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HISTOLOGICAL AND FRAMBOIDAL TEXTURES IN DIAGENETIC PYRITE FROM THE GONDWANA COAL BEDS, BRAZIL *

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ABSTRACT

Pyrite occurs in the Gondwana coal measures of the Tubarão Group, in the Paraná sedimentary basin, Southern Brazil.

Polished sections of pyrite from the Cambui area show framboidal and histological textures which are interpreted as evidence for the syngenetic origin of the pyrite, deposited during diagenesis. Subordinate marcasite, which occurs as secondary veins and concentric bands with colloform textu res, would indicate formation in a locally acid environment.

The anatomical structures observed in polished sections of pyrite show parts of a complex vascular system which suggests that current opinion concerning the affinities of the forms of the Southern Hemisphere with those of the Northern Hemisphere should be revised.

RESUMO

Nas camadas de carvão do Grupo Tubarão, depositadas na Bacia do Paraná, no sul do Brasil, ocorre pirita.

As piritas do carvão da região de Cambui, na Bacia do Rio do Peixe, estudadas em seção polida, apresentam texturas framboidal e histológicas que são interpretadas como evidências de piritas singenéticas, depositadas durante a diagênese. Marcassita subordinada, que ocorre como veios e em bandas concêntricas de textura coloforme, indicaria formação num meio localmente acidificado.

As estruturas anatômicas observadas nas seções polidas de pirita correspondem a partes de sistema vascular complexo de plantas fósseis, que sugerem a revisão da idéia corrente de possíveis afinidades de formas do Hemisfério Sul com as do Hemisfério Norte.

INTRODUCTION

The coal deposits of Southern Brazil are part of the Gondwanian sedimentary sequence of the Tubarão Group, which underlies more than 1,000,000 square kilometers of the Brazilian portion of the intracratonic Paraná Basin. Coal measures occur generally in the supraglacial sequence of the Guatá subgroup, except in Northern Paraná and in São Paulo, where interglacial coal occurs.

The Tubarão Group lies unconformably on Lower Devonian and pre-Devonian sedimentary and metamorphic rocks, and is overlain concordantly by the Passa Dois Group of Permian age. The Tubarão group is divi-

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ded into two subgroups; the lower, the Itararé sub-group, which is composed of sandstones, rhythmites, siltstones, shales and diamictites, and the upper, subgroup Guatá, a post--glacial sequence which contains sandstones, siltstones, shales, limestones, conglomerates and coal zones. The coal deposits occur in the states of São Paulo, Paraná, Santa Catarina and Rio Grande do Sul. These deposits have been interpreted as authochthonous and formed in a lacustrine environment or in a basin affected by marine conditions.

The thickness of individual coal beds varies from 40 centimeters to four meters. These beds contain numerous fine partings of argillaceous matter, pyrite lenses and pyrite nodules which make them unsatisfactory for metallurgic use.

Mega and micro-plants are commom fossils both in the glacial complex of the Itararé subgroup and in the Guatá subgroup. These fossils according to frond impressions and plant remains, belong to the Glossopteris Flora.

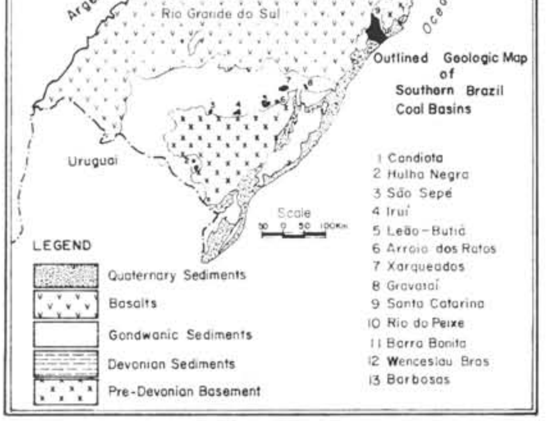


Fig. 1 – Outlined Geologic Map of Southern Brazil Coal Basins (According to Machado, 1970)

Only a few references describe the fossilized plant remains in the Brazilian Gondwana coal measures. Descriptions of the Flora have been based on frond impressions.

The present paper describes the histological and framboidal textures found in polished sections of pyrite which occurs in the coal beds, and discusses the significance of the plant fossils and the origin of framboidal pyrite.

Our botanical analysis is restricted to the occurrences of Cambui coal, in the state of Paraná. Among several occurrences, this one seems peculiar by the high abundance of xilic structures with a minor abundance of cuticles, foliar strands, fertile structures, etc. In contrast the foliar and fertile structures are to be found in the Santa Catarina coal measures in major abundance.

The discovery of vegetal structures of pyritized plant remains in the coal measures is not novel. There are important studies based on pyritic samples in the Northern Hemisphere, but these samples generally occur undamaged, that is to say they are fossilized plant specimens in the true sense of the word.

The study of pyrite of the coal beds in the Paraná Basin was planned originally to focus on mineralogy and textures. Our discovery of the anatomical features of plants in the polished sections was not antecipated but we decided to concentrate on these features because these types of fossils have not been discovered in Brazil.

TEXTURES OF PYRITE

Framboidal pyrite have been found in sedimentary rocks, in metallic sulfide deposits of syngenetic origin, in volcanic rocks, and more recently they have been synthesized as aggregates of pyrite crystals by Berner (1969) and by Sunagawa, Endo and Nakai (1971).

The origin of framboidal pyrites has been attributed to the replacement of organisms such as bacteria, to crystallization of iron sulfides, from an inorganic gel or as production of H_2S by bacterial action.

Fig. 2 – Veins of secondary pyrite.

From the results obtained in recent studies, it seems that the formation of framboidal pyrites is not dependent on the bacteria action or on the replacement of micro-fossils.

In the Gondwana coal beds studied pyrite occurs as distinct conformable beds and lenses ranging in thickness from a few millimeters to 5 cm. In the coal measures, nodules of pyrite can also be found.

Pyrite occurs as massive crystals, as anhedral to subhedral grains, and as pseudomorphs after plant remains. Secondary pyrite, which shows post-depositional textures, forms veins which cut both the coal and the primary pyrite beds (Text Fig. 2).

The pseudomorphs of pyrite after plant remains are good evidence of partial replacement during which parts of the cell structure were perfectly preserved. The histological textures of pseudomorphs of pyrite and marcasite resulted from the filling of open spaces in the replaced tissues, primarily of the vascular system, and of cuticles of the plants.

Crystals of anisotropic marcasite occur as secondary veins in pyrite and as concentric bands associated with pyrite in colloform textures (Text Figs. 3,4).

The framboidal pyrites occur as spherical aggregates, aproximately 20 to 30 microns in diameter. These spherical aggregates, consisting of rounded minute granules, are commonly confined to enclosing elliptic organic structures (Text Figs. 5,6,7,8,9 and 10).

