EARLY PERMIAN PALAEOFLORAS FROM SOUTHERN BRAZILIAN GONDWANA: A PALAEOCLIMATIC APPROACH

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ABSTRACT In evaluating the parameters supplied by the taphofloras from different sedimentary facies in the Early Permian sedimentary sequences of the southern part of the Paraná basin, Brazil, it has become evident that the palaeofloristic evolution was related to palaeoecological and palaeoclimatic evolution. The homogeneous composition of Early Permian floral assemblages, which are characterized mainly by herbaceous to shrub-like plants considered to be relicts from the rigorous climate of an ice age (e.g. *Botrychiopsis plantiana*) suggest the persistence of the cold climate. The dominance of *Rubidgea* and *Gangamopteris* leaves with palmate venation associated with glossopterids with penate venation seems to indicate a gradual warming of climate. In roof-shales of coalbearing strata pinnate glossopterids related to *Glossopteris* are common, while *Gangamopteris* and *Rubidgea* (palmate forms) are poorly represented. The sudden enrichment of herbaceous articulates and filicoids fronds is characteristic of this stage and trunks of arborescents lycophytes become important elements. These antrocophilic paleofloras are characterized by typical elements of the "*Glossopteris* flora" associated to tree lycophytes and ferns communities. Therefore, the cool seasonal climate of Early Permian changed into the moist seasonal interval during the Artinskian-Kungurian. This climatic change was significant to the meso-hygrophitic to hygrophitic vegetation registered in roof-shale ferns of the Gondwana Southern Brazilian coalbearing strata.

Keywords: roof-shale floras, Gondwana, Southern Brazil, Paraná basin, *Glossopteris* Flora

INTRODUCTION The intracratonic Paraná basin, with a total area of 1.700.000 Km^2 (1.100.000 Km^2 of which correspond to Brazil) is situated in east central South America. It contains Paleozoic, Mesozoic and locally, also Cenozoic sedimentary rocks. In southern Brazil the major coal-bearing strata occur in the intracratonic Paraná basin, in isolated coalfields located along the margin of the Precambrian shield, from the southernmost part of the state of Rio Grande do Sul, through Santa Catarina to the north of the state of Paraná. The coal measures are considered to range in age from Artinskian to Kungurian (Burjack 1978) and occur in the Rio Bonito Formation, included in the Carboniferous-Early Triassic Sequence (regressive package - Fig. 1).

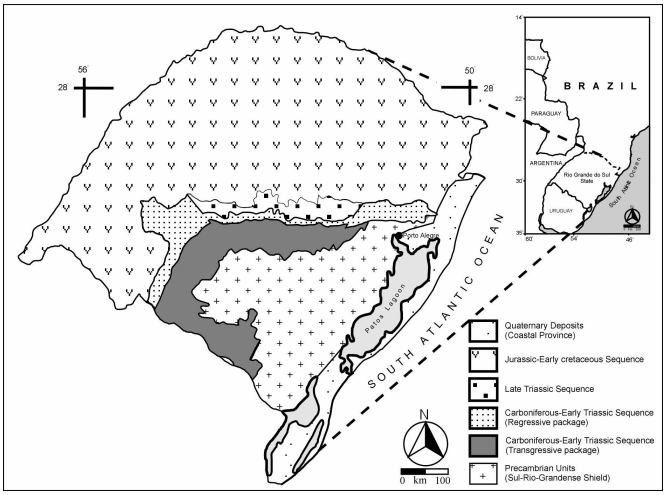

Figure 1 – Location of the Gondwana Sequence in Rio Grande do Sul, southern Brazil (modified after Scherer et al. 1999)

