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PALEOBOTANY AND PALYNOLOGY OF THE RIO BONITO FORMATION (LOWER PERMIAN, PARANÁ BASIN, BRAZIL) AT THE QUITÉRIA OUTCROP

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Abstract. The sedimentary section at the Quitéria outcrop (Pantano Grande, central portion of Rio Grande do Sul State, Brazil) carries diverse and abundant fossil associations of plants and palynomorphs. This section includes coal deposits of the Early Permian Rio Bonito Formation in the Paraná Basin. This contribution presents a taxonomic re-evaluation on paleobotanical records based on an in-depth revision of available data as well as direct analysis from materials deposited in collections (published and unpublished). A taxonomic list is presented, based on the anlysis of all published data. A stratigraphic framework is offered, showing previous and new records in order to better understand the biostratigraphy of the rocks involved. Accordingt to this re-evaluation, the Quitéria Outcrop carries 14 morphospecies of plant macrofossils —including leaves and seeds of Glossopteridales— constituting a typical coal-forming flora. New palynological data derived from six samples taken in this section reveal diversified and abundant associations, including 29 species of spores, 36 of pollen grains and four taxa related to algae and fungi. Quantitative analysis shows that most samples are closely correlated with the previously known "*Lundbladispora-Punctatisporites-Portalites* Association", derived from a hygrophilous environment. The associations are compatible with the *Glossopteris-Rhodeopteridium* Zone and with the *Protohaploxypinus goraiensis* Subzone (base of the *Vittatina costabilis* Zone), related to the Cisuralian (Early Permian). Stratigraphical considerations are based on comparision with neighboring sections and on the regional erosional surface recognized in this outcrop.

Key words. Palynology. Paleobotany. Early Permian. Paraná Basin. Biostratigraphy.

Resumen. PALEOBOTÁNICA Y PALINOLOGÍA DE LA FORMACIÓN RÍO BONITO (PÉRMICO INFERIOR, CUENCA DE PARANÁ, BRASIL) EN EL AFLORAMIENTO QUITÉRIA. La secuencia sedimentaria expuesta en el afloramiento Quitéria (Encruzilhada do Sul, Rio Grande do Sul, Brasil) contiene abundantes y variadas asociaciones palinológicas y restos de plantas fósiles. Esta secuencia es referida a los yacimientos de carbón de la Formación Río Bonito, Pérmico Temprano de la Cuenca Paraná. En este trabajo se presenta una nueva evaluación taxonómica de los registros paleobotánicos sobre la base de una revisión exhaustiva de los datos disponibles, así como el análisis directo de los materiales depositados en las colecciones (publicados y no publicados). Una lista taxonómica se presenta con los registros histórico-sistemáticos y el control estratigráfico de cada taxon con el fin de comprender mejor su importancia bioestratigrafía. De acuerdo con esta reevaluación, el afloramiento contiene 14 morfoespecies de macrofósiles vegetales de hojas y semillas de Glossopteridales, constituyendo una flora típica en la formación de carbón. Los nuevos análisis palinológicos de 6 muestras revelaron asociaciones variadas y abundantes, incluyendo 29 especies de esporas, 36 granos de polen y cuatro relacionadas con los elementos algales y hongos. El análisis cuantitativo demuestra que la mayoría de las muestras está estrechamente relacionada con la conocida asociación de "*Lundbladispora-Punctatisporites-Portalites*, que se describe como de ambiente higrófilo. Las asociaciones son compatibles con la Zona *Glossopteris-Rhodeopteridium* y la Subzona *Protohaploxypinus goraiensis* (base de la Zona *Vittatina costabilis*) del Cisuraliano, Pérmico Temprano. Se proporcionan consideraciones estratigráficas sobre la base de comparaciones con las secciones adyacentes, y de la superficie erosiva regional reconocida en el afloramiento.

Palabras clave. Palinología. Paleobotánica. Pérmico inferior. Cuenca Paraná. Bioestratigrafía.

The main coal-bearing strata of southern Brazil have been known since the 19th century (Carruthers, 1869; White, 1908). They were included in the Permian Rio Bonito Formation of the Paraná Basin. These deposits represent the "Greenhouse phase", which followed the "Icehouse period" affecting Gondwana during the end of the Paleozoic. Plant remains and palynological associations have been commonly recorded from several outcrops of this unit. These fossils elicited reconstructions of the coal-generating paleoflora (Marques-Toigo and Corrêa da Silva, 1984; Guerra-Sommer *et al.*, 1991; Cazzulo-Klepzig *et al.*, 2007). Furthermore, these fossil assemblages have provided records of index-species biostratigraphically useful for correlation.

Among the fossil-bearing horizons within these coal-bearing strata, those exposed at the Quitéria outcrop are regarded as a key section because of their paleobotanical and palynological content (Jasper *et al.,* 2008a). Impressions, adpressions and casts are very abundant, especially casts of *in situ* roots of

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Brasilodendron pedroanum in the upper portion of the section. This outcrop is located in Pantano Grande, in the central part of Rio Grande do Sul State (RS), southern Brazil. The first geological data from this section was provided by Fernandes *et al.* (1989), followed by paleobotanical studies illustrating some Lycophyta casts and specimens of Sphenophyta and *Rhodia*? [*sic*] (begun by Guerra-Sommer, 1989). These occurrences spurred proposals of new taxa that broadened the paleofloristic list recognized in this part of Gondwana.

This paper presents a taxonomic revision of macrophytofossils from this outcrop based on literature and direct examination of specimens housed in various scientific collections, together with new specimens recently collected by us. An updated taxonomic list is presented, including all recent systematic changes made in the last few years, new paleobotanical and palynological records, and new paleoecological and biostratigraphic interpretations. Phytostratigraphic significance is discussed based on frameworks previously proposed for this portion of the basin (Guerra-Sommer and Cazzulo-Klepzig, 1993). Thirteen palynological samples were studied; these provided new paleoecological and biostratigraphical records, taking into account the general biostratigraphic framework established for the southern border of this basin by Souza and Marques-Toigo (2003, 2005).

GEOLOGICAL AND PALEONTOLOGICAL CONTEXT

The Paraná Basin covers about 1,700,000 km^2, mainly in Brazil but also spreading into Paraguay, Uruguay and Argentina. This is an intracratonic basin filled with *c.* 6200 m of Paleozoic and Mesozoic sediments, as well as Mesozoic volcanics (Schneider *et al.*, 1974; Milani, 1997). According to Milani (1997), the basin includes six supersequences, bounded by significant unconformities, *i.e.*, Rio Ivaí (Ordovician–Silurian), Paraná (Devonian), Gondwana I (Pennsylvanian–Permian), Gondwana II (Triassic), Gondwana III (Late Jurassic–Early Cretaceous) and Bauru (Late Cretaceous). The three oldest sequences correspond to transgressive cycles during the Paleozoic, while the other ones represent continental deposits and associated Mesozoic igneous rocks.

Pennsylvanian–Permian strata in the Paraná Basin belong to the Gondwana I Supersequence, which represents a long transgressive-regressive cycle, lithostratigraphically including the Pennsylvanian–Cisuralian Tubarão Group (Itararé Subgroup, and Aquidauana, Rio Bonito, Palermo and Tatuí formations) and the Cisuralian–Lopingian Passa Dois Group (Irati, Serra Alta, Corumbataí and Rio do Rasto formations). This supersequence is characterized by a heterogeneous lithology resulting from different processes and environments. It involves glacial and post-glacial records of marine, continental and transitional facies (Milani and Zalán, 1999). The Rio Bonito Formation represents the onset of post-glacial conditions in this sector of Gondwana during the Early Permian. Predominance of sandstones and pelites —associated to thick coal beds in this formation— represent typical transitional environments such as deltas, lagoons and estuaries (Milani, 1997). These deposits carry a diverse and abundant fossil record of continental and marine faunas and plant macro- and microfossils (Rocha-Campos, 1967). Based on surface and subsurface data, Holz *et al.* (2006) recorded three depositional sequences in the early Permian deposits in the southern part of the Paraná Basin (RS). The second (S2) and the third (S3) sequences are respectively correlated to the deposits of Rio Bonito and Palermo formations; the sequence boundary between them was named SB3.

Sedimentary facies at the Quitéria outcrop were correlated with the final sequences of the Rio Bonito Formation transgressive tract, where coal beds are thinner (Jasper *et al.*, 2006). In order to coordinate phytostratigraphic, palynostratigraphic and sequence-stratigraphic frameworks in Rio Grande do Sul State, Iannuzzi *et al.* (2010) identified the SB3 erosional surface in the upper portion of the section, placing this locality in the uppermost portion the Rio Bonito Formation within the currently accepted regional stratigraphic framework. The data of these authors allowed them to allocate the beds exposed at Quitéria to the uppermost portion of the Rio Bonito Formation, within such stratigraphic framework.

Paleontological studies in the Quitéria outcrop began during the late 1980s. Ten lithofacies (I to X) were recognized by Piccoli *et al.* (1991) in the area surrouding Quitéria. Lithofacies VI was identified in the basal beds and interpreted as a deltaic-system plain in a peat-forming environment. Four biofacies (D to H) were also identified, but it appears that only biofacies E to H occur at this locality. Biofacies E includes a large assemblage of leaf compressions and fructifications, mainly glossopterids, as well as remains of sterile (*Phyllotheca*) and fertile Sphenopsida. This biofacies was subdivided into E1 and E2 based on different palynological assemblages. Trilete spores predominate in E1 (accompanied by a small proportion of pollen grains) while E2 was very similar to E1—lacking spores of Lycopsida and with more fequent pollen grains of Gymnospermae. Biofacies F includes a microflora predominantly constituted by trilete spores (Pteridophyta). Spores of Pteridophyta dominate biofacies G, while pollen grains of Gymnospermae are less frequent.

In the uppermost levels, lithofacies VII was interpreted as fluvial and linked to a delta plain. Biofacies H —only in these levels— inlcuded an assemblage of *in situ* (= in growth position) compressed-impressed stems of arborescent lycophytes, and frond compressions of a probable Pteridophyta (*Rhodea* sp.), reproductive structures, leaf impressions of Glossopteridales and a few branches of *Buriadia*-type Coniferales. A paleosoil horizon with small roots marks the end of the fossil succession.

Plant remains recognized by several authors in this section were reassessed over the past few years (Mombach and Guerra-Sommer, 1990; Guerra-Sommer and Cazzulo-Klepzig, 1993; Guerra-Sommer *et al.*, 1995a, 1995b; Jasper and Guerra-Sommer, 1998, 1999; Jasper *et al.*, 2003, 2005, 2006; Boardman *et al.*, 2006; Iannuzzi and Boardman, 2008; Tybusch and Iannuzzi, 2008; Salvi *et al.*, 2008; Boardman and Iannuzzi, 2010). After careful analysis, all occurrences are mentioned in this paper in order to update knowledge on the fossil content and stratigraphic framework of the beds exposed at the Quitéria outcrop.