DISCUSSION

The occurrences of conformable pyrite beds and lenses in the coal measures, as well as the histological textures observed in the polished sections of pyrite, constitute an important argument in favor of the syngenetic origin of the pyrite, which would have been

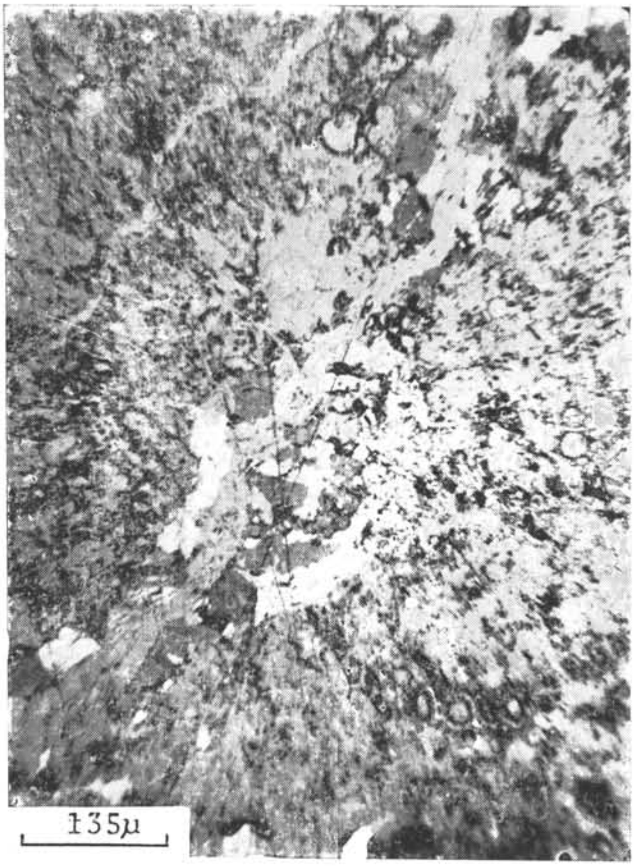


Fig. 3 – Crystals of anisotropic marcasite.

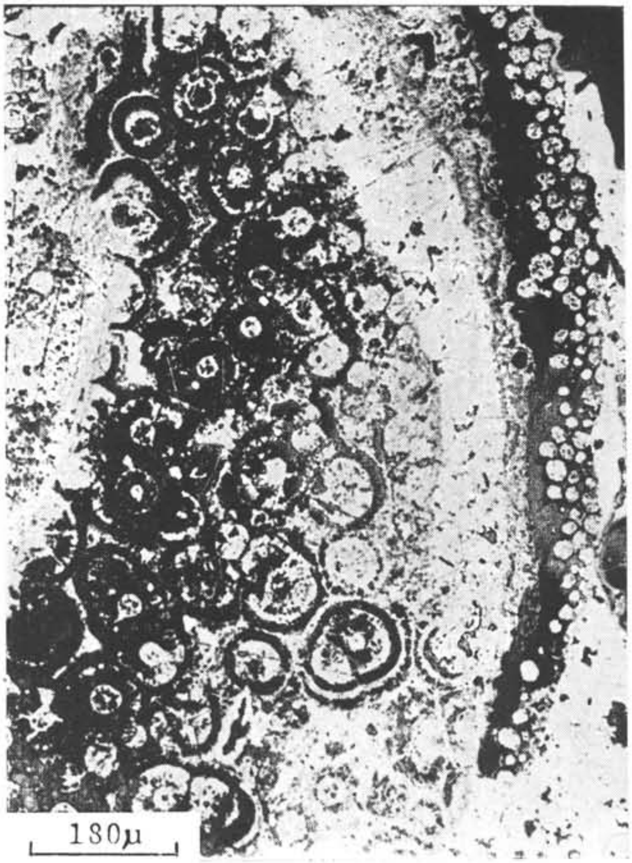


Fig. 4 – Marcasite and pyrite with colloform texture.

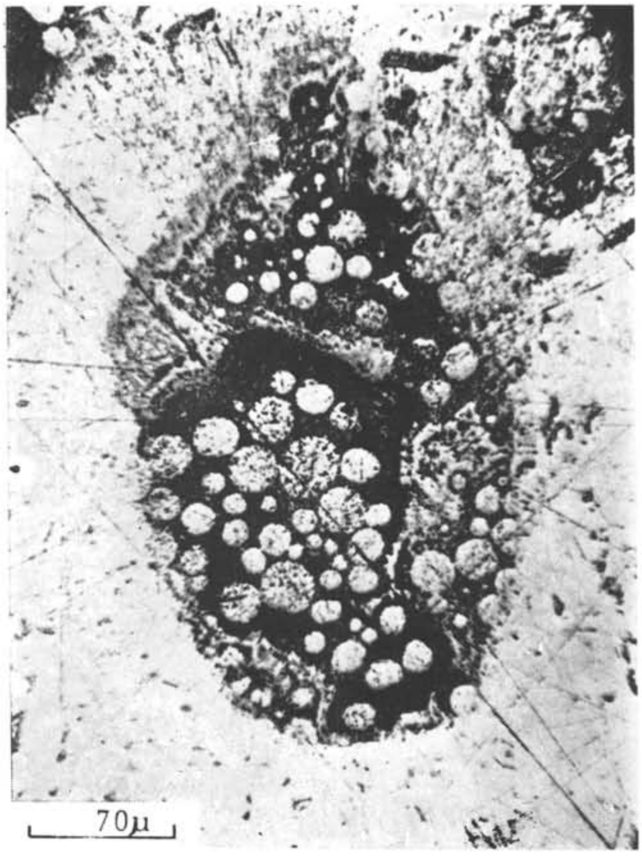


Fig. 5 – Framboidal pyrite confined in organic structure.

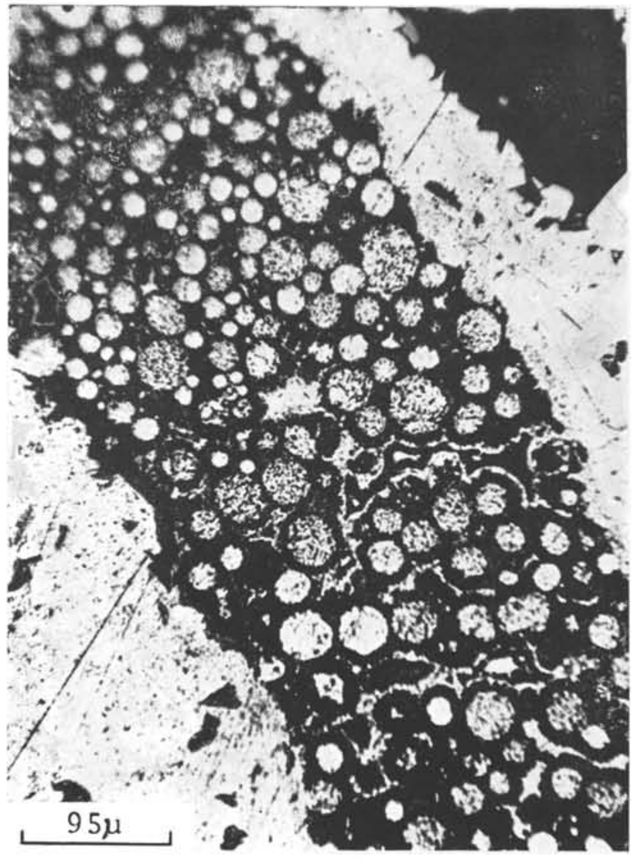


Fig. 6 – Framboidal pyrite and organic structure with marcasite.

