



## Pennsylvanian – Early Cisuralian interglacial macrofloristic succession in Paraná Basin of the State of São Paulo



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### ABSTRACT

One of the most completely preserved glacial sedimentary records from the Late Carboniferous to the Early Permian time corresponds to the Itararé Group, which presents a large outcropping thickness in the northeastern border of Paraná Basin, especially in the State of São Paulo. This unit corresponds to the base of the Gondwana I Supersequence and is composed of continental to marine glacial and interglacial deposits. Based on some macrofloristic, lithostratigraphic and palynostratigraphic data, a formal scheme of the macrofloral succession is herein proposed for this interval, comprising five associations in ascending stratigraphic order namely: (1) *Dwykea-Sublagenicula-Calamospora* Association (recorded in Campinas Municipality), composed of lycophyte megaspores (*Sublagenicula*, *Trileites* and *Calamospora* sp.) and some bryophytes (*Dwykea*), concerning to a coastal glacial or coastal interglacial environment; (2) *Eusphenopteris-Nothorhacopteris-Botrychiopsis* Association (registered in Itapeva and Buri municipalities), composed of *Eusphenopteris*, *Nothorhacopteris*, *Botrychiopsis*, *Paracalamites* spp. along with *Sphenophyllum*, *Koretrophyllites*, *Noeggerathiopsis* and rare *Cordaicarpus* and *Samaropsis* – concerning to an interglacial deltaic plain associated to coal forming swamps with cold temperate hydro-hydrophilous vegetation; (3) *Paranocladus-Ginkgophyllum-Brasilodendron* Association (registered in Monte Mor Municipality), composed of the first conifers of the Paraná Basin (*Paranocladus*, *Paranospermum* and few *Buriadia*-type), lycophytes (*Brasilodendron*, *Bumbudendron*), *Ginkgophyllum*, *Noeggerathiopsis*, *Samaropsis* and *Cordaicarpus* and rare *Nothorhacopteris*, *Botrychiopsis*, *Koretrophyllites* and *Sphenophyllum*, interpreted as interglacial deltaic flood plain; (4) *Dwykea-Sublagenicula-Calamospora* Recurrent Association (recorded in Salto Municipality), composed of bryophytes (*Dwykea*) and lycopod megaspores, very similar to the first association, related to a coastal glacial or coastal interglacial depositional environment with a type- tundra vegetational cover; and (5) *Gangamopteris-Arberia-Stephanophyllites* Association (occurring in Tietê and Cerquillo municipalities), composed of the first glossopterid leaves and fructifications of the Paraná Basin (abundant *Gangamopteris*, *Arberia*, *Arberioopsis* and *Hirsutum*) and sphenophytes (*Stephanophyllites* and *Phyllothea*), suggested as coastal prograding or alluvial environment, of an interglacial phase at the end of the sedimentary history of the Itararé Group. The first four associations are of Pennsylvanian age while the last one is of Asselian-Sakmarian age.

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## 1. Introduction

The Gondwana continent was modified continuously in relation to its environment, climatic conditions and latitudinal positions, mainly during the Late Carboniferous–Early Permian interval, when it was closer to the South Pole (Scotese, 2000; Torsvik and Cocks, 2013). These modifications viz., variations in the sea level, paleo-latitudinal position, oceanic circulation, beyond other factors, had contributed for the establishment of the well-known Late Palaeozoic Ice Age (LPIA). Vast areas of the Gondwana were under glacial

cover having records of movements of glaciers from the center-south of Africa to the southeastern region of South America, from Antarctica to the southwestern region of Australia and from Antarctica to north-northeast India (Isbell et al., 2012). The glacial climate not only caused the low temperatures in the polar or sub-polar regions, but also the drying of the subtropical regions, leading to great changes in floras and accentuated global provincialism (Wnuk, 1996; Rees et al., 1999; 2002).

There are evidences of the occurrence of several interglacial/interstadial phases when the glaciers retreated and other (fluvial,

deltaic, lacustrine and marine) environments were established in the Gondwanan sedimentary basins during which plant associations succeeded themselves in floristic and/or evolutionary aspect.

One of the most complete sedimentary records of the LPIA in Gondwana from the Pennsylvanian to the Early Cisuralian corresponds to the Itararé Group (lower stratigraphic unit of the Tubarão Supergroup) of the Paraná Basin. It is constituted by marine and continental glacial sediments and interglacial deposits which are thicker in São Paulo State area than in other parts of the basin (Rocha-Campos and Rosler, 1978; Petri and Souza 1993). On the basis of detailed paleobotanical studies of the Itararé Group outcrops in the northeastern margin of the Paraná Basin (Brazil) and also based on known palynological data (e.g., Souza et al., 1997, 2006; Longhim et al., 2002; Souza and Callegari, 2004; Souza, 2006; Jha et al., 2012) and corresponding lithostratigraphic data, a new attempt of correlation among the interglacial floristic successions of this Gondwanan area is presented here.

Souza (2006) emphasized that the palynological content is the most efficient biostratigraphical tool for the Paraná Basin, because it is abundant and diversified, with wide distribution from the Pennsylvanian to the Middle Permian. But, the biostratigraphy based on Mississippian to Permian Gondwanan plant megafossils has been improved since the last decades of the 20 century, mostly for South America, as made evident by Archangelsky and Cúneo (1991) and Azcuy et al. (2007) indicating the potentiality of phytostratigraphic studies in the Paraná Basin.

Several biostratigraphic schemes based on plant megafossil successions were already proposed for the Gondwanan basins in Argentina (Archangelsky and Cúneo, 1984, 1991; Archangelsky et al., 1987) and for the Paraná Basin, in Brazil (Rösler, 1978; Cazzulo-Klepzig and Guerra-Sommer, 1985a,b; Millan, 1987a,b; Guerra-Sommer and Cazzulo-Klepzig, 1993; Iannuzzi et al., 2007).

The first scheme of macrofloristic successions proposed by Rösler (1978) for the Pennsylvanian to Triassic deposits of the Paraná Basin comprises seven taphofloras, of which the lowest two are concerning the Itararé Group, named (from base to top): 'A' and "Transitional". Despite its frequent utilization, this scheme stands informal and inaccurate due to the scarcity of available taxonomic and taphofloristic data at that time and the difficulties of their lithostratigraphic and chronostratigraphic correlations. Other regional schemes were suggested for the northeastern area of the Paraná Basin in the State of São Paulo by Millan (1987a) and for the southeastern area in the State of Rio Grande do Sul, by Guerra-Sommer and Cazzulo-Klepzig (1993). Whereas, in the State of São Paulo, the taxonomic and biostratigraphic knowledge of the associations were yet incipient, making impossible the establishment of more accurate macrofloristic successions.

Iannuzzi and Souza (2005) described three successive informal floras from the Pennsylvanian to Early Permian interval namely, Pre-Glossopteris, Phyllothea –Gangamopteris, Glossopteris-Brasilo-dendron and Polysolenoxylon-Glossopteris. They established the associations from the base to the middle part of the Itararé Group as Pre-Glossopteris Flora and the associations of the upper part of Itararé Group and basal portions of Rio Bonito Formation as Phyllothea-Gangamopteris Flora.

Meanwhile, at the 12th International Gondwana Symposium at Mendoza, Bernardes-de-Oliveira and her team presented informally a preliminary scheme of the macrofloristic succession for this sedimentary interval occurring in the northeastern area of the Paraná Basin, State of São Paulo which was published only as an abstract in the volume of the proceedings of the symposium (Bernardes-de-Oliveira et al., 2005). Ever since this macrofloristic succession has never been formally established. Therefore the present work aims to formally establish this macrofloristic succession wherein it details the taxonomic components characteristic

of each association, highlights new records on the basis of which the succession is built, also taking into consideration the palynostratigraphic data from this sedimentary interval of this part of the State. Further, integrating macrofloral data with palynological and lithological data the paleoecology has been reconstructed.

## 2. Summary on floristic succession schemes of the Itararé Group in the study area

In a practical sense, the deposits of the Itararé Group in the northeastern border of the Paraná Basin are restricted to the State of São Paulo. Therefore, we will address here only the phytostratigraphic schemes that concern more specifically to the fossiliferous localities or outcrops situated in this state (Fig. 1).

### 2.1. Rösler (1978) Scheme

Rösler (1978) established the Early Gondwanan paleofloristic succession for the Paraná Basin wherein he recognized only two levels for the Tubarão Supergroup in the State of São Paulo, Table 1:

#### 2.1.1. Taphoflora A

It is characterized by the dominance of *Paracalamites*, *Paranocladus*, *Lycopodiopsis* and *Samaropsis* genera, the presence of *Botrychiopsis*, *Noeggerathiopsis*, *Buriadia*, etc. and absence, at least, apparently of *Gangamopteris* and *Glossopteris*.

Stratigraphic position: Itararé Group.

Type-locality: Volpe Ranch (previously named as Mine Ranch), municipality of Monte Mor (São Paulo State).

Age: Probable Stephanian "Pre-Glossopterids", according to Rösler (1978) who considered this taphoflora as records of the oldest paleoflora in the studied sequence.

#### 2.1.2. Transitional taphoflora

It is characterized by the presence of the oldest megafossils of glossopterid leaves (*Gangamopteris* and possible *Rubidgea*, now included in *Gangamopteris* according to Tybusch and Iannuzzi, 2008 and Hoelzel, 2014) from Paraná Basin, associated with some elements of *Paranocladus*, *Noeggerathiopsis* and *Phyllothea*.

Stratigraphic position: upper part of the Itararé Group.

Type localities: Cerquilha (São Paulo State) and Acampamento Velho (Rio Grande do Sul State).

Age: Putative early Sakmarian age, after Rösler (1978) who considered it as a transitional taphoflora between the Taphoflora "A" (Pre-Glossopterids flora, Stephanian) and the Taphoflora "B" (rich in Glossopterids in association with abundant northern elements such as *Asterotheca*, *Pecopteris* spp. and *Annularia* of the Sakmarian to early Artinskian age, occurring in the São João do Triunfo Member of the Rio Bonito Formation in Paraná State).

### 2.2. Millan (1987a) Scheme

With the further increase in the knowledge of palaeobotanical occurrences in the following decade, Millan (1987a) presented a phytostratigraphic scheme for the Itararé Group in the São Paulo State, which can be resumed from the base to the top as in Table 2.

Millan (1987a) recognized three floristic stages:

*Montemorensis* stage - The lowermost stage is compared to the macrofloristic zone Trampeaderense of the Paganzo Basin, in Argentina (Azcuy and Jelin, 1980), which is equivalent to the pre-glossopterids taphofloras or "Taphoflora A" (*sensu* Rösler, 1978) of the Paraná Basin. The association of *Botrychiopsis* cf. *B. weissiana* (ancestral) with the *B. cf. B. plantiana* (descendent) in the Monte Mor taphoflora and the corresponding lithostratigraphic position of the Itu Formation (considered then lower portion of the Itararé

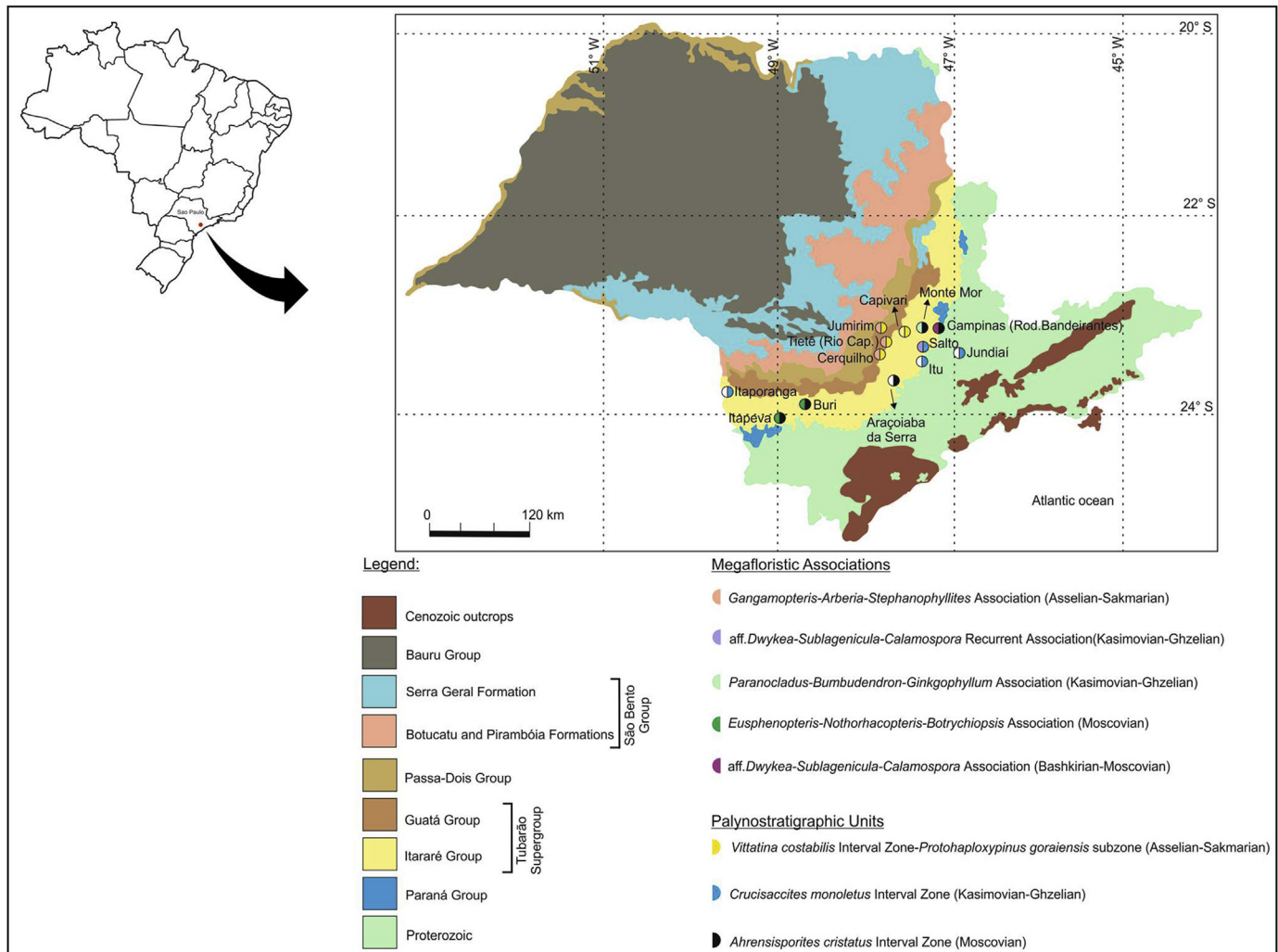


Fig. 1. Map of the State of São Paulo showing the principle occurrence locations of macrofloristic associations.

Group) were arguments for Millan (1987a) to consider the age of the Montemorens stage as transitional Westphalian – Stephanian.

**Medianense stage** - An intermediate stage comprised of three floristic substages viz., Buriense, Cesario-langense and Itapevense. Without reliable evidence, the author considered this intermediate stage not presenting sufficient floristic affinities with “taphoflorules” older or younger to it. Further, he considered the sequence of the substages to be provisional due to the incipient floristic knowledge, recognizing that, the absence of data in those taphofloras did not permit to characterize and distinguish very well one from the other.

**Cerquilhense stage.** The uppermost floristic stage occurring as the Itapema Ranch taphoflora (Cerquillo Velho County, in Cerquillo municipality) recorded the rise of the glossopterids (as

*Rubidgea*, *Gangamopteris*, etc) in the State of São Paulo, a group absent in the lower strata. Based on the absence of the genus *Glossopteris* and presence of microflora in Cerquillo, Millan (1987a) considered it to be similar to the Pre-*Striatiti* palynozone of Arai (1980). Further he correlated Cerquilhense stage to the basal part of the macrofloristic zone *Lubeckense* A or basal part of the Bajo de Veliz Formation of the Paganzo Basin in Argentina suggesting a Stephanian age to it and also suggested this stage to be older than Acampamento Velho in the state of Rio Grande do Sul, which is of early Permian age.