The use of new tools —in addition to the existing data on fossil content— has lately been the focus of work carried out at the locality. Jasper *et al.* (2006) associated paleobotanical, palynological, petrographic and faciologic data in an attempt to establish a relation between depositional cycles and paleoecological patterns. In this work, the record of *Striatopodocarpites fusus* (Balme and Hennelly) Potonié 1958 allowed assigning the deposits to the *Hamiapollenites karroensis* Subzone, base of the *Vittatina costabilis* Zone (Souza and Marques-Toigo, 2003, 2005; Souza, 2006). Guerra-Sommer *et al.* (2008a) used petrographic data and charcoal analysis to establish a depositional and successional model of plant communities. This was possible because at this outrcrop the peat-forming process preserved a roof shale flora (*sensu* Guerra-Sommer *et al.*, 2008a), including the upper bed of fossil macroplants until definite clastic burial of the vegetation. According to Jasper *et al.* (2008b) charcoal fragments from this level are evidence of wildfires at this locality during the early Permian.

BIOSTRATIGRAPHIC CONTEXT

Phytostratigraphy

Plant macrofossil biostratigraphic studies have been conducted in rocks from the Paraná Basin since the 1970s. Permian phytofossiliferous assemblages from the southern part of the basin including the Quitéria outcrop were discussed by Rösler (1978), Guerra-Sommer and Cazzulo-Klepzig (1993), Jasper *et al.* (2003) and Iannuzzi and Souza (2005). As a result, formal biostratigraphic frameworks were proposed by Guerra-Sommer and Cazzulo-Klepzig (1993) and Jasper *et al.* (2003). Iannuzzi *et al.* (2007) discussed the available proposals and considered valid —for the southern portion of the Basin— the phytostratigraphic arrangement of Guerra-Sommer and Cazzulo-Klepzig (1993), which was reviewed by the authors based on previous studies (Vieira and Iannuzzi, 2000; Iannuzzi *et al.*, 2003a, 2003b, 2009; Jasper *et al.*, 2003, 2005; Tybusch, 2005; Iannuzzi and Souza, 2005; Tybusch and Iannuzzi, 2008; Iannuzzi and Boardman, 2008).

The first record of *Botrychiopsis valida* in rocks of the Paraná Basin inspired a new phytostratigraphic framework (Jasper *et al.*, 2003) including the *Botrychiopsis* Zone. This zone is subdivided into the *Botrychiopsis plantiana* and *Botrychiopsis valida* subzones, the two of them characterized mainly by the ranges of these two species. This most recent zonation is difficult to apply. The main reason for this is the lack of a proper formal description and characterization of the zone as required by the Brazilian and International Stratigraphic Codes (Petri *et al.*, 1986; Murphy and Salvador, 1999). In addition, comparisons with previous zonations proposed for the same age, such as that one by Guerra-Sommer and Cazzulo-Klepzig (1993), are also wanting according to the discussion in Iannuzzi *et al.* (2007). Besides, the single record of *B. valida* at only one locality (Quitéria) is a factor limiting the potential biostratigraphic usefulness of this taxon. Recent contributions have indicated the co-occurrence of the two index species of *Botrychiopsis* used by Jasper *et al.* (2003) —*i.e.*, *B. valida* and *B. plantiana*, in the upper part of the section at the Quitéria outcrop (Iannuzzi and Boardman, 2008)—, therefore overlapping the stratigraphic distribution of the two subzones proposed by Jasper *et al.* (2003).

The phytozonation used here is the one proposed by Guerra-Sommer and Cazzulo-Klepzig (1993) as reviewed by Iannuzzi *et al.* (2007), which includes two interval zones from base to top, *i.e.*, the *Botrychiopsis plantiana* and the *Glossopteris-Rhodeopteridium* zones. The first is subdivided into *Gangamopteris obovata* and *Phyllotheca indica* subzones.

Currently, the *Botrychiopsis plantiana* Zone is characterized by the first appearance of glossopterids and the occurrence of *Gangamopteris obovata* (Carr.) White 1908. The occurrence of this zone is related to the oldest Permian strata exposed in Rio Grande do Sul State, *i.e.*, the Sakmarian Itararé Subgroup. The *Gangamopteris obovata* Subzone may be identified by the abundance of species of *Gangamopteris* associated to relict Carboniferous taxa such as *Botrychiopsis plantiana*, and by the absence of several taxa of the overlying subzone, such as *Phyllotheca indica* (Bunbury) Pant and Kidwai 1968 and *Glossopteris occidentalis* (White) Tybusch and Iannuzzi 2010. The *Phyllotheca indica* Subzone is defined mainly by the availability and abundance of this taxon (currently considered as a synonym of *Phyllotheca australis*), the appearance of *G. occidentalis*, *Scutum* sp. and *Kawizophyllum* sp., and the occurrence of *Stephanophyllites* sp., *Samaropsis kurtzii* Leguizamón 1971, *Cheirophyllum speculare* Césari and Cúneo 1989. In addition, this subzone shows a significant increase in the frequence of *Glossopteris* and a concomitant reduction in the frequency of *Gangamopteris*.

The overlying *Glossopteris-Rhodeopteridium* Zone is characterized by the occurrence of *Sphenopteris* cf. *S. ischanonensis* Zallesky 1934, *Rhodeopteridium* sp., *Brasilodendron pedroanum*, *Plumsteadia sennes* Rigby 1963, several species of Glossopteridales (*G. browniana* and *G. obovata* var. *major* (Feistmantel) Dolianiti 1954), and *Arberia minasica*, among others. This zone is linked to the youngest Early Permian (Artinskian) strata in Rio Grande do Sul and included in the Rio Bonito Formation.

In their original proposal, Guerra-Sommer and Cazzulo-Klepzig (1993) placed the lower and upper portions of the section exposed at the Quitéria outcrop respectively in the *Phyllotheca indica* Subzone of the *Botrychiopsis plantiana* Zone, and in the *Glossopteris-Rhodeopteridium* Zone. Currently, after the review by Iannuzzi *et al.* (2007), only the *Glossopteris-Rhodeopteridium* Zone is recognized at the locality. These authors also highlighted correlations considering an erosional surface (SB2 of Holz, 1997, 1998) separating the *Botrychiopsis plantiana* and *Glossopteris-Rhodeopteridium* biozones, and established their correlation with the (palynozone) *Vitattina costabilis* Zone (Souza and Marques-Toigo, 2003, 2005; Souza, 2006), ranging from the top of the Itararé Subgroup to the middle-upper portion of the Rio Bonito Formation.

Palynostratigraphy

Several palynostratigraphic frameworks were proposed for the Pennsylvanian–Permian interval in the Paraná Basin. Daemon and Quadros (1970) offered the most comprehensive stratigraphic and geographic approach (Souza and Milani, 2007). However, continuous updating of knowledge on the palynoflora and stratigraphic distribution of taxa significantly improved resolution of the biostratigraphic units involved. Souza and Marques-Toigo (2003, 2005) and Souza (2006) published biostratigraphic charts based on interval zones characterized by well-defined boundaries based on appearance and disappearance events of selected taxa reflecting the general succession of sporomorphs in the basin.

According to Souza and Marques-Toigo (2003, 2005) and Souza (2006), the Late Paleozoic succession in the Paraná Basin includes four interval zones, *i.e.*, in ascending stratigraphic order, *Ahrensisporites cristatus* (AcZ), *Crucisaccites monoletus* (CmZ), *Vittatina costabilis* (VcZ) and *Lueckisporites virkkiae* (LvZ) interval zones. The AcZ and CmZ characterize the Pennsylvanian interval of the basin, related to the lower and medium portions of the Itararé Subgroup and recorded in the northeastern part of the basin. Only the two upper zones were recorded in Rio Grande do Sul State (RS) and part of Santa Catarina State (SC). They range from the top of the Itararé Subgroup to the upper units of the Passa Dois Group.

The top of the Itararé Subgroup carries the basal occurrences of the VcZ, which reaches the top of the Rio Bonito Formation. The bottom of the VcZ is marked by the first appearance of *Vittatina* species (*V. saccata*, *V. subsaccata*, *V. costabilis*, *V. vittifera*), *Protohaploxypinus* species [*P. goraiensis* (Potonié and Lele) Hart 1964, *P. limpidus*] and *Illinites unicus* (Kosanke) Jansonius and Hills 1976; the upper boundary of this zone is marked by the appearance of diagnostic species of the overlying LvZ. The VcZ is divided into two units, *i.e.*, the *Protohaploxypinus goraiensis* Subzone (PgSz) —defined by the range of *P. goraiensis*, *P. limpidus* and *Illinites unicus*— and the *Hamiapollenites karrooensis* Subzone (HkSz), defined mainly by the range of the eponymous species and by the first appearance of *Striatopodocarpites fusus* and *Staurosaccites cordubensis* Archangelsky and Gamerro 1979. The PgSz includes coal seams in RS and SC that were earlier related to the *Caheniasaccites ovatus* Subzone (Marques-Toigo, 1988, 1991) and considered as an ecofacies within the VcZ (Souza and Marques-Toigo, 2003, 2005; Souza, 2006).

The LvZ occurs stratigraphically above the VcZ, from the top of Rio Bonito Formation and base of the Palermo Formation reaching the base of the Rio do Rasto Formation (Serrinha Member), according to recent data from Neregato (2007) and Neregato *et al.* (2008). It records relatively diversified assemblages in the deposits of the latter unit, which had been previously considered sterile. The lower boundary of the LvZ is defined by the last appearance of *Hamiapollenites karrooensis* (Hart 1963) Hart 1964, *Stellapollenites talchirensis*, *Lundbladispora riobonitensis*, *Potonieisporites novicus*, and by the first appearance of several species of taeniate and polyplicate pollen grains such as *Lueckisporites* [*L. virkkiae* (Potonié and Klaus) Clarke 1965, *L. stenotaeniatus* Menéndez 1976, *L. agoulaensis* (Jardiné) Premaor, Fischer and Souza 2006], *Marsupipollenites striatus* (Balme and Hennelly) Foster 1975, *Protohaploxypinus* [*P. hartii* Foster 1979, *P. sewardi* (Virkki) Hart 1964, *P. microcorpus* (Schaarschmidt) Clarke 1965], *Lunatisporites variesectus* Archangeslky and Gamerro 1979, *Alisporites nuthallensis* Clarke 1965, *Striatopodocarpites pantii*, *Weylandites lucifer* (Bharadwaj and Salujha) Foster 1975 and *Staurosaccites*; the base of this zone is an important biostratigraphic *datum* for the basin. The LvZ is marked at the top by the disappearance of species of *Lueckisporites*.

MATERIAL AND METHODS

Location and description of the outcrop

The analysed material comes from Quitéria outcrop, located in the municipality of Encruzilhada do Sul, Rio Grande do Sul (30°20′17″S–52°10′12″W), approximately 130 Km from Porto Alegre (Fig. 1).

