The paleoflora of Figueira in the context of the neopaleozoic of the Paraná Basin, Brazil

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ABSTRACT *This study involved the Paleoflora of the Figueira Region (City of Figueira, PR, Brazil), which is part of the Triunfo Member of the Rio Bonito Formation. The specimens were collected from the refuse in the mining fields of the Companhia Carbonífera do Cambuí. After the systematic study, it was found that the species belong to the lycopodiaceous group and to the coniferae group. In the lycopsids species it was possible to study the stem, microphyllous, and megaspores. Three vegetal communities were represented in a general form in the studied Paleoflora: a swamp community, composed mainly of Brasilodendron cf. B. pedroanum, a community found in the composed flooding plain, formed of glossopterids among others, and a community of more elevated or less frequently flooded terrains, dominated by conifers (example: Paranocladus dusenii). Based on the results it can be concluded that the studied Paleoflora had great similarity to the other Early Permian taphofloras found in Paraná State at the Triunfo Member of the Rio Bonito Formation.*

KEYWORDS *Permian, Paraná Basin, Rio Bonito Formation, Glossopteris Flora*

Introduction

The Paraná Basin is a large Paleozoic-Mesozoic intracratonic basin that extends throughout Brazil, Paraguay, Uruguay, and northeast of Argentina (Zalán *et al.* 1991).

The studied region is located in the eastern area of the Brazilian portion of the basin, northeast of the Ponta Grossa Arc near the City of Figueira, in Paraná State (Fig. 1). The Neopaleozoic record in this region is well preserved, beginning with the sediments of the Tubarão Group (Subgroup Itararé, Rio Bonito and Palermo formations). In the Figueira area the post glacial sediments of the Rio Bonito Formation are not complete in relation to the stratification shown in Santa Catarina State, by the absence of the upper Member, called Siderópolis (Soares and Cava 1982). Inside the Triunfo or lower Member of the Rio Bonito Formation, in the Figueira area, a coal seam was found where the studied vegetal fossils were located.

The Figueira region is characterized by the occurrence of coal inside the lithological association siltstone-coal-siltstone. Several authors (Morrone and Daemon 1985, Della Favera *et al.* 1993, etc.) suggested that this area had a deposition environment formed by a delta-plain system with extensive swampy areas, covered by vegetation and possibly protected by sand bars. This plain would belong to a delta system developed in the Lower Permian.

