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Pennsylvanian conifers from interglacial taphoflora of Monte Mor, Itararé Group, State of São Paulo, Brazil: the earliest of the Paraná Basin

Coníferas pensilvanianas da tafoflora interglacial de Monte Mor, Grupo Itararé, São Paulo, Brasil: as mais antigas da Bacia do Paraná

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Abstract

The pre-glossopterid macroflora from the Volpe Ranch, in Monte Mor (State of São Paulo), was deposited during an interglacial context of the Itararé Group. It is characterized by the *Paranocladus-Ginkgophyllum-Brasilodendron* Association and is included in the middle-basal part of the Itararé Group outcrop, in the NE of the Paraná Basin. It is similar to the Argentine macrofloristic association *Krauselcladus-Asterotheca* Phytozone (ex-Interval Zone) and its palynofloristic contents belong to the *Crucisaccites monoletus* Palynozone (Kasimovian to Gzhelian). The conifers in this assemblage are represented by macro and microfossils and record the first level of occurrence of conifers in the basin. They are documented by leafy branches impressions and compressions of *Paranocladus dusenii* Florin and *Buriadia heterophylla* (Feistmantel) Seward and Sahni *emend.* Singh, and platyspermic seeds of the genus *Paranospermum.* Cuticular studies allowed to correlate the presence of *Paranocladus dusenii* with the platyspermic seeds *Paranospermum cambuiense* Ricardi-Branco and to identify a new species of *Paranospermum* as well. Previous palynological studies in this level led to the recognition of some pollen grains affinis to the gymnosperms (conifers, ginkgoaleans and pteridospermales) comprising monosaccate and bisaccate forms allocated to the genera *Cannanoropollis, Plicatipollenites, Potonieisporites* and *Caheniasaccites* indicating certain diversity of conifers as early as in Pennsylvanian. The association of conifers and *Ginkgophyllum* represents a mesoxerophytic tree community. The abundance of their fragmented material in the taphofloral assemblage suggests allochthonous origin transported toward a deltaic plain which were associated to a parautochthonous origin material. Their fossiliferous sandy matrix overlying the coal also suggests a higher energy agent of transport.

Keywords: Early conifers; *Paranocladus-Ginkgophyllum-Brasilodendron* Association; Paraná Basin.

Resumo

A macroflora pré-glossopterídea do sítio Volpe, em Monte Mor (Estado de São Paulo), depositou-se, durante um interglacial do Grupo Itararé. Essa ocorrência caracteriza a Associação *Paranocladus-Ginkgophyllum-Brasilodendron* da porção médio-basal do Grupo Itararé aflorante no NE da bacia do Paraná. Corresponde à associação macroflorística argentina Fitozona *Krauselcladus-Asterotheca* (ex-Zona Intervalo) e seu conteúdo palinoflorístico pertence à Palinozona *Crucisaccites monoletus* (Kasimoviano a Gzheliano). As coníferas dessa associação estão representadas por macro e microfósseis e registram o nível mais inferior de ocorrência do grupo na bacia. São impressões e compressões de ramos folhosos de *Paranocladus dusenii* Florin e *Buriadia heterophylla* (Feistmantel) Seward and Sahni *emend.* Singh e de sementes platispérmicas do gênero *Paranospermum*. Estudos cuticulares possibilitaram relacionar a presença de *Paranocladus dusenii* com as sementes

platispérmicas *Paranospermum cambuiense* Ricardi-Branco e detectar uma nova espécie de *Paranospermum.* Estudos palinológicos anteriores, neste nível, permitiram identificar a presença de grãos de pólen afins às gimnospermas (coniferales, ginkgoales e pteridospermales) compreendendo formas monossacadas e bissacadas dos gêneros: *Cannanoropolis, Plicatipollenites, Potonieisporites e Caheniasaccites,* indicando já certa diversidade do grupo no Pensilvaniano. A associação das coníferas e *Ginkgophyllum* representaria uma comunidade arbórea mesoxerofítica. A abundância de seu material fragmentado, na assembleia fitofossilífera, sugere aloctonia com transporte em direção a uma planície deltaica onde associa-se a material parautoctone. A matriz fossilífera arenosa, sobreposta ao carvão, também evidencia um agente transportador de maior energia.

Palavras-chave: Coníferas primitivas; Associação *Paranocladus-Ginkgophyllum-Brasilodendron*; Bacia do Paraná.

INTRODUCTION

Evidences of interglacial phases during the late Paleozoic *icehouse* (the longest ice age of the Phanerozoic, Montagnez, 2013) are registered in various Gondwana sedimentary basins when glaciers retreated, leading to other sedimentary environments (fluvial, deltaic, lacustrine and marine).

These interglacial events allowed the establishment of characteristic landscapes, where distinct floristic associations developed under ecological influences and/or vertically differentiated by plant evolution factors. There are some diachronic evidences of these events in Gondwana sediments of Brazil, Argentina, Africa, India, Antarctica and Australia (Mukhopadhyay et al., 2010).

In Paraná Basin (Brazil), the Itararé Group represents glacial and interglacial events which occurred during the late Paleozoic.

The pre-glossopterid paleoflora of Monte Mor thrived in one of those Late Paleozoic interglacial phases whose deposits associated with thin beds of coal lie in the middle strata of the Itararé Group, corresponding to the lower part of the Gondwana I Supersequence in the Paraná Basin (Milani, 1997; Milani et al., 2007).

The taphoflora of Monte Mor is rich in remains of lycophytes and conifers and is considered the type-locality for the third level of the interglacial macrofloral succession in the Pennsylvanian-Cisuralian strata of the NE margin of the Paraná Basin (State of São Paulo). This level was designated as "Association PGB - *Paranocladus-Ginkgophyllum-Brasilodendron*" by Bernardes-de-Oliveira et al. (2005, 2016).

This level records the appearance of the conifers in the Paraná Basin (represented by the common occurrence of *Paranocladus dusenii*, some *Paranospermum* and rare occurrence of *Buriadia*), associated with lycophytes (*Brasilodendron, Bumbudendron*), leaves of *Ginkgophyllum* and *Noeggerathiopsis*, many species of seeds like *Samaropsis* and *Cordaicarpus* and few *Notorhacopteris* Archangelsky 1983 emend. Azcuy, Carrizo, Iannuzzi, 2011 (as recorded by Mune and Bernardes de Oliveira, 2007; Jha et al., 2012).

In the present work, based on cuticular observations, it was possible to correlate the presence of *Paranocladus dusenii* Florin 1940, with platyspermic seeds of the type *Paranospermum cambuiense* Ricardi-Branco 1997, whose cuticular details are similar to those shown in Figure 12A and B. The abundance of seeds also enabled the identification of a new species *Paranospermum millanianum* sp. nov. (Figure 12, F, G, H, L) suggesting the presence of another species of the genus *Paranocladus* yet unknown.

Palynological analysis of some Monte Mor samples also revealed the presence of the species *Scheuringipollenites maximus* and *Crucisaccites monoletus* raising it to a younger stratigraphic level, Kasimovian to Gzhelian (Mune and Bernardes-de-Oliveira, 2007, 2009; Jha et al., 2012).

The earliest records of conifers in South America

The earliest records related to conifers are leafy branches fusinized, exhibiting paracytic stomata arranged in rows. They were found in Yorkshire (UK) and dated as Westphalian B or Moscovian. Such fossils identified as *Swillingtonia denticulata* were not the dominant component of the vegetation during that time. They could be plants of upland features and drier environments (Scott and Chaloner, 1983).

In South America, the first known records of conifer macrofossils (*Buriadia figueirensis* Ricardi-Branco, *Buriadia* sp., *Paranocladus dusenii* Florin, *Paranocladus*? *fallax* Floirn, *Paranospermum cambuiense* Ricardi-Branco) are from the basal portion of Rio Bonito Formation (Paraná Basin in Brazil), in the localities of Teixeira Soares (Florin, 1940; Rigby, 1972), Municipality of Cambuí- Patrimonio/ Figueira (Read, 1941; Rigby, 1972; Ricardi-Branco, 1997), Rio Carvãozinho, Barra Bonita (Florin, 1940; Rigby, 1972) (all localities in State of Paraná). But, the oldest record of conifers in Paraná Basin is from the taphoflora of Monte Mor (State of São Paulo, Itararé Group) where *Paranocladus*? has been recorded by Rigby (1972) and described and illustrated by Millan (1972, 1974) as *Paranocladus* (?) *fallax* Florin, who also recorded the occurrence of *Buriadia heterophylla* (Feistmantel) Seward and Sahni emend. Pant and Nautiyal. This taphoflora has been dated as middle Pennsylvanian (Moscovian), based on palynomorphs (Souza et al., 1997; Souza, 2000).