Economic interest in coal seams in the Southern Brazilian Gondwana sequence led to the documentation of the megafloristic composition of the coal-bearing strata at the end of the XIX Century and at the beginning of the XX (Plant 1869, Carruthers 1869, Feistmantel 1876-1886, Zeiller 1895, Seward 1903, Arber 1905). White (1908) introduced the term "pure *Glossopteris* flora" to characterize these associations in coalfields of the states of Santa Catarina and Rio Grande do Sul. Relevant studies on megafloras from coal-bearing strata of Southern Brazil were developed since the first half of the century (Lundqvist 1919, Mendes 1952, Rigby 1970, Guerra-Sommer *et al.* 1991) These studies aim characterize the evolution of Early Permian palaeofloras of the southernmost Paraná basin, emphasizing the "antracophilic" or roof-shale floras. These floras correspond to fossil plant association related to coal seams, but without any further implication regarding the relationship between the vegetation and coal formation (Meyen 1987).

In the present study is adapted the chronological representation proposed by Milani *et al*. (in press) for the Paraná basin. These authors, using sequence stratigraphy, characterize six megasequences for the Paleozoic and Mesozoic intervals of the Basin limited by interregional unconformities and partially eroded. Each megasequence consist of lithological packages formally individualized as lithostratigraphic units by different authors.

PALEOFLORISTIC SUCCESSION The lower part of the Early Permian Gondwana succession in the Southern Brazil is characterized by sediments comprising mainly sandstones and diamictites, deposited in a marked periglacial climate. The megafloral remains recovered from glaciocontinental sediments related to lowlands (Milani *et al*. in press) and included into Itararé Group are assigned to Glossopteridales (*Gangamopteris obovata*, *Gangamopteris buriadica, Gangamopteris angustifolia, Rubidgea lanceolatus*, *Rubidgea obovata*, *Glossopteris indica* Schimper 1874, *Glossopteris communis*, Feistumantel 1896). *Botrychiopsis plantiana* (Carruthers) Arch. Arrondo 1971, is the second taxon in importance; on the other hand, Cordaitales (*Cordaites hislop,* Unger 1850), Coniferales (*Buriadia* sp), Ginkgoales (*Ginkgoites eximia* Seward 1919) are complementary elements. Herbaceous Pteridophyta are rare, represented by a few preserved specimens of *Phyllotheca* sp. (Acampamento Velho, Cambaí, Faxinal, Fazenda Goulart outcrops). The homogenous composition of Early Permian floral assemblages, which are dominated by foliar organs of plants with arborescent habit and shrub-like plants (*Botrychiopsis plantiana*) indicates the persistence of a cold climate (Cazzulo-Klepzig & Guerra-Sommer 1983).

With the retreat of ice caps, the glaciogene sedimentation was replaced by fluviodeltaic and estuarine facies. The taphofloras of the basal siltstones of this sequence recovered from the lower section of Papaléo outcrop (Pasqualini *et al*. 1986) are characterized by the presence of *B. plantiana* associated with articulates (*Phyllotheca indica* Bunburi 1861), conifers (*Buriadia* sp.), and glossopterids with dominant pinnate venation. *Gangamopteris*, *Cordaites* and protoglossopterids (*Rubidgea*) occur as minor elements.

The increasing of herbaceous articulates in this level in relation to those of the basal Permian sequences, and evidences of foliar phytofagy point out to a climate amelioration. The depositional sequence grades upward to more restricted environment conditions that allowed the formation of peat swamps, formed in lagoons protected by barriers under retrograding regime (Holz 1998, Milani *et al*. 1997).

Detailed studies of "roof-shale" floras have revealed some vegetation heterogeneity in roof-shale floras within any one coalfield in Southern Brazilian Gondwana. Some floristic assemblages contains dominant elements of gymnospermic affinity whereas a rich pteridophytic association is registered in others.

