and submergence of the land is an unreasonable explanation. An explanation of the unsolved problem of the formation of cyclothems bears directly, of course, on the issue of the autochthonous versus allochthonous deposition of plants and coal.

Upright Fossil Trees Interpreted

If the *in situ* position of these stumps is questioned, their upright orientation in the strata calls for some explanation. Trees and logs floating in an upright position are not rare under certain conditions. Saturated timbers that have gotten away from log booms and have drifted for some time in the waters of Puget Sound in the Northwest, often float upright with their tops barely visible at the surface of the water. Loggers from British Columbia and Alaska say trees or stumps ripped out of the ground by ocean storms or logging operations frequently float upright. I have noticed and photographed recent stumps sitting upright along the beach or among piles of driftwood along the Bay of Fundy where they were left by high tides or storms.

Francis[17] reports, ". . . it is natural for short stems attached to heavy roots or trees to float upright, with the roots downwards, when transported by deep water, particularly if the roots enclose a ball of clay or gravel."

Ager[18] makes the following comment:

> E. D. McKee (personal communication, 1963), has told of palm trees being swept from a Pacific atoll during hurricanes and coming to rest in considerable depths of water in an upright position because of their heavy, stone-laden roots, so that even trees in position of life may not be completely beyond question.

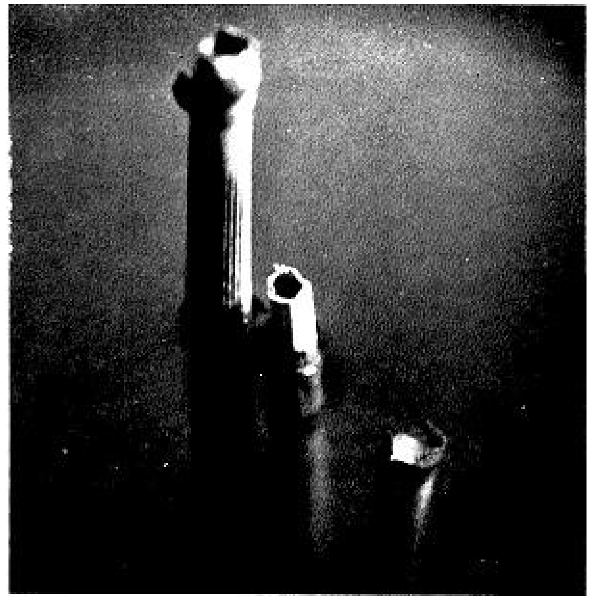

Figure 14. Cluster of *Equisetum* floating upright.

While sailing along the coast of New Guinea the Challenger Expedition ran into long lines of driftwood brought down perhaps by flooding rivers. The following appears in the report:

> Much of the wood was floating suspended vertically in the water, and most curiously, logs and short branch pieces thus floating often occurred in separate groups apart from the horizontally floating timbers. The sunken ends of the wood were not weighted by any attached masses of soil or other load of any kind; possibly the water penetrated certain kinds of wood more easily in one direction with regard to its growth than the other, hence one end becomes water-logged before the other.[19]

Travelers from the Amazon region of South America report frequent observance of trees floating upright down the river, especially following high water and floods.

Upright trees have been uncritically taken as *a priori* evidence of unchanged growth position but much caution is advised against such automatic assumptions. Stevenson,[20] in his monograph on the formation of coal beds, decides that upright trees are not important in settling the problem of autochthonous or allochthonous origins of coal.

Results of Flotation Experiments

Flotation experiments have been undertaken by the author with *Equisetum* in an attempt to clarify the vertical position of *Calamites* stems. Some findings: (a) Clusters of horsetail stems attached to the same roots float upright because

Figure 15. Individual stems of *Equisetum* suspended from the surface or standing upright on the bottom. To facilitate obtaining a sharp focus, the stems were moved to near the front of the tank, but they are not leaning against the glass or each other.

of the heavy rootstock and associated soil. (Figure 14) (b) Individual stems floated horizontally for some days until they became saturated and swung into an upright position suspended from the surface of the water. (c) As saturation increased, they sank and rested on the bottom of the tank in a vertical position. (Figure 15) (d) Eventually a few days later they fell over to lie prone. Contemporaneous sedimentation would have incorporated many of them upright in the sediments.