In Argentina, the first conifers appeared a little later, in the late Pennsylvanian (latest Carboniferous = Gzhelian) in the paleofloristic associations of Carrizo and Azcuy (2006, 2015), Phytozone *Krauselcladus-Asterotheca* of Paganzo Basin: Libertad (upper portion), Los Sauces (lower portion), Tupe (upper portion) formations; in the Rio Blanco Sub-basin:

Cerro Agua Negra (uppermost portion) and Rio del Peñon (uppermost portion) formations and Calingasta-Uspallata Sub-basin: Santa Maxima Formation and San Rafael basin: El Imperial Formation (upper). In this phytozone occur *Krauselcladus argentinus* Archangelsky 1979, *Paranocladus? fallax* Florin and *Paranocladus*? sp. (Azcuy et al., 2007).

Archangelsky and Cúneo (1987) established the Family Feruglioclad aceae with the species *Feruglioclad us riojanus*, which includes branches of various orders bearing small linear leaves and cones ovulated in terminal position, in the lower Permian (Cisuralian) of Argentina (Phytozone *Gangamopteris)*, occurring in the Paganzo Basin (La Colina, Bajo de Veliz, Arroyo Totoral, Tasa Cuna and de la Cuesta formations) and San Rafael Basin (El Imperial Formation).

In the Tepuel-Genoa Basin (Rio Genoa, Mojon de Hierro formations) conifers such as *Feruglioclad us patagonicus, Paranocladus*? *fallax* and *Ugarteclad us genoensis* occur with ovulated cones in Superphytozone *Feruglioclad us* of Archangelsky and Cúneo (1984) which is dated lower Permian (Cisuralian). Cúneo (1985) established the genus *Genoites* and the species *G.patagonica* to conifers that could be the ancestor of the Family Feruglioclad aceae, since it had the features such as branches in helical arrangement, forked leaves and orthotropous stalked ovules on the axils of some leaves. It occurs in the Rio Genoa Formation.

GEOGRAPHIC, LITHOSTRATIGRAPHIC AND FACIOLOGIC ASPECTS OF THE FOSSIL FLORA OCCURRENCE AREA

The Itararé Group outcrop at the Volpe Ranch is located in the NNE area of the Monte Mor Municipality (State of São Paulo), located at the latitude of 22º 56' 48" S and the longitude of 47º 18' 57" W, at the left margin of a stream which rises in this locality (Figure 1).

Souza Filho (1986) prepared a lithostratigraphic, structural and faciologic geological map of the Itararé Group in the Campinas region which covers the Municipality of Monte Mor (State of São Paulo).

According to him, the Monte Mor area with its carbonaceous levels would be included in his proposed Unit IV (consisting of several sandstone bodies occurring in different stratigraphic levels of the proposed Unit III) (Figure 2).

The dominant lithology in the Unit IV are conglomeratic sandstones and medium and fine sandstones, associated with conglomeratic bodies, mudstones and coal. The identified lithofacies consisted of tabular and trough cross-stratification sandstones, very fine-grained sandstones, ripple marked sandstones, massive conglomerates, mudstones with coal and purplish mudstones.

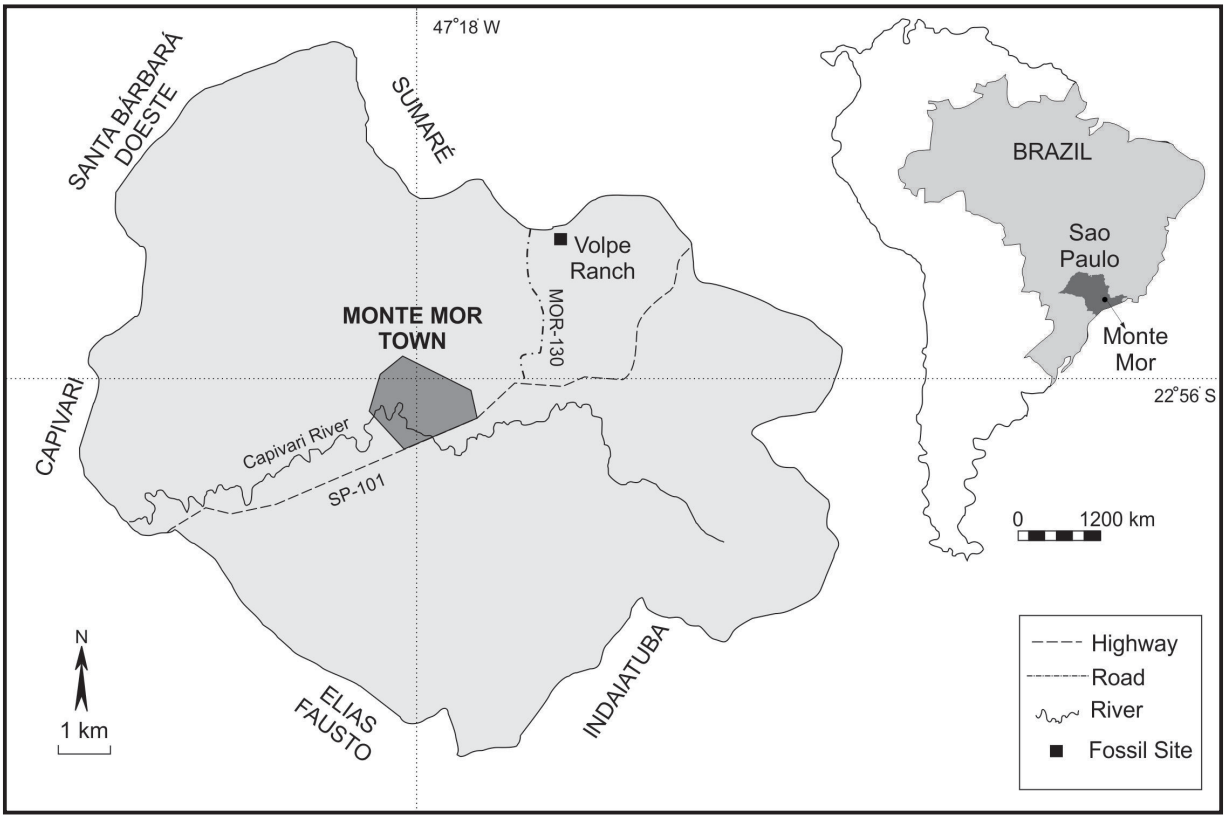

Figure 1. Monte Mor Municipality map showing the location of the Volpe Ranch (previously named Mina Ranch). Modified from Mune and Bernardes-de-Oliveira (2007).

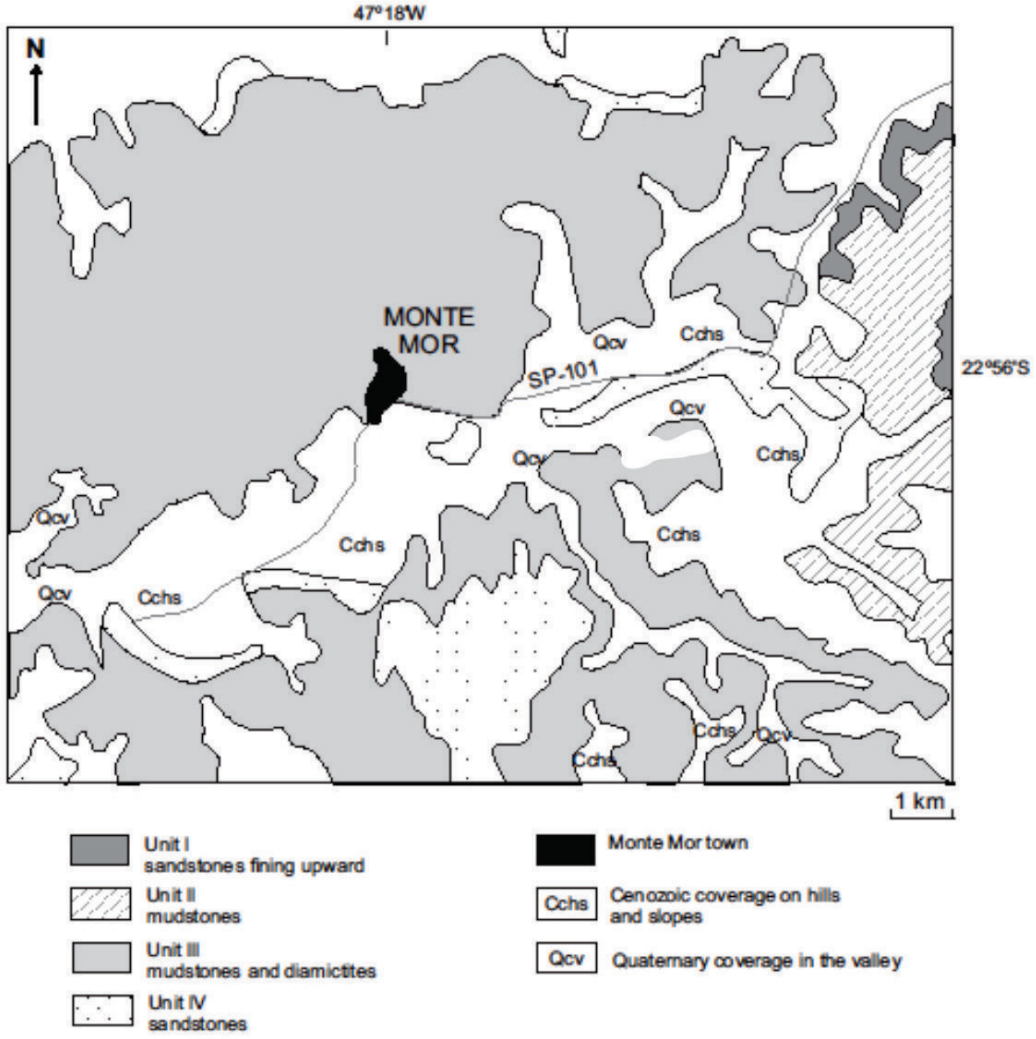

Figure 2. The Lithological/ Faciological Units of Souza Filho (1986).