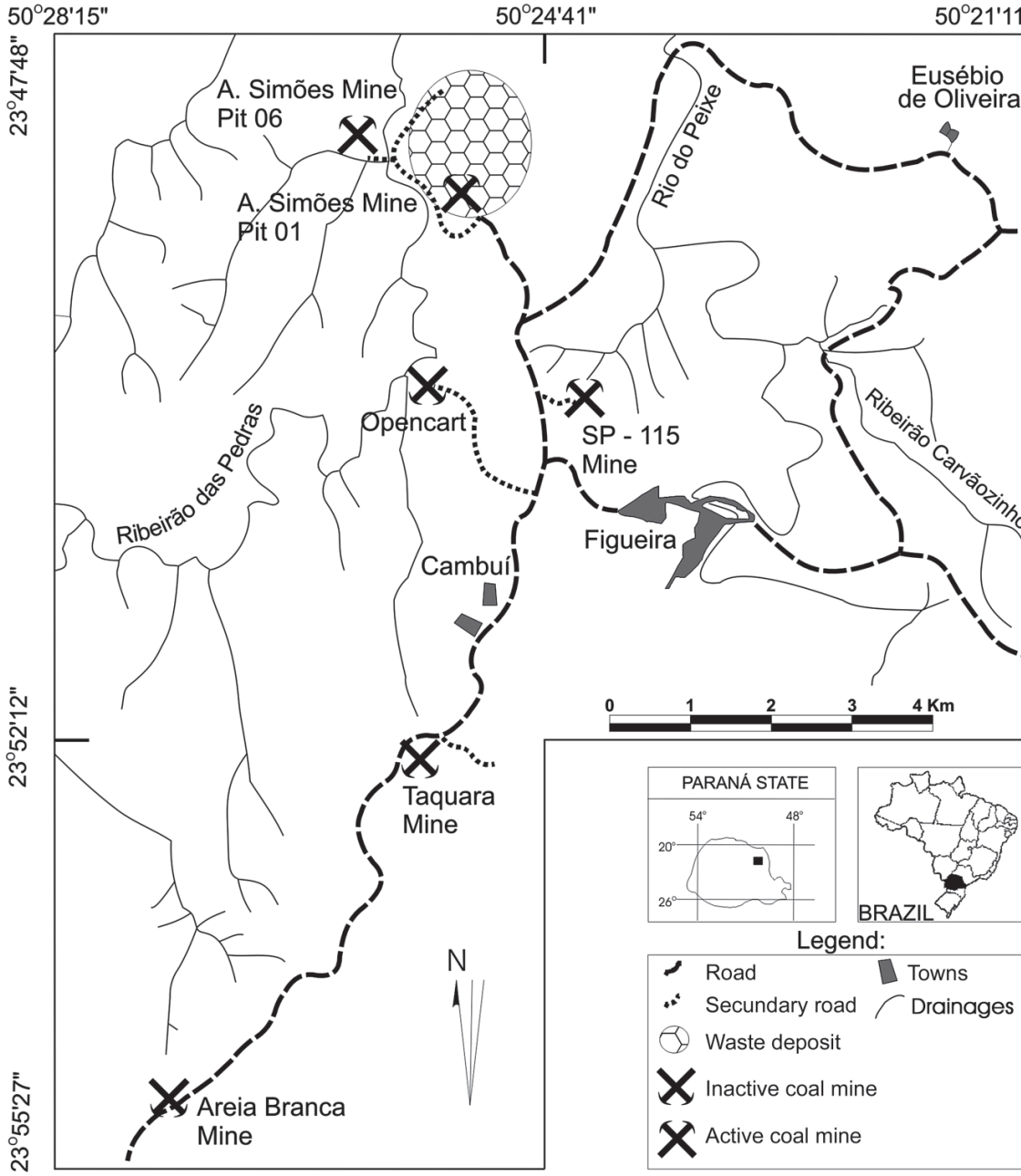

Figure 1: Localization map of Figueira region

Paleobotanic study at the Figueira region

The plant megafossils in Figueira are from gray siltstones located at the top of the coal seams and the plants fossils were preserved by carbonized compression.

Several taphofloras have been studied from this Paleoflora since the beginning of the Twentieth Century (Table 1 and Fig. 1). They were known as: Cambuí Farm (now the Amando Simões Mine), Carvãozinho River, Rio do Peixe Company Mine (Taquara Mine), Areia Branca Mine and Barra Bonita (near Ibaiti). The first researchers to collect and illustrate vegetal remains from the region were Lundqvist (1919 *apud* Rösler 1972) and Oliveira (1927), followed by Florin (1940) and Read (1941), who performed systematic studies on Oliveira's collection (Table 1).

In the 70's, Rösler (1972) returned to collecting and studying samples from the classical expositions

(Cambuí Farm, Carvãozinho River and Barra Bonita). Years later, Castro (1985) studied a collection previously collected by Elias Dolianiti at the Areia Branca Mine (Fig. 1 and Table 1).

Because the plant fossils are carbonaceous with cuticles, anatomical studies were performed from the beginning. Florin (1940) described the genus of conifers *Paranocladus* using epidermic characteristics as a reference, identifying *P. dusenii* with type specie. Fittipaldi (1981) later studied and characterized the cuticle of the *Glossopteris communis*. Feismantel (in Figueira's area, Fittipaldi and Rösler 1985) and Fittipaldi and Rösler (1978) studied the cuticle characteristics of another species of *Paranocladus,* called *P.* ? *fallax* Florin.