The *Calamites* stems in Nova Scotia strata are generally single. They are probably not in growth position but have been buried by the elastic deposits in a way similar to that suggested by the flotation experiments.

Henry Fayol[21] undertook flotation experiments for several years in an artificial pond. This comprehensive research gave percentages for the vertical and horizontal floating of living trees similar to those for prone and erect petrified trees in the coal measures of Central France. His results with *Equisetum* were the same as those of this investigator.

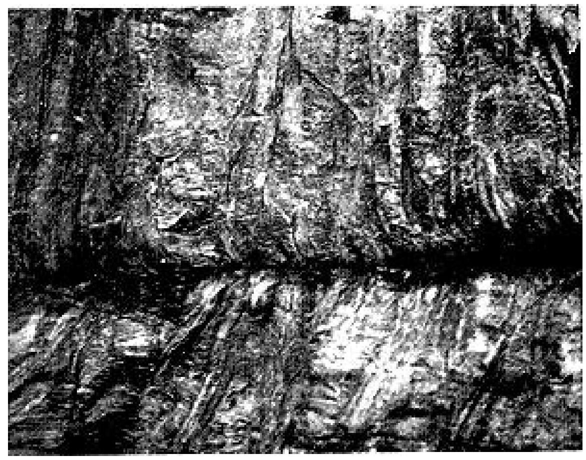

Figure 16. Appendages extending up and down from a *Stigmaria*. This *Stigmaria* has been flattened as is true for many. Sydney Mines.

Seven Points of Interpretation

The problem of the *Stigmaria* and associated appendages has long puzzled paleobotanists. There are aspects dissimilar to anything seen today that make it impossible for researchers to be unanimous in their conclusions on the stigmariae. However, few question the *in situ* position of the structures even though the true nature of their function is not known. Rootlet-bearing stigmariae have been traced several feet toward *Lepidodendron* or *Sigillarian* trees where they become the flaring roots of the trees. Thus the stigmariae and their rootlets assume a position like roots to a tree.

Present thinking on *Stigmaria* is aptly summarized by Arnold,[22]

> The true morphology of stigmariae and its relation to the stem, remains, even after more than a century of research, one of the great unsolved problems of Paleobotany. . . . Modern research has thrown little additional light on the *Stigmaria* problem and the remains are generally ignored by presentday paleobotanists.

The following points concern interpretation of the stigmariae as true roots *in situ*. If the stigmariae are not assumed to be in growth position, the dead end of the present state of knowledge is bypassed by a new approach that holds promise of a solution to the problem.

1. Appendages extend from *Stigmaria* in parallel orientation. (Figure 16) These "rootlets" follow each other around bends and corners in a manner untypical of normal rootlets which pursue an independent course through the soil. Occasionally all of the appendages may be confined to the same horizontal plane on which the *Stigmaria* rests.

Figure 17. Cross section through *Stigmaria* showing radiating appendages. Sydney Mines.

2. Appendages usually radiate from the *Stigmaria* in all directions into the rock; consequently, many of them have an upward orientation which would be termed negative geotropism if they are in position of growth. (Figure 17) Yet a nearly universal characteristic of normal rootlets is positive geotropism.

Furthermore, if these are true roots that grew where now located, some of the appendages were positively geotropic, some were negatively geotropic, and some were not sensitive to gravity; but no noticeable difference in morphology is apparent. "Rootlets" which extend upward are usually longer and less bent than those penetrating downward. This feature has significance when comparison is made with the living *Lycopodium* (see item 4 below).

3. Stigmariae do not have the dendritic branching and resulting taper in diameter typical of roots. Long sections often have the same diameters at the two ends as illustrated by one somewhat flattened, 20 meter length found by this investigator near Sydney Mines with diameter measurements of 6.5 cm by 10 cm at both ends.