MATERIAL AND METHODS

Fossils were collected from the carbonaceous shale bed lying below thin coal layer and from a brown laminated mudstone covering this coal layer. The plant fossil levels are stratigraphically positioned in the basal portion of a sequence of shales, coals, siltstones and sandstones overlapped by diamictite at the left margin of a stream in the Volpe Ranch (Figure 3).

The material studied is deposited in the Scientific Collection of the Sedimentary and Environmental Geology Department of the Geosciences Institute of the University of São Paulo under the code numbers GP/3E and in the scientific collection of National Museum of Rio de Janeiro (UFRJ), under code numbers DGP MN.

The macroscopic material was studied using Carl Zeiss binocular stereomicroscope with lucida camera, model Stemi SV 6, with photographic camera Canon EOS – 300 adapted to the stereomicroscope.

The palynological slides were examined using binocular optical microscope Carl Zeiss Axiophot II and the photos were taken with Digital Sony Cyber Shot DSC-S75 camera adapted to the optical microscope. These slides are also deposited in the Scientific Collection of the Sedimentary and Environmental Geology Department of the Geosciences Institute of the University of São Paulo under the numbers Slide GP/3E.

The cuticular features were obtained using the Chemical Method of Preparation after Fittipaldi and Rösler (1978) for Paleozoic plants and subsequently measured by the Software Axiovision Zeiss 3.0.

The block maceration method was performed by immersing the samples in a Schulze solution, in varying concentrations (20%, 50% and 100%) for some time. Nitric acid (100%) was used for maceration in thicker and darker samples.

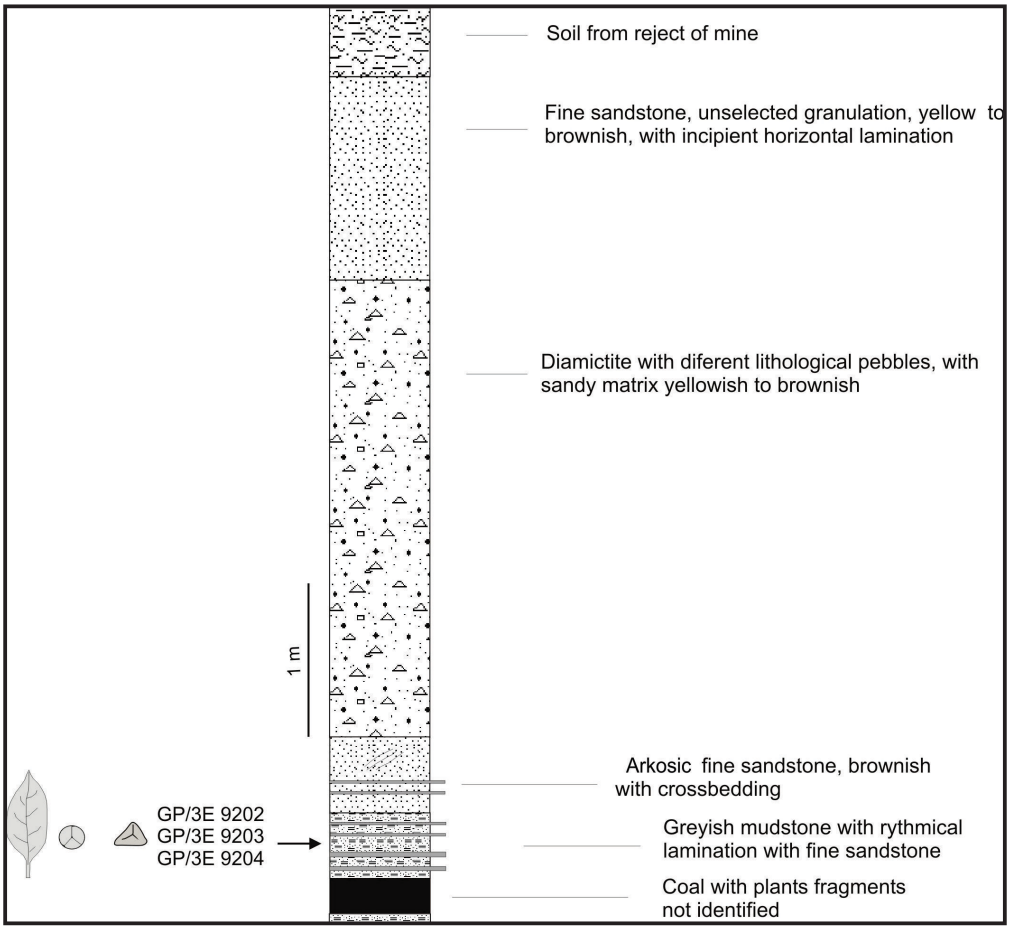

Figure 3. Columnar section of the outcrop showing the fossil plant levels. Modified from Mune and Bernardes-de-Oliveira (2007).

After the detachment of the cuticles, KOH (10%) was used to remove organic remains still present followed by several washes with distilled water and, finally, dehydration with ethanol (20%). Some cuticles were immersed into an alcoholic solution of safranine in order to highlight better their cellular structures. Entellan was used as a mounting medium for the preparation of slides.

For the taxonomic classification of plant macrofossils the systematics proposed by Taylor et al. (2009) was followed. For the classification of seeds the scheme of Maithy (1965) and Millan (1974) modified by Bernardes-de-Oliveira et al. (2007) was followed, with additions suggested in this work. For palynomorphs, the classification adopted by Souza (2000) was followed.

PALEOBOTANY SYSTEMATICS

CONIFEROPHYTES
Order Voltziales

Coniferophytes appeared in the geologic record from the Pennsylvanian and reached their great diversity and wide geographic distribution in the Mesozoic. They comprise both extinct (Voltziales) and extant (Coniferales) orders. Sometimes they are considered of monophyletic origin, linked to Utrechtiaceae (Lebachiaceae) which, in turn, would originate from Cordaitales (Florin, 1951; Bowe et al., 2000), other times considered polyphyletic (Du et al., 2009).

The voltzialean conifers are characterized by orthotropic ramification with broad leaves, dwarf shoots which bear flattened, partially fused scales, scattered stomatal complexes and bisaccate pollen (Taylor et al., 2009). Rothwell et al. (2005) included the walchian conifers within the Voltziales despite possessing plagiotropic branching with needlelike leaves, dwarf shoots with radially arranged scales, stomata in bands, and pollen that is monosaccate (Looy, 2007).

Family Feruglіocladaceae
Genus *Paranocladus* Florin, 1940
Paranocladus dusenii Florin 1940
Figures 4 and 5; Figures 11A-D and F; Figures 12I-J.

Local Synonymy:
1958 - *Paranocladus* sp. Barbosa, p. 206.
1972 - *Paranocladus* ? Rigby, p. 577.

1972 - *Paranocladus* ? *fallax* Florin. Millan, p. 89-90, Plate X, figures. 3-5.
1974 - *Paranocladus* ? *fallax* Florin. Millan, p. 128-129, Plate I, figures. 3-5.
1975 - *Paranocladus* ? *fallax* Florin. Millan, p. 3.
1977- *Paranocladus* ? *fallax* Florin. Millan, p. 87.
1987 - *Paranocladus* ? *fallax* Florin. Millan, p. 836.

Locality: Volpe Ranch (previously named Mina Ranch), Municipality of Monte Mor (State of São Paulo).

Stratigraphic and geographical distributions: *Brazil,* Paraná Basin – Itararé Group (Pennsylvanian): Volpe Ranch (previously named Mina Ranch), Monte Mor (State of São Paulo) (in this research); Rio Bonito Formation (Triunfo Member, Cisuralian): Teixeira Soares, Figueira (Coal Mine Inclined Plane 115, Armando Simões, Areia Branca, Campos da Companhia Carbonífera Cambuí, Rio Carvãozinho), Ibaití (Barra Bonita) (State of Paraná) (Fittipaldi and Rösler, 1978; Ricardi-Branco, 1997).