The presence of a rich coalfield compressed flora from a "tonstein" layer associated with a coal seam in the Faxinal Mine allowed the identification of an autochthonous taphoflora characterized by the predominance of arborescent gymnospermic forms (Guerra-Sommer 1989, 1992). Fragments of leaves, branches and feminine reproductive

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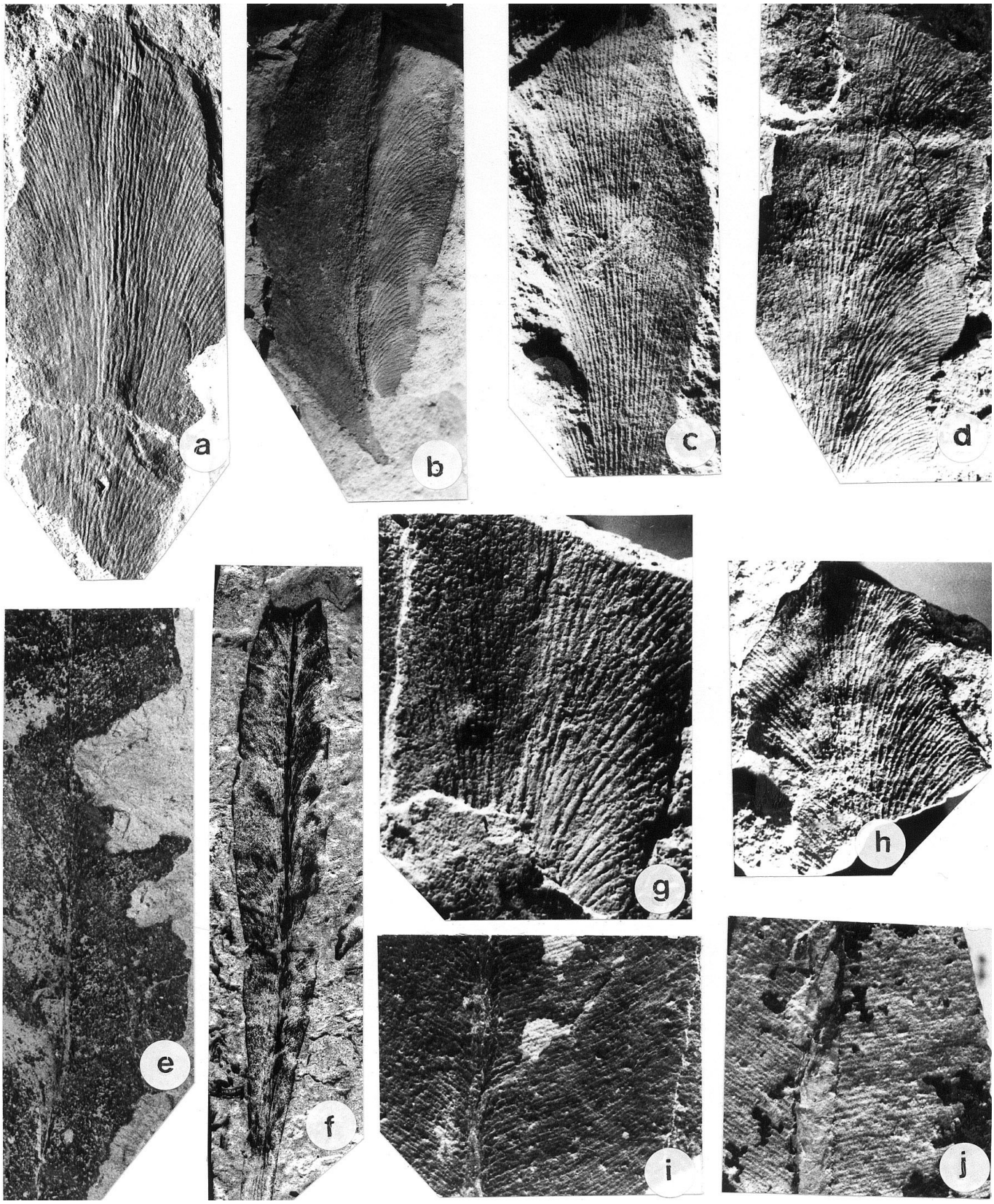