The deposits at this locality are about 6.5 m thick (Fig. 2) and include argillite, carbonaceous siltstones and thin coal seams interbedded with paraconglomerates (with silty or clay matrix) in the basal and medium portions of the deposits. Overlying the last coal seam in the basal portion is a porcellanite level with sandy lenses at the top and a silty level above them. Paleosoils are vertically recurrent.

Facies analysis by Jasper *et al.* (2006) revealed—in the basal and medium portions of the outcrop— a depositional model inferred as a peat-forming environment associated with a restricted lagoon protected by barrier islands interspersed with alluvial fan-deposits. Overlying this sequence

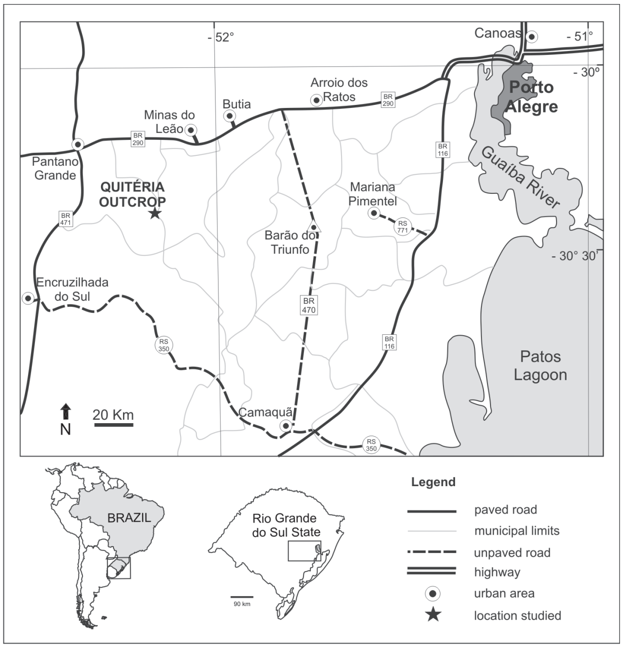

Figure 1. Location map of the Quitéria outcrop/ *Mapa de localización del afloramiento Quitéria.*

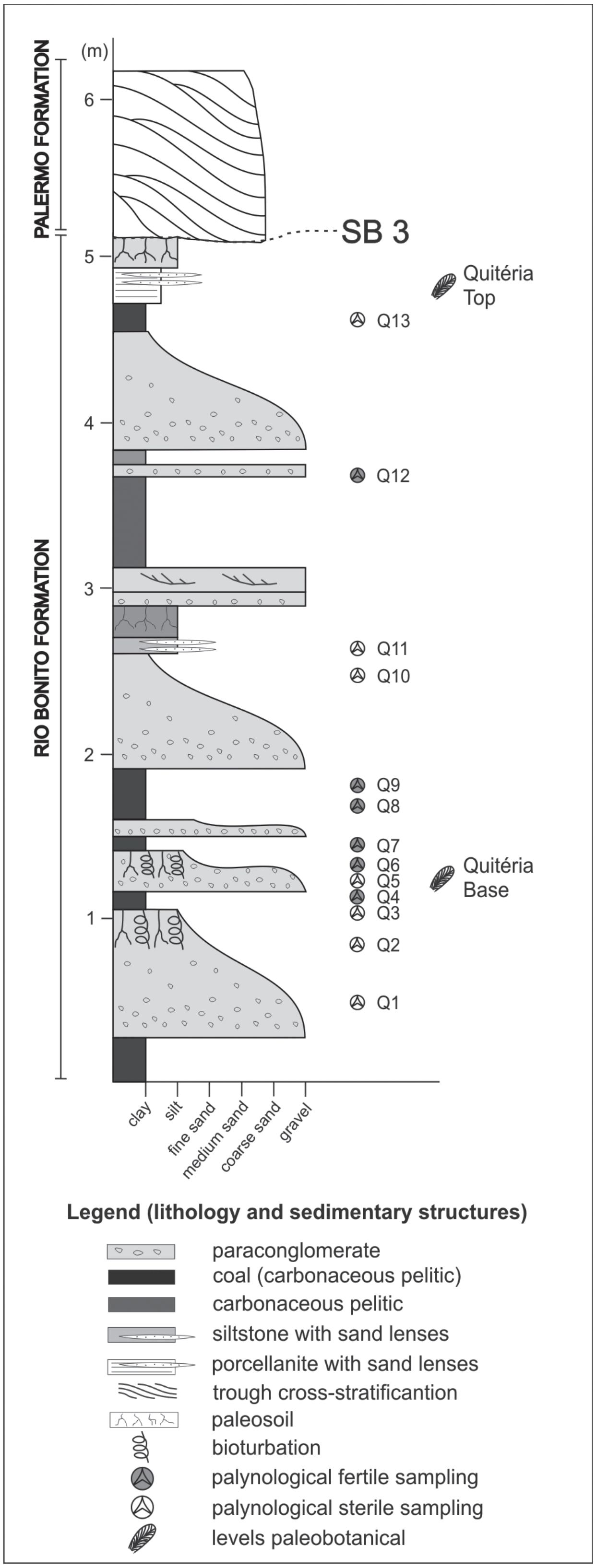

Figure 2. Stratigraphic section of the Quitéria outcrop indicating the levels yielding the paleobotanical and palynological samples studied/ *Perfil estratigráfico de la seccion del afloramiento Quitéria y ubicación de los niveles con muestras paleobotânicas y palinológicas*.

rich in organic matter appears a facies representing washover fans and more open lagoons, without depositation of organic matter. Correspondence between phytostratigraphic, palynostratigraphic and sequence stratigraphic frameworks in Rio Grande do Sul State was established by Iannuzzi *et al.* (2010) by means of the SB3 erosional surface they identified in the upper portion of the section.

A paraconglomerate bed at 1.2 m from the base —bearing paleosols and bioturbated structures— includes phytofossiliferous assemblages named herein as "Quitéria Base" (Fig. 2). A second assemblage of macrofossil plants ("Quitéria Top"; Fig. 2) occurs in the porcellanite with sandy lenses (approximately 5 m from the base). Overlying this sequence of cabonaceous and fine sediments is about 1 m of medium- to coarse-grained sandstone with cross-stratification; its basal erosive contact was linked by Iannuzzi *et al.* (2010) to the third order sequence boundary SB3 of Holz (1997, 1998) and Holz *et al.* (2006). This sequence boundary, together with facies analysis, allowed us placing the beds exopsed at the locality on top of the Rio Bonito Formation within a regional stratigraphic framework.

Paleobotanical material

Paleobotanical analysis required a detailed revision of the material from Quitéria, including the material housed in different institutions such as (1) Museu de Paleontologia, Departamento de Paleontologia e Estratigrafia, Instituto de Geociências, Universidade Federal do Rio Grande do Sul (DPE/IG/UFRGS), MP-Pb; (2) Laboratório de História da Vida e da Terra, Universidade do Vale do Rio dos Sinos (LaViGaea/ UNISINOS), ULVG; (3) Universidade do Vale do Taquari (UNIVATES), PbU. Specimens from "Quitéria Top" were found in all the institutions mentioned above; however, only DPE/IG/UFRGS houses material from "Quitéria Base". A total number of 635 samples was analysed, 597 from Quitéria Top and 38 from Quitéria Base. All fossil plant samples from this outcrop were revised in detail.

A comprehensive review of the published records of fossil plants from this locality was carried out in order to update systematic data. Thus, the available taxonomic list provided herein is an updated report on the paleobotanical diversity and botanical affinities of taxa recorded at this locality. Suprageneric classification follows Stewart and Rothwell (1993). Estimated relative frequency (RF) for the paleobotanical and palynological data was calculated according to the percentages of each taxon per stratigraphic level.

Palynological material

Thirteen samples from different stratigraphic levels were collected for palynological analysis (recorded as Q1 to Q13; Fig. 2). Best results were observed from six levels only; four of them are composed of carbonaceous pelite (Q4, Q7, Q8 and Q9) and the other two levels are paraconglomerates (Q6 and Q12).

Samples were processed at the Laboratório de Palinologia "Marleni Marques Toigo", DPE/IG/UFRGS, following the standard method for Paleozoic samples as described in Quadros and Melo (1987). About 10 g of each sample were separated and mechanically dissociated and then exposed to hydrochloric and hydrofluoric acids for dissolution of the carbonate and silicate compounds. Slides were mounted from the 25–250 μm residues, separated by manual sieving. All slides are housed in the Laboratório de Palinologia "Marleni Marques Toigo", as part of the Museu de Paleontologia (DPE/IG/UFRGS), under the codes MP-P 6197–6202 and MP-P 6534–6540.

Taxonomic identification of palynomorphs was made under 200–1000x optical microscope; minimum counts of 350 specimens per stratigraphic level were considered in quantitative characterizations. Species selected for the biostratigraphic interpretation were those included in the biozones of Souza and Marques-Toigo (2003, 2005) and Souza (2006). The general classification of the palynofloras into paleobotanical groups is based on Stewart and Rothwell (1993), while the botanical affinities are mainly from Balme (1995) and additionally from Azcuy (1978).

RESULTS

Paleobotany

Collections including paleobotanical material from Quitéria outcrop contained 75 specimens from Quitéria Base and 694 specimens from Quitéria Top. Besides an update of the nomenclatural data for each taxon (Fig. 3) representing diversity at the locality allowed estimation of the relative frequency of each taxon in each level (Tab. 1, Fig. 4).

Quitéria Outcrop yielded two assemblages of plant macrofossils typical of coal-associated floras, including remains of Glossopteridales (*Glossopteris* and *Gangamopteris*), Lycopsida (*Brasilodendron*) and Sphenopsida (*Giridia, Phyllotheca* and *Paracalamites*), among others (Tab. 1).

Some differences between the two beds are readily noticed. Quitéria Base is dominated by Sphenopsida (*Paracalamites*, *Phyllotheca* and reproductive structures, *i.e.*, *Giridia quiteriensis*), about 59% of RF; Glossopteridales are the second most representative group, with RF of 38%, but only the genus *Glossopteris* (*G. communis*, *G.* sp.) and *Arberia*-type reproductive structures were found. *Glossopteris indica* Schimper 1869 and *G. browniana* were recorded from this level in previous studies (Guerra-Sommer *et al.*, 1995b). However, during the current review these taxa were not identified, or else they may correpond to the specimens herein identified as *Glossopteris communis* and *G.* sp. Lycopsida (*Brasilodendron*), Filicopsida (Rhodeopterid fronds) and some *incertae sedis* seeds are the less representative groups of this level (Tab. 1). Quitéria Base can be considered a parautochthonous assemblage because of the significant occurrence of roots (paleosols) with elements in growth position, and because of the large number of reproductive structures of Glossopteridales (*Arberia*) and Sphenopsida (*Giridia*). All these elements indicate minimum or no transport.