### 3. Materials and method

Taxonomic revision of the taphofloras already known and the

**Table 1**  
Phytostratigraphic scheme for the Itararé Group in the Northeastern border of the Paraná Basin, after Rösler (1978).

Floristic stage	Type taphofloras	Characteristic elements	Age
Transitional Taphoflora	Cerquillo (São Paulo State) and Acampamento Velho (Rio Grande do Sul State).	Presence of the oldest megafossils of glossopterid leaves ( <i>Gangamopteris</i> and some forms previously considered <i>Rubidgea</i> ) associated with elements of <i>Paranocladus</i> , <i>Noeggerathiopsis</i> and <i>Phyllothea</i> from Paraná Basin.	<b>Early Sakmarian</b>
Taphoflora A	Volpe Ranch (previously Mine Ranch),municipality of Monte Mor (São Paulo State).	<b>Dominant genera:</b> <i>Lycopodiopsis</i> , <i>Paranocladus</i> , <i>Paracalamites</i> , and <i>Samaropsis</i> ; <b>Common genera:</b> <i>Botrychiopsis</i> , <i>Noeggerathiopsis</i> , <i>Buriadia</i> , etc. and <b>Absence:</b> at least, apparently of the genera <i>Gangamopteris</i> and <i>Glossopteris</i> .	<b>Stephanian</b>

**Table 2**  
Phytostratigraphic scheme for the Itararé Group in the Northeastern border of the Paraná Basin, after Millan (1987a).

Floristic stage	Sub-stage	Type taphofloras	Characteristic elements	Age
Cerquilhense stage		Mine Road (Alliance County)	<i>Phyllothea</i> , <i>Paracalamites</i> , <i>Cordaiteis</i> .	<b>Stephanian/Sakmarian</b>
		Itapema Ranch	First Glossopterids ( <i>Gangamopteris</i> spp.)-Proto Glossopterids ( <i>Rubidgea obovata</i> , <i>R.lanceolata</i> , <i>R.lanceolata</i> var. <i>truncata</i> , <i>R.itapevense</i> , <i>Fertiliger Brasiloides</i> ), <i>Phyllothea</i> , <i>Paracalamites</i> , <i>Cordaiteis</i> , <i>Stephanophyllites</i> .	<b>Stephanian/Sakmarian</b>
Medianense stage	Itapevense	Santa Marta Farm	<i>Botrychiopsis plantiana</i> , <i>Paracalamites australis</i> , <i>Sphenophyllum</i> , <i>Cordaiteis</i> , <i>Cordaicarpus</i> .	<b>Upper Stephanian</b>
	Cesario-Langense	Santa Catarina Farm	Stem and leaves of lycophytes, with roots <i>in situ</i> . Palynology similar to Buriense substage	<b>Lower Stephanian</b>
	Buriense	Paineira Farm/Ribeirão da Enxovia	<i>Nothorhacopteris</i> with 70–80% of trilete spores ( <i>Vallatisporites</i> , <i>Kraeuselisporites</i> , <i>Cingulatisporites</i> , <i>Cirratriradites</i> , <i>Acanthotriletes</i> ), 5% of monoletes and 20% of monosaccate pollen grains.	<b>Lower Stephanian</b>
Montemorensense stage		Mine Ranch (now Volpe Ranch)	<i>Lepidodendron pedroanum</i> , <i>Lycopodiopsis derby</i> , <i>Brasilidendron pedroanum</i> , <i>Nothorhacopteris</i> sp A, N.sp B, <i>Botrychiopsis</i> cf. <i>plantiana</i> , B.cf. <i>weissiana</i> , <i>Adiantites</i> sp, <i>Ginkgophyllum</i> sp, <i>Paranoeladus?</i> <i>fallax</i> , <i>Buriadia</i> sp, <i>Paracalamites australis</i> , <i>P. levis</i> , <i>P. montemorensis</i> and megasporites: <i>Trileites</i> , <i>Lagenosporites</i> , <i>Calamospora</i> , <i>Duosporites</i> , <i>Setosisporites</i> and absence of Glossopterids.	<b>Westphalian/Stephanian</b>

discovery of new macrofloristic occurrences and their taxonomic identification were being done by Amaral (2000), Amaral and Ricardi-Branco (2004), Amaral et al. (2004), Rohn and Lages (2000), Lages et al. (2002a,b), Rohn et al. (2000), Zampirolli (2001), Zampirolli et al. (1999a,1999b), Longhim (2003), and Mune (2005). Based on these studies, Bernardes-de-Oliveira et al. (1999, 2000, 2001a, 2001b, 2005) were gradually improving the macrofloristic scheme of the Itararé Group in the State of São Paulo, while several local palynofloristic studies were being done by Souza (1996, 2000), Zampirolli et al. (2000), Callegari (2001), Amaral et al. (2001), Souza et al. (2006, 2010), Longhim et al. (2002), Longhim (2003), Mune et al. (2004) and Jha et al. (2012).

Most part of these studies culminated in the palynostratigraphic zonation presented by Souza (2006) for the Pennsylvanian-Cisuralian strata of the Itararé Group at the Northeastern Paraná Basin based on subsurface and outcrop sampling data from São Paulo and Paraná states. On the other hand, based on the paleobotanical data obtained from outcrops located in the State of São Paulo, a biostratigraphic macrofloristic succession is formally recognized and presented as follows, which is composed of five interglacial associations based on the vertical distribution of the identified macrofloral taxa, their relative frequency and the corresponding palynostratigraphic zonation (Table 3).

In order to establish the stratigraphic succession of macrofloras in the northeastern part of the Paraná Basin the following aspects were taken into consideration.

- 1 This scheme is based on lithostratigraphy and lithofacies recognized by authors who studied the succession of beds or facies after careful analysis on the field in different places. Souza Filho (1986) for the area of Campinas until Capivari; Ciantelli Jr. et al. (1983), Cabral and Motta (1985), Silva (1994) for the area of Buri and Itapeva in the south of the State; Gama et al. (1992a, 1992b) for the area of Itu and Salto; and Massoli et al. (1986), Martini and Rocha-Campos (1991), Santos et al. (1996) and França et al. (1996) for the area of Cerquilho. It is also based on the observations made by some of the authors of this work such as presence of diamictites situated below and above the coal or fossiliferous beds in Mont Mor area.
2. The scheme is also based on the taxonomic composition of each macroflora taking into consideration the presence and absence of important plant groups and their first and last appearance or reappearance.

3. The scheme is also based on comparison with the palynostratigraphic zones established by Souza and Marques-Toigo (2005) and Souza (2006) because, although the succession is based on macroflora, the strongest arguments of the palynomorph associations in a completely continental sequence must also be considered.

#### 4. The newly proposed phytostratigraphical scheme

##### 4.1. aff. *Dwykea-Sublagenicula-Calamospora* Association (DSC As)

It is the oldest of all macrofloristic associations known in the northeastern margin of the Paraná Basin.

##### 4.1.1. Type locality

This association occurs in the 96 km of the Bandeirantes Highway in the Campinas Municipality and it is hitherto the only known taphoflora in this biostratigraphic level. Its study was developed by Amaral et al. (2004).

##### 4.1.2. Occurrence

This association is recognized only in the type-locality.

##### 4.1.3. Stratigraphic position

The phytossiliferous assemblage contains abundant megasporites, some bryophyte leafy gametophytes (Amaral et al., 2004), unidentifiable stems and palynomorphs (Souza et al., 2006) preserved in a massive dark grayish mudstone, intensely bioturbated and rhythmically interlaid with fine sandstones. The mudstone outcrop of the 96 Km of the Bandeirantes Highway corresponds to the lithostratigraphic Unit II of Souza Filho (1986) which was stratigraphically positioned in the basal portion of the Itararé Group. This Unit II has its lower contact directly on the crystalline basement and it is intermixed laterally with the Unit I (fining upward sandstones), covering Unit I with siltstones and shales in its upper part. Its upper contact with the Unit III (mudstones and diamictites) is gradational. The Hortolândia (SP) marine fossil fauna, composed of *Phestia*, *Nuculopsis*, *Edmondia* (?) and indeterminate pholadomids (Rocha-Campos and Rosler, 1978), is positioned in the Unit II and cannot be considered as the lateral extension of the Capivari (SP) fauna (composed of *Peruvispira delicata*, *Attenuatella*, *Limipecten capivariensis*, *Rhynchopora grossopunctata*, *Streblopteria* sp. and *Phestia* sp. considered early

**Table 3**

The Macrofloristic Associations of the Itararé Group on the Northeastern margin of the Paraná Basin and their paleobotanical characteristics.

Macrofloristic association	Characteristics	Age	Paleoecology	Occurrences
GAS Association <i>Gangamopteris</i> - <i>Arberia</i> - <i>Stephanophyllites</i>	<b>Abundant taxa:</b> <i>Gangamopteris</i> <i>Paracalamites</i> <i>Phyllothea</i> <i>Stephanophyllites</i> <b>Exclusive taxon:</b> <i>Stephanophyllites</i> <i>sanpaulensis</i> <b>Taxa with first appearance:</b> <i>Arberia</i> <i>Arberiopsis</i> <i>Hirsutum</i>	Asselian/Sakmarian	Communities of interglacial interval composed by: Hydrophilous: sphenophytes living on the margins of interdistributarian channels and on deltaic plains. Mesophilous: proto-glossopterids, gangamopterids, and cordaitales, living on fluvial plains not so far from the margins.	Cerquillo and Tietê
DSC Rec Association Recurrent aff. <i>Dwykea</i> - <i>Sublagenicula</i> - <i>Calamospora</i>	<b>Frequent forms:</b> Stems not identified <b>Taxa recurrent:</b> aff. <i>Dwykea</i>	Late Bashkirian to Moscovian/Late Moscovian to Ghzelian	Probably coastal vegetation like Tundra. This association could be related to the beginning of glacier retreat.	Itu and Salto
PGB-Association <i>Paranocladus</i> - <i>Ginkgophyllum</i> - <i>Brasilodendron</i>	<b>Abundant taxa:</b> <i>Paranocladus</i> <i>Paranospermum</i> <i>Brasilodendron</i> <i>Ginkgophyllum</i> <i>Paracalamites</i> <b>Frequent tax:</b> <i>Bumbudendron</i> <i>Noeggerathiopsis</i> <i>Buriadia</i> <i>Samaropsis</i> <i>Cordaicarpus</i>	Late Bashkirian to Moscovian/Late Moscovian to Ghzelian	Communities of interglacial interval composed by: Hydro-hydrophilous: lycophytes and sphenophytes Hygro-mesophilous: progymnosperms, pteridosperms and cordaitales Xerophilous: conifers in submountain environment, interglacial landscape under a moderate cold climate.	Monte Mor
ENB-Association <i>Eusphenopteris</i> - <i>Nothorhacopteris</i> - <i>Botrychiopsis</i>	<b>Exclusive taxon:</b> <i>Eusphenopteris</i> <b>Abundant taxa:</b> cf. <i>Eusphenopteris</i> sp. <i>Botrychiopsis plantiana</i> <i>Nothorhacopteris</i> cf. <i>N.argentinica</i> <i>Paracalamites levis</i> <i>Paracalamites australis</i> <i>Paracalamites montemorensis</i> <i>Sphenophyllum rhodesii</i> <i>Cordaicarpus zeilleri</i> <b>Taxa with first appearance:</b> <i>Botrychiopsis</i> , <i>Sphenophyllum</i> , <i>Nothorhacopteris</i>	Late Bashkirian to Moscovian	Communities of an interglacial interval composed by: Hydro-mesophilous: represented by pteridosperms or progymnosperms Meso-xerophilous: cordaitales ( <i>Noeggerathiopsis</i> ) probably lived in higher areas not so far from the margins. climate under a moderate cold.	Itapeva and Buri
DSC-Association aff. <i>Dwykea</i> - <i>Sublagenicula</i> - <i>Calamospora</i>	<b>Frequent forms:</b> Stems not identified Abundant taxa: <i>Sublagenicula brasiliensis</i> , <i>Sublagenicula sinuata</i> , <i>Trileites</i> <i>tenuis</i> , <i>Calamospora</i> sp. <b>Taxa with first appearance:</b> aff. <i>Dwykea</i>	Late Bashkirian to Moscovian	Probably coastal vegetation like Tundra. This association could be related to the beginning of glacier retreat.	Campinas (Rod.Bandeirantes Km 96)

Permian), as suggested by those authors. The Capivari fauna is included in the Unit III according to Souza Filho (1986). The lower stratigraphic positioning of this taphoflora is confirmed by palynostratigraphic data of Souza et al. (2006).

#### 4.1.4. Macrofloristic taxonomic contents

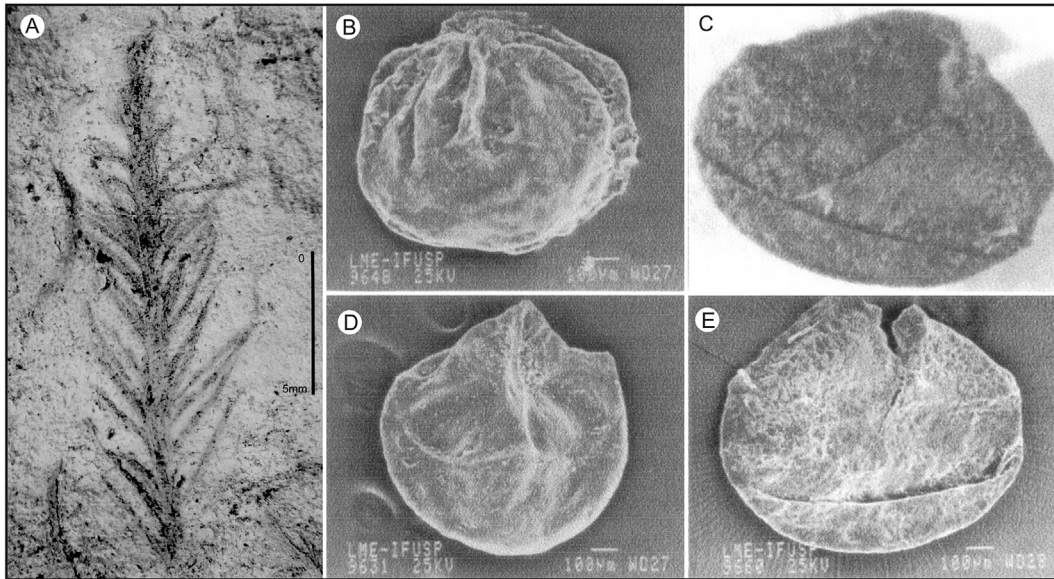
The bryophyte remains were identified by Amaral et al. (2004) as belonging to Class Bryopsida, aff. *Dwykea* sp. presenting many features of this genus which occurs in the tillites of the Dwyka Group of the Karroo Basin (Lower Permian) of South Africa (Anderson and Anderson, 1985).

The bryophyte gametophyte remains of the Itararé Group contain *caulids* covered by *phyllids*. On the axil of one of these *phyllids* a sporophyte is preserved (Amaral et al., 2004). These few bryophytic macro remains occur associated with a huge quantity of megaspores of the species *Sublagenicula brasiliensis* (the most abundant),

*Sublagenicula sinuata*, *Calamospora* sp. and *Trileites tenuis* (Fig. 2) and some unidentifiable stems (Amaral and Ricardi-Branco, 2004).