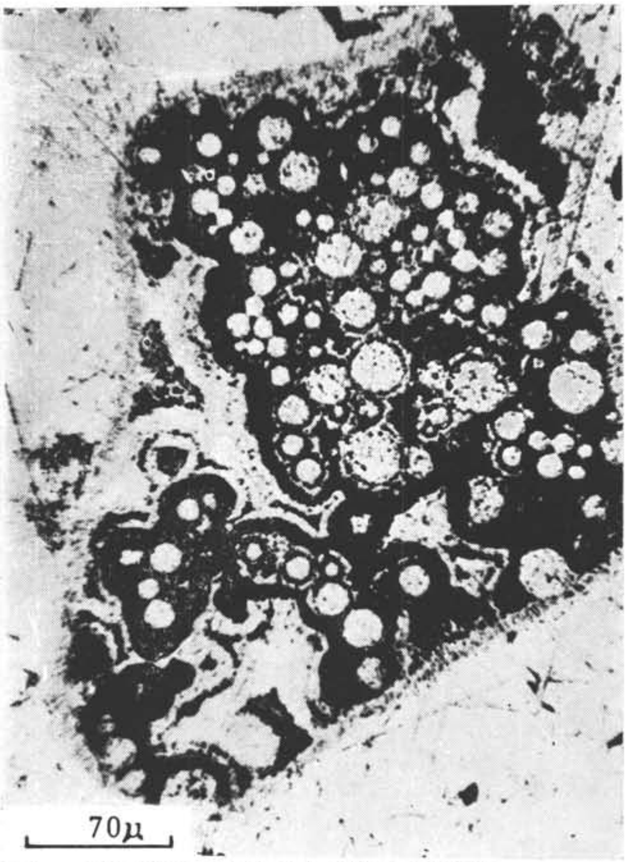


Fig. 7 – Framboidal pyrite and organic structure with marcasite.

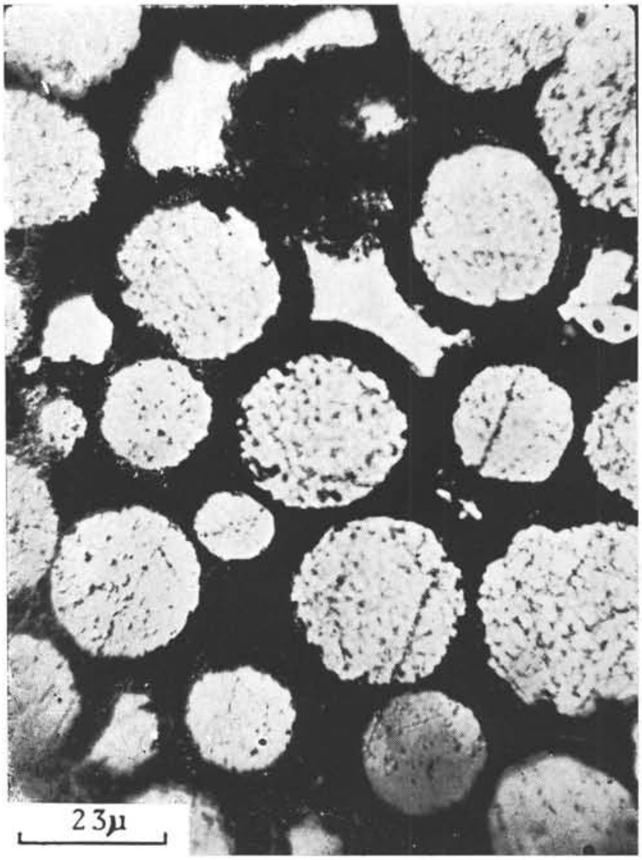


Fig. 8 – Framboidal pyrite.

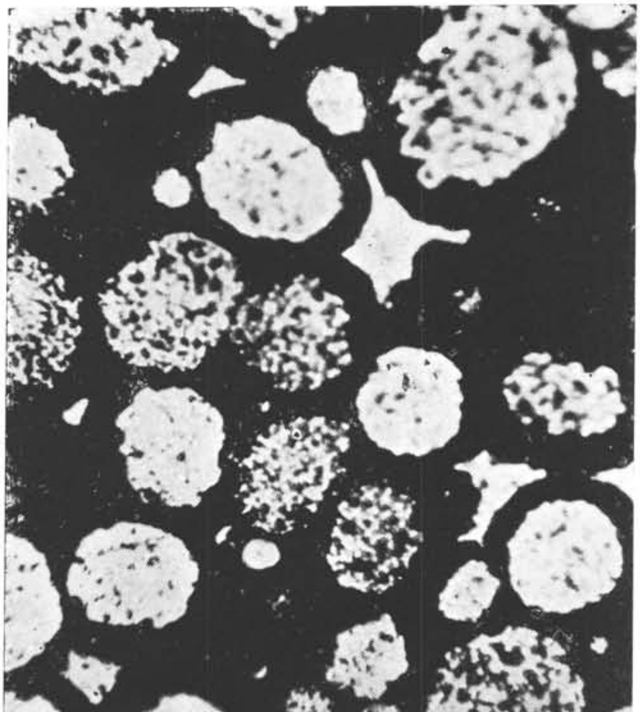


Fig. 9 – Framboidal pyrite.

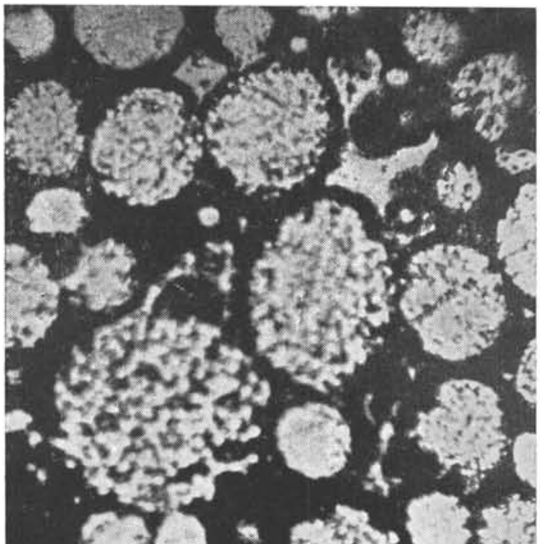


Fig. 10 – Framboidal pyrite.

deposited during diagenesis.

The coal could be interpreted as having been generated in an environment where conditions favored the reduction of sulphates by anaerobic bacteria. H_2S formed as a result of this process reacted with iron supplied from sediments overlying the coal beds, to precipitate both pyrite and marcasite.

Under laboratory conditions marcasite forms from acid solutions, whereas pyrite requires neutral or slightly alkaline solutions (Allen, Crenshaw and Johnston, 1912; Twenhofel, 1932). According to Edwards and Baker (1951), the form of ferrous sulfide found in supergene deposits thus may be used as an indicator of the acidity of the environment of deposition. On the other hand, it is known that the redox potential affects the formation of pyrite.

As mentioned by Mackowsky (1973), pyrite is most common in coal beds deposited under marine conditions. The high pyrite content of the coal from Cambui area suggests that the sedimentary basin could have been affected by marine conditions. The deposition of syngenetic pyrite of the Gondwana coal measures took place under anaerobic, alkaline, neutral or even slightly acid conditions. The presence of secondary veins of marcasite as well as of concentric bands of colloform marcasite would indicate a local acidification subsequent to deposition of pyrite.