Numbers of studied specimens: DGP MN 846 Pb a, b; DGP MN 1094 Pb; DGP MN 1095 Pb a, b.; GP/3E 9109; GP/3E 9135; GP/3E 9141, GP/3E 9142; GP/3E 9143; GP/3E 9144; GP/3E 9145; GP/3E 9148; GP/3E 9149; GP/3E 9150; GP/3E 9152 ; Slides with cuticles - GP/3E- 9179 e GP/3E 9180.

Description: Impressions and compressions of leafy branches of last orders, decussate arrangement on a monopodial axis. Principal axis with length up to 127 mm and diameter of 4 to 5.5 mm (including adpressed leaves) in the basal portion and diameter of 6.6 to 8 mm in distal portion. The lateral branches have the diameter of 3.5 mm in proximal portion and 7.5 mm in distal portion. The lower branches measures are 45-55 mm long and upper branches is 35-43 mm long. The emergence angle of the branches is around 45º. The leaves present heterophylly and coriaceous aspect, helical disposition along the axis and more adpressed to stem in the basal region, away from it in the apical portion, where they become larger and falcate. These leaves are 4 mm in length and 1 mm in maximum width. Regarding the morphology, they are triangular, lanceolate, broad base and present acute apex, decurrently to the stem and imbricate each other. Venation is not clear, showing a fine keel in the area of midrib.

Some epidermal features of cuticle: In spite of getting very small cuticle fragments, it was possible to detect some important diagnostic characters for the generic and specific identification of the cuticle. This material presents cuticles pertained to adaxial and abaxial surfaces, however, it was not possible to separate them due to the small nature of these fragments.

Polymorphic cells are observed, most of them being elongated polygonally, measure 50-69 µm in length and 12-14 µm in width. Short tetragonal cells are also observed, measuring 32-39 µm in length and 10-14 µm in width with anticlinal wall thickness around 0.68-1.70 µm. There are pits on the anticlinal walls (Figures 4 and 11B).

Papillae are detected on cell surface. It was possible to observe two or three stomata on the slide GP/3E 9179 (Figures 5 and 11D).

They are sunken stomata with monocyclic 6 to 7 papillate subsidiary cells surrounding the guard cells forming a star shaped aperture for the suprastomatal chamber. The occlusive slit is noted at the bottom of one of these stomatal apparatus. There is a suggestion of presence of a stomatal band; however, the small size of the cuticular fragment does not allow perceiving exactly the stomatal pattern distribution.

Discussion and comparison: The Monte Mor conifers were identified first by Millan (1972, 1974), as *Paranocladus*? *fallax* Florin 1940, considering the absence of cuticles, although he recognized a certain morphographic similarity with *P. dusenii* Florin 1940 (type species of *Paranocladus*, defined on epidermal structures).

Fittipaldi and Rösler (1978) identified some specimens from Rio Bonito Formation (Triunfo Member), locality of Cambuí (State of Paraná), as *P.*? *fallax*, based on morphographic aspects, describing their epidermal characteristics. These authors attributed the material studied to *P.*? *fallax*, based on a geographical origin close to that of the specimen of Florin (1940), designated *P.* ? *fallax* and cuticles with significant differences at specific and generic level from *P. dusenii* (such as presence of stomata only in abaxial surface of the cuticle, absence of papillae and hairs on both faces).

Ricardi-Branco (1997) identified *P. dusenii* in the material from the Triunfo Member (Rio Bonito Formation) Municipality of Figueira (State of Paraná), based on the morphographic and cuticular characters of vegetative and reproductive forms. Through morphographical comparisons, she allocated *P.*? *fallax* described by Millan (1972, 1974) in Monte Mor (State of São Paulo), and also that by Fittipaldi and Rösler (1978) in synonymy with *P. dusenii.*

Considering the descriptions, figures and epidermal aspects of *P.*? *fallax* studied by Fittipaldi and Rösler (1978) in the material from Cambuí (State of Paraná), they should be held separate from *P. dusenii*, based on the absence of hair and papillae in both the surfaces and the presence of stomata only on the lower surface of the cuticle, with straight and thin anticlinal cell walls. But the Monte Mor material is characterized by heterophilly and some morphographic aspects such as adpressed leaves on the proximal region of the branches and falcate and decurrent in the distal region which allows considering with the synonymy proposed by Ricardi-Branco (1997). This synonymy is now confirmed by epidermal characteristics such as polymorphic cells, four or six sided polyhedral shaped, with anticlinal walls slightly thickened and pitted, papillae and sunken stomata in both the leaf surfaces. The cuticle surface showed on the slide (Slide GP/3E 9179, Q51/2) displays their cells longitudinally oriented, i.e., not chaotically arranged, leading

to the consideration that is possibly the adaxial surface, according to the description of Ricardi-Branco (1997, p.100). It was not possible to confirm the multivenation assigned to *P. dusenii*, by her, as it is not possible to observe it neither in print nor in tiny cuticular fragments, due to the preservation of their small surfaces.

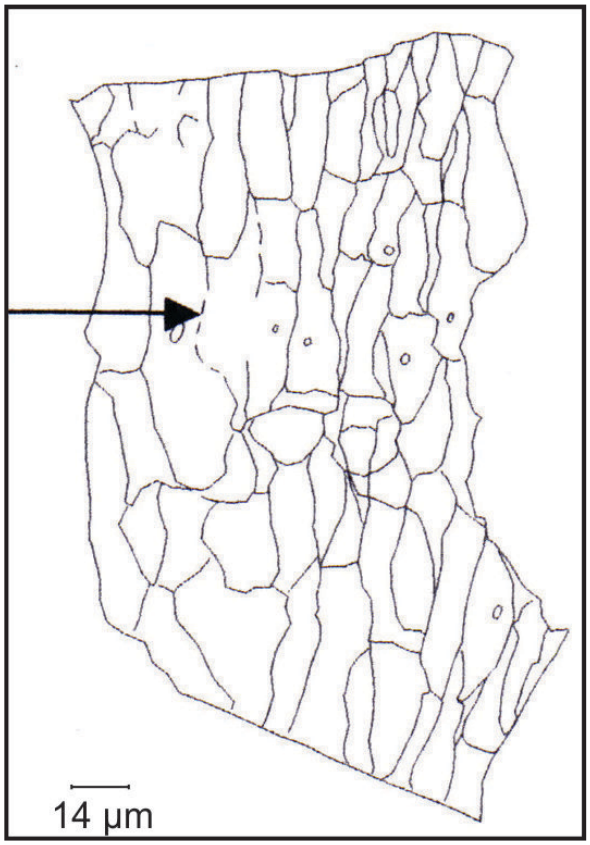

Figure 4. Elongated Polymorphic cells with punctuations. (Slide GP/3E 9179, Q51/2).

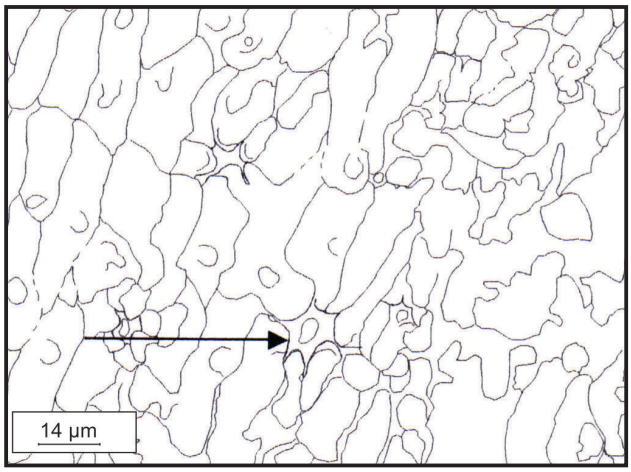

Figure 5. Sunken Stomata in the suprastomatal chamber. In one of them the occlusive aperture and the papillae on the periclinal walls of epidermal cells can be seen(GP/3E 9179, Q51).

The association of *P. dusenii*, in the plant assemblage of Monte Mor (State of São Paulo), with platyspermic seeds like *Paranospermum cambuiense* Ricardi-Branco 1997 from Figueira (State of Paraná), with cuticular details similar to those presented here (Figure 12B and C), supports the interpretation that they could be parts of the same plant species.

This morphology is distinct to that of *Coricladus quiteriensis* Jasper et al. (2005) because in spite of its lower branches to be unknown, there is an absence of globular apex form on top branches. Their leaves present heteromorphy, adpressed to the stem and become distally far from the axis. Cones are not observed on apical area.

According to Ricardi-Branco (1997), *Paranocladus dusenii* is distinct of *Ugartecladus* Archangelsky and Cúneo 1987 and *Feruglíocladus* Archangelsky and Cúneo 1987, by its heterophylly.

It should be emphasized that *P. dusenii* was described based on fossils from Triunfo Member, Rio Bonito Formation (Cisuralian.), in State of Paraná. The confirmation of this species in Monte Mor (State of São Paulo) extends its biostratigraphic distribution to Pennsylvanian.