#### 4.1.5. Palynological content and age

According to Souza (2006), the palynological content of this unit comprises: *Psomospora detecta*; *Retusotriletes nigrtellus*; *Lundbladispora braziliensis*; *L. riobonitensis*; *Kraeuselisporites volkheimerii*; *K. punctatus*; *Vallatisporites vallatus*; *V. drybrookensis*; *Cristatisporites inordinatus*; *C. stellatus*; *C. crassilabratius*; *C. morningavensis*; *C. microvacuolatus*; *Reticulatisporites asperidictyus*; *Leiotriletes virkkii*; *Punctatisporites gretensis*; *Cyclogranisporites parvigranulosus*; *Anapiculatisporites argentinensis*; *Apiculatisporites variornatus*; *Raistrickia pinguinis*; *R. paganciana*; *R. rotunda*; *Foveosporites hortonsensis*; *Cannanoropollis janakii*; *C. triangularis*; *Plicatipollenites malabarensis*; *P. densus*; *P. gondwanensis*; *Potonieisporites novicus*; *P. neglectus*; *P. barrelis*; *P. brasiliensis*; *P. magnus*;



**Fig. 2.** aff. *Dwykea*-*Sublagenicula*-*Calamospora* Association. **A.** aff. *Dwykea* sp. GP/3T 2284. **B.** *Banksisporites tenuis* (Dijkstra) emend. Glasspool 2003. B 14- Slide No. GP/3E 9172 stub B 60° SW. **C, E.** *Calamospora* sp. A7-GP/3E 9172 stub A (70° NE) Figure E-A7- GP/3E 9172 stub B (70° NE). **D.** *Sublagenicula brasiliensis* (Dijkstra) Dybová-Jachowicz et al. 1987 emend. Glasspool 2003 A1- GP/3E 9172 stub A 90° SE.

*Divarisaccus stringoplicatus*; *Caheniasaccites flavatus*; *Limitisporites rectus*; *L. hexagonalis*; *Protohaploxylinus amplus*; cf. *Hamiapollenites* sp. and *Botryococcus braunii*. Based on the presence of *Anapiculatisporites argentinensis*, *Cristatisporites inordinatus* and *Psomospora detecta*, these strata were characterized into the *Ahrensisporites cristatus* Interval Zone (AcZ) of Souza (2000, 2006), corresponding to the lower portion of the Itararé Group, corresponding to a Westphalian (= Bashkirian-Moscovian) age.

#### 4.1.6. Paleoecology

This macrofloristic association suggests the existence of a vegetation, probable tundra-like, consisting of bryophytes and lycophytes, in association with sphenophytes, filicophytes and gymnosperms (possible Pteridospermales and/or Coniferales) as indicated by palynomorphs. This phytofossiliferous association allows recognizing a para-autochthony because it aggregates elements of marine coastal environments like tidal plains to others of riparian environments or of fluvial flood plains and to the high continental areas. The autochthony is represented by thalli of bryophytes, which could thrive on rock coast and lycophyte megaspore tetrads on the tidal plains. The allochthonous elements are represented by spores of sphenophytes and filicophytes which could have thrived on the flood plains and the pollen grains of pteridosperms or conifers in mesophytic areas.

The depositional environment could be shallow coastal waters and related to delta evidenced by the huge quantity of megaspores, the equal proportion of pollen grains and spore tetrads and by the preservation of delicate folioid caulids of bryophytes, which suggest a very short transport (Tyson, 1995). The massive mudstone and fine to very fine granodécrescent sandstones were interpreted by Souza Filho (1986) as distal subaqueous fan facies. But the presence of bioturbation and cross stratification or plano-parallel lamination associated with delicate macrofossils could suggest a marine coastal environment like tidal plains in a shallow epicontinental sea with variable rate of sediment influx (P.R. dos Santos, personal communications; Amaral and Ricardi-Branco, 2004). This coastal vegetation, tundra-like suggests the beginning of a deglaciation context of an interglacial phase, with glaciers recession, i.e.,

of proglacial landscape. This situation is very unusual in the paleontological record of the world.

#### 4.1.7. General considerations of the aff. *Dwykea*-*Sublagenicula*-*Calamospora* Association

Based on its stratigraphical position, i.e., near the lower contact of the Itararé Group with the crystalline basement, in the Campinas Municipality (SP) area and also because it belongs to the *Ahrensisporites cristatus* Interval Zone (AcZ) of Souza (2006) and Souza et al. (2006), this macrofloristic association is considered the oldest among those described herein (Table 3). The specific diversity of palynomorphs preserved in shallow marine rhythmic sediments with ichnofossils, in a general context of the Permo-Carboniferous glaciation situated under diamictites, indicates the existence of vegetation near the coast, tolerant to rigorous climates. This vegetation could occupy different habitats such as brackish, occupied by lycophytes (made evident by the short transport of megaspore tetrads), coastal rocky areas covered by bryophytes (also of small transport as demonstrated by the delicate preservation of their foliar sporophyte axis), flood plains of continental fresh water where sphenophytes and filicophytes thrived (revealed by the presence of *Calamospora*, *Punctatisporites* and *Raistrickia*) and inland higher and drier environments covered by pteridospermales and coniferales (revealed by the presence of pollen grains and unidentifiable branches or stems with 1 or 2 cm of diameters). The vegetation could be similar to tundra (present day biome of Alaska and north Canada or south extremity of Argentina and Chile), perhaps associated with a marine transgression at the end of a glacial phase, inferred in the area by the occurrence of the Hor-tolândia marine fauna. The reconstruction of the landscape is given in Fig. 3.

#### 4.2. *Eusphenopteris*-*Nothorhacopteris*-*Botrychiopsis* Association (ENB As)

##### 4.2.1. Type locality

This association has as taphoflora type that occurs in the Santa Marta Farm, in the Itapeva Municipality, São Paulo State (Fig. 4).

#### 4.2.2. Occurrences

Santa Marta Farm (Itapeva Municipality, São Paulo State), Paineira I Farm and Paineira II Farm and Enxovia stream (Buri Municipality, São Paulo State).

#### 4.2.3. Stratigraphic position

The area of Buri and Itapeva in the southwestern part of the state of São Paulo is situated at the north of the Ponta Grossa Arch, near the Guapiara Lineament. The sediments of the Itararé Group are predominant in this area, directly on the crystalline basement in the southern part of the area or on Devonian rocks in other areas and are covered by the sediments of the Tatuí Formation in the north. According to Cabral and Motta (1985), tectonically, the area shows a staggered faulting system like “horst and graben”, in two preferred directions NW-SE and NE-SW with displacements ranging up to more than two hundred meters (Fig. 4). Here, the Itararé Group is characterized by the presence of a large variety of lithologies dominated by very fine to conglomeratic sandstones but also with diamictites, rhythmites, siltstones, shales, and massive claystones including coal layers.

According to Cabral and Motta (1985), there are four lithofacies units recognized within the Itararé deposits in this region viz. **Unit A**- Basal pelitic rocks with some sandstones interpreted as prodelta and deltaic front facies; **Unit B**- Immediately above them are fine to medium sandstones along with conglomerates and siltstone lens with plant remains and coal layers with a thickness of 50 m–100 m, interpreted as deposits of deltaic plain environment; **Unit C**- composed of siltstones and fine sandstones interlaminated and intensely bioturbated. Micro cross stratification, wavy lamination and flaser type suggest a deltaic front environment to a shallow platform environment in a transgressive phase on the deltaic plain sediments of the unit B with accumulation of interglacial coal. **Unit D**- comprises predominantly sandstones and diamictites. There is a basal lithological assemblage of sandstones of diverse granulometry, sometimes arkosic with conglomeratic levels and coal fragments and an upper lithologic assemblage comprising sandstones, diamictites and pelitic beds. This unit represents a relation of continental facies truncating marine sequences showing a coastal marine depositional environment of the deltaic fan type. The sedimentation in this area shows a cyclic character indicating

sedimentation by pulses caused by advances and retractions of glaciers (Silva, 1994). Some authors such as Ciantelli Jr. et al. (1983), Cabral and Motta (1985) and Silva (1994) have considered this area in an upper-middle stratigraphic position of the Itararé Group (Fig. 4).

Lithostratigraphically, this association was included in the “Unit B” of Cabral and Motta (1985), in a horst outcropping within a matrix of fine clastic lithologies associated with coal, under the fine sediments of the “Unit C”, which are overlapped by diamictites of the “Unit D” (Cabral and Motta, 1985). This association is also situated at the middle lower part of the Itararé Group, based on its palynological content given by Zampirolli et al. (2000).

#### 4.2.4. Macrofloristic taxonomic contents

The Santa Marta Farm taphoflora had its components preliminarily identified by Millan et al. (1982) and later in a series of papers published by Millan (1987b, 1989a, 1991a, 1991b, 1993, 1995a, 1995b). The resultant macrofloristic taxa list was modified by revisions done by Zampirolli et al. (1999); Zampirolli (2001); Zampirolli and Bernardes-de-Oliveira (2001) resulting in the following taphofloristic composition: *Paracalamites australis*; *P. montemorensis*; *P. levis*; *Paracalamites* sp.; *Sphenophyllum* cf. *S. churulianum*; *S. cf. S.rhodesii*; *S. sp.*; cf. *Koretrophyllites* sp.; *Botrychiopsis plantiana*; cf. *Eusphenopteris* sp.; *Nothorhacopteris* cf. *N. argentinica*; *Noeggerathiopsis* sp.; *Cordaicarpus zeilleri* and *Samaropsis itapevensis*. The most abundant forms are: cf. *Eusphenopteris* (the only locality in the Itararé Group where this genus was hitherto recognized), *Botrychiopsis plantiana*, *Paracalamites levis*, *P. australis*, *P. montemorensis*, *Sphenophyllum rhodesii* and *Cordaicarpus zeilleri*. In this level, *Botrychiopsis*, *Sphenophyllum* and *Paracalamites* appeared for the first time in the Paraná Basin.

The macroflora of Buri has only one element recognized hitherto, *Nothorhacopteris* sp. It was registered by Perinotto and Rösler (1987) from a subsurface material. The macrofloral composition of this association is given in Table 4 and illustrated in Fig. 5.

#### 4.2.5. Palynological content and age

The microflora of Santa Marta Farm comprises of *Potonieisporites brasiliensis*, *P. congoensis*, *Caheniasaccites flavatus*, *Divarisaccus stringoplicatus*, *Plicatipollenites malabarensis*, *P. densus*,

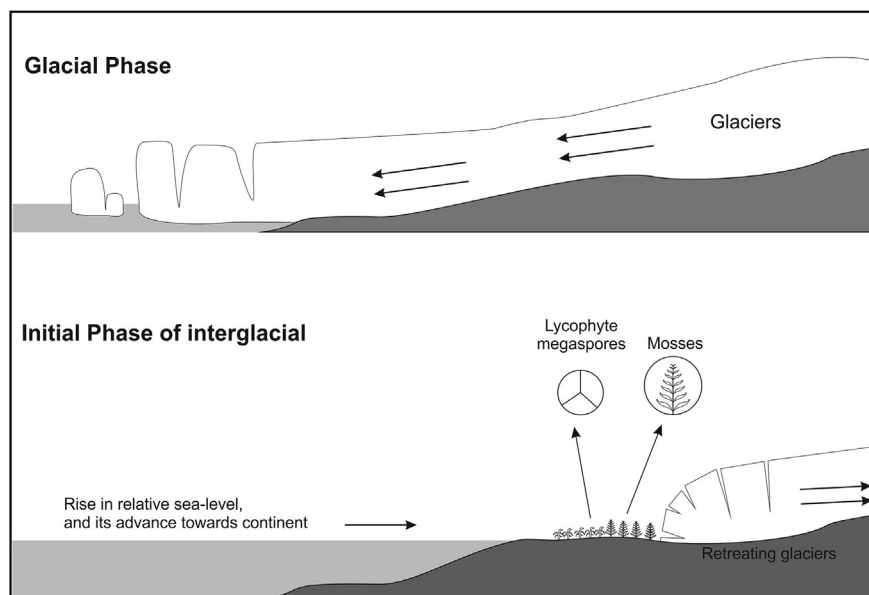


Fig. 3. Reconstruction of the landscape in Campinas during Late Bashkirian to Moscovian, as proposed by R.Rohn (personal communication) with modifications.



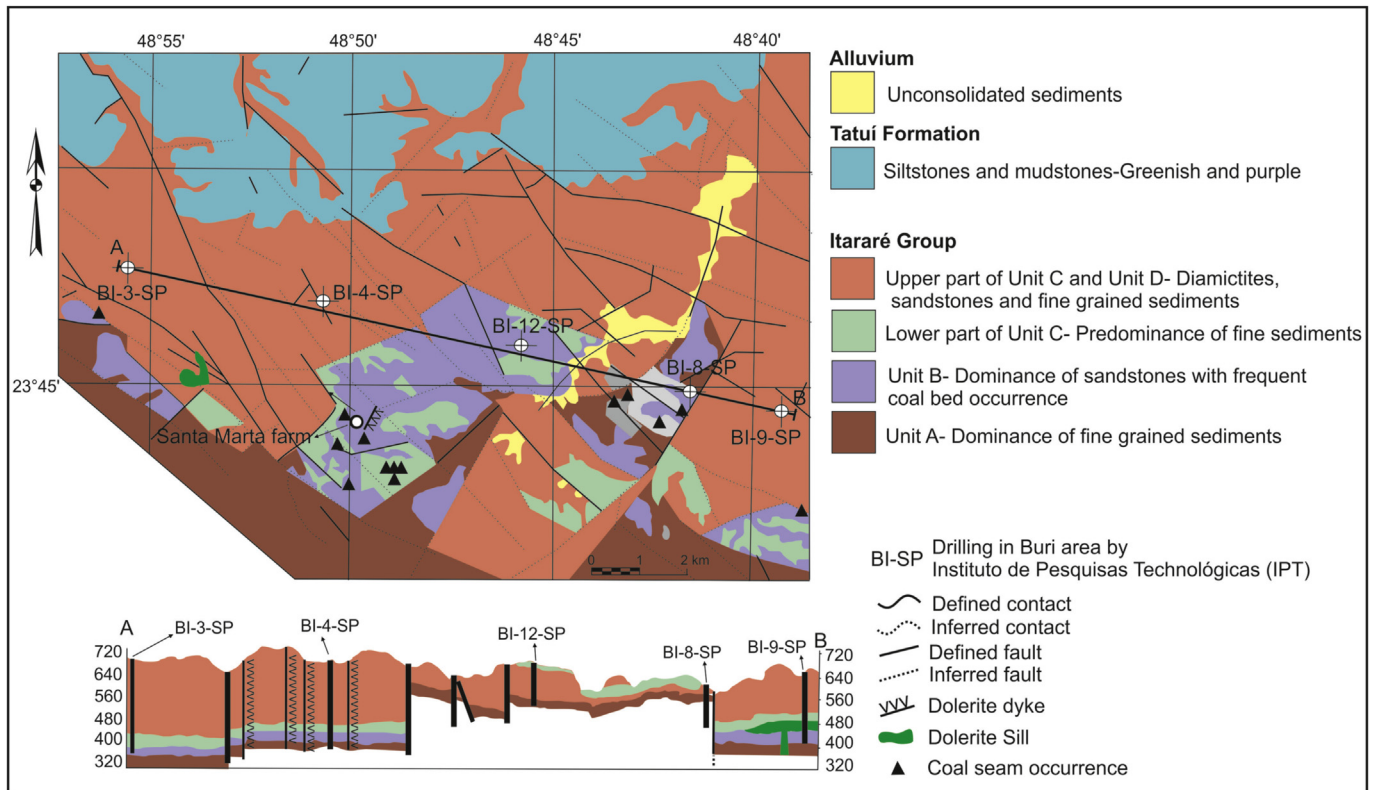


Fig. 4. Map and geological section of Buri and Itapeva area, after Cabral and Motta (1985) (modified from Zampiroli, 2001).