DESCRIPTION OF FOSSIL PLANT STRUCTURES

The anatomical features preserved in some areas of the polished sections indicate an affinity with the "many steled" (sensu Delevoryas, 1955) vascular system in the Paleozoic pteridospermous. The features we shall describe are not suggestive of a very young part of a stem, although we cannot be certain of its width or height.

The transverse sections demonstrate a number of anatomical types, each representing a particular view, and all of which must be understood together. Ocasionally, different domains are continuous in the same section, in spite of evident crushing of the material. Certainly each one represents a part of a general transverse view of the stem. Even where the central axis is not well preserved, part of it is represented by small, ovoid, semi--elongated or ameboid steles, dispersed in a ground mass of parenchymatic crushed tissue (Pl. 1, Fig. 11).

Under high magnification they seem to be paralell, but there is no regular stelar arrangement either in a radial or tangential direction. Rather they are singly dispersed in a crushed parenchymatic matrix. This distinctive configuration is similar to that of Cladoxylales or other fossil forms distinguished by the polystelic arrangement of the vascular system - for example, the Pteropsida ferns. However, the dispersed steles sometimes present anastomosing arms (Pl. 1, Fig. 2), and encircling them there is no sort of thick-walled tissue, like sclerenclyma, as is so prominent among fern stems. In our specimens, this type of thick-walled tissue is visible only in the cortical layers, and even then they are regular in part or they are encircling the foliar traces.

In some of the well-preserved transverse domains it is possible to detect some suspected phloem elements and layers of parenchyma cells between two steles, as sketched on Text Fig. 11. According to the classical description of Medullosae with "many steled" stems, this zone has been designated by some authors as a "periderm". In the center of each stele there is a semi-destroyed area, which was probably occupied by secondary tracheids and by some parenchyma cells. Here and there, neighbouring the central part of the stele there are some protoxylem elements. This configuration has been classicaly designated as "endocentry" according to Schopf (1939-b, in Delevoryas 1955). Each stele in the "many steled" zone is extended tangentially and its mean tangential lenght is about 1.5 cm to 2.5 cm. A primary growth that subordinates the secondary growth is evident in them. A continuous and definite strand of crushed parenchymatic tissue encircles the zone of small steles, and this in turn is followed by a field of radial rows of secondary tracheids (Pl.3, Fig.7). In some sections we can see these strands introduced in places as a continuous ring in the secondary zone of growth (Pl. 3, Fig. 8). They

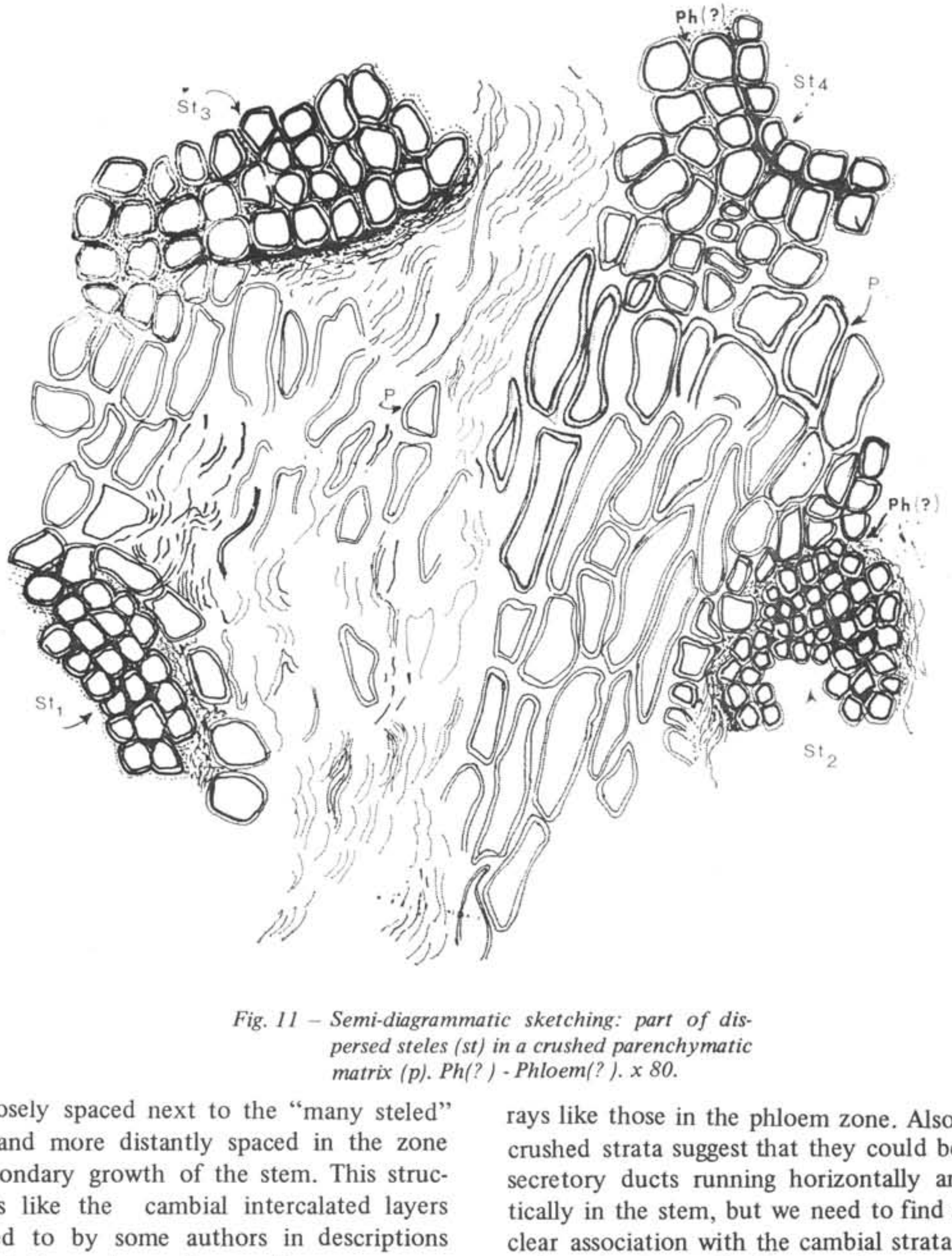


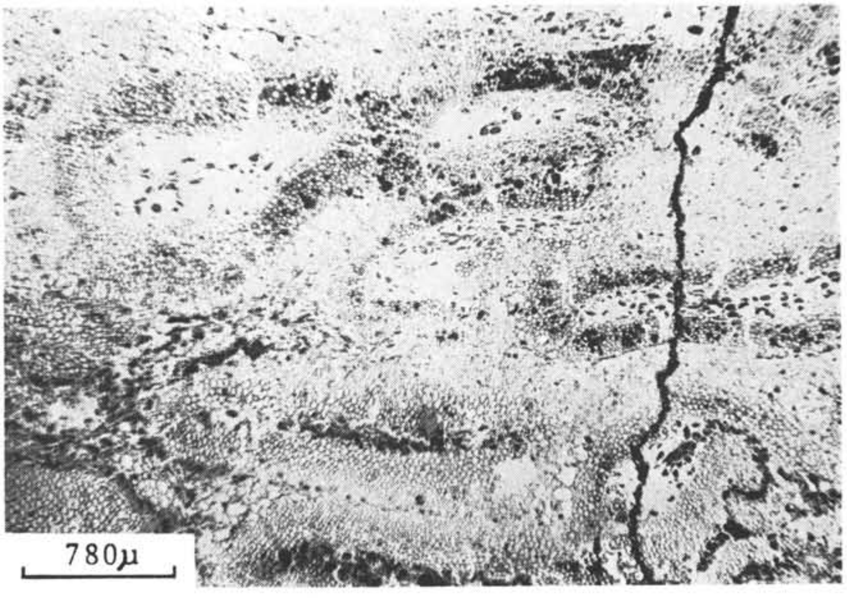
Fig. 11 – Semi-diagrammatic sketching: part of dispersed steles (st) in a crushed parenchymatic matrix (p). Ph(?) - Phloem(?). x 80.