Family Buriadiaceae
Genus *Buriadia* Seward and Sahni (1920)
Buriadia aff. *B. heterophylla* (Feistmantel) Seward and Sahni *emend.* Singh, Rothwell, Mapes and Chandra, 2003
Figures 6 and 7; Figures 11- E, G and H

Local Synonymy:
1972 - *Buriadia heterophylla* (Feistm.) Seward and Sahni *emend.* Pant and Nautyal 1967. Millan, p. 93-96, Plate IX, figures. 3-5; Plate XI, fig.4
1973 - *Buriadia sewardi* Sahni. Maithy, p. 111-112.
1974 - *Buriadia heterophylla* (Feistm.) Seward and Sahni *emend.* Pant and Nautyal 1967. Millan, p.131-133, Plate I, figures. 6-9.
1975 - *Buriadia heterophylla* (Feistm.) Seward and Sahni *emend.* Pant and Nautyal 1967. Millan, p. 3.
1977 - *Buriadia heterophylla* (Feistm.) Seward and Sahni *emend.* Pant and Nautyal 1967. Millan, p. 87.
1987 - *Buriadia heterophylla* (Feistm.) Seward and Sahni *emend.* Pant and Nautyal 1967. Millan, p. 836.
Locality: Volpe Ranch (previously named Mina Ranch), Municipality of Monte Mor (State of São Paulo).

Stratigraphic and geographical distributions: *Brazil,* Paraná Basin – Itararé Group (upper Carboniferous), Volpe Ranch (previously named Mina Ranch), Municipality of Monte Mor (State of São Paulo) (Millan, 1974 and here); Guatá Group, Rio Bonito Formation, Municipality of Candiota (State of Rio Grande do Sul); Municipality of Teixeira Soares (State of Paraná); Municipality of Lauro Müller and Bainha outcrop in Municipality of Criciúma

(State of Santa Catarina) (Florin 1940). *India:* Buriadih, Giridih Coalfield - Karharbari Stage (Cisuralian) (Pant and Nautiyal, 1967; Tewari, 1990).

Numbers of studied specimens: DGP MN 871 Pb, DGP MN 877 a, b and DGP MN 884 Pb; GP/3E- 9147 a, b and GP/3E 9161.

Description: Last order branches impressions measuring from 33 to 40 mm of length and from 1 to 1.2 mm of maximum diameter and from 1.8 to 5 mm of diameter in proximal portions. These branches are covered by leaves, arising decurrently attached by their bases, bifacial and of polymorphic serrated distal margin (linear or bifurcated and linear-cuneate) (Figures 6 and 11E), helically arranged, very close each other, with a well-marked bundle of simple or bifurcated veins in linear leaves and multifurcate in the linear-cuneate leaves.

These bundles measure from 6 to 11.5 mm in length and from 0.4 to 1 mm in width in the linear to lanceolate leaves, they measure from 5 to 10 mm in length and 0.4 to 1.0 mm in width in the bifid leaves with lanceolate shape and 8 mm in length and 5.5 mm in maximum width in the cuneate shapes with serrate distal margin.

In the specimen GP/3E 9147a it is possible to observe the outline of small pedunculated seeds or ellipsoidal ovules, with possible connection in axillary position on vegetative leaves with micropyle in outward position. They measure 2.5 mm in length and 1mm of maximum width. Cuticle not observed (Figures 7 and 11H).

Discussion and comparison: *B.heterophylla* had been identified in the taphoflora of Monte Mor (State of São Paulo), based only on morphographic characters (Millan, 1972, 1974, 1975). Singh et al. (2003), considering the reproductive structures in this species as unknown, reinterpreted the holotype, paratypes and lectotypes, studied by Feistmantel (1879, 1881), Pant and Nautiyal (1967) and Pant et al. (1995), presenting an emended diagnosis, adding the epidermal characters of cuticle. The authors do not admit any seeds connection with leafy branches. This fact leads to designate the Monte Mor material as *affinis*, the specimens studied by Millan (1972, 1974) and the specimens recently collected (GP/3E 9147a, b and GP/3E 9161), where it is possible to delineate lightly seeds in orthotropic position on the leaves axils, (contrary to the observation of Pant and Nautiyal (1967) who observed that seeds are in anatropic position strangely attached by the micropyle to the foliar branches), a fact denied by Singh et al. (2003).

Cúneo (1985) described another conifer *Genoites,* as a plant having branches with helically arranged bifid leaves. In the axils of some leaves are stalked, orthotropous ovules. These features were interpreted by him as a possible ancestor of the Feruglio cladaceae considering the reduction in the length of fertile branches toward ovulate cone organization. The specimens studied here are distinct from *Genoites* in having heterophilly with leaves arising decurrently attached by their bases, bifacial and of polymorphic serrated distal margin (linear or bifurcated and linear-cuneate) helically arranged, very close each other.

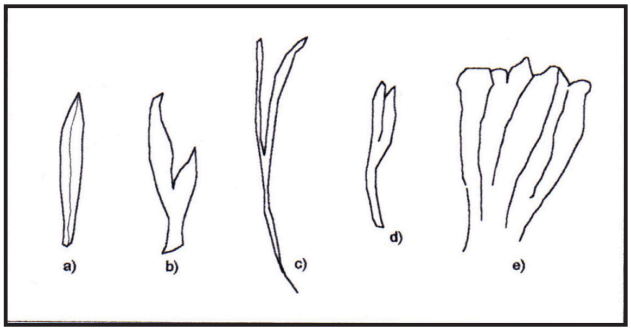

Figure 6. Polymorphic leaves shown in *Buriadia* aff. *B. heterophylla*: (a) Simple leaves; (b to d) bifid leaves and (e) linear-cuneate leaves (specimen GP/3E 9147a).

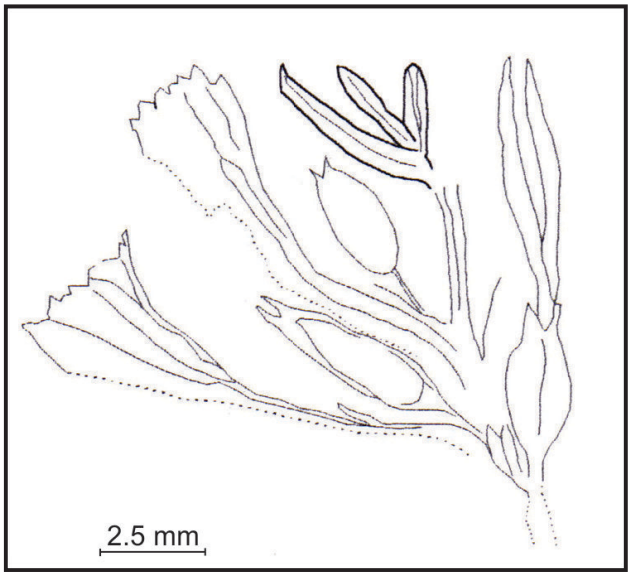

Figure 7. Suggestive forms like small seeds or ovules in axillary branch position with micropyle facing outward (specimen GP/3E-9147a).

The form under analysis resembles *B. figueirense* Ricardi-Branco 1997 (Triunfo Member - Rio Bonito Formation, from Figueira, State of Paraná) in having branches with leaves in a helical and bifacial arrangement, however, differs from it by having polymorphic leaves, linear to linear-cuneiform shape, varying size, with bifurcated to multifidus apex and absence of cuticle. By similar distinctive features, it differs from *B. mendesii* Bernardes-de-Oliveira and Yoshida (1982) (from the Siderópolis Member - Rio Bonito Formation, Municipality of Criciúma, State of Santa Catarina), too. Also differs from *B. isophylla* Guerra-Sommer and Bortoluzzi (1982) (Rio Bonito Formation, Municipality of Candiota, State of Rio Grande do Sul) by heterophilly,

leaf arrangement, absence of cuticle and due to the higher forms and distally multifids.

The species *Buriadia heterophylla* is only found in India, in Lower Permian strata (Karharbari) therefore its presence in Monte Mor (State of São Paulo) possibly corresponds to its first record in Gondwanan continent.

Group 1 – With sinnus on one side (after Maithy, 1965)

1.8 - ***Paranospermum cambuiense*** **Ricardi-Branco 1997**

Figures 8; 12 - A, B, C, K

Regional Synonymy:

1958 - *Cardiocarpus nitens* (Feruglio) Barbosa. Barbosa, p. 206, 213.

1972 - *Cordaicarpus nitens* (Feruglio) Millan. Millan, p. 96-105, Plate XII, figures. 1-4 and 6 (*non* figures. 5, 7).

1975 - *Cordaicarpus nitens* (Feruglio) Millan. Millan, p. 3, 11 (*pars*).

1977 - *Cordaicarpus nitens* (Feruglio) Milan. Millan, p. 34-40, Plate 1, figures. 1- 4 and 6 (*non* figures. 5, 7).