*Cannanoripollis janaki* (Zampiroli et al., 2000). The Buri palynological composition shown by Souza et al. (1993) was revised by Souza (2003) resulting in the following taxa list: *Ahrensiporites* sp., *Anapiculatisporites argentinensis*, *Apiculiretusispora tuberculata*, *Brevitriletes levis*, *Cingulizonates landesii*, *Convolutispora muriornata*, *C. ordonenzii*, *Cristatisporites connexus*, *C. inordinatus*, *C. spinosus*, *C. menendezii*, *C. sp. 1* and *2*, *Densosporites* spp., *Dictyophyllidites* sp. 1 and *2*, *Foveosporites hortonensis*, *Laevigatosporites* sp., *Lundbladispora braziliensis*, *L. riobonitensis*, *Murospora bicingulata*, *Pso-mospora detecta*, *Punctatisporites foveolatus*, *P. gretensis*, *Raistrickia paganciana*, *R. pinguis*, *R. rotunda*, *R. sp. 2*, *Secarisporites irregulares* S. sp., *Stenozonotriletes clarus*, *Vallatisporites ciliaris*, *V. spinosus*, *V. vallatus*, *Caheniasaccites flavatus*, *Cannanoripollis densus*, *C. sp.*, *Crucisaccites latisulcatus*, *Divarisaccus stringoplicatus*, *Plicatipollenites malabarensis*, *P. trigonalis*, *Potonieisporites brasiliensis*, *P. magnus*,

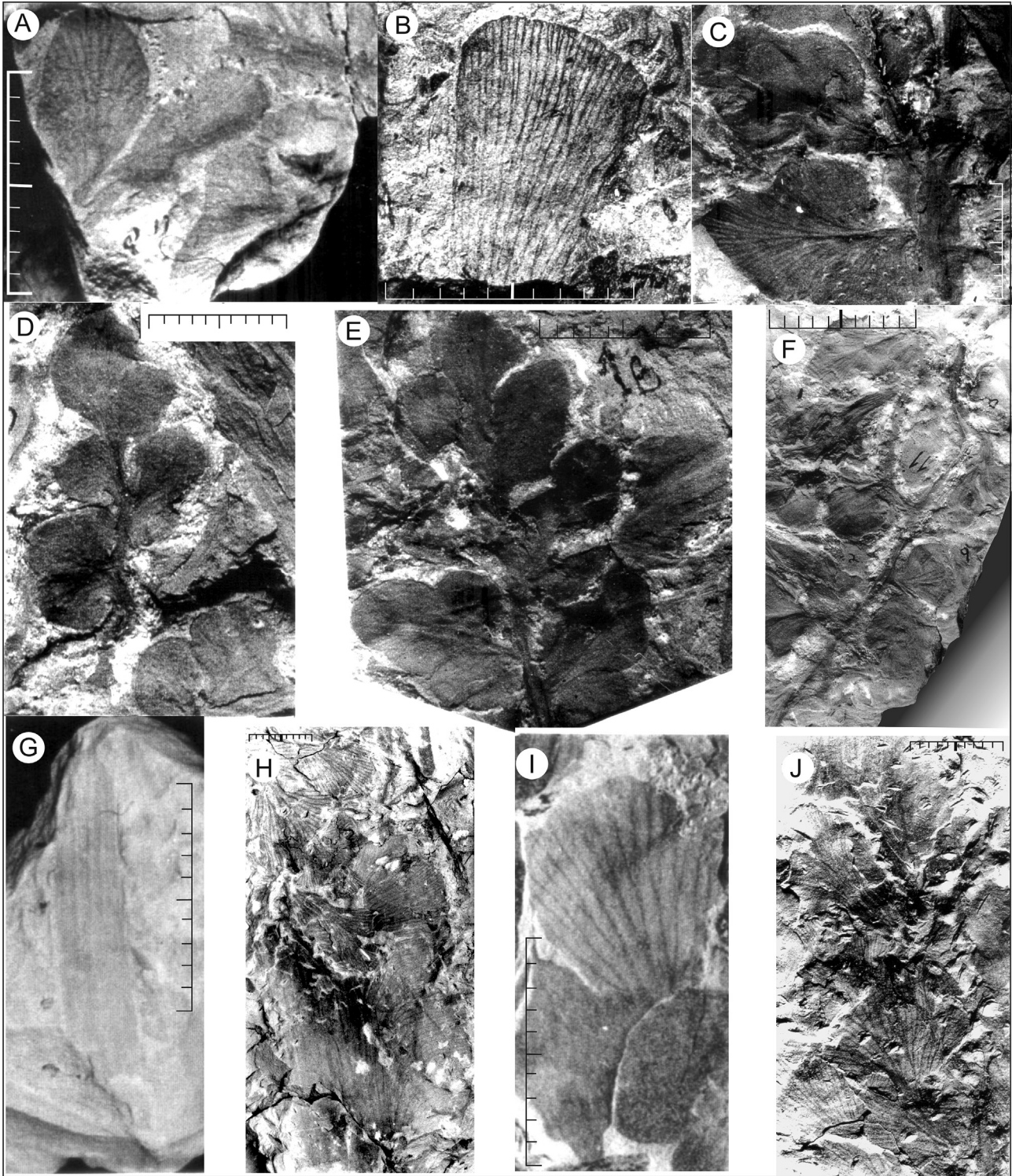
*Protohaploxyipinus* sp., *Tetraporina horologia*, *Deusilites tenuistriatus*, *Portalites gondwanensis* and *Mychrystridium* sp. This composition was ascribed to the *Ahrensiporites cristatus* Interval Zone (AcZ) of Souza (2006), attributed to the Late Bashkirian to Moscovian age. Correlation between the Buri coal and the Malanzán Formation of the Paganzo Basin, Argentina was also proposed. Souza et al. (1993) detected the presence of an Acritarch like *Mychrystridium* sp. typical of coastal shallow marine waters in the palynocomposition of the Buri coals. The predominant palynological components suggest a vegetation characteristic of wet lowlands (lycophytes, sphenophytes and filicophytes) indicating the deposition of sediments in a deltaic plain.

#### 4.2.6. Paleocology

The sedimentary environment of the “B Unit” of Cabral and

**Table 4**  
Macrofloral composition of *Eusphenopteris*-*Nothorhacopteris*-*Botrychiopsis* Association.

Taphofloral group	Millan et al., 1982; Millan (1987a,b–1995a,b)	Zampiroli (2001)
Sphenopsids	<i>Paracalamites australis</i> <i>Sphenophyllum</i> cf. <i>S. churulianum</i> <i>Sphenophyllum</i> sp.	<i>Paracalamites australis</i> <i>Paracalamites montemorensis</i> <i>Paracalamites levis</i> <i>Paracalamites</i> sp. <i>Sphenophyllum</i> cf. <i>S. Churulianum</i> <i>Sphenophyllum</i> cf. <i>S. rhodesii</i> <i>Sphenophyllum</i> sp. cf. <i>Koretrophyllites</i> sp. <i>Botrychiopsis plantiana</i> cf. <i>Eusphenopteris</i> sp. <i>Nothorhacopteris</i> cf. <i>N. argentinica</i> <i>Aphlebia</i> of <i>Nothorhacopteris</i> cf. <i>N. argentinica</i> <i>Noeggerathiopsis</i> sp. <i>Cordaicarpus zeilleri</i> <i>Samaropsis itapevensis</i>
Pteridophylls/Progymnospermopsids	<i>Botrychiopsis plantiana</i> <i>Nothorhacopteris argentinica</i>	
Gymnospermopsids	<i>Cordaites</i> cf. <i>C. Spathulata</i> <i>Cordaicarpus zeilleri</i> <i>Samaropsis itapevensis</i>	



**Fig. 5.** *Eusphenopteris*-*Nothorhacopteris*-*Botrychiopsis* Association. **A, I.** *Sphenophyllum* cf. *S. rhodesii* Rigby 1966. Specimen no. GP/3E 8912D' and D", Figure I- GP/3E 8912. **B.** *Sphenophyllum* sp. MN/UFRJ-1961 Pb **B, C, E.** *Botrychiopsis plantiana* (Carr.) Archangelsky & Arrondo 1971, MN/UFRG-1847 Pb, Figure E- MN/UFRG-1843 Pb. **D, F.** Cf. *Eusphenopteris* sp. Novik 1947, MN/UFRJ-1854 Pb, Figure F- MN/UFRJ-1855 Pb. **G.** *Paracalamites montermorensis* Millan 1977 nov. Emend. GP/3E-2264. **H.** *Aphlebia* of *Nothorhacopteris* cf. *N. argentinica* Archangelsky 1983. GP/3E-892 8B. **J.** *Nothorhacopteris* cf. *N. argentinica* Archangelsky 1983, GP/3E8928 A.

Motta (1985) is interpreted as a deltaic plain, with a large accumulation of woody material and other macrophytofossils. The evidences for this environment are indicated by lithologies such as medium to fine sandstones, with conglomerate lens, siltstones and coal beds with sedimentary structures such as cross-stratifications

and bioturbation by roots. The accumulation of terrestrial organic matter giving rise to the coal beds and foliar stem and seed impressions deposited over each other with few clastic material among them is suggestive of plants deposited "in situ" or with short transport in a deltaic plain context. It was in a reducing,

undisturbed, aquatic environment of interdistributary plains, where the hygrophyll, hygro-mesophyll and putative mesophyll plants of short transport were accumulated.

The hydro-hygrophyll coal precursor communities are represented by the sphenophytes (*Sphenophyllum*, *Koretrophyllites*, etc.). The communities with hygro-mesophylls to mesophylls edaphic exigencies are represented by pteridosperms or progymnosperms (*Nothorhacopteris*, *Botrychiopsis* and *Eusphenopteris*) (Archangelsky, 1983; Cúneo, 1986; Archangelsky and Cúneo, 1991). The meso-xerophytic communities were formed by pteridospermales, cordaitales and probable conifers whose presence is denoted only by pollen grains (like *Plicatipollenites*, *Potonieisporites*, *Caheniasaccites* and *Limitisporites*). These plants would have probably existed far away from this depositional site on higher regions and their pollen grains would have been transported to the site by wind or run-off. The abundant vegetation would suggest that an interglacial phase of warmer climate was predominant in this area.

#### 4.2.7. General assessment of the *Eusphenopteris*-*Nothorhacopteris*-*Botrychiopsis* Association

The ENB Association that occurs in the type-locality, Santa Marta Farm in Itapeva (SP), and also in Paineiras I and II Farms and Enxovia stream in Buri (SP), comprises of herbaceous forms like lianes or hydro-hygrophilous type of lowlands, partially or completely flooded with several species of *Sphenophyllum*, generally associated with wet cold temperate climates; riparian to lake forms such as *Koretrophyllites*, arbustive forms of principal axes with verticillate stems which permitted certain stability on soft substrata of stagnant waters related to marginal lacustrine areas and deltaic interdistributary basins; arbustive pteridosperm communities of *Botrychiopsis* that could grow as dwarfish forms in proglacial “tundra” environments in association with cordaitalean forms (*Noeggerathiopsis*) of hygro-mesophilous to meso-xerophilous edaphic exigencies. These elements suggest that they thrived in areas where the glaciers retreated, in a mild warm climate and marine transgressive phase with wet coastal conditions

favoring peat bog formation. These plants, in general, of short appearance and low diversification are evidences of cooler climatic conditions, with long and few mild winters. A schematic figure of this type of landscape is given in Fig. 6.

The components of this association favor its correlation with the NBG Phytozone of Argentina and with the *Nothorhacopteris* flora of Australia, giving it a Bashkirian to Kasimovian age (Azcuy et al., 2007). Based on the radiometric dating, Césari et al. (2011) established recently an older interval for NBG Phytozone in Argentina, considering it as spanning from Serpukhovian to Bashkirian.

#### 4.3. *Paranocladus*-*Ginkgophyllum*-*Brasilodendron* Association (PGB As)

##### 4.3.1. Type locality

Volpe Ranch (previously named Mine Ranch), in the Monte Mor Municipality (State of São Paulo), Fig. 1.

##### 4.3.2. Occurrence

Only in Volpe Ranch, Monte Mor Municipality (SP).

##### 4.3.3. Stratigraphic position

Lithostratigraphic position of this taphoflora in the Itararé Group is very difficult to be precised. In the Volpe Ranch outcrop, it is possible to observe that the clayey siltstones, shales and claystones associated with the coal beds are under a tillite. They are considered belonging to the Unit IV of Souza Filho (1986: 32–35, Fig. 7) because the lithologies of this unit also contain several bodies of conglomeratic sandstones and medium-fine mudstones including coal or carbonaceous beds. These lithologies occur within different stratigraphic levels of the Unit III which is considered by Souza Filho (1986) as lower middle part in this outcropping area of the Itararé Group (Fig. 7). Based on its macro and microfloristic contents, Rocha-Campos and Rosler (1978) and Souza et al. (1997) inserted Monte Mor occurrence in the middle-lower part of the Itararé Group.

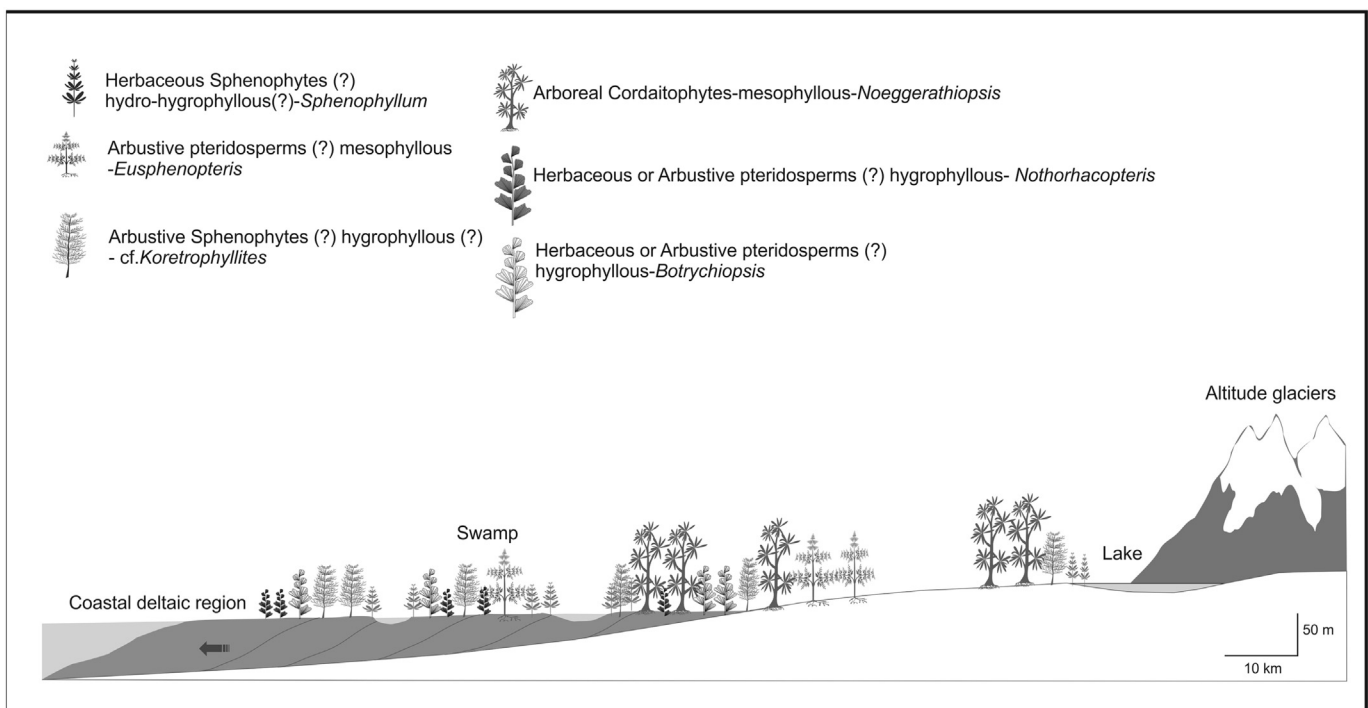


Fig. 6. Reconstruction of the landscape in Itapeva and Buri area during Late Bashkirian to Moscovian, as proposed by R. Rohn (personal communication) with modifications.