are closely spaced next to the "many steled" zone and more distantly spaced in the zone of secondary growth of the stem. This structure is like the cambial intercalated layers referred to by some authors in descriptions of Medullosae stems; it resembles some cycadacean living stems as well. We cannot estimate the number of strands or cambial strata intercalated in the cylinder of secondary growth, because the entire diameter of a transverse section is not yet known. In Plate 2, Figs. 3-5 and Plate 3, Fig. 6 we see strata that in some fields suggest an origin by ray-cell proliferation as described by Delevoryas (1955; Pl. 13, Fig. 12). In a longitudinal section (Pl. 4, Fig. 10), some bundles of secondary tracheids are intercalated amongst these crushed strata which could be interpreted as larger rays like those in the phloem zone. Also, these crushed strata suggest that they could be some secretory ducts running horizontally and vertically in the stem, but we need to find a more clear association with the cambial strata observed in the longitudinal views. In some of the radial sections we can see tracheids with spiral thickining near the "many-steled" area (Pl.4, Figs. 11,12). The secondary tracheids are pitted, and some of them combine spiral thickening with areolated pits (Pl.5, Figs. 14,15,17). There are generally one to two rows of pits, but as many as 3 rows of them may occur mostly alternated with oblique to round lumina (Pl. 5, Fig. 16). In cross section the pitting is not well discernible although there is some indication of numerous simple pits.

PLATE 1

Fig. 1 – Transverse section. General view showing a "many steled" portion of a stem.

Fig. 2 – Detail of the Fig. 1 section. It seems that some of the small "steles" emit branches.



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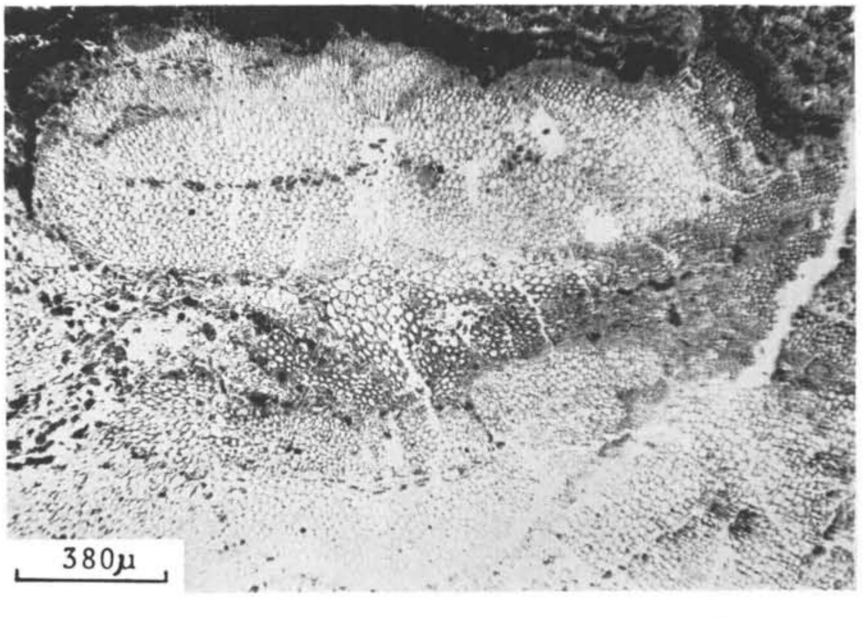

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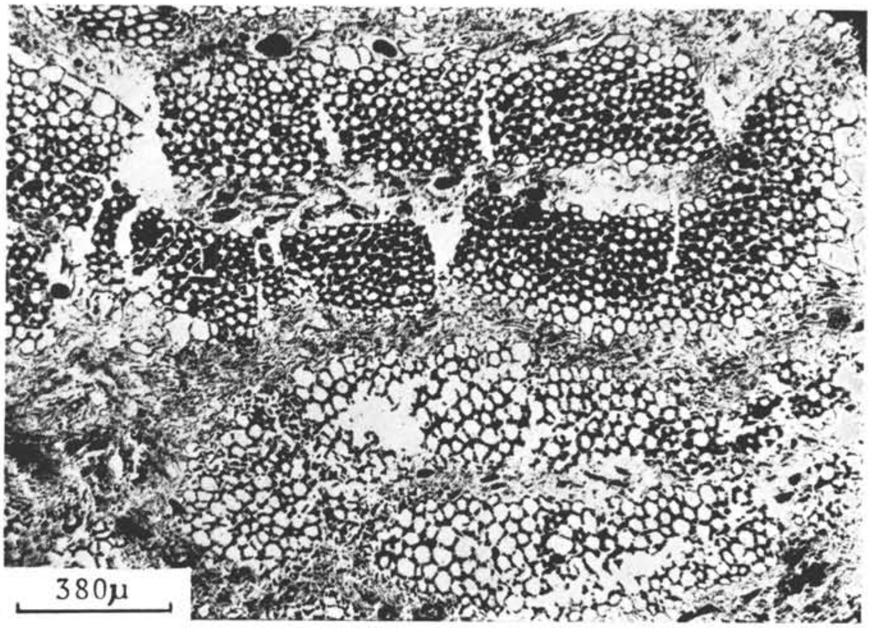
PLATE 2

Fig. 3 — Transverse section showing that between two steles there is parenchyma and some phloem.

Fig. 4 — Transverse section. Some emited leaf-traces.

Fig. 5 — Transverse section. Bands of crushed parenchyma evidently formed by proliferation of ray cells. See on the right side.