Quitéria Top is a widely studied macrofloristic assemblage, considered an autochthonous-parautochthonous as-

Taxonomy according our interpretation	Previous records	Stratigraphic position
Brasilodendron pedroanum (Carruthers) Chaloner, Leistikow and Hill 1979	Arborescent lycophyte (Piccoli, *et al.*, 1991, p. 36, fig. 5; Guerra-Sommer *et al.*, 1995b, fig. 3); *Brasilodendrum* (Jasper and Guerra-Sommer 1998, p. 51; 1999, p. 53, fig. 3 and 4; Jasper *et al.*, 2005, p. 158); *Brasilodendrum pedroanum* (Guerra-Sommer *et al.*, 2008a, p. 20 and 21, fig. 9 to 11, tab. 4; Jasper *et al.*, 2003, p. 519 and 529; 2006, p. 284, fig. 6, tab. 1; 2008a, p. 6, fig. 9; 2008b, p. 439).	Quitéria Base Quitéria Top
Lycopodites riograndensis Salvi *et al.* 2008	*Lycopodites* sp. (Jasper *et al.*, 2006, p. 284, fig. 6, tab. 1; Guerra-Sommer *et al.*, 2008a, p. 20, fig. 13, tab. 4); *Lycopodites riograndensis* (Salvi *et al.*, 2008, p. 558, fig. 3; Jasper *et al.*, 2008a, p. 7; 2008b, p. 439).	Quitéria Top
Giridia quiteriensis Boardman and Iannuzzi 2010	*Gondwanostachyaceae*? (Mombach and Guerra-Sommer, 1990, fig. 2); *Gondwanostachys* (Piccoli *et al.*, 1991, p. 36); *Gondwanostachys australis* (Guerra-Sommer *et al.*, 1995a, p. 68, fig. 1 and 2); *Giridia quiteriensis* (Boardman and Iannuzzi 2010, p. 8, fig. 4 and 5).	Quitéria Base
Phyllotheca australis (Brongniart) Townrow 1955	*Phyllotheca indica* (Piccoli *et al.*, 1991, p. 36, fig. 4; Mombach and Guerra-Sommer, 1990, fig. 1); *Phyllotheca australis* (Guerra-Sommer *et al.*, 1995a, p. 68 and 70).	Quitéria Base
Paracalamites australis Rigby 1966	*Paracalamites* sp. (Guerra-Sommer *et al.*, 1995a, p. 68 and 70).	Quitéria Base
Rhodeopterid fronds	*Rhodea* sp. (Piccoli *et al.* 1991, p. 36, fig. 4; Guerra-Sommer *et al.*, 1995a, p. 66); Rhodeopterid fronds (Jasper *et al.*, 2006, p. 284, fig. 6, tab. 1; Guerra-Sommer *et al.*, 2008a, p. 20, fig. 13, tab. 4).	Quitéria Base Quitéria Top
Botrychiopsis valida Archangelsky and Arrondo 1971	*Botrychiopsis* sp. (Jasper and Guerra-Sommer, 1999, fig. 2); *Botrychiopsis valida* (Jasper *et al.*, 2003, p. 524, fig. 5 and 6; 2005, p. 158; 2006, p. 284, fig. 6, tab. 1; 2008a, p. 5 and 6, fig. 5; Guerra-Sommer *et al.*, 2008a, p. 20, fig, 13, tab. 4).	Quitéria Top
Botrychiopsis plantiana (Carruthers) Archangelsky and Arrondo 1971	*Botrychiopsis plantiana* (Iannuzzi and Boardman, 2008; Jasper *et al.*, 2008b, p. 439).	Quitéria Top
Arberia minnasica (White) Rigby 1972	*Arberia minnasica* (Piccoli et *al.* 1991, p. 35, fig. 4; Guerra-Sommer *et al.*, 1995a, p. 66).	Quitéria Base
Cordaicarpus sp.	*Cordaicarpus* sp. (Piccoli *et al.*, 1991, p. 35)	Quitéria Base Quitéria Top
Gangamopteris buriadica Feistmantel 1879	*Rubidgea?* (Jasper and Guerra-Sommer, 1999, fig. 1); *?Rubidgea* sp. (Jasper *et al.*, 2008a, p. 6, fig. 10); *Rubidgea* sp. (Jasper *et al.*, 2003, p. 519 and 529; 2006, p. 284, fig. 6, tab. 1; 2008b, p. 439; Guerra-Sommer *et al.*, 2008a, p. 22, fig. 14, tab. 4); *?Cordaites* sp. (Guerra-Sommer *et al.*, 2008a, p. 7, fig. 11); *Cordaites* sp. (Jasper *et al.*, 2003, p. 519 and 529; 2005, p. 158; 2006, p. 284, fig. 6, tab. 1; 2008b, p. 439; Guerra-Sommer *et al.*, 2008a, p. 22, fig. 15, tab. 4); *Gangamopteris buriadica* (Tybusch and Iannuzzi, 2008, p. 79, fig. 4 e 5).	Quitéria Top
Gangamopteris revoluta Tybusch and Iannuzzi 2008	*Gangamopteris revoluta* (this work).	Quitéria Top
Glossopteris communis Feistmantel 1876	*Glossopteris* sp. and *Glossopteris browniana* (Piccoli *et al.* 1991, p. 35, fig. 4); *Glossopteris browniana* and *Glossopteris indica* (Guerra-Sommer *et al.*, 1995a, p. 66); *Glossopteris* sp. (Guerra-Sommer *et al.*, 1995b, fig. 1).	Quitéria Base
Glossopteris browniana Brongniart 1828	*Glossopteris* sp. (Jasper *et al.*, 2003, p. 519); *Glossopteris browniana* (Boardman *et al.*, 2006, p. 13, fig. 3).	Quitéria Top
Coricladus quiteriensis Jasper, Ricardi-Branco and Guerra-Sommer 2005	*Buriadia* sp. (Piccoli *et al.*, 1991, p. 36, fig. 5); *Coricladus quiteriensis* (Jasper *et al.*, 2005, p. 160, fig. 2 to 7; 2006, p. 284, fig. 6, tab. 1; 2008a, p. 6, fig. 1 and 6; 2008b, p. 439; Guerra-Sommer *et al.*, 2008a, p. 12, fig. 14, tab. 4).	Quitéria Top

Figure 3. Systematic history of the paleobotanical taxa from Quitéria outcrop/ *Historia sistemática de los taxones paleobotánicos del afloramiento Quitéria.*

semblage by Guerra-Sommer *et al.* (2008a). It carries stem bases of *Brasilodendron pedroanum* in growth position (autochthonous elements). The other taxa forming this assemblage (*Glossopteris browniana*, *Gangamopteris buriadica, Coricladus quiteriensis*, *Botrychiopsis valida*, *B. plantiana*, Rhodeopterid fronds and *Lycopodites riograndensis*) are preserved as parautochthonous elements constituting a typical roof shale flora, overlying a coal seam. There is a predominance of Lycopsida bases (*Brasilodendron*) in this level, with a RF of 42.3%. Branches of Coniferales (*Coricladus quiteriensis*) (RF 23.3%) and leaves of Glossopteridales (RF 22.3%) are abundant. Among the Glossopteridales leaves, *Gangamopteris buriadica* is very common in the sandstone lenses, while *Glossopteris browniana* is not so abundant. Pteridophylla (*Botrychiopsis valida* and *B. plantiana*), *Lycopodites riograndensis* (Lycopsida) and Rhodeopterid fronds (Filicopsida) are less representative elements in this assemblage (Tab. 1). The absence of Sphenopsida from this level is remarkable considering its abundance in the underlying Quitéria Base level.

Table 1 - List of identified taxa in the two levels of macrofossils along the section of Quitéria Outcrop: Quitéria Base and Quitéria Top. The species are grouped according to their botanical affinity/ Lista de los taxones identificados en los dos niveles de macrofósiles a lo largo de la sección de Quitéria Afloramiento. Las especies se agrupan de acuerdo a su afinidad botánica

Paleobotanical material identified	*FR(%)*
QUITÉRIA BASE (based in 75 specimens)	
Brasilodendron *sp.*	*1.41*
SPHENOPSIDA	*59.15*
Giridia quiteriensis *Boardman and Iannuzzi 2010*	*5.63*
Phyllotheca australis *(Brongniart) Townrow 1955*	*12.68*
Paracalamites australis *Rigby 1966*	*40.85*
FILICOPSIDA	*1.41*
Rhodeopteridium *sp.*	*1.41*
GLOSSOPTERIDALES	*38.03*
Arberia minasica *(White)* emend. *Rigby 1972*	*6.94*
Cordaicarpus *sp.*	*5.63*
Glossopteris communis *Feistmantel 1876*	*15.49*
Glossopteris *sp.*	*9.86*
QUITÉRIA TOP (based in 694 specimens)	
LYCOPSIDA	*44.73*
Brasilodendron pedroanum *(Carruthers) Chaloner, Leistikow and Hill 1979*	*42.35*
Lycopodites riograndensis *Salvi, Jasper, Ricardi-Branco, Bernardes-de-Oliveira and Guerra-Sommer 2008*	*2.38*
FILICOPSIDA	*1.78*
Rhodeopteridium *sp.*	*1.78*
PTERIDOPHYLLA	*7.58*
Botrychiopsis plantiana *(Carruthers) Archangelsky and Arrondo 1971*	*7.58*
Botrychiopsis valida *Archangelsky and Arrondo 1971*	
GLOSSOPTERIDALES	*22.59*
Gangamopteris buriadica *Feistmantel 1879*	*14.12*
Gangamopteris revoluta *Tybusch and Iannuzzi 2008*	*0.15*
Gangamopteris *sp.*	*5.79*
Glossopteris browniana *Brongniart 1828*	*2.23*
Cordaicarpus *sp.*	*0.30*
CONIFERALES	*23.33*
Coricladus quiteriensis *Jasper, Ricardi-Branco and Guerra-Sommer 2005*	*23.33*

The grey lines express the total relative frequency of each higher taxonomic group in each level/ Las líneas grises expresar la frecuencia relativa total de cada grande grupo taxonómico en cada nivel.

Palynology

The analyzed samples yielded abundant, diverse and well preserved palynological assemblages. A total of 69 sporomorphs were identified, including 29 species of spores, 36 pollen grains and four taxa related to algae elements and fungi spores. The complete list of recorded taxa together with their stratigraphic position along the section is shown in Table 2. Generic relative frequencies were obtained for each sample according to botanical affinities. Most common palynomorphs and those identified as index-species were preferentially illustrated (Fig. 5 and 6).

The palynological assemblage observed along the section (Q4, Q6-Q9 and Q12) are generally dominated by spores instead of pollen grains, which are rare and frequently not well preserved. The genus *Lundbladispora* dominates five of the six quantified levels, while *Granulatisporites* is predominant in one level only (Tab. 3).