4.3.4. Macrofloristic taxonomic contents

The study of the Volpe Ranch macroflora was developed firstly by Millan (1972) followed by many of his successive publications (Millan, 1974, 1975, 1977a, 1979, 1980a, 1980b, 1981a, 1981b, 1985). This macroflora was also the subject of revision in the Master Degree Dissertation of Mune (2005) and other studies by Mune et al. (2012a,b).

This taphoflora is mostly rich in lycophytes (*Brasilodendron* and *Bumbudendron*) and conifers (*Paranocladus* and *Buriadia*) with some subordinate elements of sphenophytes (*Paracalamites* spp and *Koretrophyllites*), pteridospermales (*Botrychiopsis* and *Nothorhacopteris*), Ginkgoales (*Ginkgophyllum*), occurring in clayey siltstones and shales associated with coal beds. The revision of this macroflora by Mune and Bernardes-de-Oliveira et al. (2007a) furnished the following composition list (Table 5).

The dominant forms of this association are: *Paranocladus*, cf. *Paranospermum*, *Ginkgophyllum*, *Brasilodendron*, and *Paracalamites*.

Common forms include: *Bumbudendron*, *Noeggerathiopsis*, *Buriadia*, *Samaropsis* and *Cordaicarpus*. Other forms present in this association are: *Nothorhacopteris*, *Botrychiopsis* cf. *B. plantiana*, cf. *Cyclocladron* sp. and *Leptophloeum* cf. *L. sanctae-helenae*. The conifers *Buriadia* and *Paranocladus dusenii* and its respective seed *Paranospermum* have their first biostratigraphic appearance in Paraná Basin in the Monte Mor macroflora. The macrofloral composition of this association is given in Fig. 8.

4.3.5. Palynological content and age

The palynological contents of the Monte Mor sediments were initially identified by Daemon (1974), who verified the occurrence of laevigate, apiculate and zonate spores and monosaccate and striate pollen grains along with *Tasmanites* sp? and unidentified hystrichospherid, considered reworked. He attributed the Monte Mor coal to the H<sub>1</sub>/H<sub>2</sub> subintervals in palynostratigraphic position of Sakmarian age in the Daemon and Quadros (1970) scheme. Later

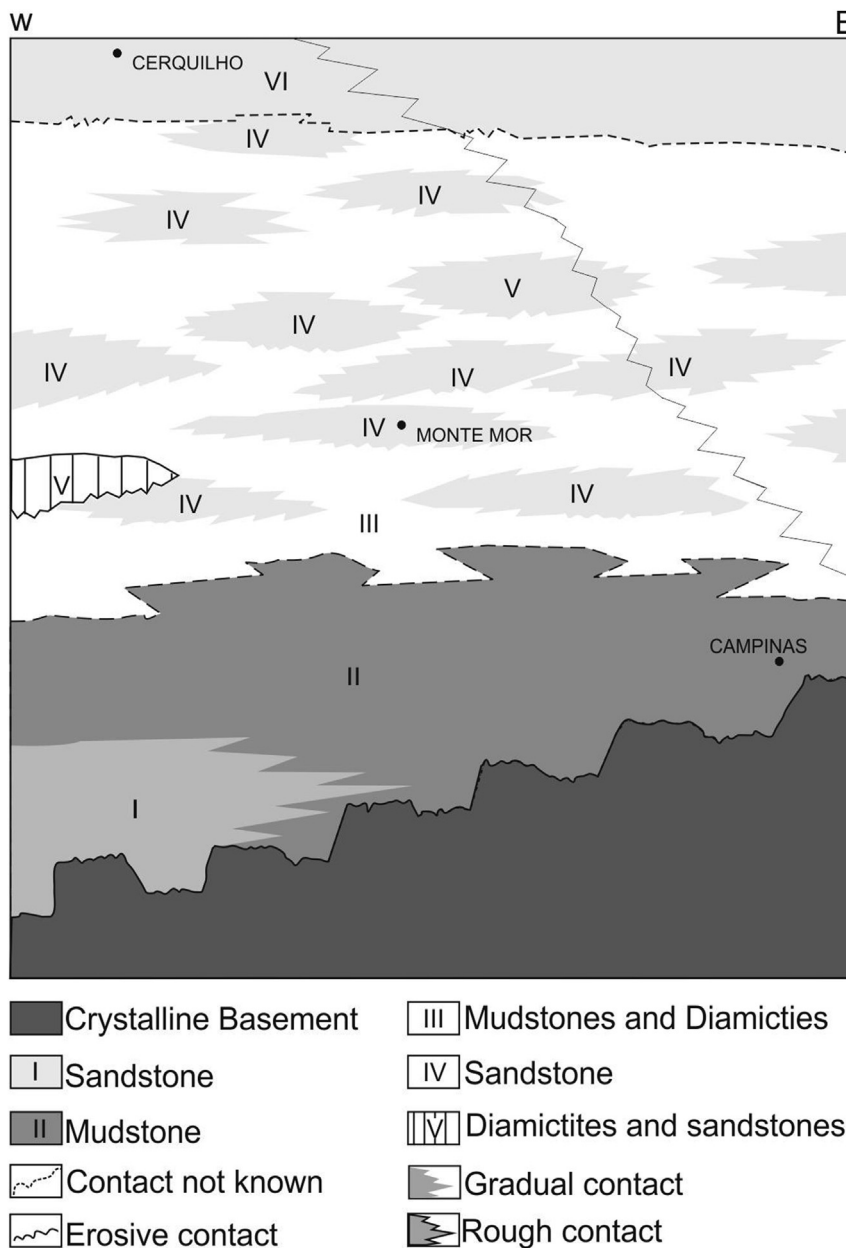


Fig. 7. Lithostratigraphical units of Itararé group in Monte Mor (modified from Souza Filho, 1986).

**Table 5**

List of megafossil components of the Volpe Ranch (Monte Mor, SP), macroflora (\*\*\*) = Not identified before).

Milan 1972 to 1987	Actual list	No. Of specimens
<i>Lepidodendron pedroanum</i>	<i>Leptophloeum</i> cf. <i>L. sanctae-helenae</i>	1
<i>Lycopodiopsis pedroanus</i> (parts)/ <i>B. pedroanum</i> (parts)	<i>Brasilodendron pedroanum</i>	7
***	aff. <i>Brasilodendron</i> sp.	1
<i>Lycopodiopsis pedroanus</i> (parts)/ <i>B. pedroanum</i> (parts)	<i>Bumbudendron</i> cf. <i>B. paganianum</i>	3
<i>Lycopodiopsis</i> sp. A; <i>Lycopodiopsis pedroanus</i> (parts)/ <i>B. pedroanum</i> (parts)	<i>Bumbudendron millanii</i>	3
<i>Lycopodiopsis derbyi</i>	cf. <i>Cyclodendron</i> sp.	3
<i>Sphenophyllum</i> sp. A (parts)	<i>Trizygia</i> sp.	1
<i>Sphenophyllum</i> sp. A (parts)	Indeterminate <i>Sphenophyllales</i>	4
<i>Paracalamites</i> cf. <i>P. levis</i> (parts)	<i>Koretrophyllites</i> sp.	4
<i>Paracalamites australis</i> (parts)	<i>Paracalamites australis</i>	8
<i>Paracalamites</i> cf. <i>P. levis</i> (parts)	<i>Paracalamites levis</i>	10
<i>Paracalamites montemorensis</i> (parts)	<i>Paracalamites montemorensis</i>	12
<i>Paracalamites australis</i> (parts)	<i>Paracalamites</i> sp.	1
<i>Nothorhacopteris</i> cf. <i>N. ovata</i>	cf. <i>Nothorhacopteris</i> sp. A	3
<i>Nothorhacopteris</i> cf. <i>N. chubutiana</i>	cf. <i>Nothorhacopteris</i> sp. B	2
<i>Botrychiopsis</i> cf. <i>B. Plantiana</i> ; <i>Adiantes</i> sp.	<i>Botrychiopsis</i> cf. <i>B. plantiana</i>	4
? <i>Botrychiopsis</i> cf. <i>Weissiana</i>	cf. <i>Botrychiopsis</i> sp.	2
cf. <i>Ginkgophyllum</i> sp. A	<i>Ginkgophyllum</i> cf. <i>G. diazzi</i>	10
***	<i>Ginkgophyllum</i> cf. <i>G. kidsonii</i>	1
***	(?) <i>Ginkgophyllum spatulifolia</i>	1
<i>Noeggerathiopsis hislopii</i>	<i>Noeggerathiopsis</i> cf. <i>N. hislopii</i>	6
<i>Paranocladus</i> ? <i>fallax</i>	<i>Paranocladus duseii</i>	14
<i>Buriadia heterophylla</i>	<i>Buriadia</i> aff. <i>B. heterophylla</i>	5
<i>Cordaicarpus barbosanus</i>	<i>Cordaicarpus barbosanus</i>	1
***	<i>Cordaicarpus cesarii</i>	1
***	<i>Cordaicarpus</i> sp.	3
<i>Cordaicarpus nitens</i> (parts)	<i>Paranospermum cambuiense</i>	34
<i>Cordaicarpus nitens</i> (parts)	<i>Paranospermum millanianum</i>	8
***	<i>Samoropsis barcellosa</i>	1
***	<i>Samoropsis</i> cf. <i>S. cuerdai</i>	1
<i>Samoropsis seixasi</i>	<i>Samoropsis</i> aff. <i>S. seixasii</i>	2

the microfloristic studies of the Monte Mor sediments were carried out by Souza et al. (1997), Souza (2000), Mune (2005); Mune and Bernardes-de-Oliveira, (2007a) and Jha et al. (2012).

Souza et al. (1997) analyzed the Monte Mor palynological assemblage and found it richer in striate pollen grains such as *Protahaploxylinus* in comparison with Buri palynological assemblage (Souza et al., 1993). They concluded that this difference could be attributed to a paleoecological control or an older age of Buri Coal. Souza (2000) preferred to consider as more probable the possibility of this difference in palynocomposition as a result of distinct paleoecological sources because Araçoiaba da Serra and Monte Mor not only presented a greater diversification of striate pollen grains than Buri but also were associated with spores (*Ahrensiporites cristatus*, *Cristatisporites* spp., *Reticulatisporites muricatus*) and monosaccate pollen grains (*Florinites occultus*, *Caheniasaccites flavatus*, *Cannanoropollis janakii*, *C. perfectus*, *Limitisporites rectus*, *Plicatipollenites malabarensis*, *Potonieisporites barrelis*, *P. magnus*, *P. novicus*) which meant a Westphalian age, similar to Buri. Therefore, Souza (2000, 2006) and Azcuy et al. (2007) considered Monte Mor, Araçoiaba da Serra, Buri and Itapeva as belonging to the same *Ahrensiporites cristatus* Interval Zone of Westphalian age (=Late Bashkirian to Moscovian age).

However, Mune (2005) and Jha et al. (2012) have observed *Scheuringipollenites maximus* in the palynological assemblage of Monte Mor and have attributed to it a Kasimovian to Gzhelian age, i.e., to the *Crucisaccites monoletus* Interval Zone (CmZ) of Souza (2006).

This work which is based on macrofossil associations agrees with this point of view considering that it corresponds to the first appearance of conifers (*Paranocladus*, *Buriadia* and seeds such as *Paranospermum*) in Paraná Basin, and the greater number of species in common with *Krauselcladus-Astherotheca* Phytozone of Argentina. Therefore, both micro and macrofossils are indicative of

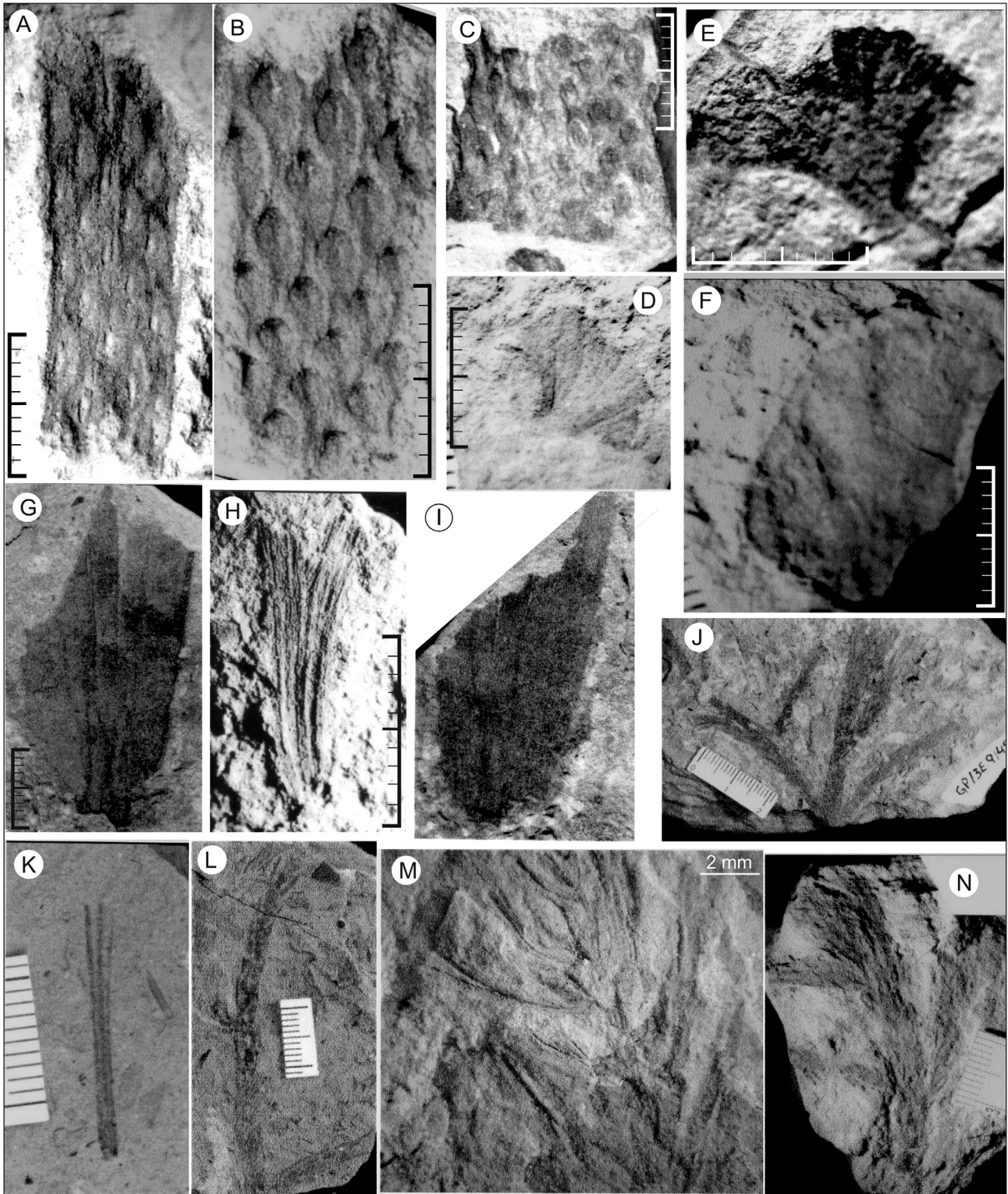
better correlation with *Krauselcladus-Astherotheca* than with NBG Phytozone.

It must be noted that the pollen grains of gymnosperms are very anemophilous, mostly, those of conifers. This factor could lead to a palynological homogenization mainly among areas very close to the coast with marine and continental breeze, as was this entire region. But this homogenization did not take place. New unpublished data was obtained from Monte Mor coal levels in these last years, increasing the palynological taxa list including certain species of plant spores (such as *Convolutispora ordonenzii*, *Psomospora detecta*) and fungi (*Portalites gondwanensis*).