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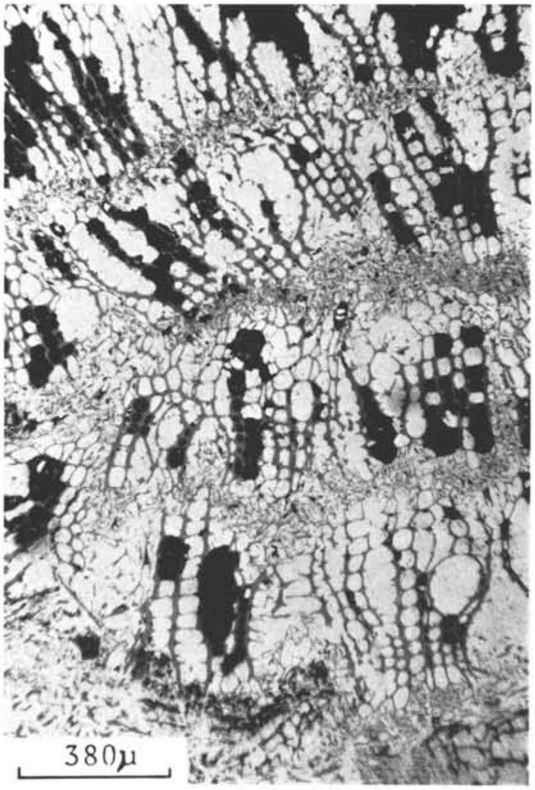

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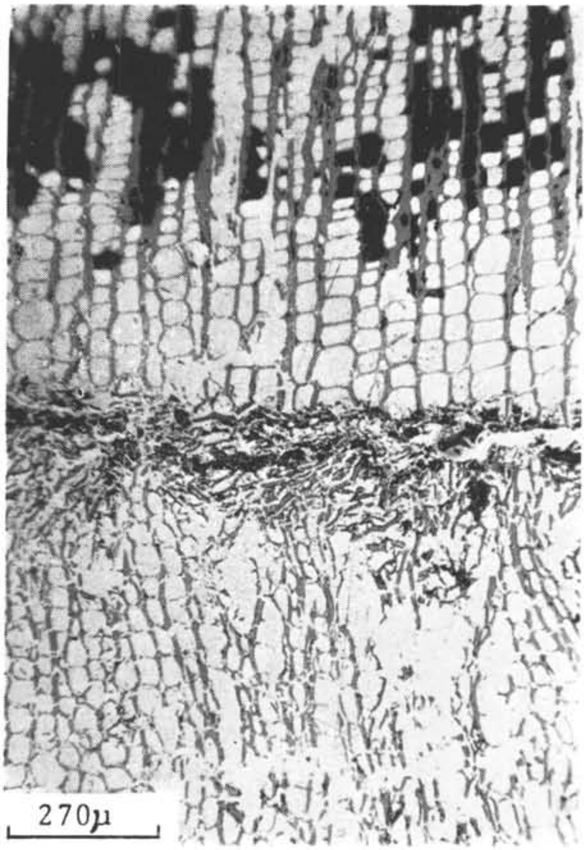
PLATE 3

Fig. 6 – Transverse section. Secondary xylem interrupted by bands of secondary crushed parenchyma. The space between these bands is wider to the periphery of the stem.

Fig. 7 – Transverse section. A region with continuous secondary xylem.

Fig. 8 – Narrowly spaced bands of thin walled cell in xylem.

Fig. 9 – Nests of sclerenchyma possibly in the cortical zone of the stem.



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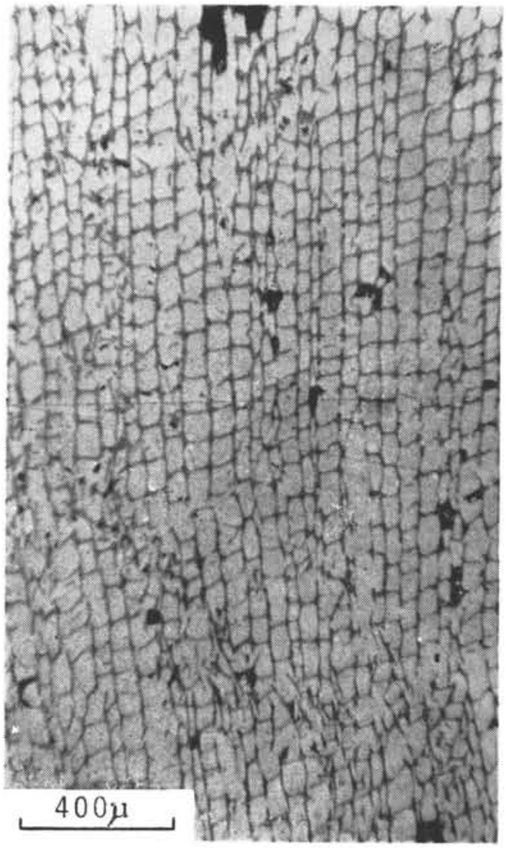

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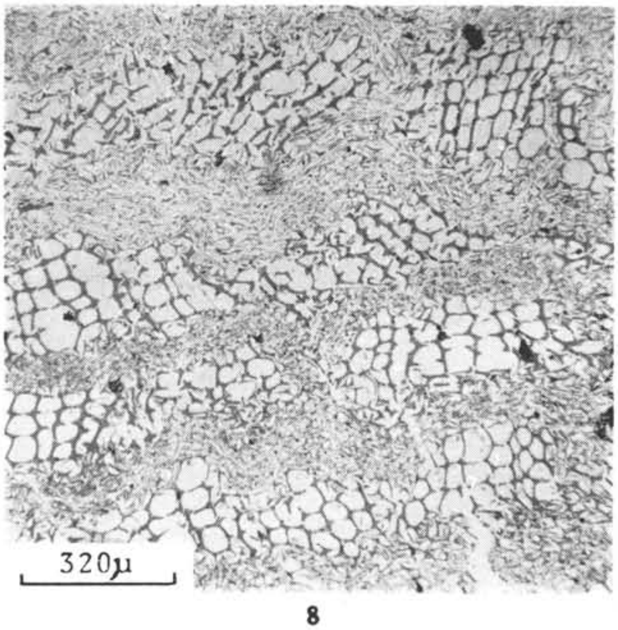

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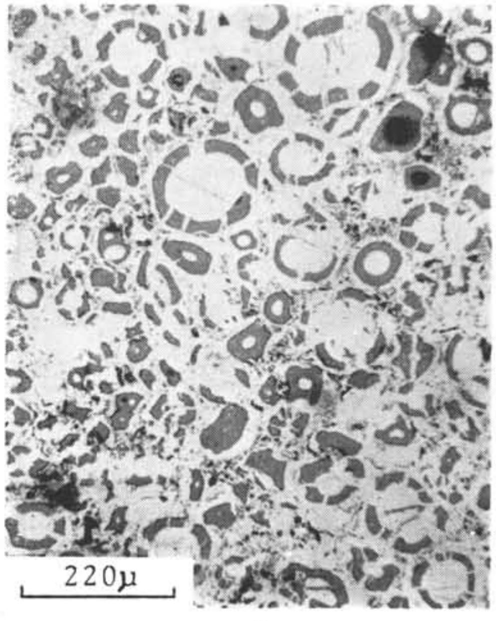

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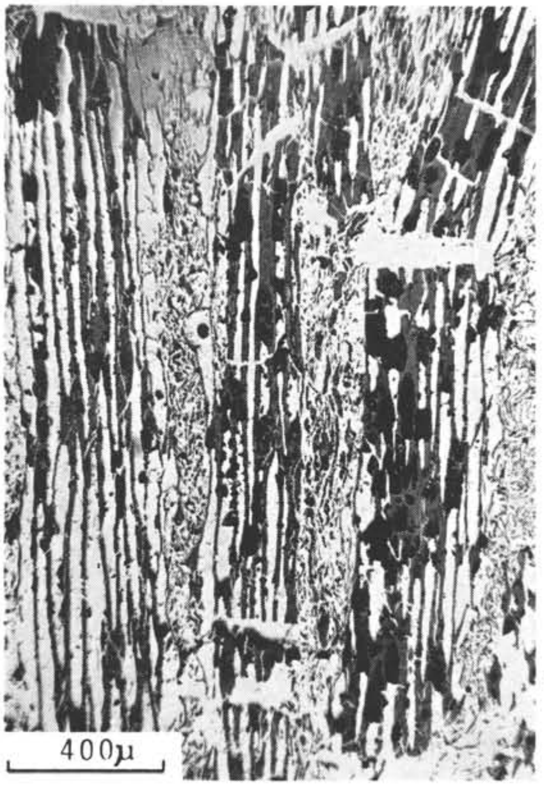
PLATE 4

Fig. 10 – Radial view of a specimen showing the same crushed zone of thin walled cells between tracheid bundles. On the left we can see some of those preserved parenchyma cells.