Spores associated to different plant groups were observed, such as those of Lycopsida (*Kraeuselisporites* and *Lundbladispora*), Sphenopsida (*Apiculatisporis, Calamospora* and *Laevigatosporites*), Filicopsida (*Granulatisporites, Convolutispora, Horriditriletes* and *Punctatisporites*). Pollen grains related to two groups of Gymnospermopsida were recorded, *i.e.*, Glossopteridales (*Vittatina, Fusacolpites, Protohaploxypinus* and *Vesicaspora*) and Coniferales (*Alisporites, Caheniasaccites, Cannanoropollis, Potonieisporites* and *Hamiapollenites*) (Tab. 3).

Lundbladispora is predominant in levels Q4, Q6, Q7 and Q9 (RF >51%), while in Q8, it is still dominant together with *Horriditriletes* (about RF 23% each). *Lundbladispora* is considerably reduced in the topmost level (Q12) with about 1%, while *Granulatisporites* is predominant (RF 36.44%) there. This genus presented 1.29–5.08% in the lower levels. *Portalites* occurs in all levels dominated by *Lundbladispora*; thus it does not occur in Q12. The abundance of *Portalites* (1.34–13.09%) is directly related to the abundance of

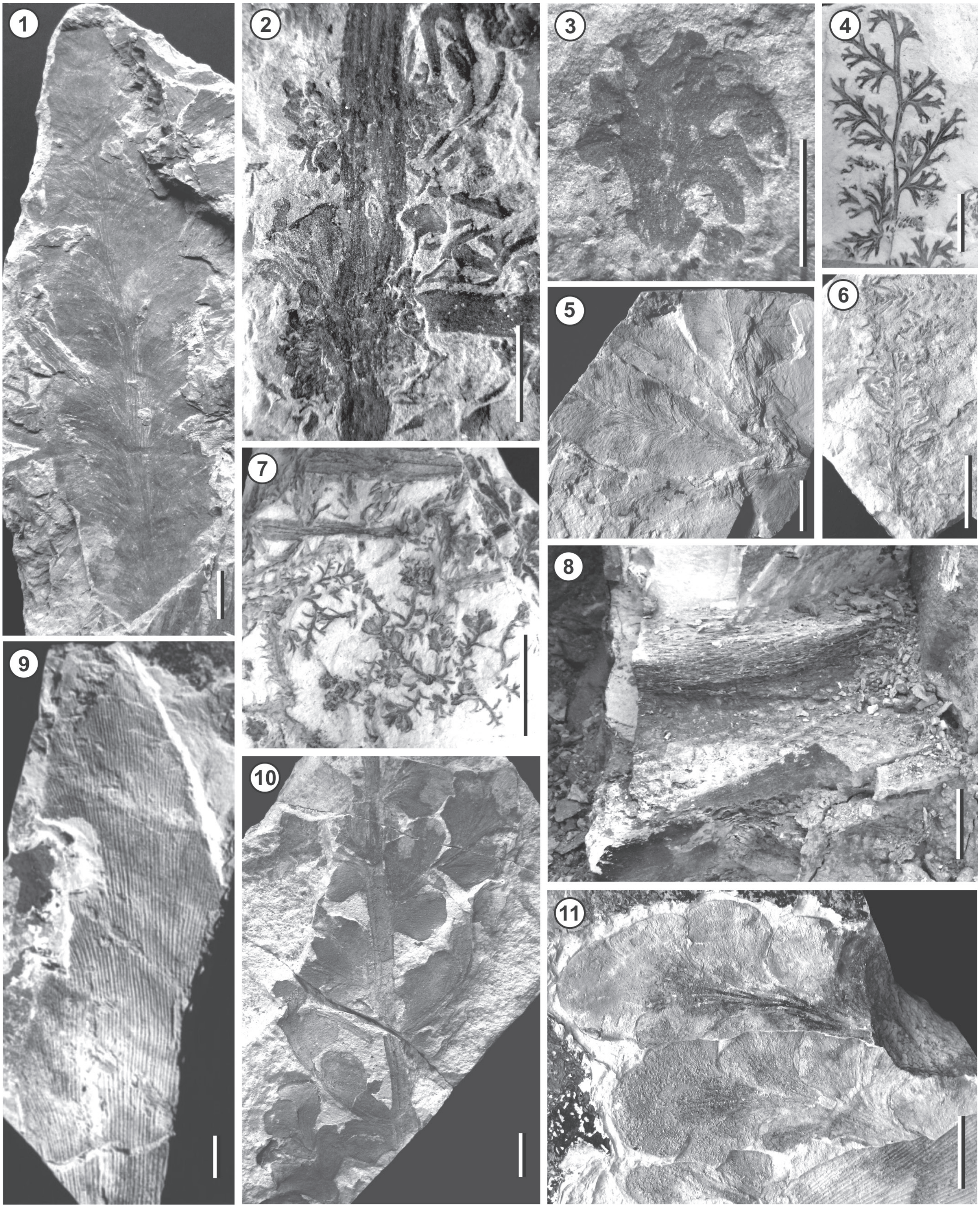

Figure 4. Paleobotanical material from Quitéria outcrop. Quitéria Base/ *Material paleobotánico del afloramiento Quitéria*. **1, *Glossopteris communis*** (MP-Pb 2864); **2, *Giridia quiteriensis*** (MP-Pb 2863); **3, *Arberia minasica*** (MP-Pb 3104), Quitéria Top; **4,** Rhodeopterid fronds (PbU 254); **5, *Glossopteris browniana*** (MP-Pb 5175b); **6, *Lycopodites riograndensis*** (MP-Pb 4912); **7, *Coricladus quiteriensis*** (PbU 194); **8,** *in situ* stem of ***Brasilodendron pedroanum***; **9, *Gangamopteris buriadica*** (MP-Pb 4008a); **10, *Botrychiopsis plantiana*** (MP-Pb 4293); **11, *Botrychiopsis valida*** (MP-Pb 4291). Scale= 10 mm/ *Escala= 10 mm.*

TABLE 2 - List of the identified palynomorphs and their distribution along the studied section/ **Lista de los palinomorfos identificados y su distribución a lo largo de la sección estudiada**

Palynological Assemblages	***Q4***	***Q6***	***Q7***	***Q8***	***Q9***	***Q12***
SPORES						
Apiculatisporis *spp.*	*X*	*X*	*X*	*X*	*X*	*X*
Ahrensisporites *spp.*	*X*	*X*	*X*	*X*	*X*	
Apiculiretusispora sparsa *Menéndez and Azcuy 1971*	*X*		*X*		*X*	*X*
Brevitriletes cornutus *(Balme and Hennelly) Backhouse 1991*	*X*	*X*				*X*
Brevitriletes irregularis *(Nahuys, Alpern and Ybert) Césari, Archangelsky and Seoane 1995*	*X*	*X*	*X*	*X*	*X*	*X*
Calamospora *spp.*	*X*	*X*	*X*	*X*	*X*	*X*
Converrucosisporites confluens *(Archangelsky and Gamerro) Playford and Dino 2002*	*X*	*X*	*X*	*X*	*X*	*X*
Converrucosisporites micronodosus *(Balme and Hennelly) Playford and Dino 2002*	*X*		*X*	*X*		
Convolutispora candiotensis *Ybert 1975*	*X*	*X*	*X*	*X*	*X*	*X*
Cyclogranisporites *spp.*	*X*	*X*	*X*	*X*	*X*	*X*
Granulatisporites austroamericanus *Archangelsky and Gamerro 1979*	*X*	*X*	*X*	*X*	*X*	*X*
Horriditriletes gondwanensis *(Tiwari and Moiz) Foster 1975*	*X*	*X*		*X*	*X*	
Horriditriletes ramosus *(Balme and Hennelly) Bharadwaj and Salujha 1964*	*X*	*X*				
Horriditriletes superbus *(Foster) Césari, Archangelsky and Seoane 1995*	*X*			*X*		
Horriditriletes uruguaiensis *(Marques-Toigo) Archangelsky and Gamerro 1979*	*X*	*X*	*X*	*X*	*X*	*X*
Horriditriletes *spp.*	*X*	*X*	*X*	*X*	*X*	*X*
Kraeuselisporites spinosus *Jansonius 1962*		*X*	*X*			
Laevigatosporites vulgaris *Ibrahim 1933*	*X*	*X*		*X*		*X*
Leiotriletes virkkii *Tiwari 1965*	*X*	*X*	*X*	*X*	*X*	*X*
Lophotriletes *spp.*	*X*	*X*	*X*	*X*	*X*	*X*
Lundbladispora braziliensis *(Pant and Srivastava) Marques-Toigo and Picarelli 1984*	*X*	*X*	*X*	*X*	*X*	*X*
Lundbladispora riobonitensis *Marques-Toigo and Picarelli 1984*	*X*	*X*	*X*	*X*	*X*	*X*
Murospora bicingulata *Ybert 1975*						*X*
Punctatisporites gretensis *Balme and Hennelly 1956*	*X*	*X*	*X*	*X*	*X*	*X*
Retusotriletes baculiferous *Ybert 1975*	*X*		*X*		*X*	
Retusotriletes golatensis *Staplin 1960*	*X*	*X*	*X*			
Retusotriletes nigritellus *(Luber) Foster 1979*						*X*
Retusotriletes simplex *Naumova 1953*		*X*		*X*		
Verrucosisporites *spp.*		*X*	*X*	*X*	*X*	*X*
POLLEN GRAINS						
Alisporites *spp.*		*X*	*X*	*X*		*X*
Caheniasaccites *sp. cf.* **C. elongatus** *Bose and Kar 1966*		*X*				
Caheniasaccites flavatus *Bose and Kar 1966*		*X*		*X*		*X*
Cannanoropollis densus *(Lele) Bose and Maheshwari 1968*		*X*				
Cannanoropollis janakii *Potonié and Sah 1960*		*X*				
Costapollenites ellipticus *Tschudy and Kosanke 1966*		*X*				
Divarisaccus stringoplicatus *Ottone 1991*		*X*				
Fusacolpites fusus *Bose and Kar 1966*				*X*		
Fusacolpites ovatus *Bose and Kar 1966*						*X*
Hamiapollenites *sp. cf.* **H. fusiformis** *Marques-Toigo 1974*		*X*				