The palynological differences between the compositions of Itapeva/Buri and Araçoiaba da Serra/Monte Mor associations can be interpreted by the following reasons: (i). They are stratigraphical levels chronologically distinct, better than paleoecologically controlled; (ii). These associations are related to the same palynozone (ZAc), but not necessarily to the same correlatable stratigraphical horizons, with some chronological and paleoecological differences between them; (iii). The possibility of *C. monoletus* has an extensive range than previously known must be checked and then adjustments in palynozones are needed.

#### 4.3.6. Paleoecology

The *lobe deltaic facies* of Monte Mor would be included genetically in a deltaic system, into a continental platform shallow sea where pro-gradational and retro-gradational events are recorded. The basal sequence documents the initial *prodelta domain* (siltstones intercalated with fine sandstones), which passes into the *proximal deltaic front facies* (very fine sandstones), thereafter to a *deltaic plain* or *floodplain* (massive conglomerates, tabular and fluted cross-bedding sandstones, purplish mudstones and mudstones with coal, plan parallel sandstone and with ripple marks), followed on the top by a thin facies, such as sandstones with ripple



**Fig. 8.** *Paranoeladus-Ginkgophyllum-Brasilodendron* Association. **A,B,C.** *Brasilodendron pedroanum* (Carr.) Chaloner, Leistikow & Hill 1979. DGP MN Pb a, Figure B- DGP MN Pb b, Figure C- DGP MN804 Pb., **D,E.** Cf. *Nothorhacopteris* sp B. DGP MN 1084 Pb, Figure E-DGP MN 1076 Pb. **F.** Cf. *Nothorhacopteris* sp A DGP MN 1081 Pb. **G,I.** *Ginkgophyllum* cf. *G. kidstonii* (Seward) emend. Anderson & Anderson 1985. GP/3E 9099 a, Figure I- GP/3E 9099 b. **H.** Basal portion of leaf of *Ginkgophyllum* Archangelsky & Arrondo emend. Archangelsky & Leguizamón 1980. DGP MN 891 Pb. **J,L,N.** *Paranoeladus dusenii* Florin 1940. GP/3E 9145, Figure L-GP/3E 9075, Figure N-DGP MN 846 Pb. **K.** *Ginkgophyllum* cf. *G. diazii* Archangelsky & Arrondo emend. Archangelsky & Leguizamón 1980. GP/3E 9073 a. **M.** *Buriadia* aff. *B. heterophylla* (Feistmantel) Seward & Sahni emend. Singh, Rothwell, Mapes & Chandra 2003. GP/3E 9147 a.

marks, cross-bedding of high angle, siltstones and shales (Souza Filho, 1986; Souza et al., 1997). The deposition site is a sequence

of prodelta, deltaic front, beach, flood plains and dune environments before the initiation of the new glacial cycle. In the deltaic

plain, fluvial channel deposits aggregated the mudstones with coal, muddy sandstones and grey sandstones, rich in organic matter and coal with massive structures of flaser and lens, silts with plant remains and freshwater fossils. The proximal deltaic front or tidal plain and delta plain fluvial channel deposits characterize the outcrop of Volpe Ranch finalizing in an ablation flux till supraglacial facies and clasts pavements and loading tillites, at the top (Souza Filho, 1986).

The Monte Mor taphoflora, deposited in the delta plain or floodplain, records the development of hydro-hygrophyll vegetation in peat bogs evidenced mostly by the presence of lycophytes such as *Bumbudendron*, *Brasilodendron*, *Leptophloeum*, *Cyclodendron* and sphenophytes such as *Paracalamites* and *Koretrophyllites*. This association presents hydro-hygrophyllic forms typical of total or partially flooded riparian zones. These forms would be inhabitants of quiet to stagnant water borders of plain rivers or interdistributary areas of deltaic basins. These areas were dominated, probably, by well diversified lycophytes which accumulated in large quantities in some areas, leading to the generation of coal peatery.

This community was represented by hygrophyll and mesophyll elements of the progymnosperms and pteridosperms like *Nothorhacopteris*, *Botrychiopsis*, Ginkgoales like *Ginkgophyllum* and Cordaitales like *Noeggerathiopsis*. The predominance of conifers (*Paranocladus*, *Buriadia* and seeds such as *Paranospermum*) associated to Ginkgoales (*Ginkgophyllum*), i.e., of allochthonous elements in upper beds (20–40 cm above) constituted by thicker clasts (silty sands to arkosic thick sandstones), with paucity or absence of filicophytes and progymnospermic or pteridospermic elements (*Botrychiopsis*, *Nothorhacopteris*) lead to the conclusion of dominance of a montane elements. This indicates that the Coniferales (such as *Paranocladus* and *Buriadia*) were proliferating in a more xerophytic montane to sub-montane environment.

The vegetation is suggestive of a cool temperate climatic biome of an interglacial phase. The interglacial Monte Mor flora flourished under a latitude of 60° S, as suggested by the paleogeographic maps (Scotese, 2000) which confirmed this condition (Fig. 9).

The milder climate established with the retraction of the glaciers and the probable proximity of marine environment from west, allowed the development of relatively abundant vegetation, enabling the formation of coal beds, although not very thick. The presence of *Botryococcus* and conchostraceous carapaces which are

characteristic of fresh water are suggestive of continental environment of deposition. A reconstruction of this scenario is shown in Fig. 10.

This scenario culminated with the arrival of another new glaciation documented 3 or 4 m above by Elias Fausto diamictites/tillite.

#### 4.3.7. General considerations of the *Paranocladus*–*Ginkgophyllum*–*Brasilodendron* Association

Despite the bad preservation of the specimens of this association studied by Millan (1972, 1974, 1975, 1977a, 1979, 1980b, 1981a, 1981b, 1985) and also of the recently collected specimens, the presence of many identified taxa registered were confirmed and new ones were identified by Mune (2005) and Mune and Bernardes-de-Oliveira (2007b). Analysing the taxonomy of the component elements of Monte Mor association in Volpe Ranch outcrop, it is possible to assert that the strata underlying the coal (foot-wall) contains abundant lycophytes: *Brasilodendron* (the more frequent), *Bumbudendron*, *Leptophloeum* and cf. *Cyclodendron*. In the level over the coal (hanging-wall or cap-rock), were preserved sphenophytes (rare *Koretrophyllites* and abundant *Paracalamites*) and some representatives of progymnospermales/pteridospermales (*Nothorhacopteris* and *Botrychiopsis* but differ from Itapeva taphoflora by an absence of *Eusphenopteris*). Some Ginkgoales (*Ginkgophyllum*) and some Cordaitales (*Noeggerathiopsis*) are common among the abundant conifers (*Paranocladus*, *Paranospermum* and *Buriadia*).

Iannuzzi (2001) considered that the macroflora of Monte Mor presented characteristic elements of three Argentinean phytotozones: NBG (*Nothorhacopteris*–*Botrychiopsis*–*Ginkgophyllum*); Interval and *Gangamopteris* (Archangelsky and Cúneo, 1984). Above the NBG phytotozone, Azcuy et al. (2007, Fig. 3.1, 3.2, 3.3), recognized, in the Uspallata-Iglesia, Paganzo and Tepuel-Genoa basins, another Late Carboniferous phytotozone formally proposed by Carrizo and Azcuy (2006) for Paganzo and Rio Blanco basins as *Krauselcladus*–*Astherotheca* Phytotozone for the previously named Interval phytotozone. The characteristic species of this phytotozone are *Botrychiopsis plantiana*, *B. weissiana*, *Brasilodendron* sp., *Bumbudendron nitidum*, *Cordaicarpus cesariae*, *Eusphenopteris sanjuanina*, *Ginkgophyllum diazii*, *Nothorhacopteris argentinica*, *Paracalamites australis*, *Paracalamites levis*, *Paranocladus? fallax*, *Samaropsis cuerdae* which are common or with affinities with the present PGB Association.

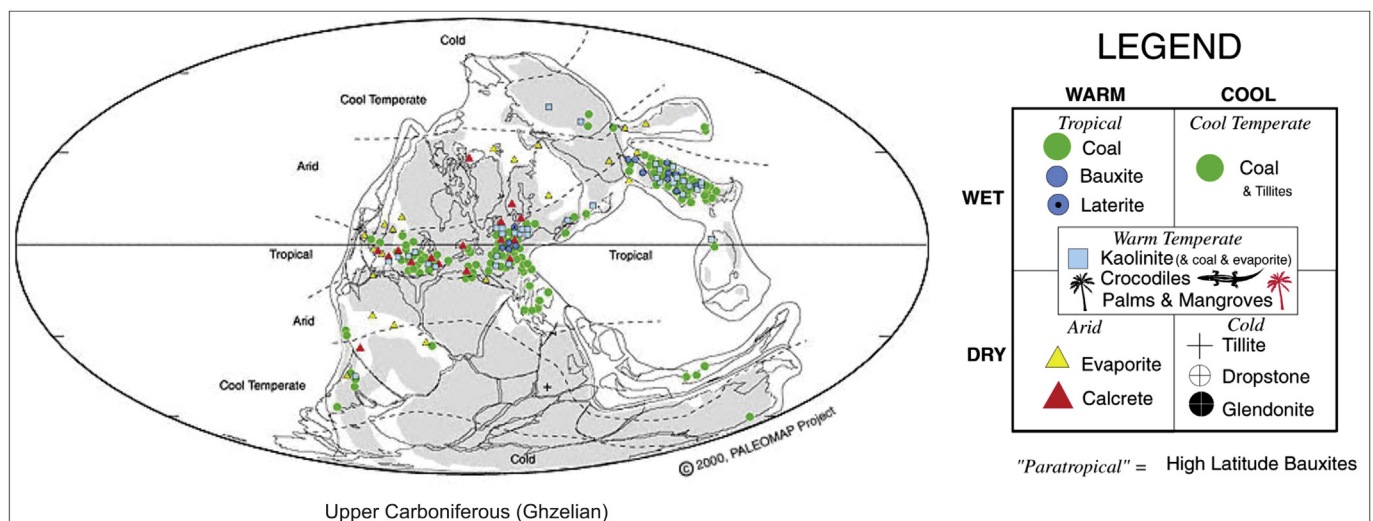


Fig. 9. Paleogeographic map showing the climatic realm of the study area during the Ghzelian. Extensive rainforests covered the tropical regions of Pangea which was bounded in the north and south by deserts. An ice cap covered the South Pole. Source: <http://www.scotese.com/gzelclim.html>.

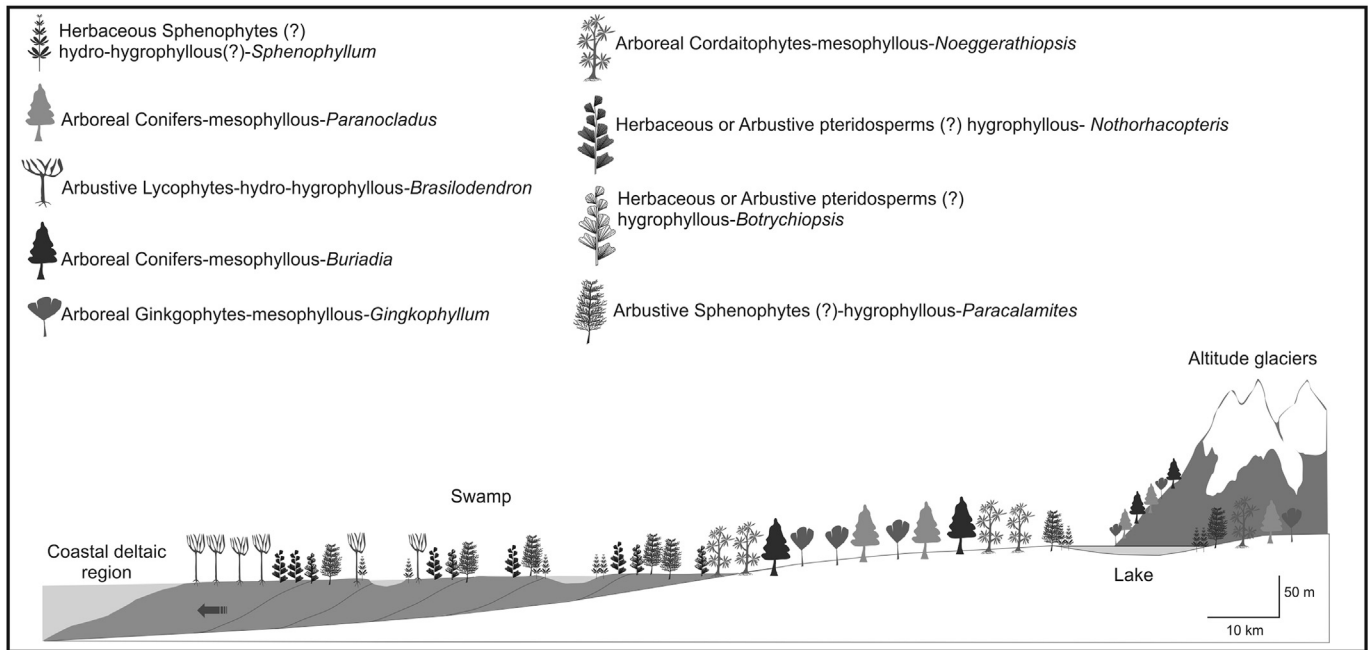


Fig. 10. Reconstruction of the landscape in Monte Mor (SP) during Kasimovian-Gzhelian (modified from R.Rohn personal communication).

Although the PGB association has some species in common with the Argentinean NGB Association, qualitatively the PGB association shares more species in common with the *Krauselcladus-Astherotheca* Phytozone. Moreover, the first appearance of conifers Voltziales in both the Brazilian PGB association (*Paranocladus* and *Buriadia*) and the Argentinean KA Phytozone (*Krauselcladus*) are also indicative of a better correlation. This correlation corroborates better with the *Crucisaccites monoletus* Interval Zone palynoflora (CmZ of Souza, 2006) as attributed by Mune (2005) and Jha et al. (2012) based on the presence of *Crucisaccites monoletus* and *Scheuringipollenites maximus* thereby assigning a Kasimovian-Gzhelian age to it.

#### 4.4. aff. *Dwykea-Sublagenicula-Calamospora* Recurrent Association (DSCRec As)

##### 4.4.1. Type - locality

This association has as taphoflora-type that occurs in the outcrop of the Itararé Group at the km 101.7 of the SP 75 Highway, near the crossing of this route with the SP-308 Highway, in Salto Municipality (State of São Paulo). (see Fig. 1).

##### 4.4.2. Occurrences

This association is recognized only in the type-locality.

##### 4.4.3. Stratigraphic position

The phytofossiliferous assemblage contains abundant megaspores, some bryophyte leafy gametophytes and palynomorphs. They are recovered from a 0.60 m of rhythmites intercalated with massive basal medium grained sandstones and covered by breccias and greenish sandy siltstones, situated below thick and deformed massive sandstones and other lithologies. These rhythmites also contain dropped pebbles. Gama et al. (1992a,b) recognized over this sedimentary sequence other rhythmites, diamictites and sandstones including channels of fluvial sandstones.

##### 4.4.4. Macrofloristic taxonomic content

The macro remains contain bryophyte leafy gametophytes that

have very similar features to those of the Class Bryopsida identified as aff. *Dwykea* found in the basal association - occurring in the 96 km of the Bandeirantes Highway (Campinas, SP). These bryophyte macro-remains as in the first mentioned association also occur among a huge amount of lycophyte megaspores and some unidentified stems. Apparently, the macrophyte association could be considered the same of Bandeirantes Highway but its sufficiently distinct palynological content gives to it a younger age (Kasimovian-Gzhelian) of the *Crucisaccites monoletus* Interval Zone (Souza, 2006). Thus, the best interpretation for this association is of recurrence of a vegetation type of tundra after the end or beginning of another glaciation.