New samples were collected during this study. A profound systematic study was performed, and new species not mentioned in the literature were found in the Figueira Paleoflora (Table 1). This was the case of the lycopsid *Brasilodendron* cf. *B. pedroanum* Chaloner *et al*., its possible microphyllous, an abundant assembly of megaspores (Ricardi *et al*. 2002), and the gondwanic conifer *Buriadia*, as well as other species already known.

In addition, a cuticle study was performed on the genus *Paranocladus*, which extended the original diagnosis (Ricardi-Branco 1998), since specimens of feminine strobile were collected and found to be organically connected and had established relations at the cuticle level with the seed of the species *Paranospermum cambuiense* sp. nov (Ricardi-Branco 1998).

In relation to the megaspore assembly, 167 specimens were studied (Ricardi-Branco *et al.* 2002), belonging to four species. The species *Lagenoisporites triunfensis* Arai *et* Rösler and *L. scutiformis* Trindade were widely dominant, with 123 and 35 specimens respectively. The other two species, *Sublagenicula cf. S. brasiliensis* (Dikstra) Dybová-Jachowicz *et al.* and *Setosisporites* cf. *S. furcatus* (Dikstra) Dybová-Jachowicz *et al.* were scarce, with 7 and 3 species respectively.

The plants fossils come from the coalfields of Companhia Carbonífera do Cambuí. The collection was done from the Amando Simões Mine (pit 01 and 06), Slope Plane 115 (PI -115) and from the general waste deposit (GWD). All plant fossils studied, the cuticle slides and the megaspores were housed in Paleobotanical Collection 3T, which belongs to the Laboratory of Systematic Paleontology at the Geosciences Institute, University of São Paulo (IG/USP), and were numbered from 2137-2207 and 2223.

Table 1

Author	Lundqvist (1919)	Oliveira (1927)	Florin (1940)	Read (1941)
Locality	Patrimônio	Cambuí	Cambuí	Cambuí
Fossil Plants		Rio Carvãozinho	Rio Carvãozinho	Rio Carvãozinho
Licopsida		Stems		*Brasilodendron* cf. *B. pedroanum* (=*Lepidodendron pedroanum*)
Sphenopsida	*Sphenophyllum brasiliensis* (=*Sphenophyllum oblongifolium*) *Annularia australis*	Stems		*Sphenophyllum brasiliensis* (=*Sphenophyllum oblonguifolium*) *Annularia occidentalis* (*Annularia* sp.)
Filicopsida		branches		*Asterotheca derbyi* (=*Pecopteris paranaense*)
Pteridophylla	*Pecopteris* sp.			Pecopteris cambuyensis (=*Pecopteris pedrasica* e Pecopteris cambuyensis) *Sphenopteris lobifolia* (=*Zeilleria oliverai*)
Gymnospermopsida Glossopteridales	*Gangamopteris obovata* *Glossopteris comunis* (=*Glossopteris indica*)	*Glossopteris* sp.		*Glossopteris browniana* *Glossopteris comunis* (=*Glossopteris indica*)
? Voltziales	*Paranocladus* ? *fallax* (=*Brachiophyllum australe*) *Cordaicarpus* sp. (*Cordaicarpon* sp.)	*Paranocladus* ? *fallax* (=*Lepidodendron*)	*Paranocladus dusenii* *Paranocladus* ? *fallax*	*Paranocladus* ? *fallax* (=*Brachiophyllum australe*) *Cordaicarpus* sp. (*Cardiocarpon* sp.)

Paleoecological aspects of Figueira

In the last decades, paleobotanists are showing an increased interest in studying and understanding which is the real portion of vegetation from an area that is preserved in the form of taphoflora. Authors such as Spicer (1980), Scheihing and Pfefferkorn (1984) and Greenwood (1991), among others, performed excellent studies of this subject.

Even though the vegetation represented by taphoflora goes through a selection process due to transport, it is possible to propose distribution models for the different species, since it is accepted that taphofloras are most often formed by both autochthonal and foreign material. Scott (1979) emphasized that the assemblages of phytofossils present in a layer show its ecology as well as its transportation history.