1985 - *Cordaicarpus nitens* (Feruglio) Millan. Castro, p. 551, figures. 1, 2.

1997 - *Paranospermum cambuiense* Ricardi-Branco. Ricardi-Branco, p. 115-125, Plate XV, figures. 1-7, Plate XVI, figures. 1-7 and Text fig. 5.

Locality: Volpe Ranch (previously named Mina Ranch), Municipality of Monte Mor (State of São Paulo).

Stratigraphic and geographical distribution: *Brazil,* Paraná Basin – Itararé Group (Pennsylvanian), Volpe Ranch, Municipality of Monte Mor (State of São Paulo) (now included); Guatá Group, Rio Bonito Formation (Triunfo Member – Cisuralian), Coal mines, Inclined Plane 115, Amando Simões (Wells 01 and 06) and Areia Branca (Rio do Peixe Carboniferous Company), Municipality of Figueira (State of Paraná) (Ricardi-Branco, 1997).

Numbers of studied specimens: DGP MN 900, DGP 901 Pb, DGP 904 Pb, DGP 1096 Pb, 1098 Pb, GP/3E 9093 A; GP/3E 9095; GP/3E 9096; GP/3E 9101; GP/3E 9211; GP/3E 9212; GP/3E 9213; GP/3E 9214; GP/3E 9216; GP/3E 9217; GP/3E 9218; GP/3E 9221; GP/3E 9230; GP/3E 9233; GP/3E 9234; GP/3E GP/3E 9235; GP/3E 9236; GP/3E 9238; GP/3E 9239; GP/3E 9240; GP/3E 9241; GP/3E 9242; GP/3E 9243; GP/3E 9244; GP/3E 9245; GP/3E 9246; GP/3E 9247; GP/3E 9268 and Slide: GP/3E 9192.

Description: Compressions and impressions of platyspermic seeds, with triangular or cuneiform shape, approximately symmetrical, measuring from 5 to 7.4 mm of length and from 7 to 10 mm of maximum width, in the distance 4.4 to 5.1 mm from the base.

The apex is tapered and bifid, consisting of two straight triangular appendages with sharp edges, which are part of micropyle. These appendages measure from 1.1 to 2.3 mm length and 1 to 2 mm width.

The base is acute-rounded. In impressions, a groove or keel runs through the base to the apex of the seed. The central body or nucellus has obovate shape, measuring 3.5 to 6 mm in length by 2.5 to 6 mm in maximum width, wrapped by a thin sclerotesta.

The sarcotesta surrounds all the nucellus, being narrower at the base, where it measures from 1 mm to 1.6 mm and becomes larger at the level of maximum width of the nucellus (1.3 to 3.0 mm) tapering towards the bifidus apex (Figure 8).

Epidermal aspects of the cuticle:

In the region of the sarcotesta near the micropyle, rectangular or polyhedral cells are elongated, with 4-6 faces; measuring 60-74 μm of length and 15-21 μm in width, showing papillae and pores (detached papillae bases) on their periclinal walls; anticlinal walls irregularly thick, resulting in lightly undulate aspect and transverse walls thinner (Figure 12C). In the sarcotesta near the basal area of the nucellus there are rectangular to polyhedral (with 4 to 5 faces) cells less elongated measuring 37-73μm in length and 18-31 μm in width. On the periclinal walls there are papillae or pores (detached papillae bases) with anticlinal walls thinner (Figure 12B). On the lateral sarcotesta region, the cells become more elongated but on the maximum width of the sarcotesta they become short polyhedral or less elongated (35-51 μm in length and 18-28 μm in width).

From the basal area up to the beginning of the apical region, beyond the papillae numerous hairs and/or spikes are observed. The nucellus is covered by smaller, square-rectangular or polyhedral short cells with thick anticlinal walls, always

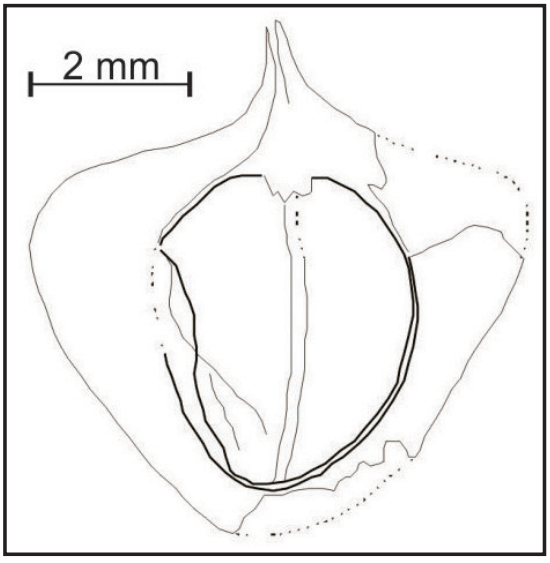

Figure 8. *Paranospermum cambuiens*e Ricardi-Branco (1997). Specimen GP/3E 9192.

carrying a papilla on periclinal walls. It was not possible to recognize stomata in any area.

Discussion and comparison: These seeds are very abundant in certain fossiliferous levels of Monte Mor (State of São Paulo). Initially, Millan (1972, 1977) identified and described some of these specimens as *Cordaicarpus nitens* (Feruglio) Millan, however, he did not notice its epidermal and cuticular aspects. He misinterpreted these specimens due to observation in inverted position and therefore described the nucellum much larger than the original one. Later, Ricardi-Branco (1997) obtained seeds morphographically similar to those from Monte Mor but from Rio Bonito Formation, in region of Figueira (State of Paraná) and observed epidermal and cuticular features. She designated these specimens as *Paranospermum cambuiense* Ricardi-Branco (1997) and considered the forms of Millan in synonymy of the new species.

Based on cuticular characteristics she related the new seed species to the conifer *Paranocladus dusenii* Florin 1940. The specimens from Monte Mor now examined are identical in all morphographic and epidermal aspects to *Paranospermum cambuiense* (described and figured by Ricardi-Branco, 1997, Plate XV, figures. 1-4, 6, 7, Plate XVI, figures. 1, 4 and Text-fig. 10). It is interesting to note that the specimens from Volpe Ranch, Monte Mor, are also associated to *Paranocladus dusenii* in the fossiliferous assemblage. Epidermal features in the nucellum region was observed, described and illustrated, too. These features were added to the diagnostic characters of the species described by Ricardi-Branco (1997).

1.9 - ***Paranospermum millanianum*** **sp. nov.**

Figures 9 and 10; Figures 12D, E, F, G, H, L

Synonymy:

1972 - *Cordaicarpus nitens* (Feruglio) Millan. Millan, p. 96-105, Plate XII, figures. 7 (*non* figures.1-4, 6).
1975 - *Cordaicarpus nitens* (Feruglio) Millan. Millan, p. 3, 11 (*pars*).
1977 - *Cordaicarpus nitens* (Feruglio) Millan. Millan, p. 34-40, Plate 1, figures. 5, 7.
1987 - *Cordaicarpus nitens* (Feruglio) Millan. Millan, p. 836.

Locality: Volpe Ranch (previously named Mina Ranch), Municipally of Monte Mor (State of São Paulo).

Stratigraphic horizon: *Brazil*, Paraná Basin – middle-lower portion of the outcropping part of the Itararé Group (Pennsylvanian).

Holotype: Slide GP/3E 9197.

Paratypes: GP/3E 9084, GP/3E 9097, GP/3E 9220, GP/3E 9233, GP/3E 9237.

Numbers of studied specimens: DGP MN 1097Pb and DGP MN 1103Pb B, GP/3E 9084, GP/3E 9097, GP/3E 9220, GP/3E 9233, GP/3E 9237 and Slide GP/3E 9197.

Derivatio nominis: *millanianum*. Specific epithet dedicated to Dr. José Henrique Millan – an important Brazilian paleobotanist, researcher of taphoflora from Monte Mor (State of São Paulo).

Specific diagnosis: *Platyspermic seed, wedge shaped or triangular with base facing upwards, almost symmetrical, with funnel-shaped and bifid apex and rounded acute base. Entire sarcotesta turning round all the central body, narrow at the base and widening gradually until the beginning of the apical area where it becomes almost horizontal. In impressions, the seeds display a ridge or furrow from the micropylar area up to the base. The nucellus or central body is subcircular in shape. In compressions, it is possible to observe the nucellus enveloped by the sclerotesta which thickens in the apical portion, in order to constitute the inner wall of the micropyle, giving to the nucula a lageniform aspect. There is one papilla on the periclinal surface of each cell of the sarcotesta and central body. But they are absent only on the elongated, vertically disposed and thinner cells of apical area. On the nucellus surface the cells are of slightly thicker walls with horizontal striations.*

Description: Platyspermic seeds of triangular shape with base facing upward, approximately symmetrical, with funnel-shaped, bifid apex and rounded base. Measures 5-7 mm in length by 5-9 mm of maximum width close to 3-4 mm from the base. The sarcotesta of entire margin surrounds the central body, being narrow in the basal area (0.30 mm) and widening (1.92 mm) until the beginning of the apical area, then become almost horizontal until the base of micropyle area. The lageniform nucula shows a subcircular shape of 4 mm in diameter in the median-basal area and quickly narrowing in the apical area, where the sclerotesta begins to form the micropyle internal wall (Figure 9).