4. Stigmariae have remarkable resemblances to the creeping stems or rhizomes of the modern clubmoss *Lycopodium*. In both, appendages which are poorly equipped with vascular tissues are attached in spiral arrangement. Both have little or no taper and have large fibrous vascular cylinders. The lower scale-like leaves around the creeping stems of *Lycopodium* are shorter and assume a more acute angle of attachment; whereas, the upper ones are longer and extend nearly perpendicularly from the stems.

As mentioned above, this feature is also true for stigmariae and "rootlets." (Figures 18 and 19) Thus it is probable that the "rootlets" of *Stigmaria* are not "rootlets" at all but slender leaf-like appendages. Several paleobotanists have been impressed with the possibility that stigmariae are giant rhizomes or creeping stems.[23]

An evidence for *in situ* burial that requires more detailed consideration is the report of plant parts such as roots growing into or penetrating the tissues of trees, before carbonization. Among the examples cited in the literature are: (a) *Stigmaria* "rootlets" penetrating from one level down into the trees of a lower level,[24] (b) *Stigmaria* protruding through the wall of a stump,[25] and (c) *Stigmaria* "rootlets" growing into the tissue of *Stigmaria.*[26]

My study of the stigmariae indicates that "rootlets" and plant fragments are often found in the sand or shale inside the stigmariae even though these structures are seldom more than 10 cm in diameter. These phenomena may be interpreted as intrusions by growth from outside, but the scattered and fragmentary nature of the plant structures and the presence of bedding, obviously water laid, inside the stigmariae leave this interpretation open to question.

In no case was I able to find any actual penetration of the carbonaceous wall of the *Stigmaria* by "rootlets" or other plant structures that might have grown into it. The possibility of stigmariae and "rootlets" being rhizomes or creeping stems casts some shadow on the ability of *Stigmaria* "rootlets" to grow into other *Stigmaria* in a manner one would expect of true rootlets.

Even if growth penetration is a correct observation, it is not overly relevant because whether the coal and plant specimens are autochthonous or allochthonous, penetration by growing plant parts could be a reality. In the latter case, the growth into partly decayed or soft tissues by a rootlet or underground stem would have taken place before the forest was rafted to the position of burial.

5. Quantitative measurements of orientation of 69 stigmariae in locations near Sydney Mines and Joggins indicate a strong parallel orientation. Measurements were taken in shale and sandstone directly above and below coal seams. These stems, often visible for several feet, have the typical radiating appendages assumed to indicate *in situ* plants.

Orientation measurements of stigmariae in coal have been taken and with similar results.[27] Thus stigmariae below, in, and above coal seams

Figure 18. Creeping stem and upright shoots of *Lycopodium*. Note that the scale-like leaves are spirally arranged around the stem and the lower ones do not extend as broadly from the stem as do the upper ones.