Paleoecological studies have been performed for the Brazilian portion of the Paraná Basin on some assemblages from the Rio Bonito Formation (Pasqualini *et al.* 1986, Guerra-Sommer 1989, among others) in Rio Grande do Sul State, Brazil.

Pasqualini *et al.* (1986) studied an outcrop located in the Mariana Pimentel area and identified the vegetal communities of: alluvial plains, swampy areas and meandering distributaries that were part of a delta-plain system. Guerra-Sommer (1989) related the association *Botrychiopsis – Phyllotheca* – Lycophyte species with meso-hygrophilous environments and sphenopsids, ferns and glossopterids with mesophyll environments. Guerra-Sommer (1989) considered the low diversity of species as a consequence of inherent abiotic stress from flooding areas of high latitude that are stable for a long period of time.

Paleoecological proposal for the vegetal communities found in the Figueira paleoflora

An obstacle was found when trying to establish the possible paleoecological relationship as well as the special distribution of the species from the Figueira Paleoflora due to the lack of knowledge of facies in which the studied vegetation was deposited, since the study was performed with phytofossils collected from the waste deposits from Amando Simões Mine. However, even with this complication, an approximate relationship for the vegetal communities present can be suggested.

Two or tree large communities can be inferred. As evidence, some characteristics presented by the fossils plants can be used, such as specimen size, preservation, associated species in the samples, type of vegetal organ represented, fragmentation, orientation of samples and others.

Two or tree communities are described, associated with delta environments:

a- of swamps;
b- of flood-plain (or intermediary) and;
c- of elevated terrains or terrains less subject to flooding.

Even though each of them showed a well defined geomorphological position, some places with mixed species certainly existed, which can be correlated with ecotons.

a – Swamp vegetal community

This community was composed of all those species that grew within permanently or temporarily flooded areas. This community was characterized by presenting tolerance to abiotic stress, unique to swamp areas (Guerra-Sommer 1989). It is possible to observe the presence of a stomatic device submerged in the microphyllous cuticle, as an adaptation to this type of environment. In the Figueira Paleoflora this community was composed mainly of *Brasilodendron* cf. *B. pedroanum*, the fossils of which show a lack of or small transportation due to size (length of 1.5 – 35.0 cm; width of 2.1 cm to more than 16.5 cm), preservation (5 stages of bark loss) and great abundance.

Additional evidence of the low diversity of the lycopsid species was provided by the presence of few megaspore species, of which *Lagenoisporites triunfensis* (Ricardi *et al.* 2002) was amply dominant. The presence of few species with abundant numbers of individuals is characteristic of environments were there is stress.

Since the microphyllous were always found isolated and showed evidence of transportation, it is possible to deduce that these microphyllous became part of the accumulation of plant residues on the vegetal community floor at the time they detached from the plants. This accumulation could later be removed by currents during the flooding period and deposited together with other fragments, as suggested by Gastaldo (1987).

It is possible to suppose that some sphenopsids grew among the lycopsids species, represented by the species *Paracalamites australis* Rigby, from which some portions corresponding to the rhizome were found in this study. Earlier studies (Rösler 1972) had already mentioned the presence of sphenopsids in the area, as well as some ferns.

b – Flood-Plain or intermediary vegetal community

This community was represented by all those species that developed next to water ways (levees, etc.), that were able to resist flooding for some time and even though their remains were transported, they were deposited in places nearby, representing a portion of the hypo-autochthonal Paleoflora.

It is believed that the sphenopsids species *Sphenophllyum brasiliensis* Rösler, *Annularia occidentalis* Rösler, filicineans *Arterotheca derbyi* Rösler, pteridosperns *Pecopteris cambuyensis* (Read) Rösler, *Sphenopteris lobifolia* Morris, as well as glossopterids *Glossopteris communis* Feistmantel, formed this large vegetal community. It is possible that more than one community existed inside of this vegetal community, as in the case studied by Scott (1979).