Figure 2 – ***a*** - Rubidgea sp. (*Papaléo outcrop (lower horizon, Rio Bonito Formation) x 0,5;* ***b*** - Gangamopteris sp., *(Acampamento Velho outcrop, Itararé Group) x 1;* ***c*** - Rubidgea sp. *(Acampamento Velho outcrop, Itararé Group) x 0,5;* **d, g, h** - Gangamopteris buriadica *(Acampamento Velho outcrop, Itararé Group) x 1;* ***e*** - Glossopteris sp., *evidence of herbivory (roof-shale, Faxinal mine, Rio Bonito Formation) x 0,8;* ***f*** - Glossopteris sp. *(Quitéria outcrop, Rio Bonito Formation) x 0,4*; ***i, j*** -Glossopteris occidentalis *(roof-shale - Faxinal mine - Rio Bonito Formation) x 1.*

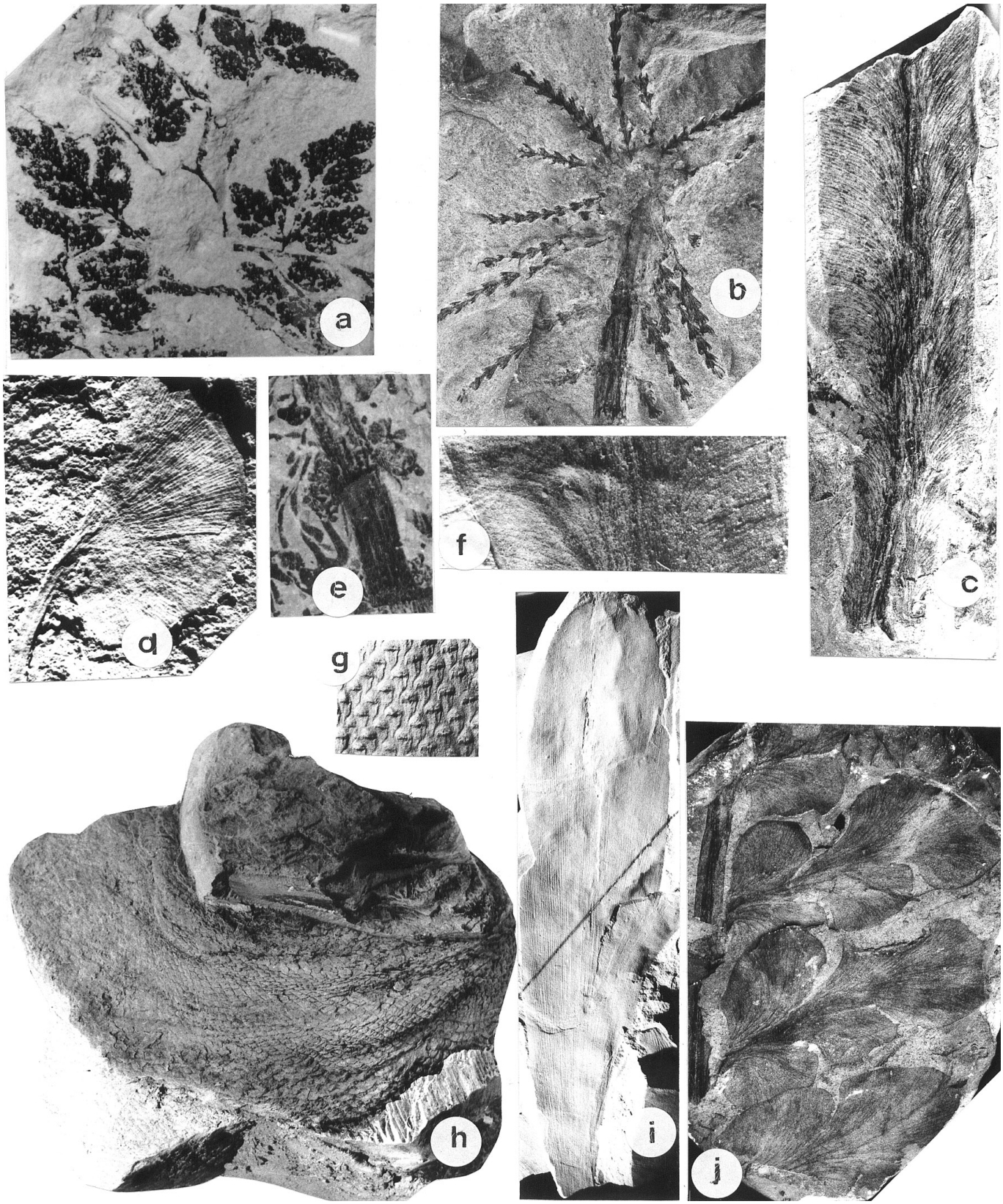

Figure 3 - ***a*** - Sphenopteris *cf*. ischanovensis *(roof-shale, Faxinal mine, Rio Bonito Formation) x 2;* ***b*** - Phyllotheca indica *(Papaléo outcrop, roof-shale, Rio Bonito Formation) x 0,8;* ***c, f*** - Glossopteris communis *(Papaléo outcrop, roof-shale, lower horizon) x 1- x 2;* ***d*** - Gingkoites eximia *(Faxinal outcrop, Itararé Group) x 1,5;* ***e*** - Gondwanostachys sp. *(Quitéria outcrop, Rio Bonito Formation) x 2;* ***g, h*** - Brasilodendron pedroanum *(Quitéria outcrop, roof-shale) x 0,2;* ***i*** - Cordaites sp. *(Papaléo outcrop, roof-shale, upper horizon) x 0,5;* ***j*** - Botrychiopsis plantiana *(Papaléo outcrop, lower horizon, Rio Bonito Formation) x 1.*

structures of glossopterids constitute 70% of the whole association (*Glossopteris brasiliensis* Guerra-Sommer 1992, *G. papillosa* Guerra-Sommer 1992, *G. similis-intermittens* Guerra-Sommer 1992, *Plumsteadia sennes* Rigby 1963, *Platycardia* sp.), cordaitean leaves (*Ruffloria gondwanensis* Guerra-Sommer 1989) occur as a subordinate group (20%); very delicate