Palynological Assemblages	***Q4***	***Q6***	***Q7***	***Q8***	***Q9***	***Q12***
Limitisporites *spp.*		*X*	*X*	*X*	*X*	*X*
Plicatipollenites gondwanensis *(Balme and Hennely) Lele 1964*		*X*				
Plicatipollenites malabarensis *(Potonié and Sah) Foster 1975*		*X*				
Potonieisporites barrelis *Tiwari 1965*			*X*			
Potonieisporites *sp. cf.* **P. neglectus** *Potonié and Lele 1961*		*X*				
Potonieisporites congoensis *Bose and Maheshwari 1968*		*X*				
Potonieisporites methoris *(Hart) Foster 1979*		*X*				
Potonieisporites marleniae *Playford and Dino 2000*		*X*				
Potonieisporites novicus *(Bhardwaj) Poort and Veld 1997*			*X*			
Potonieisporites *spp.*		*X*	*X*			
Protohaploxypinus amplus *(Balme and Hennelly) Hart 1964*	*X*	*X*				
Protohaploxypinus limpidus *(Balme and Hennelly) Balme and Playford 1967*		*X*				
Protohaploxypinus *spp.*				*X*		*X*
Scheuringipollenites medius *(Burjack) Dias-Fabrício 1981*		*X*	*X*			*X*
Stellapollenittes talchirensis *Lele 1965*		*X*				*X*
Striatoabieites *spp.*			*X*			
Striatopodocarpites pantii *(Jansonius) Balme 1970*		*X*				
Vesicaspora *spp.*	*X*	*X*	*X*			
Vittatina corrugata *Marques-Toigo 1974*		*X*				
Vittatina costabillis *Wilson 1962*		*X*	*X*			
Vittatina saccata *(Hart) Playford and Dino 2000*		*X*		*X*		
Vittatina subsaccata *Samoilovich 1953*		*X*				
Vittatina vittifera *(Lüber and Valtz) Samoilovich 1953*			*X*			
Vittatina *spp.*		*X*				*X*
cf. **Weylandites**					*X*	
Undetermined poliplicate				*X*	*X*	*X*
OTHERS (algae elements and fungi)						
Botryococcus braunii *Kutzing 1849*	*X*				*X*	
Brazilea scissa *(Balme and Hennelly) Foster 1975*	*X*	*X*		*X*		*X*
Portalites gondwanensis *Nahuys, Alpern and Ybert 1968*	*X*	*X*	*X*	*X*	*X*	
Tetraporina *spp.*	*X*	*X*				*X*

Lundbladispora (Q4, Q6, Q7 and Q9). Several spores of Filicopsida (*Granulatisporites, Cyclogranisporites, Horriditriletes* and *Leiotriletes*) occur relatively abundantly in all levels, but as *Lundbladispora* is predominant in most of the levels, Lycopsida is the dominant group in Q4, Q6, Q7 and Q9, while Filicopsida is the most abundant in Q8 and Q12. *Lundbladispora* tetrads are present in the five levels where the genus is predominant, occurring very expressively in Q4, Q7 and Q9, related to carbonaceous pelites.

Pollen grains are poorly represented in almost all the beds, except in Q6 (4.66%), which bears most of the genera found in the section.

DISCUSSION

Paleobotany and palynology

According to this taxonomic analysis, the Quitéria outcrop carries 14 morphospecies of plant macrofossils including leaves and seeds of Glossopteridales (identified at generic level) and *Brasilodendron* (recorded in two fossil-bearing levels). The taxon lists presented (Fig. 3 and Tab. 1) include all systematic changes for each taxon recorded at this outcrop. *Glossopteris indica* and *G. browniana* (Guerra-Sommer *et al.*, 1995b), in Quitéria Base, are currently *Glossopteris communnis* and *Glossopteris* sp.; *Buriadia* sp. (Piccoli *et al.*, 1991; Jasper *et al.*, 2003) was assigned to *Coricladus quiteriensis*

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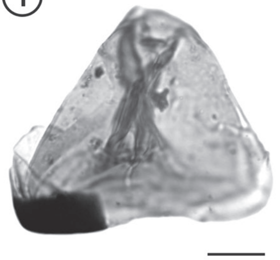

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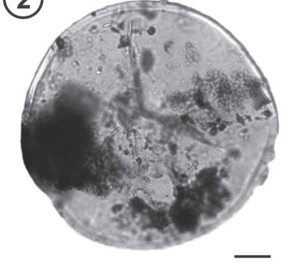

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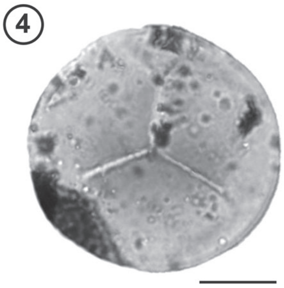

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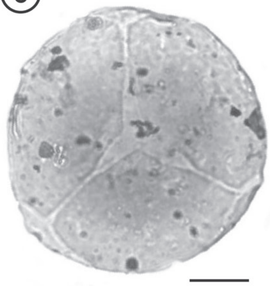

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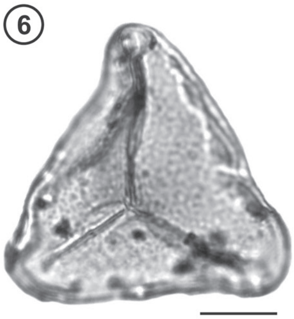

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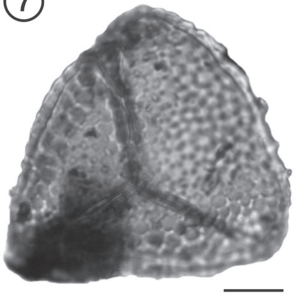

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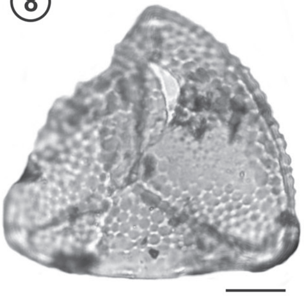

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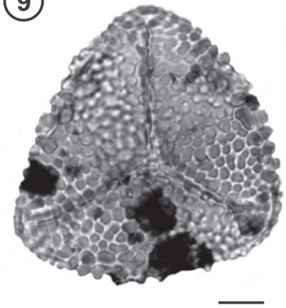

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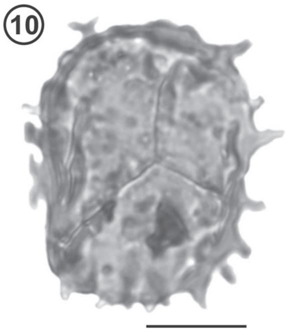

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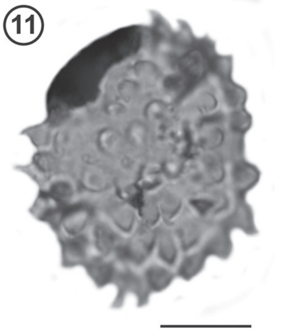

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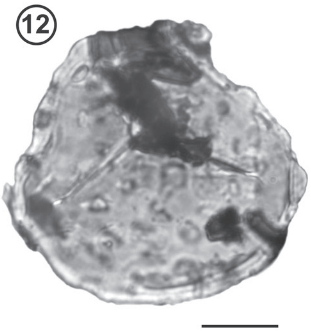

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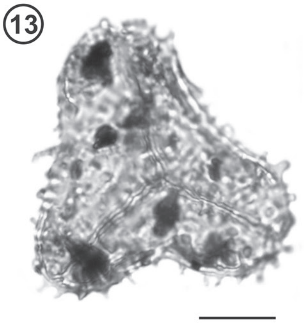

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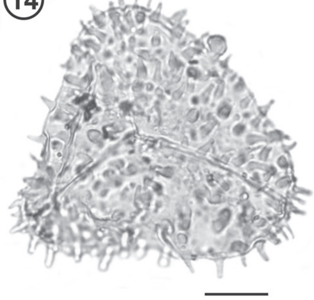

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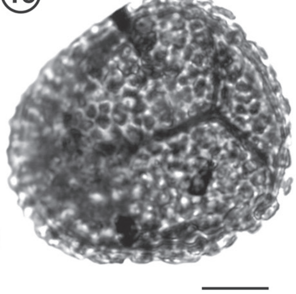

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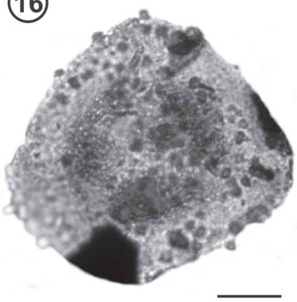

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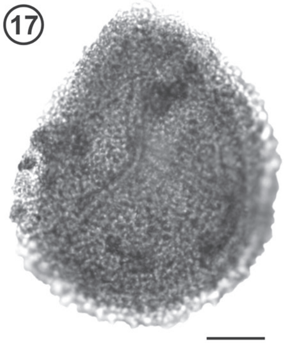

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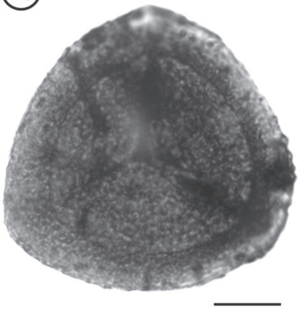

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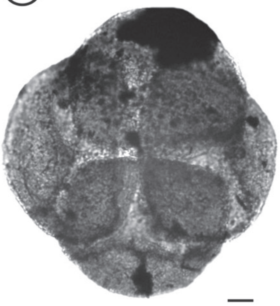

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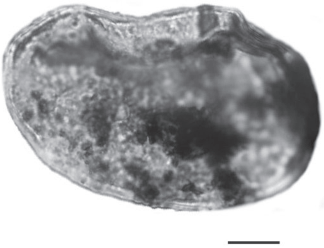

(Jasper *et al.*, 2005); *Rubidgea* sp. (Jasper and Guerra-Sommer, 1999; Jasper *et al.*, 2003) and *Cordaites* sp. (Jasper *et al.*, 2003, 2005) are now identified as *Gangamopteris buriadica* (Tybusch and Iannuzzi, 2008); and *Gondwanostachys australis* (Guerra-Sommer *et al.*, 1995a) was re-identified as *Giridia quiteriensis* (Boardman and Iannuzzi, 2010).

An in-depth palynological analysis based on previous work from this locality is necessarily limited because only important taxa were listed and/or illustrated (Piccoli *et al.*, 1991; Guerra-Sommer *et al.*, 1995a, 2008a; Jasper *et al.*, 2006). Some taxa previously described from the outcrop were not verified, such as *Cristatisporites*, *Vallatisporites*, *Lunatisporites variesectus*, *Protohaploxypinus goraiensis*, some species of *Potonieisporites*, *Caheniasaccites, Cannanoropolis* and algae elements such as *Cymatiosphaera* and *Navifusa*. However, new species were identified, such as *Ahrensisporites* spp., *Converrucosiporites micronodosus*, *C. confluens, Costapollenites ellipticus, Divarisaccus stringoplicatus*, several species of *Potonieisporites* (*P. barrelis*, *P. neglectus*, *P. congoensis* and *P. marleniae*) and of *Vittatina* (*V. corrugata*, *V. costabilis*, *V. saccata*, *V. subsaccata* and *V. vittifera*).