Even though the glossopterids were not studied in detail, it is possible to deduce from its leaf size (approximately 12.0 x 3.2 cm) and its preservation (as a whole) that they belonged to a vegetation that did not exist in the swamp interior with the lycopsids species, but were closer than the conifers or in an intermediate area between them.

In the same manner, the preservation of the species *Sphenopteris* and *Pecopteris* that showed fertile foliage reinforces the idea suggested above, even though some glossopterids species could also inhabit more elevated areas.

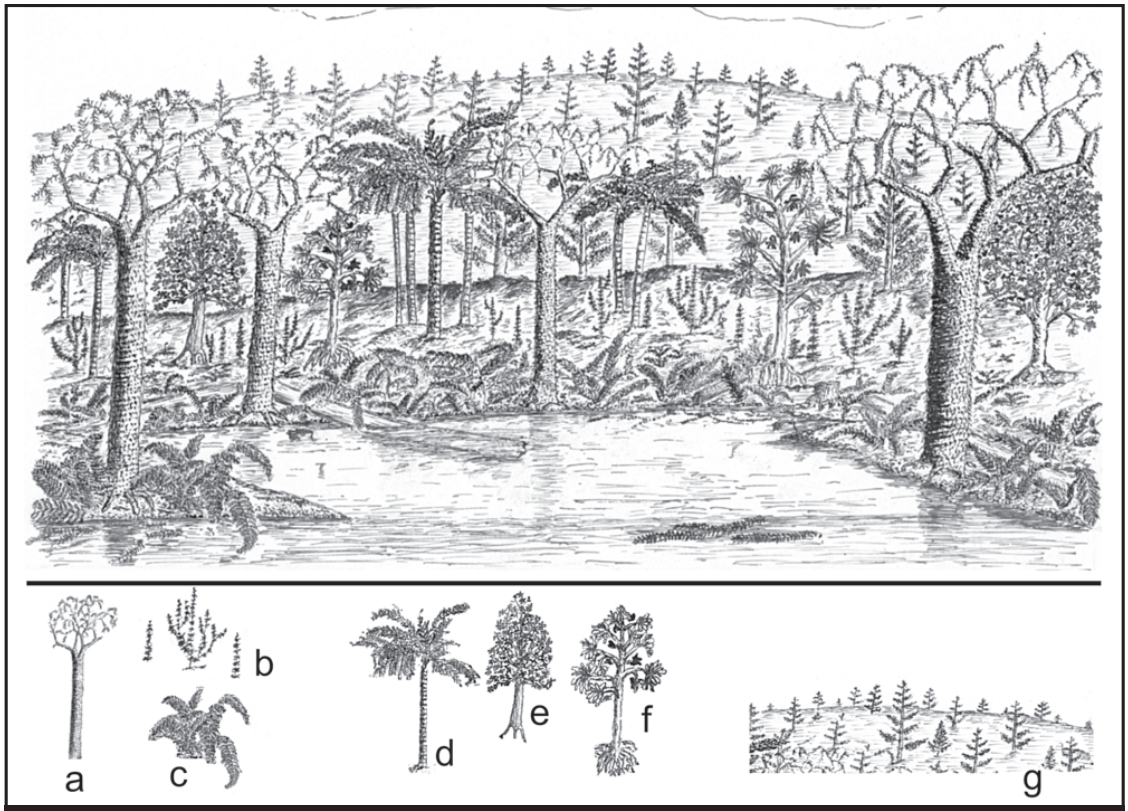

Figura 2 – Suggested distribution of Plant Paleocomunities for Figueira region during the Lower Permian period

c – Elevated Terrains or Vegetal Community Less Subject to Flooding

Regarding conifers, their distribution is more complicated, since the fossils for *Paranocladus*, for example, are very abundant, even though they belong to terminal branches in most cases. They could then inhabit a flood plain with the glossopterids, as mentioned by Cúneo (1983). They could also occupy more elevated terrains that are located away from the coast line, characterizing a third vegetal community or both ecospaces.