filicoid fronds (*Sphenopteris* cf. *ischanovensis*) frequently cross-cutting the lamination represent herbaceous forms that lived under the canopy. Epidermis analyses on cuticles of glossopterid revealed xeromorphyc patterns, similar to those from Raniganj coal fields. Studies on recent floras suggest that such features may be related to nitrogen restriction, that occurs nowadays in temperate climate swamps (Lotschert 1969). On the other hand, phytofagy evidences in leaves, caused by herbivore insects suggest that the climate was mild. (Guerra-Sommer 1995)

The cordaitean leaves found in this association are assigned on the basis of their epidermic patterns to *Ruffloria* MEYEN, a typical Angara flora form, which is the most important element in the peat-forming plant association in the Late Paleozoic coals in Angara Province (Meyen 1987).

Herbaceous articulates of hygrophytic habitat such as *Phyllotheca indica*, and its fertiles structures like *Gondwanostachys*, predominate in a megaflora recovered from an antracophylic association at Pantâno Grande region near the Leão Mine (Guerra-Sommer *et al*. 1995). Glossopterids of meso-hygrophytic habitat are important forms (*Glossopteris communis*, *G. browniana*, *G. occidentalis* White 1908, *Gangamopteris mosesii* Dolianiti 1954, and *Rubidgea sp.*). Feminine reproductive structures (*Arberia minasica* (White) Rigby 1972) are common elements. Cordaitean leaves (*Cordaites hislopi*) and seeds (*Cordaicarpus irapuensis* Oliveira 1977 and *Samaropsis* sp) are less frequent. Delicate filicoid fronds (*Sphenopteris* sp, *Rhodeopteridium* sp.) occur as complementary elements. Damaged secondary shoots of *Buriadia* sp. are rare in this association.