##### 4.4.5. Palynological content and age

The first taphofloristic occurrence was presented by Longhim et al. (2002), which comprised a content of 50 species, of which 26 species are of spores and 23 of pollen grains and 1 species of algae. They include *Calamospora hartungiana*, *Punctatisporites grentensis*, P.sp., *Retusotriletes* sp., *Apiculatisporites* cf. *variornatus*, *Apiculiretusispora alonsoi*, *A. tuberculata*, *Granulatisporites triconvexus*, *Verrucosisorites morulatus*, *V. microtuberosus*, *Dibolisporites disfacies*, *Raistrickia paganciana*, *R. rotunda*, *Reticulatisporites pseudopalliatus*, *Cirratiradites* sp., *Cristatisporites irradiatus*, *C. stellatus*, *C. morungavensis*, *Jayantisporites* sp., *Krauselisporites volkheimeri*, *Lundbladispora brasiliensis*, *L. riobonitensis*, *Vallatisporites arcuatus*, *V. ciliaris*, *V. vallatus*, *Velamisporites* sp., *Cannanopolis densus*, *C. janakki*, *C. triangularis*, *Crucisaccites monoletus*, *Plicatipollenites densus*, *P. malabarensis*, *P. trigonalis*, *Florinites occultus*, *Potonieisporites novicus*, *P. neglectus*, *P. brasiliensis*, *P. magnus*, *P. methoris*, *Divarisaccus stringoplicatus*, *Caheniasaccites flavatus*, *C. sp.*, *Meristocarpus* sp., *Scheuringipollenites maximus*, *Limitisporites rectus*, *L. luandensis*, *L. hexagonalis*, *Protohaploxypinus amplus* and *Botryococcus braunii*. This palynological composition led Souza (2006) to attribute these strata to the *Crucisaccites monoletus* Interval Zone (CmZ), corresponding to the middle part of the Itararé Group, with Westphalian-Stephanian (=Kasimovian-Gzhelian) age, based on the presence of guide species from this zone (*C. monoletus* and *S. maximus*).



#### 4.4.6. Paleoecology

This phytostatigraphical association suggests shallow fresh to brackish water environment due to the presence of *Botryococcus*. On the other hand, the macroflora suggests the existence of a type-tundra vegetal cover, consisting of bryophyte gametophytes, lycophytes (represented by abundant megaspores) and unidentifiable stems. Pebbles dropped into the rhythmite indicate the glacier proximity and confirm the idea of tundra-type for this type of vegetation, while some pollen grains can be associated to more distant vegetation communities. This association can be related to the beginning or ending of a glaciation around the Kasimovian to Gzhelian, based on palynological data (Souza, 2006).

#### 4.4.7. General considerations of the aff. *Dwykea-Sublagenicula-Calamospora* Recurrent Association

The palynoflora recovered from a rhythmite of the Itararé Group outcropping in the Salto region, São Paulo State aroused particular interest to initiate studies with the view of identifying the biostratigraphic level of the macrofossils of mosses and megaspores discovered in this association. Additionally, this rhythmite presented fallen pebbles, attesting the presence of icebergs and therefore leading to the interpretation of a very cold climate during its deposition. Despite this climate, the palynological analysis revealed relatively high diversity of spores and pollen grains (Longhim et al., 2002). Based on its palynological contents characterizing the *Crucisaccites monoletus* Interval Zone (CmZ) (Longhim et al., 2002; Souza, 2006), this association is placed in a median chronostratigraphic position of the Itararé Group. From the macrofloral point of view it corresponds to a recurrence of aff. *Dwykea-Sublagenicula-Calamospora* Association (DSCAs) in superior level when similar periglacial environmental conditions occurred again.

#### 4.5. Gangamopteris-Arberia-Stephanophyllites Association (GAS As)

##### 4.5.1. Type locality

The taphoflora-type occurs in an outcrop of the “Toca do Índio Ranch” (ex-“Itapema Ranch”), situated 9 km SW of the city of Cerquilha (São Paulo State). It is located on the left margin of a stream at the latitude of 23°13' 52" S and longitude 47°25'24" W (Fig. 1).

##### 4.5.2. Occurrence

Beyond the “Toca do Índio Ranch” occurrence, other occurrence localities of this association are: a) Taphoflora of the “Bairro Aliança” (former Ranch of the Mine), located at WNW of the city of Cerquilha, next to the Sewerage Treatment Plant. This taphoflora was studied by Millan et al. (1982); b) Taphoflora of the “Lapa of the Coal” of the “Bairro Aliança” occurring next to the old coal mine of the Figueira Velha stream and in a drill core. This taphoflora was studied by Perinotto and Rösler (1987); c) Taphoflora of the “Rio Capivari” occurring to the left margin of the river Capivari (Municipality of Tietê, SP), about 400 m upstream from the bridge of the old road Piracicaba-Tietê. This outcrop has an extension of more than 100 m along the margin of the river, toward NE direction, at the coordinates 22° 59' 3" S and 47° 45' 05" W, in the altitude of 475 m. This taphoflora was preliminarily described by Rohn et al. (2000).

##### 4.5.3. Stratigraphic position

The “Rio Capivari” taphoflora is included in the upper portion of the Itararé Group, being interglacial because, as observed in field by Rohn et al. (2000), in the outcrop, there is a basal diamictite and near the Tietê - Piracicaba old road, there is another outcrop of

diamictite about 550 m after the bridge (toward Tietê). It is topographically and probably stratigraphically at least 40 m or more above the phytofossiliferous level.

Soares et al. (1977) presented a geological profile carried throughout the Tietê-Piracicaba new road, approximately, parallel to the old road (Fig. 11).

In this profile, an occurrence of plant remains is indicated approximately in the same altitude of the outcrop of the Capivari river (about 475–480 m). This occurrence could be registering the last interglacial events of the Paraná Basin, because it is overlapped by diamictite of the Itararé Group and the contact with the Tatuí Formation (= Rio Bonito and/or Palermo formations), documenting the post-glacial phase occurring at the altitude of ~500 m. However the taphoflora-type locality of the “Toca do Índio Ranch”, in Cerquilha, SP, is subject of different opinions regarding its lithostratigraphic position. According to Perinotto (1987), Rohn (1987), Fúlfaro et al. (1991), Perinotto (1992) and Perinotto and Fúlfaro (2001), this outcrop would belong to the Tietê Formation or Rio Bonito Formation, with post-glacial character. According to these authors, the lithostratigraphic position and the age of the deposits with plant macrofossils of Cerquilha (Toca do Índio Ranch) was not determined with precision because: a) the lithologies are not characteristic of the Itararé Group, probably belonging to the overlapping unit; b) the outcrop occurs isolated, surrounded by geologic faults, making correlation difficult; c) the samples of the outcrop always resulted barren in palynological terms.

Whereas Nagalli and Consoni (1984), based on interpretation of drill core profiles, considered that the Cerquilha coal is situated in the upper portion of the Itararé Group. Souza Filho (1986) based on sequence stratigraphic analysis concluded that the coal of Cerquilha could be among the mudstones and diamictites of the Unit III. Massoli et al. (1986) observed the presence of rhythmites stratigraphically situated 5 m above the coal and phytofossiliferous beds of the “ex Itapema ranch”. According to Martini and Rocha-Campos (1991) and Santos et al. (1996), the coal layers of Cerquilha had been the result of deposits in a prograding coastal, alluvial environment included in the Itararé Group. Considering also the sketch of França et al. (1996), the Cerquilha coal could be included in the Chapéu de Sol Member outcropping into the package of diamictites that could be partially correlated to the Rio do Sul Member, comprising fine lithologies occurring in south of the basin. To summarize, it seems that geologically the phytofossiliferous occurrence of the Toca do Índio Ranch, in Cerquilha (SP) is included in the Chapéu de Sol Member (among the diamictites and sandstones), of the lithostratigraphic unit Taciba Formation, superior strata of the Itararé Group.

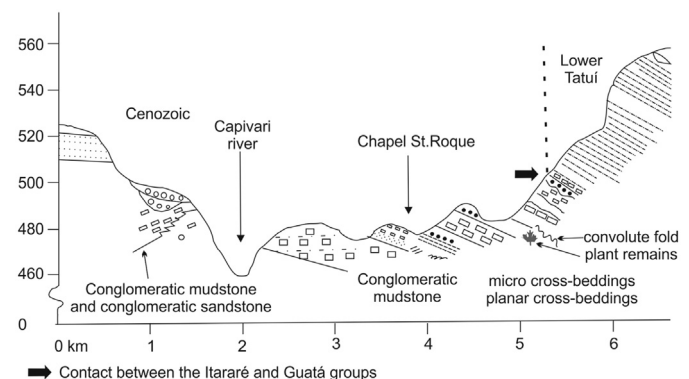


Fig. 11. Geological profile along the Tietê-Piracicaba new road (Soares et al., 1977).

#### 4.5.4. Macrofloristic taxonomic contents

The “Toca do Índio Ranch” occurrence, in Cerquilha (SP), was discovered by Dolianiti and Millan (1973). It was studied by Millan (1977a,b, 1989b, 1991a, 1994 and 1995a,b), Millan and Dolianiti (1977, 1979, 1980a, 1980b, 1981 and 1982), Iannuzzi and Rohn (1995), Ricardi-Branco and Bernardes-de-Oliveira (2000), Rohn and Lages (2000), Bernardes-de-Oliveira et al. (2007) and Hoelzel (2014).

The sphenopsids are represented by four distinct species of three genera (*Paracalamites australis*, *Phyllothea australis*, *P. sp* and *Stephanophyllites sanpaulensis*). According to Rohn and Lages (2000), the *Stephanophyllites sanpaulensis* is a taxon exclusive for this association and the sphenopsids are the most common plant macrofossils from the “Toca do Índio” outcrop. The abundance of sphenophytes has been ascertained, but by our observation the forms most characteristic and diversified in this association are the gangamopterids. Initially eight distinct forms of them namely *Gangamopteris obovata*, *G. angustifolia*, *G. stephensonii*, *G. dolianitii*, *G. aff. G. obovata*, *G. roesleri*, *G. cf. G. mosesii*, *G. sp.* and *G. cf. G. buriadica* were identified by Dolianiti and Millan (1973) and Ricardi-Branco and Bernardes-de-Oliveira (2000). Five distinct forms of protoglossopterids were identified as *Rubidgea* (*Rubidgea lanceolata*, *R. lanceolata* var. *truncata*, *R. itapemensis*, *R. obovata* and *R. sp.* (by Millan and Dolianiti, 1982). Later, Hoelzel (2014) recognized six species of *Gangamopteris* (*G. angustifolia*, *G. buriadica*, *G. dolianitii*, *G. obovata*, *G. roesleri* and *G. stephensonii*) considering all the species of *Rubidgea* synonymized into *Gangamopteris* and Tybusch and Iannuzzi (2008) had already done with similar forms of *Rubidgea* present in the state of Rio Grande do Sul, southern portion of the Parana Basin.

Fructifications like *Arberia*, *Arberioopsis* and *Hirsutum* type (Millan and Dolianiti, 1980b; Bernardes-de-Oliveira et al., 2000)

and putative and very rare forms attributed to *Glossopteris* (Dolianiti and Millan, 1973; Iannuzzi and Rohn, 1995) have their first appearance in this association in the Paraná Basin. Cordaitales are present as *Cordaites* (Millan and Dolianiti, 1981). Platyspermic seeds such as *Samaropsis* and *Cordaicarpus* are also numerous and diversified (Bernardes-de-Oliveira et al., 2007b).

The Table 6 lists the content of taxa of the plant megafossils of the *Gangamopteris-Arberia-Stephanophyllites* Association, as in its localities of occurrences and the macrofloral composition of this association is given in Fig. 12.

Previously the phytofossiliferous assemblage of “River Capivari” (Tietê, SP) was considered older than that of the “Toca do Índio Ranch” (Cerquilha, SP) based on the following arguments: the first assemblage occurs in the superior portion of the Itararé Group, below the last diamictites and its gangamopteroid foliar forms lack a well marked median veins parallel bundle which is a character less evolved than that of the Toca do Índio taphoflora (Cerquilha, SP) (Rohn et al., 2000). But, considering the few forms collected from River Capivari taphoflora, their bad preservation and the presence of *Gangamopteris*, *Arberia* and *Ottokaria* as in the Toca do Índio Ranch taphoflora, it is tentatively also included in the GAS association.

#### 4.5.5. Palynological content and age

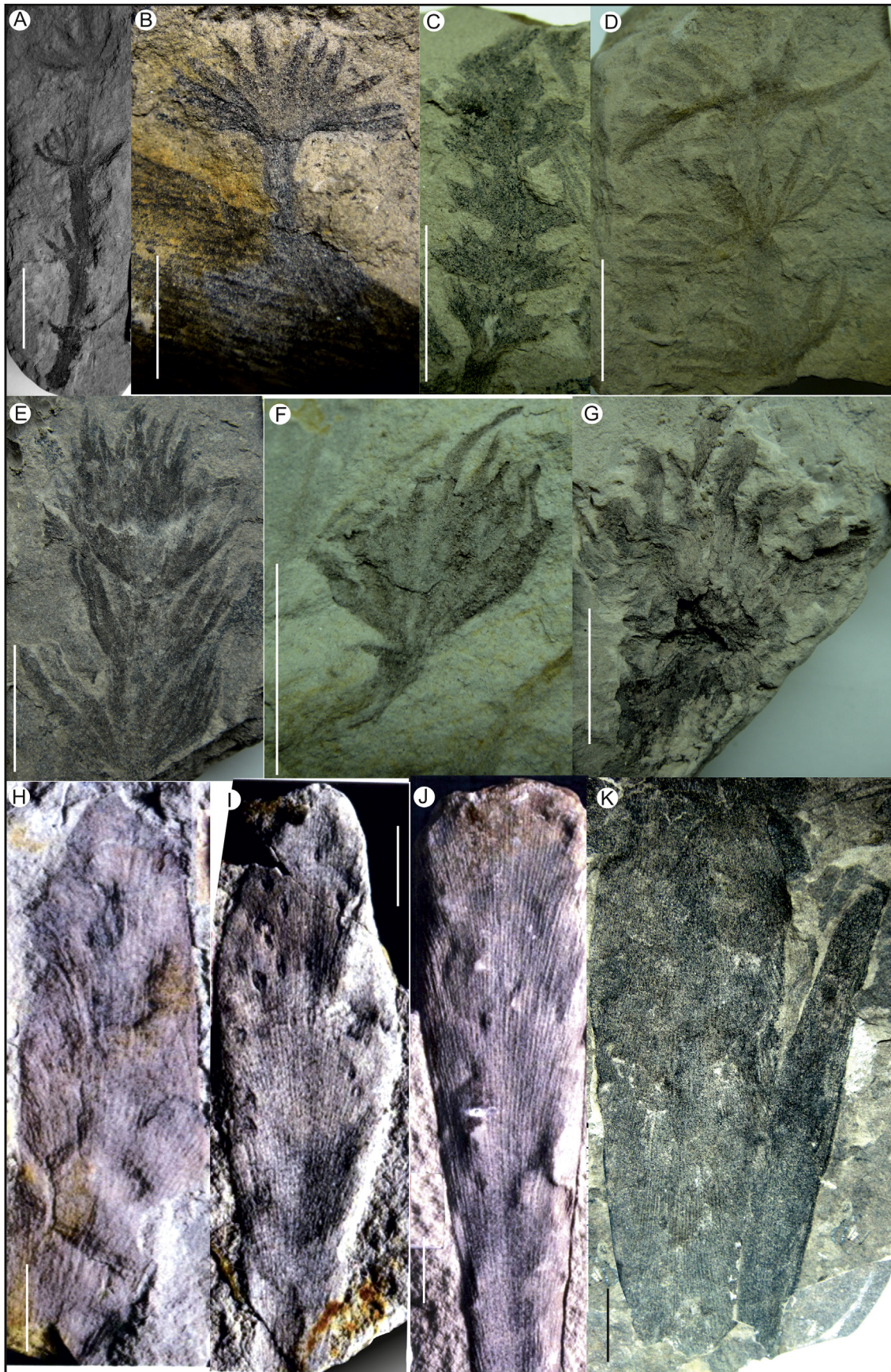
For the upper part of Itararé Group and for almost all the Rio Bonito Formation, Souza and Marques-Toigo (2001, 2003, 2005) proposed the *Vittatina costabilis* Interval Zone divided into two subzones: *Protohaploxylinus goraiensis* and *Hamiapollenites karroensis*.