Based on comparison between the relative frequency of the sporomorphs recorded herein and associations of peat-forming plant communities of Marques-Toigo and Corrêa da Silva (1984), we can state that all levels are compatible with the "*Lundbladispora-Punctatisporites-Portalites* Association", developed in a hygrophilous environment. Levels Q4, Q6, Q7 and Q9 are typical examples of this association, in which the frequency of *Lundblasdispora* is higher than 51%. In level Q8 —despite its frequency drop — *Lundbladispora* is still dominant. The absence of *Vallatisporites* and *Cristatisporites* and especially the rare presence of *Lundbladispora* in Q12 distinguishes this level from the others; yet, the dominance of spores —mainly *Granulatisporites*, *Cyclogranisporites Punctatisporites*— over pollen grains, allows correlating these levels with the "*Lundbladispora-Punctatisporites-Portalites* Association".

Palynological assemblages from carbonaceous pelitic levels Q4, Q7 and Q9 are very similar in composition; they bear abundant spores and tetrads of *Lundbladispora* and *Portalites*, as well as scarce pollen grains. These characteristics indicate conditions of a minimum of sedimentary transport within a more restricted depositional location. Although the assemblage recovered in Q8 comes from a lithological level similar to Q4, Q7 and Q9, it shows a decrease in the relative frequency of *Lundbladispora* (23.8%) and *Portalites* (1.34%), a dominance of Filicopsida (*Horriditriletes*, *Cyclogranisporites*), and an increase of pollen grains, when compared to the other pelitic levels. These data indicate that the depositional site may correspond to a more open environment than the environment in which lycophytes are predominant (which was slightly removed from the peat). In this situation, microfloristic taxa from nearby water bodies are better represented.

The assemblage recovered in Q6 shows significant quantities of *Lundbladispora* and *Portalites* and few tetrads of *Lundbladispora*. Pollen grains are more frequent (4.66%) and diverse, but not well preserved. These characteristics indicate intermediate conditions between the two previously described environments. However, the sedimentary features (granulometry coarser than pelite) indicate a higher energy in the depositional system, which might have contributed to the low frequency of tetrads and unfavorable conditions for preservation of pollen grains.

Level Q12 includes a distinct palynological content, with absence of *Portalites* and tetrads, and low frequency of *Lundbladispora* —the dominant genus in the other underlying levels— whereas spores of Filicopsida are dominant (>90%) and pollen grains are well represented (3.46%), when compared to other levels. This level exhibits the coarsest granulometry among all analysed samples, containing around 20% of clasts in a pelite matrix. This is probably the depositional site farthest from the main peat, reflecting a more efficient tractive sedimentary transport.

Generally, the most basal levels present a very similar palynological assemblage (Q4, Q7, Q8 and Q9) except in Q6, in which the frequency and diversity of pollen grains is higher. In the lowermost portion of the outcrop, taxa related to Glossopteridales are found among the macrofossils of Quitéria Base (*Glossopteris*, *Arberia*) and in the levels with

Figure 5. Selected species from the studied palinological material/ *Especies seleccionadas del material palinológico estudiado.* **1, *Leiotriletes virkkii*** (MP-P 6200, X59) ; **2, *Punctatisporites gretensis*** (MP-P 6202, P44-1); **3, *Cyclogranisporites*** sp. (MP-P 6198, T28-4); **4, *Retusotriletes nigritellus*** (MP-P 6202, R28); **5, *Retusotriletes golatensis*** (MP-P 6198, H52-2); **6, *Granulatisporites austroamericanus*** (MP-P 6198, S56-3); **7–8, *Converrucosisporites confluens*** (**7,** MP-P 6198, U29-3; **8,** MP-P 6199, T43-3); **9, *Converrucosisporites micronodosus*** (MP-P 6199, C52); **10, *Brevitriletes irregularis*** (MP-P 6198, E44-1); **11, *Brevitriletes cornutus*** (MP-P 6202, O38); **12, *Convolutispora candiotensis*** (MP-P 6197, Q48-3); **13, *Horriditriletes gondwanensis*** (MP-P 6201, P51); **14, *Horriditriletes uruguaiensis*** (MP-P 6200, L31-1); **15, *Verrucosisporites*** sp. (MP-P 6198, D53-4); **16, *Kraeuselisporites spinosus*** (MP-P 6198, T34-3); **17, *Lundbladispora braziliensis*** (MP-P 6200, U32); **18, *Lundbladispora riobonitensis*** (MP-P 6197, P28-3); **19, *Lundbladispora riobonitensis*** tetrad (MP-P 6199, G47-2); **20, *Laevigatosporites vulgaris*** (MP-P 6202, O49-4). Scale= 10 μm/ *Escala= 10 μm.*

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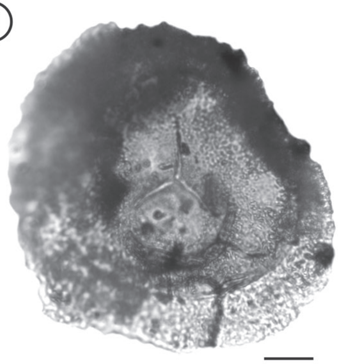

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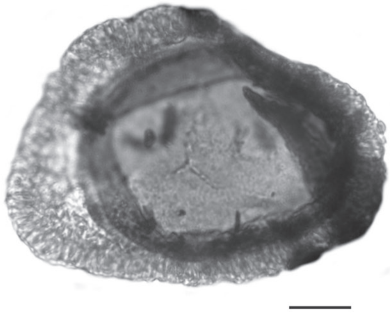

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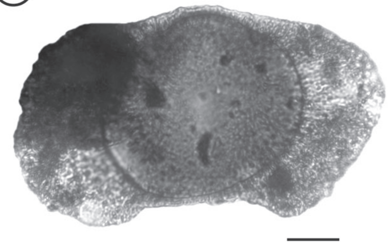

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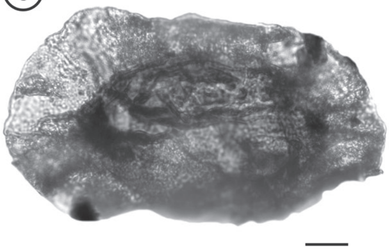

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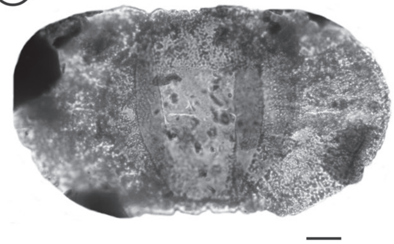

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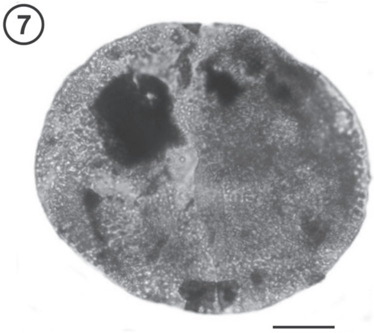

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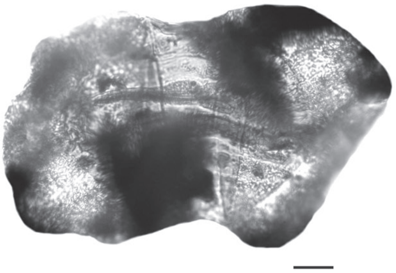

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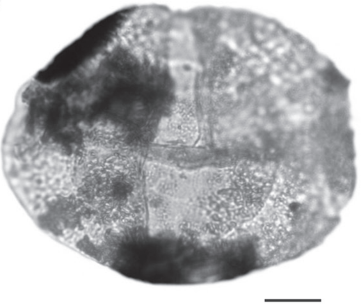

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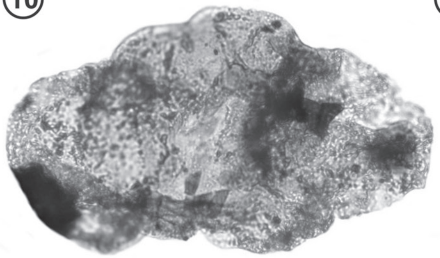

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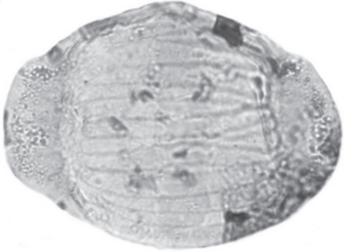

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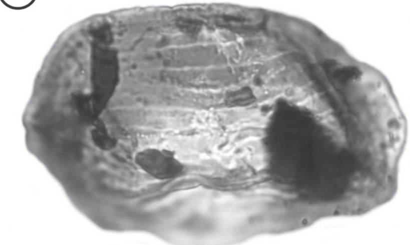

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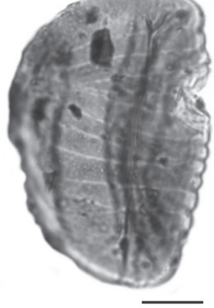

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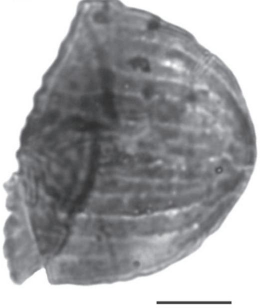

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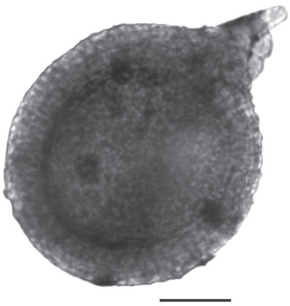

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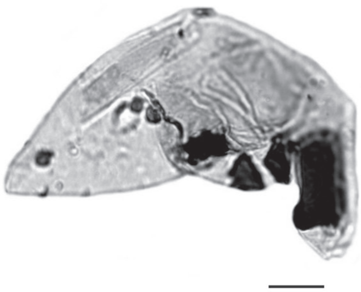

sporomorphs (*Vittatina*, *Protohaploxypinus*); Coniferales are restricted to sporomorphs. The most abundant groups in the palynological assemblages are Lycopsida and Filicopsida (*Lundblasdispora*, *Granulatisporites*, *Punctatisporites*) respectively, but these are not representative among the macrofossils (*Brasilodendron* and Rhodeopterid fronds), while Sphenopsida (*Giridia*, *Phyllotheca* and *Paracalamites*) is the most representative group among Quitéria Base macrofossils, but its occurrence in the palynological record is rare (Tab. 1 and 2).

Paleobotanically, the topmost portion of the section exposed at the outcrop is dominated by Lycopsida (*Brasilodendron* and *Lycopodites*) while Glossopteridales and Coniferales (*Glossopteris*, *Gangamopteris* and *Coricladus*) are frequent macrofossils in Quitéria Top. These elements show affinities with palynological assemblages from the base of the section (Q4 and Q6–Q9). Filicopsida are rare elements in this paleobotanical assemblage (Rhodeopterid fronds), probably due to their delicate structure, less favourable to preservation (Fig. 4.4). An attempt to correlate Quitéria Top to Q12 —the nearest stratigraphic level— shows that the differences are noticeable, mainly because of the abundance of Lycopsida among the macrofossils and the rarity of this group among the sporomorphs. A possible explanation is that Q12 displays a palynological assemblage deposited in an environment distant from peat, as Lycopsida represents a group typically found along the edges of water bodies related to the formation of peat (Guerra-Sommer *et al.*, 2008a).