Fig. 11 – Spiral thickening in tracheids.

Fig. 12 – Spiral thickening in the cambial zone.

Fig. 13 – Tangential sections. Time xylem rays, 1-seriated, short in length.



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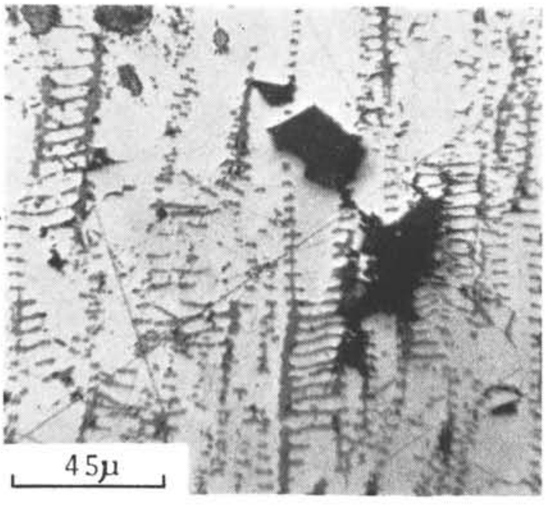

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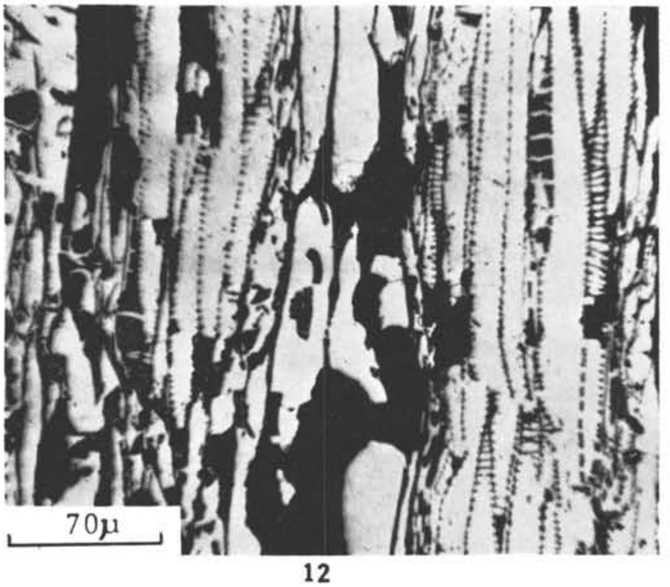

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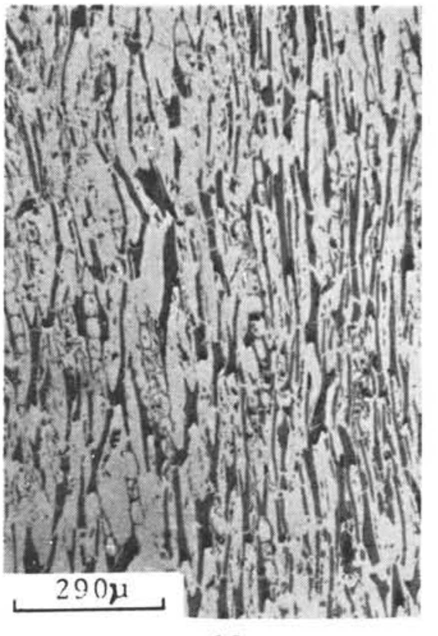

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PLATE 5

Fig. 14 – Radial section. Tracheid combining spiral thickening with some areolated pits.

Fig. 15 – The rows of alternate and areolated pits on the radial walls of tracheids. Cross section, apparently with numerous and small ovoid pits on it.

Fig. 16 – Tracheids with three rows of pits.

Fig. 17 – Tracheids with rows of pits. General view.

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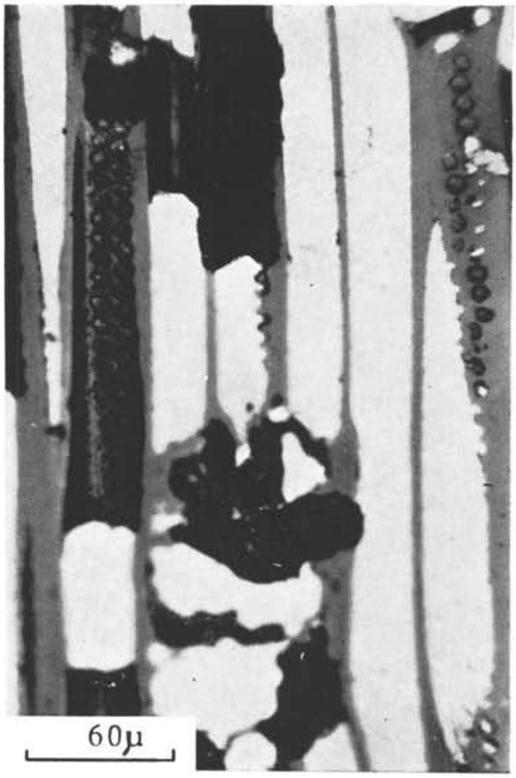

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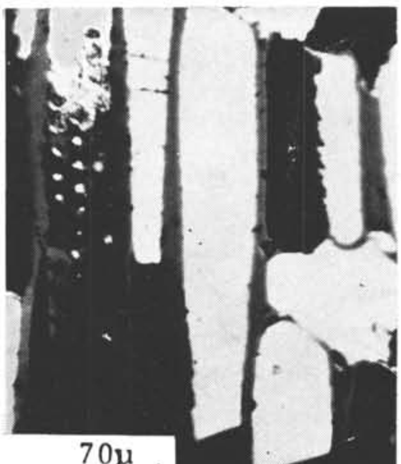

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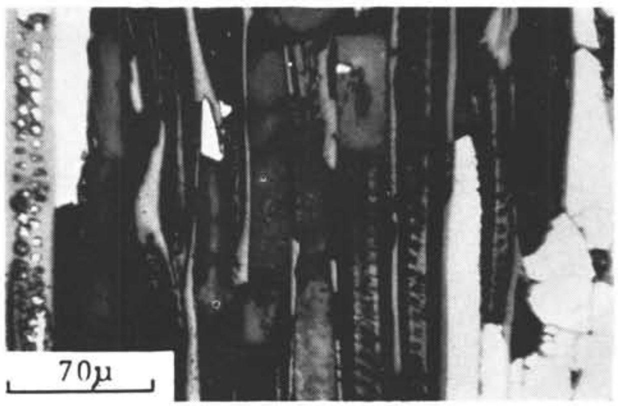