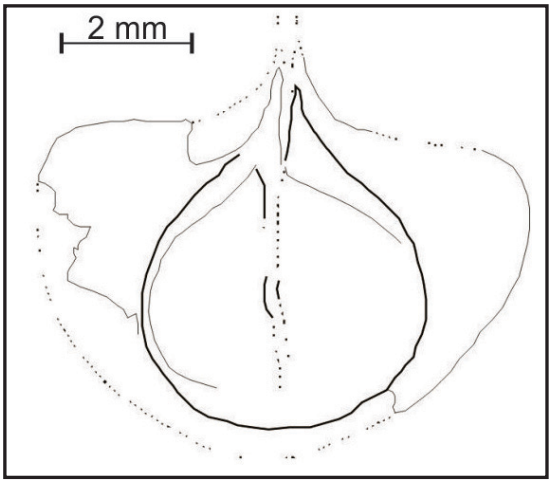

Figure 9. *Paranospermum millanianum* sp. nov. Specimen GP/3E 9197 (slide).

On impressions, a groove or keel 0.15 to 0.25 mm wide travels from the apex to the base of the nucellus. While, in the cuticles this groove or keel seems to correspond to an extension of the micropyle to the base. Papillae of different sizes occur on the paraclinal surface of all cells (one per cell) of the sarcotesta and the central body (Figure 12D, F).

They are absent in the area of the apical appendages. The cells are thin/elongate/ rectangular, vertical in disposition and measure 48 to 67 µm in length and 16 to 20 µm in width in the micropylar area (Figure 10).

In the wider area of sarcotesta, the cells measure 54-67 µm long and 22-33 µm wide and become longer close to the nucellus and shorter and wider near the edge of sarcotesta. They become narrow and elongate toward the seed base. On the surface of the nucellus, the cells are of slightly thicker walls and exhibit striations from the base of their papillae (Figure 12G).

Discussion and comparison: These forms have morphographic and cuticular features very similar to *Paranospermum cambuiense* Ricardi-Branco. Although, they are distinct in some aspects such as more triangular contour, more rounded basal region, nuculla (nucellus plus sclerotesta) of lageniform aspect, subcircular base with bigger diameter located in the middle-basal area of the seed, distinct from that species which has more obovate nuculla. In *P. cambuiense* also, the base is more acute and papillae and hairs are spread over the surface, while in *P. millanianum* n. sp. the presence of hair has not been observed, but only papillae with apex thickened. Another feature observed is the presence of horizontal striations on the nucellus cells surface. Based on these observations, the authors proposed here a new species.

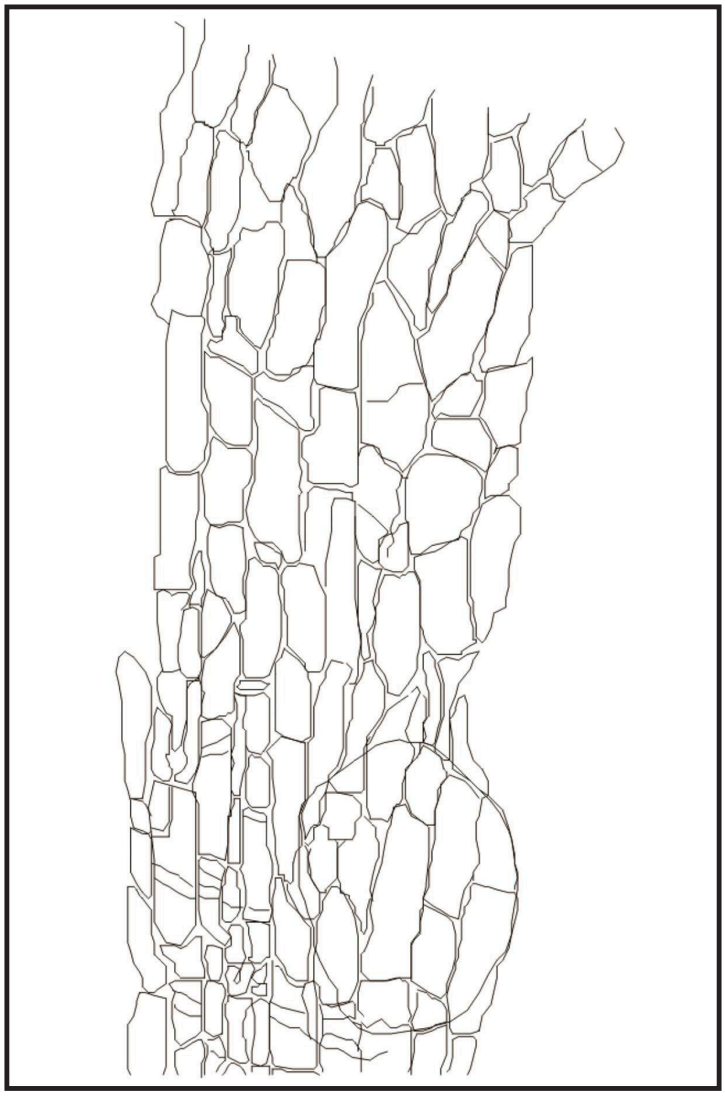

Figure 10. *Paranospermum millanianum* sp. nov. Micropyle detail with pollen grain inside. (slide GP/3E 9197-K 40/4).

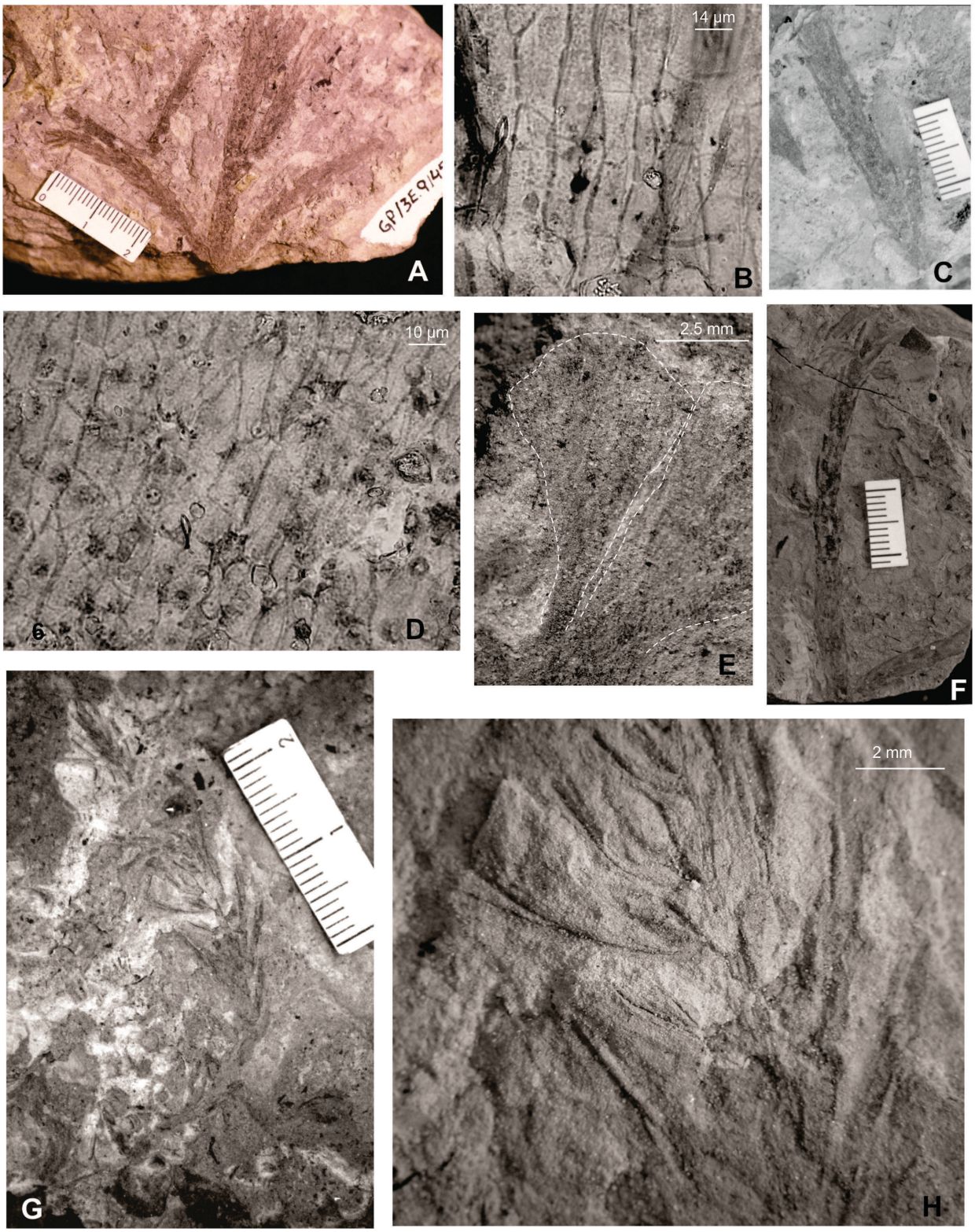

Figure 11. *Paranocladus dusenii* Florin 1940. **A** - specimen GP/3E 9145; **B** - Cuticle detail showing cells (Slide GP/3E9179, Q51/2, 20x); **C** - specimen GP/3E 9076; **D** - Cuticle detail showing papillae cells and stomata (Slide GP/3E 9179,Q51, 20x); **F** - specimen GP/3E 9075; *Buriadia* aff. *B. heterophylla* (Feistmantel) Seward and Sahni emend. Singh, Rothwell, Mapes and Chandra 2003: **E** - Cuneate shape leaves of (Specimen GP/3E 9147 20x); **G** - Specimen GP/3E 9147a; **H** - Suggestive forms of seeds or ellipsoidal ovules (Specimen GP/3E 9147, 20x).