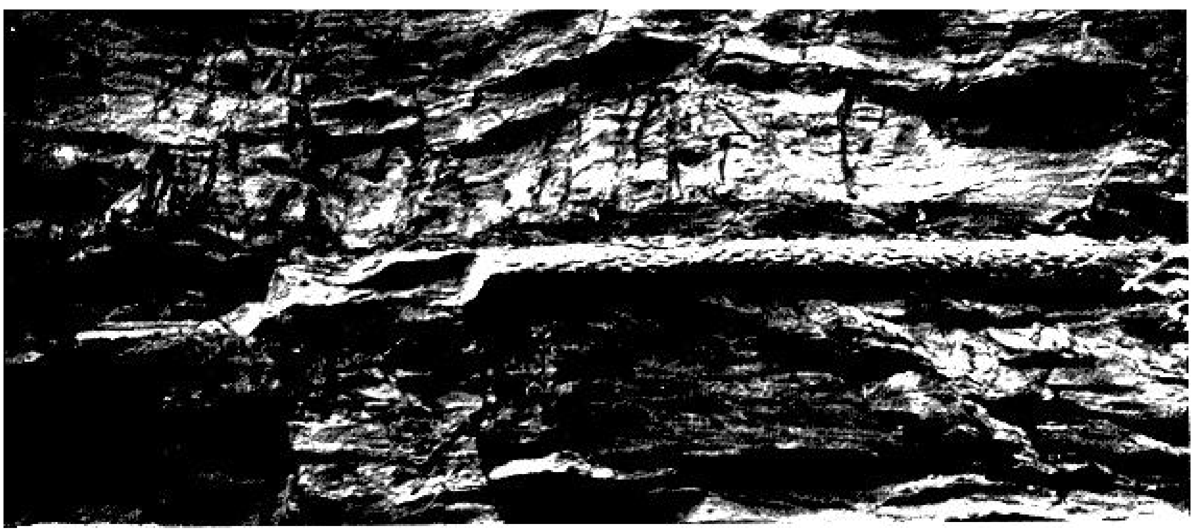

Figure 19. A section of *Stigmaria* with radiating appendages. These appendages are poorly developed compared to others but note that those extending upward are clearly visible; whereas, those extending downward are rare or absent. Spirally arranged pits or points of attachment of the appendages are visible. Sydney Mines.

have similar patterns of positioning. Yet the parallel orientation, which agrees with current direction as determined by cross-bedding and ripple marks, strongly speaks against their being in position of growth. Parallel orientation for roots of living trees growing unrestricted in sand or soil would certainly be unexpected.

6. Stigmariae are found in limestone, crude coal composed mostly of mussel shells, and other odd sediments which would not be considered suitable soils for the growth of roots.

7. Isolated sections of *Stigmaria* unattached to upright lycopods and with radiating appendages are found. Most notable of these are the ones found inside erect stumps. (Figure 7) It would appear that the appendages were stiff and their radiating position little affected when the sections were dropped or moved about in soft sediments.

Figure 20. A lycopod tree with unusual features best ascribed to an allochthonous burial (see text). Point Aconi.

Excellent Natural Object Lesson

One short section of cliff near Sydney Mines, constitutes a good case history which includes several of the points brought out above. A large, upright petrified tree (probably *Sigillaria)* originated in the same bed where compass measurements established the parallel orientation of stigmariae with each other and with the dominant current. (Figure 20) Thus, if the stigmariae were not in growth position, it is doubtful that the tree would be.

The erect tree passed through a bed of shale 1.5 meters thick which contained abundant quantities of exquisitely preserved fern leaves–good evidence of rapid sedimentation. The upper one meter of the tree was filled with sediments approaching that of crude coal. No one meter bed of coal existed outside the tree, but there was, however, directly above the broken top a 7 cm seam of this dark gray deposit.

Apparently the last meter of the hollow tree was filled with this material when it was washed out over the surface. In this case it is obvious that the thin organic layer lying directly over the tree cannot be a growth level but was a water-laid deposit.

The Nova Scotia Carboniferous sediments are rather typical of the Paleozoic coal measures of North America and Europe. Thus the objections to *in situ* theory for the coal deposits of Nova Scotia apply in some degree to the Carboniferous in general. However, before broad generalizations beyond Nova Scotia are made, research must be undertaken in other areas.

Tentative Model of Deposition

A completely satisfactory hypothesis of the depositing conditions involved in the laying down of the vegetable and organic debris that has become coal and the positioning of the erect trees and the parallel *Stigmaria* sections cannot be presented without much more research, but a brief and tentative model is as follows:

Plants were torn up by erosion and transgressing seas. As the stumps floated in the water they became saturated and slowly swung into an upright position. Clusters of horsetails washed out into the sea and floated vertically until they became saturated and sank. Individual stems tipped upright after a period of soaking. While plant flotsam was drifting, tubeworms and mussels fastened themselves to the floating mass, and fishes swam among the debris.

Eventually the stumps and *Calamites* sank down into the muds at the bottom or were stranded on a mud flat when the tide retreated. Continuing fallout of sediments from the water above or tidal movements and wave action caused sediments to accumulate around and in the stumps. This occurred repeatedly in a sinking basin, thus producing many superimposed strata containing erect stumps and other plant remains.

Following deposition, the whole area was warped, causing a tilting of up to 20° in some parts of the basin. Later still, glaciers scoured the tilted surface and left erratic boulders, glacial till, eskers, and other evidences. With the rising of the ocean when continental glaciers melted, the Bay of Fundy and the Atlantic Ocean cut back the cliffs and exposed the interesting fossils and coal seams of Nova Scotia.

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