Regarding the seed of *Paranospermum cambuiense* (Ricardi-Branco 1998) associated with the *Paranocladus dusenii* Florin, its presence can be expected with high frequency, since it is common to find an abundance of seeds in delta deposits (Scheihing and Pfefferkorn 1984).

The situation is simpler for *Buriadia*, since its fossils are less common and are always of the terminal portions of the branches. It is possible that these plants inhabited places located away from the coast, along with *Paranocladus*, close to water ways that transported the branches to the locations where they were deposited.

Relations between the paleoflora from Figueira with other Neopaleozoic paleofloras from the Paraná Basin

When the Paleoflora from Figueira is compared to the ones documented in other outcrops from Paraná State at the Triumph Member, many common elements with the taphofloras of Marins (Guerra-Sommer *et al*. 1981), Teixeira Soares and São João Triunfo (Dolianiti 1954, Rösler 1972 and 1978, Rigby 1970, Arai and Rösler 1984), were observed even though it cannot be said that they are contemporary.

There were similarities outside of Paraná State with the taphofloras from the Itararé Subgroup in São Paulo State: Monte Mor (Westphalian – *Brasilodendron pedroanum*, *Paracalamites australis*, *Paranocladus*, *Buriadia*, and *Paranospermum cambuiensis, Lageniosporites scutiformis, Sublagenicula brasiliensis* – Millan 1972). There was only one species in common with the taphofloras from Cerquilho (Early Permian) (*Paracalamites australis*).

There were some species from the genus *Glossopteris*, *Gangamopteris*, *Sphenopteris*, *Pecopteris*, and *Sublagenicula*, in common with the Paleoflora from the Siderópolis Member of the Rio Bonito Formation in Santa Catarina State, as well as the presence of the genus *Buriadia,* even though this Paleoflora represents a more advanced flora stage of *Glossopteris* (Bernardes-de-Oliveira 1977).

Finally, a few common elements were found with the taphofloras associated with coal beds from the Itararé Subgroup in Rio Grande do Sul State (*Glossopteris communis* and *Gangamopteris*).

In this state the greatest similarities are in relation to the taphoflora from the Candiota region (Artinskiano-Kunguriano; Rio Bonito Formation), where some elements are found such as *Brasilodendron pedroanum*, *Glossopteris communis*, *Sphenopteris* and *Buriadia* (Carruthers 1869, Zeiller 1895, Kräusel 1961, Chaloner *et al.* 1979, Guerra-Sommer and Bortoluzzi 1982, among others).

Considering that the partial similarities between the different taphofloras could result from similar ecological conditions, even though slightly heterochronical, it was verified that the greatest similarity from this taphoflora is related to those attributed to the Sakmariano – Artinskiano interval, that presents taxa as:

- *Paranocladus*, present in the pre-Glossopterideas Flora (Monte Mor, São Paulo State).
- *Glossopteris communis*, present in different stages of the *Glossopteris* Flora: initial (Figueira, Paraná State), advanced (Paleoflora from the Siderópolis Member, Santa Catarina State) etc.
- *Brasilodendron pedroanum* and *Sublagenicola brasiliensis* present in pre-Glossopterids stages (Monte Mor) and from *Glossopteris* Flora (Siderópolis Member).
- *Lagenoisporites triunfensis*, from beginning of the *Glossopteris* Flora, restricted to Paraná State, until today.

Conclusions

1- The presence of at least three vegetal communities inside the studied Paleoflora is suggested, which were designated as:

- Swamp Vegetal Community: formed by autochthonal elements (example: *Brasilodendron* cf. *B. pedroanum*) and characterized by low diversity of species.
- Flood Plain Vegetal Community: formed by hypo-autochthonal elements (example: sphenopsids, filicineans, etc.).
- Elevated Terrains Vegetal Community: formed by foreign elements (example: Voltziales, etc.).

2- The Paleoflora from the Figueira region, along with the taphofloras from Marins, Teixeira Soares and S. J. do Triunfo, in Paraná State, were considered closely related, having common species of megafossils and megaspores. The relationship with the other Neopaleozoic taphofloras from the Paraná Basin was considered less significant.

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