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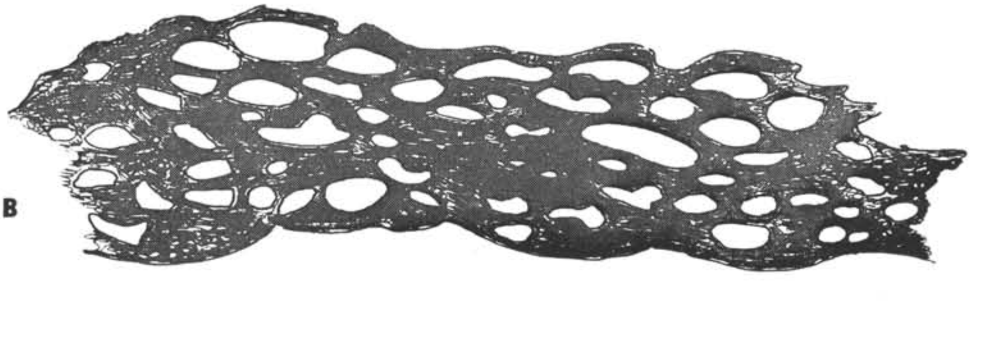
A

Fig. 12 – A- Semi - diagrammatic sections. Cortical damaged strata. Foliar traces present and a broken strand of possible thick-walled cells around the traces as well as a semi--continuous strand next to external periderm. x 50. B-Detail of the thick walled cells. x 160.

B



The rays (Pl.4, Fig. 13) are not well preserved in the sections. They are mostly l-seriated, and because their height is not known, we are not able to classify them according to the system of Andrews (1940).

One section presents secondary xylem growth like those described above associated with foliar traces.

As we see in the Text Fig. 12 (A, B) and Plate 2, Fig. 4, we are probably dealing here with a more external periderm. Related to it and to the traces is a ruptured strand of about 3 to 4 rows of cells, in which the walls were not preserved. The shape of these cells is variable like those found in the cortex of many stems, such as colenchyma. A dark homogeneous material fills the interstitial spaces among these cells, currently assuming the contour of their destroyed walls. The folliar traces present secondary growth, and in some of the well-preserved examples there are related parenchyma strata (Text Fig. 13). This suggests an origin of secondary tracheids by parenchyma proliferation. All the foliar traces are encircled by the mentioned strand supposed to be composed of thick-walled cells. In some of the fields of view groups of thick-walled cells occur separately. These cells can be interpreted as nests of sclerenchyma possibly in the cortical zone of the stems (Pl. 3, Fig. 9).

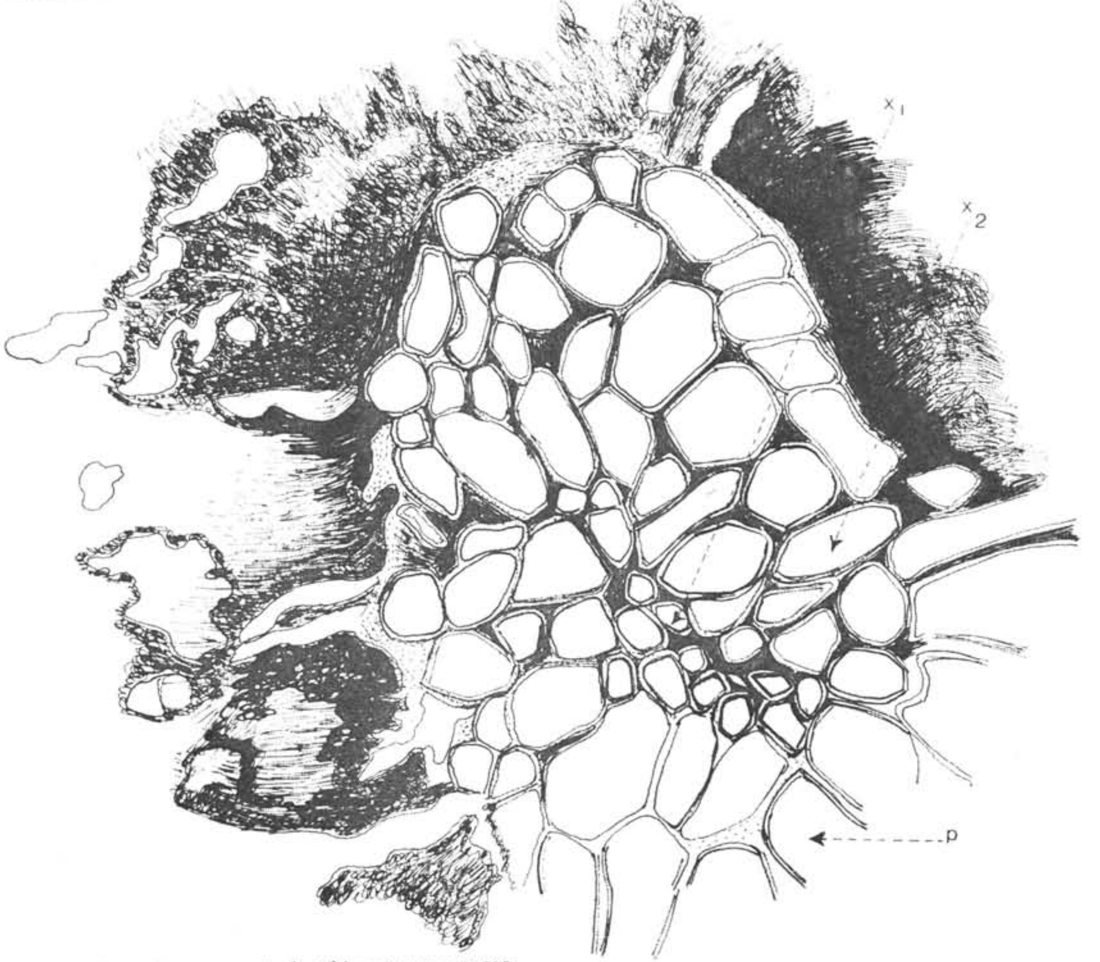


Fig. 13 – Semi-diagrammatic sketching: transverse sections of leaf trace. Secondary growth (x2) evident as well as primary vascular elements (x1). Proliferation of parenchyma (p) originated new secondary vascular elements. x 400.

DISCUSSION

Evidently we are dealing with some peculiar fossil plant remains that seem not to be closely related to any of the known configuration among ferns, except to the Northern Hemisphere group of Cladoxylales. As already mentioned, this last group is characterized by a regular and radial arrangement of steles and by the absence of successive zones of secondary growth intercalated amongst layers of cambium (or phloem and cambium). Among some fossil and living Cycads (Dioon edule) some features like those described may be found but they differ in general aspect as well as in the structure of the central zone of small steles. Only some stems like those of Medullosae from the Northern Hemisphere present such order of aspects in their anatomical configuration, and evident affinity with the fossil plant described here.

In several polished sections, different fields of view were observed in which continuity and organic connection of the plant tissues could be admitted. It is also admissible to think of these as crushed parts of different fossil plants occurring in the same sample of pyrite, even though the continuous aspect between the different plant structures strongly suggests that these forms could be compared with a group of pteridospermous plants.

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