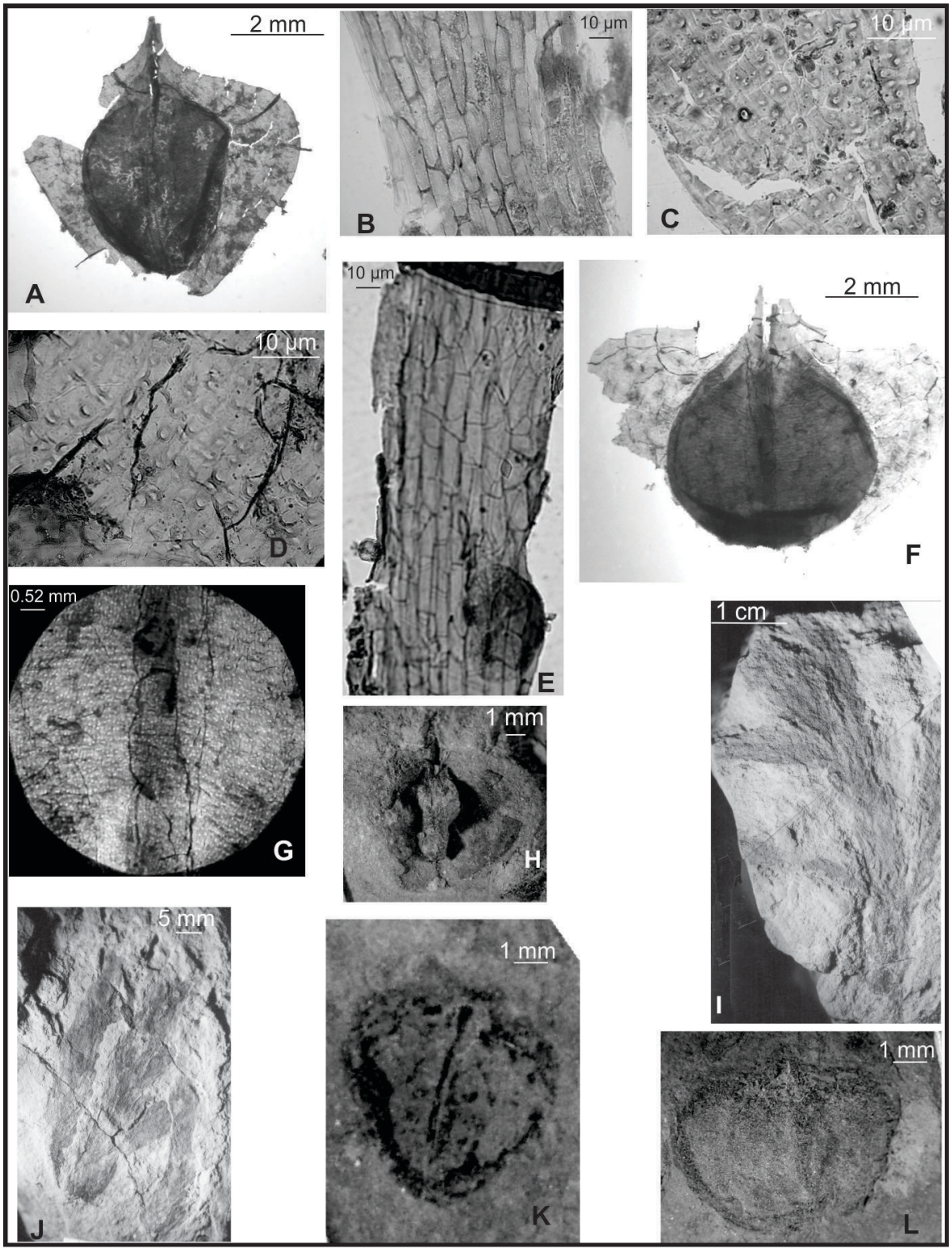

Figure 12. *Paranospermum cambuiense* Ricardi-Branco 1997. **A** - Specimen GP/3E 9192; **B** - Cuticle detail of micropyle region (Slide GP/3E 9184, N36/4, 20x); **C**- Cuticle detail of papillae cells (Slide GP/3E 9185, S 35/1, 20 x); **K** - Specimen GP/3E 9093 A; *Paranospermum millanianum* sp. nov.: **D** - Cuticle detail showing papillae cells (Slide GP/3E 9197, O38/4); **E** - Cuticle detail of micropyle region (Slide 9197, L40/2 20 x); **F** - Slide GP/3E 9197; **G** - Nucellum cells of thicker walls with horizontal striations (Slide GP/3E 9197); **H** - Specimen GP/3E 9084; **L** - Specimen GP/3E 9097; *Paranocladus dusenii* Florin 1940: **I** - Specimen DGP MN 846 Pb; **J** - Details of Specimen DGP MN 1095 Pb.

CONCLUSION

Conifers from Monte Mor taphoflora are represented by impressions and compressions of leaf branches of *Paranocladus dusenii* Florin and *Buriadia heterophylla* (Feistmantel) Seward and Sahni *emend.* Singh. The dispersed seeds are represented by predominance of genus *Paranospermum* related forms, constituting 81% of the observed seeds. It is noteworthy that these are exactly the seeds that have relatively same affinities with conifers of the genus *Paranocladus* Florin, and which is the most abundant form among the gymnosperms of phytofossiliferous assemblage from Volpe Ranch (Mune and Bernardes de Oliveira, 2007, p.436, Table 4). This representation in the assemblage is in a way reflected by macrofossil content.

It was possible to record *Paranocladus dusenii* (in place of *Paranocladus*? *fallax*), by cuticular studies and relate it with *Paranospermum cambuiense* platyspermic seeds, whose cuticular details resemble the characteristics presented in this work (Figures 12, A, B). This fact corroborates the idea that these fossils can represent different parts belonging to a same plant, and identify a new species of platyspermic seed called *Paranospermum millanianum* sp. nov.

Paleontological considerations

The association of conifer with *Ginkgophyllum* could suggest a mesoxerophytic tree community. The abundance of fragmented material suggests allochthonous origin. The fossiliferous sandy matrix lying on the coal also suggests a transport agent of greater velocity. In the pollen analysis, the pollen grains related to conifers and cordaitales are diversified within the assemblage without paleoenvironmental significance as they have a very large dispersion capability. On the other hand, shows that the conifers were relatively well established in this area.

Biostratigraphic considerations

The taphoflora of Monte Mor characterizes the III mega floristic association of the State of São Paulo, the *PGB Association "Paranocladus - Ginkgophyllum - Brasilodendron"* Bernardes-de-Oliveira et al. (2016, Figure 8), and palynofloristically related to the Interval *Crucisaccites monoletus* Zone (*CMZ*) of Souza (2006) due to the presence of *Scheuringipollenites maximus* and *Crucisaccites monoletus*. This fact rises the Monte Mor age to Kasimovian- Gzhelian (Mune and Bernardes-de Oliveira, 2007, 2009; Jha et al., 2012). This association is possibly correlated with *Krauselcladus - Asterotheca* Phytozone (Carrizo and Azcuy, 2006) of northwestern Argentine paleofloristic zone or Interval zone (Archangelsky and Cúneo, 1991) of the Paganzo Basin, based on the relative abundance of conifers that are absent in the first association of the succession scheme proposed by Bernardes-de-Oliveira et al. (2005).

The location registers the lowest level of occurrence of conifer-macrofossils in the Paraná Basin. It is noteworthy that *Buriadia heterophylla* is found in India only in lower Permian strata (Karharbari stage) and its presence in Monte Mor corresponds to its first record in Gondwanan continent.

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