According to Souza (2006), the *Vittatina costabilis* Interval Zone (VcZ) is “recorded in the northern Paraná Basin, from levels where the occurrences of the genus *Vittatina* become steady and increase

**Table 6**

The plant macrofossil taxa of the *Gangamopteris-Arberia-Stephanophyllites* Association, in its localities of occurrences. (After R.Rohn et al., 2000).

Taxa	Localities			
	Toca do Índio Ranch	Rio Capivari	Bairro Aliança	Lapa do carvão B. Aliança
cf. <i>Lycopodites</i> sp	X			
<i>Paracalamites australis</i>	X	X	X	
<i>Phyllothea australis</i>	X	Cf.		
<i>Phyllothea</i> sp. A.			X	
<i>Stephanophyllites sanpaulensis</i>	X	X		
<i>Noeggerathiopsis</i> sp	X	X	X	
cf. <i>Fertiliger</i> type Brasilóide	X			
<i>Arberia</i> cf. <i>A. minasica</i>	X			
<i>A. sp.</i>	X			
<i>Arberioopsis</i> sp	X			
<i>A. (Samaropsis) rigbyi</i>	X			
(?) <i>Hirsutum</i> sp	X			
<i>Gangamopteris obovata</i>	X	X		
<i>G. angustifolia</i>	X	cf.		
<i>G. stephensonii</i>	X			
<i>G. dolianitii</i>	X			
<i>G. aff. G. obovata</i>		X		
<i>G. roesleri</i>	X			
<i>G. cf. G. mosesii</i>		X		
<i>G. sp.</i>		X		
cf. <i>G. buriadica</i>		X		
(?) <i>Glossopteris</i> sp(?) <i>Glossopteris</i> sp	X			
<i>Cordaicarpus brasiliensis</i>	X			
<i>Samaropsis rigbyi</i>	X	X		
<i>S. dolianitii</i>	X			
<i>S. tietensis</i>	X			
<i>S. moreirana</i>	X			
<i>S. goraiensis</i>	X			
<i>S. cerquilhensis</i>	X			
<i>S. rohnii</i>	X			
<i>S. rugata</i>	X			
Roots “in situ”	X			X



**Fig. 12.** Macrofloral composition of *Gangamopteris-Arberia-Stephanophyllites* Association. **A, B, D.** *Phyllothea australis* Brongniart 1828.GP/3E 1629, Figure B.-P/3E 1509, Figure D-GP/3E 1527a. **C, E and F.** *Stephanophyllites sanpaulensis* Millan and Dolianti 1980 emend Rohn and Lages 2000. GP/3E 1617, Figure E- GP/3E 1497, Figure F-GP/3E 4566. **G.** *Arberia minasica* White emend. Rigby 1972.GP/3E 1528a. **H, K.** *Gangamopteris angustifolia* Mc Coy 1875.GP/3E 1647, Figure K-GP/3E 1497 **L.** *Gangamopteris obovata* (Carr.) White 1908, GP/3E 1611. **J.** *Gangamopteris buriadica* Feistmantel 1879.GP/3E 1488 b.

in frequency". The species *Protohaploxylinus goraiensis* and *Illinites unicus* are recognized in the northeastern Paraná Basin, in the uppermost portion of Itararé Group and/or basal portion of Tatuí Formation (Guatá Group) allowing correlation with the *P. goraiensis* Subzone.

Souza (2006) indicated as outcropping occurrences of this Subzone: Capivari (Daemon, 1974; Arai, 1980), Bairro Aliança in Cerquilha (Lages, 2000; Lages et al., 2002a,b; Souza et al., 2001) and Jumirim-Tietê (Callegari, 2001; Souza and Callegari, 2004). This Subzone would enclose deposits of the upper part of the Itararé Group and the lower part of the Rio Bonito Formation (or equivalents), not presenting resolution to separate the two units. An Asselian- Sakmarian age was attributed to this Subzone.

The most diagnostic taxa of this subzone, after Souza (2006), are taeniate and polyplicate pollen grains: *Protohaploxylinus goraiensis*, *P. amplus*, *P. limpidus*, *P. perfectus*, *Illinites unicus*, *Vittatina costabilis*, *V. woodhousei*, *V. vittifera*, *V. subsaccata*. The monosaccate pollen grains such as *Cannanoropollis* spp., *Plicatipollenites* spp. and *Potonieisporites* spp. are very common. Cingulizone spores are frequent. According to Souza and Marques-Toigo (2005) "The suggested age for the *Vittatina costabilis* Zone is based on previous palynological and paleobotanical data (e.g. Daemon and Quadros, 1970; Rösler, 1978) as well as on radiometrical data obtained from correlative *Fusacolpites fusus-Vittatina subsaccata* Interval Zone of Argentina (Césari and Gutiérrez, 2000, p. 134)".

#### 4.5.6. Paleocology

The environment of deposition for the coal measures of Cerquilha, as registered previously, is interpreted as coastal prograding or alluvial, of an interglacial phase at the end of the sedimentary history of the Itararé Group (Martini and Rocha-Campos, 1991 and Santos et al., 1996).

The early Cisuralian vegetation of Tietê (River Capivari) and Cerquilha (Toca do Índio Ranch and Bairro Aliança) would correspond to hygrophilous communities of *Phyllothea* and *Stephanophyllites* living at the margins of interdistributary channels, in deltaic plains and to communities of type-gangamopteroids as well

as Cordaitales (*Noeggerathiopsis*) living more to the interior of the continent, in fluvial plain environments, or little more raised (mesophilous). A reconstruction of this scenario is illustrated in Fig. 13.

#### 4.5.7. General evaluation of the Gangamopteris-Arberia-Stephanophyllites Association

Proto- or Glossopterids are absent in all the associations previously presented. They were Pennsylvanian associations and they were all included in the "A" taphoflora of Rösler (1978) or designated "Pre-Glossopteris Flora" by Iannuzzi and Souza (2005).

The fifth and last level of the Pennsylvanian-Early Cisuralian interglacial macrofloristic succession in the northeastern edge of the Paraná Basin comprises of associations of characteristic plant macrofossils, registering the entrance of the first elements of the *Glossopteris* Flora in the Paraná Basin as *Gangamopteris* species. According to Rösler (1978), it constitutes the "Transitional taphoflora" between "A" and "B". It corresponds to the lower portion of *Phyllothea-Gangamopteris* flora of Iannuzzi and Souza (2005) restricted to upper strata of Itararé Group.

This association with 32 species of recognized plant megafossils is the most diversified of the five presented. This record evidences that this entrance took place in an interglacial context before the last glacial phase of the Itararé Group, probably corresponding to a temperate cold climate [Rio Capivari taphoflora of Tietê (SP) and Toca do Índio and Bairro Aliança taphofloras of Cerquilha (SP)]. The palynological analysis of the Rio Capivari taphoflora (Tietê, SP) samples carried out by Callegari (2001) and of the Bairro Aliança (Cerquilha, SP) carried out by Lages (2000) include both taphofloras within the *Protohaploxylinus goraiensis* Subzone of the *Vittatina costabilis* Interval Zone of Souza and Marques-Toigo (2001). This Subzone would enclose deposits of the upper part of the Itararé Group and the lower part of the Rio Bonito Formation (or equivalents), without resolution to separate the two units. An Asselian-Sakmarian age was attributed to this Subzone by Souza and Marques-Toigo (2003, 2005) and Souza (2006).

This association, representing the transitional taphoflora *sensu*

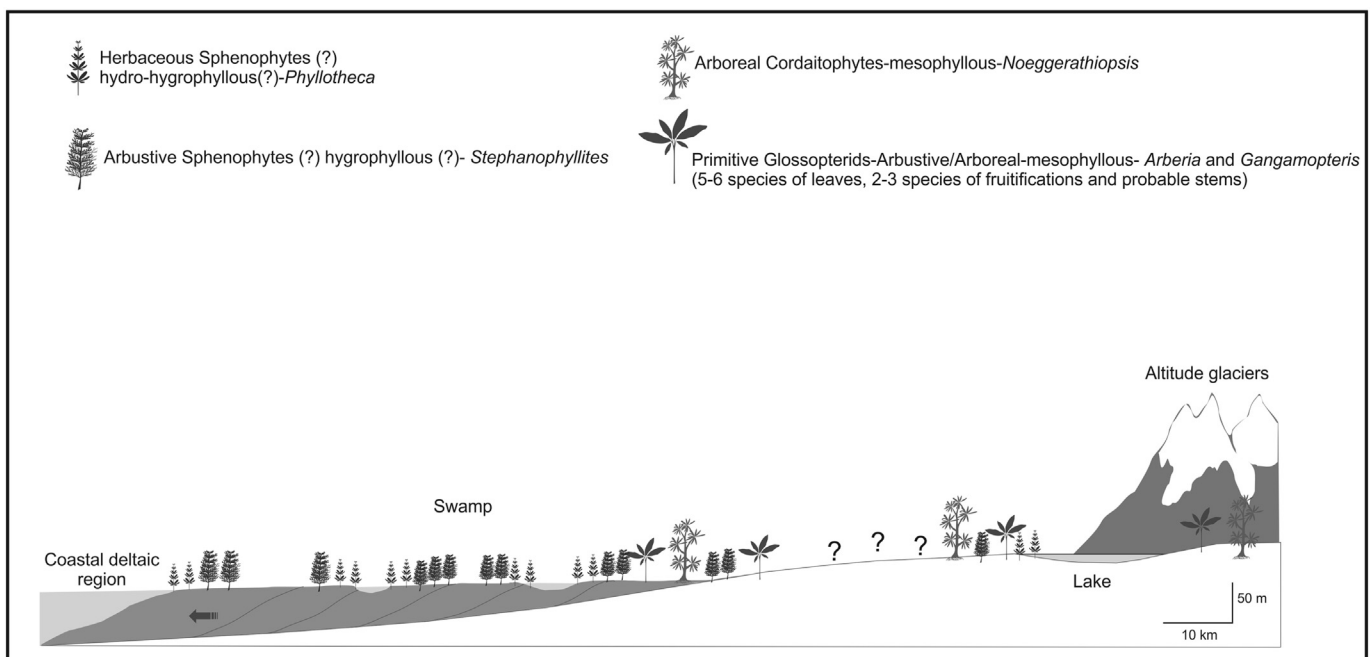


Fig. 13. Landscape scenery in Cerquilha during Asselian- Sakmarian (modified from Rohn Pers. Comm.).

Rösler (1978), could be correlated with the basal portion of the *Gangamopteris obovata* Subzone of the *Botrychiopsis plantiana* Zone of the south of the Paraná Basin *sensu* Guerra-Sommer and Cazzulo-Klepzig (1993), with which it presents in common at least four species (*Gangamopteris obovata*, *G. angustifolia*, *G. buriadica* and *Noeggerathiopsis hislopii*), however, without still presenting well defined elements of the *Glossopteris* genus, it could be considered slightly older than the *Botrychiopsis plantiana* Zone. It could also be correlated with the lower part of the *Gangamopteris* Biozone of the NW of Argentina (*sensu* Archangelsky and Cúneo, 1991). With this Asselian Biozone, it shares elements such as *Phyllothea* sp., *Gangamopteris obovata* and *Noeggerathiopsis hislopii*. It differs from the Argentinean flora mainly by the absence of *Botrychiopsis plantiana*, *Paranocladus? fallax*, *Pecopteris*, *Glossopteris occidentalis* and *G. wilsonii*. These distinctions could not only be attributed to differences in age but also to paleoecological differences.

Comparing with the Indian phytostratigraphic levels, the *Gangamopteris* - *Arberia* - *Stephanophyllites* Association corresponds probably to the lowermost portion of the Talchir Stage based on the presence of the genus *Gangamopteris* and absence of the genus *Glossopteris*. But a diversity of *Gangamopteris* species is found in Cerquilha, while only one species of *Gangamopteris* has been recorded in the basal level of the Talchir Stage suggesting that the Cerquilha area could be a dispersion center of the *Gangamopteris* southwards in the Paraná Basin and also towards the eastern Gondwana towards the Indian basins (Hoelzel, 2014).

## 5. Results and discussions

The northeastern part of Paraná Basin presents one of the oldest floral successions of the Gondwanaland, together with Argentina and Australia. The São Paulo State, in comparison to other parts of the Paraná Basin, hosts one of the most complete sedimentary records of the Gondwana glaciation from the Late Carboniferous to the Early Permian time, thus facilitating greater scope for detailed studies. They correspond to the Itararé Group sediments of the Gondwana I Supersequence. Biostratigraphical studies from a paleobotanical perspective within the State of São Paulo dates back to the pioneering contributions of Rösler (1978), followed by Millan (1987a) and more recently by Bernardes-de-Oliveira et al. (1999, 2000, 2001a, 2001b, 2005).

Considering the Rosler scheme (1978) it is possible to notice that only two phytofossil horizons were known and included in the Itararé Group of the São Paulo State during that time (Table 1). Millan (1987a) expanded the knowledge of the palaeobotanical succession adding Itapeva and Cerquilha occurrences but with many subdivisions of horizons not yet completely known and established (Table 2). Bernardes-de-Oliveira et al. (2005) in an abstract, proposed a new scheme which in this work is detailed and well based. In this work, a formal scheme of the paleofloral succession in the late Paleozoic interglacial sequence occurring in the State of São Paulo based on macroflora is proposed, along with some supporting evidences from microfloral and lithostratigraphical data. A very basal interglacial and periglacial associations are recognized just on the border of Paraná Basin- *Dwykea-Sublagenicula-Calamospora* Association (late Bashkirian- Moscovian) and its recurrence later in Salto distinguished by their different palynological compositions and stratigraphical positions (Kasimovian-Gzhelian, Souza, 2006). The *Eusphenopteris-Nothorhacopteris-Botrychiopsis* Association (Moscovian), recognized in the south of the State of São Paulo, thrived in a regressive interval forming coalseams. The *Paranocladus-Ginkgophyllum-Brasilodendron* Association (Kasimovian) in Monte Mor is characterized by the first entrance of conifers in the Paraná Basin. The *Gangamopteris-Arberia-Stephanophyllites* Association (Asselian-Sakmarian)

recognized in the Rio Capivari and Cerquilha is characterized by the entrance of the *Glossopteris* flora, although the genus *Glossopteris* is absent it is an important sign for the beginning of Permian in the Paraná Basin.

These associations are supported by palynological studies for the assignment of age and they exhibit a sequence of changes through time from late Bashkirian to Asselian-Sakmarian beginning with a tundra like vegetation which re-occurred probably several times from late Bashkirian to Kasimovian, followed by the appearance of progymnosperms and pteridosperms such as *Botrychiopsis*, *Nothorhacopteris* and *Eusphenopteris* during late Bashkirian to Moscovian, thereafter by the first arrival of conifers in Paraná Basin during Kasimovian to Gzhelian, followed by the first arrival of the elements of the *Glossopteris* Flora in the basin in the upper strata of the Itararé Group during the Asselian-Sakmarian. Along with these changes, the analysis of the components of each association indicates that a climatic amelioration favored the proliferation of the flora as shown in the fifth association (GAS Association) which is the most diversified than the others. All these associations are included in the Phase A of the paleogeographic studies for Paraná Basin of Christiano-de-Souza and Ricardi-Branco (2015).

This study should not be considered as the final because the area hosts rich palaeobotanical records facilitating further detailed studies which will aid in the enhancement of the existing knowledge in terms of taxonomy and biostratigraphy thus contributing to the establishment of a better framework of the paleofloral succession in this area.

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