At the upper section of the Papaléo outcrop (Burjack *et al*. 1982) antracophylic floras associated with two minor coal seams are dominated by arborescent glossopterids with pinnate venation (*Glossopteris communis*, *Glossopteris occidentalis*). Glossopterids with palmate venation (*Rubidgea* sp, *Gangamopteris obovata*) as well as Cordaitales (*Cordaites hislopi*) and Ginkgoales (*Dicranophyllum* and *Cheirophyllum*) are complementary elements. *Phylloteca indica* is a common herbaceous element (Guerra-Sommer *et al*. 1993). Dense associations of horizontally compressed stumps of Lycophyta (*Brasilodendron pedroanum*, Chaloner, Leistikow, Hill 1979) are important elements in the antracophylic association of the upper coal seam. Fronds of *Pecopteris* sp. with fertile structures corresponding to *Asterotheca* sp. were registered in this level by Iannuzzi and Vieira (1997).

On the other hand, the occurrence of impressions of *Cordaites* leaves in barren strata from the yellow sandstones to siltstones suggest that different taxa in the group would be adapted to distinct habitats, in wet and dry biomass.

Arborescent basal stumps of Lycophyta *in situ* cross-cutting the stratification are the dominant higrophylous element in an autochtonous antracophylic megafloral association at Quitéria region. The basal portions of these stems related to *Brasilodendron* are depicted as a rounded cornlike structure with roots. Filicoid fronds are also represented, as well as to *Botrychyopsis* sp and conifers fragments, representing sterile and fertiles shoots. Casts of lycophytes compressed longitudinally occur in the sequence, parallel to bedding, associated to rare fragments of glossopterids and cordaitean leaves. Jasper & Guerra-Sommer (1998) using taphonomic criteria corroborate the hypothesis of lagoon-barrier system for deposition of the sequence.

Transgressive surface erosion is observed at the top of coalbearing strata. Above this lag there is a package of storm generated sandstones, covered by offshore shales probably corresponding to the maximum flooding surface of the sequence in Southern Brazilian Gondwana (Milani *et al*. in press). In lithostratigraphic terms, the transgressive surface corresponds to the base of Palermo Formation.

The most significanrt taxa of Early Permian sequences in South Brazilian Gondwana are illustrated in figs. 2 and 3. All material mentioned in this paper is kept at the Palaeobotany section, Institut of Geosciences, UFRGS.

FINAL CONSIDERATIONS Palaeobotanical data allowed to establish a climatic evolution during the deposition of Early Permian sequences in South Brazilian Gondwana. It is, therefore, likely that a changeover occur from a cool cyclic climate at the basal strata to the moist, cyclic interval during coal deposition. This climatic change should be significant to the wetland vegetation which developed in lowlands at the time of the deposition of the peats. Thus, the colonization by arborescent Lycophyta, Filicophyta and herbaceous Sphenophyta indicates not only the ecological conditions but also an adaptation to climatic improvement.

It is important to observe that the paleobotanical data here presented allowed to indicate a mild climate at the time of deposition of roof-shale floras in the Southern Brazilian Gondwana. This assumption is in discordance with the inference of a cold temperate climate suggested before (Rigby 1970, Bernardes de Oliveira 1977), but in accordance to Gastaldo *et al*. (1996) which afirm that the temperate areas of Gondwana throughout the Permian was warmer than hipothetized by climatic models. Comparing Early Permian palaeofloras of Southern Brazilian Gondwana with global ice extent based upon tillites and icerafted deposits becomes clear that the correlation of Sakmarian-Kungurian floras was markedly influenced by the waning of a Permian ice age.

The importance of arborescent lycophyte trunks and stems in roof-shale floras suggested that this group of plants could be important elements in the original biomass of some peat-forming coals in South Brazilian Gondwana. This inference is in accordance with the dominance of lycophyte spores in coal bed assemblages (Marques-Toigo & Correa da Silva 1984) and according with Archangelsky & Cesari (1990) with the linkage between these spores and an arborescent habitat based on ultrastructural studies of exine.

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