A comparison between the analyzed levels and the biofacies (E–H) described by Piccoli *et al.* (1991) for the section at the ouctcrop revealed that concerning plant macrofossils, “biofacies E” is related to Quitéria Base, taking into account the presence of Sphenophyta (*Giridia quiteriens*, *Phyllotheca indica*) and elements of Glossopteridales (*Glossopteris communis*, *Arberia minasica*), and “biofacies H” refers to Quitéria Top, in which typical casts of *Brasilodendron* occur. Biofacies based on the occurrence of sporomorphs (E1, E2, F and G) are very difficult to compare, but probably “biofacies E1” and level Q6 are correlated, due to the rich assemblage of trilete spores (mainly *Lundbladispora*) and the diversity of pollen grains (in minor proportion compared to the spores); “biofacies E2” was not found, as it is characterized by the absence of *Lundbladispora*, a genus which was abundant in almost all the assemblages analysed herein; “biofacies F” can be associated to level Q8, as the majority of spores are referred to Filicopsida; “biofacies G” can not be correlated, as *Punctatisporites* does not occur as a dominant genus in any of the analysed levels.

The paleobotanical and palynological data obtained here are similar to those published by Guerra-Sommer *et al.* (1995a), levels corresponding here to Quitéria Base and Q6, except by the absence of Cordaitales, both in the macro- and microflora, a fact probably due to revisions and systematic updatings after publication of that work.

Comparisons with palynological results obtained by Jasper *et al.* (2006) became impracticable, as only general composition of recognized facies was offered by them. Stratigraphical distribution of each taxon is provided, and quantitative data is presented according to major botanical groups of sporomorphs based on their botanical affinities (Stratigraphical distribution of taxons is provided grouped for type-facies, and quantitative data are presented according to botanical affinities of palynomorphs). For plant macrofossils, the authors dealt only with the assemblages corresponding to Quitéria Top (“Sm” facies).

When considering major botanical groups, comparison between the different palynological and paleobotanical assemblages studied herein reveals that they are very similar. Differences are emphasized in the analysis of taxa frequency at each level; this could be interpreted as reflecting lateral lithofacies variation (especially in the palynological levels). Besides, taphonomic processes involved in the preservation of these fossil assemblages can act in different ways, as preservation of sporomorphs and plant macrofossils are controlled by sedimentary dynamics and by intrinsic characteristics of the organic detrital particles, such as resistance to physical damage and potential of preservation.

Biostratigraphy

Among the recorded plant macrofossils (Tab. 1), *Brasilodendron pedroanum*, Rhodeopterid fronds which occur in the two analysed paleobotanical levels, and *Glossopteris browniana*, which occurs in Quitéria Top are taxa exclu-

Figure 6. Selected species from the studied palinological material/ *Especies seleccionadas del material palinológico estudiado.* **1, *Cannanoropollis janakii*** (MP-P 6198, Q49); **2, *Cannanoropollis densus*** (MP-P 6198, J37-3); **3, *Plicatipollenites gondwanensis*** (MP-P 6198, K46); **4, *Caheniasaccites flavatus*** (MP-P 6198, H52-53); **5, *Divarisaccus stringoplicatus*** (MP-P 6198, E51); **6, *Potonieisporites methoris*** (MP-P 6198, D32-2); **7, *Scheuringipollenites medius*** (MP-P 6198, J29); **8, *Striatopodocarpites pantii*** (MP-P 6198, K34); **9, *Protohaploxypinus limpidus*** (MP-P 6198, K49-2); **10, *Hamiapollenites*** sp. cf. ***H. fusiformis*** (MP-P 6198, C46-3); **11, *Costapollenites ellipticus*** (MP-P 6198, H47-4); **12, *Vittatina subsaccata*** (MP-P 6198, O44); **13, *Vittatina costabillis*** (MP-P 6199, T55); **14, *Vittatina vittifera*** (MP-P 6199, H55); **15, *Portalites gondwanensis*** (MP-P 6197, X50); **16, *Brazilea scissa*** (MP-P 6200, T28). Scale= 10 µm/ *Escala= 10 µm.*

Table 3 - Determination of sporomorphs per stratigraphic level, according to the botanical affinity (FR; %)/ **Determinación de esporomorfos por nivel estratigráfico, de acuerdo con la afinidad botánica (FR;%)**

Identified genera	***Q4***	***Q6***	***Q7***	***Q8***	***Q9***	***Q12***
LYCOPSIDA	62.12	5135	71.97	23.80	81.44	1.06
Kraeuselisporites	0	0.27	0.29	0	0	0
Lundbladispora	62.12	51.08	71.68	23.80	81.44	1.06
SPHENOPSIDA	2.79	5.92	1.45	11.50	0.78	3.20
Apiculatisporis	2.23	4.30	1.16	10.43	0.52	1.60
Calamospora	0.28	0.54	0.29	0.80	0.26	0.27
Laevigatosporites	0.28	1.08	0	0.27	0	1.33
FILICOPSIDA	20.35	27.42	16.45	58.57	7.50	90.97
Apiculiretusispora	0.56	0	0.29	0	0.26	2.66
Brevitriletes	1.67	2.42	0.29	1.07	0.26	2.93
Converrucosisporites	0.28	1.34	0.58	0.27	0.26	0.80
Convolutispora	0.28	0.27	0.29	0.27	0.26	0.27
Cyclogranisporites	1.39	3.76	3.15	12.83	2.32	16.22
Granulatisporites	3.06	2.42	3.18	5.08	1.29	36.44
Horriditriletes	2.79	5.11	2.31	22.73	1.03	6.38
Leiotriletes	6.69	4.03	2.60	3.21	0.52	0.27
Lophotriletes	2.23	6.72	2.31	12.3	0.52	8.78
Punctatisporites	0.56	0.27	0.87	0.27	0.26	10.37
Retusotriletes	0.84	0.81	0.29	0.27	0.26	2.66
Verrucosisporites	0	0.27	0.29	0.27	0.26	3.19
SPORES OF UNKNOWN AFFINITY	0.28	0.27	0.29	0.27	0.26	0.27
Ahrensisporites	0.28	0.27	0.29	0.27	0.26	0
Murospora	0	0	0	0	0	0.27
GLOSSOPTERIDALES	0.56	1.08	0.58	0.81	0.26	1.07
Fusacolpites	0	0	0	0.27	0	0.27
Protohaploxypinus	0.28	0.27	0	0.27	0	0.27
Striatopodocarpites	0	0.27	0	0	0	0
Vesicaspora	0.28	0.27	0.29	0	0	0
Vittatina	0	0.27	0.29	0.27	0	0.53
cf. **Weylandites**	0	0	0	0	0.26	0
CONIFERALES	0	3.77	1.16	1.07	0.26	1.59
Alisporites	0	0.27	0.29	0.27	0	0.27
Caheniasaccites	0	0.27	0	0.27	0	0.52
Cannanoropollis	0	0.54	0	0	0	0.27
Divarisaccus	0	0.27	0	0	0	0
Hamiapollenites	0	0.27	0	0	0	0
Limitisporites	0	1.34	0.29	0.53	0.26	0.53
Plicatipollenites	0	0.27	0	0	0	0
Potonieisporites	0	0.54	0.29	0	0	0
Striatoabieites	0	0	0.29	0	0	0
POLLEN OF UNKNOWN AFFINITY	0	0.81	0.29	0	0	0.80
Costapollenites	0	0.27	0	0	0	0
Scheuringipollenites	0	0.27	0.29	0	0	0.53
Stellapollenittes	0	0.27	0	0	0	0.27
CHLOROPHYCEAE	0.28	0	0	0	0.26	0
Botryococcus	0.28	0	0	0	0.26	0
ZYGNEMAPHYCEAE	0.56	0.80	0	2.67	0	1.07
Brazilea	0.28	0.53	0	2.67	0	0.80
Tetraporina	0.28	0.27	0	0	0	0.27
FUNGI	13.09	8.60	7.80	1.34	9.28	0
Portalites	13.09	8.60	7.80	1.34	9.28	0

The grey lines express the total relative frequency of each higher taxonomic group in each level/ Las líneas grises expresan la frecuencia relativa total de cada gran grupo taxonómico en cada nivel.

sive to the *Glossopteris-Rhodeopteridium* Zone. *Botrychiopsis valida* and *Coricladus quiteriensis* are found in Quitéria Top; they are also exclusive of this phytozone and endemic to this locality. Thus, they are not biostratigraphically useful. The stratigraphic ranges of *Botrychiopsis plantiana*, *Gangamopteris buriadica* and *Phyllotheca australis* (= *P. indica*) were extended up to the *Glossopteris-Rhodeopteridium* Zone (Iannuzzi *et al.*, 2007). Based on the taxa listed from the two studied levels, only the *Glossopteris-Rhodeopteridium* Zone is recognized at the Quitéria ouctcrop. The *Glossopteris-Rhodeopteridium* Zone corresponds to Taphofloras B and C of Rösler (1978) and to the *Glossopteris-Brasilodendron* Flora of Iannuzzi and Souza (2005).

The phytostratigraphic sequence at the Quitéria outcrop has been discussed since the 1990s when it was considered the stratotype of the *P. indica* Subzone —which corresponds here to Quitéria Base— as well as stratotype of the *Glossopteris-Rhodeopteridium* Zone, equivalent to Quitéria Top in the first formal phytozonation proposed for Rio Grande do Sul (Guerra-Sommer and Cazzulo-Klepzig, 1993). A revision of this zonation (Iannuzzi *et al.*, 2007) revealed that only the *Glossopteris-Rhodeopteridium* Zone is present in the Quitéria section (Iannuzzi *et al.,* 2007, 2010). This biostratigraphic zonation is confirmed by the reassessment of the paleobotanical material presented herein (Fig. 3,Fig. 7 and Tab. 1).

The occurrence of *Giridia quiteriensis* (Boardman and Iannuzzi, 2010) at the Quitéria and Bainha outcrops (the latter located in Criciúma, southern Santa Catarina State), also allowed an open correlation between these two localities, as reproductive structures tend to have a short stratigraphic range, becoming thus good biostratigraphic indicators. The Bainha outcrop carries the well known "Irapuá Bed (Camada Irapuá)" flora, a coal-seam underlying the "Barro Branco Bed". The "Barro Branco Bed" is an important key bed at the top of the Rio Bonito Formation (Siderópolis Member) in the "Santa Catarina Coal Basin" (Iannuzzi, 2002). Thus, considering that the "Camada Irapuá" is a well defined stratigraphic sequence in the upper portion of the Rio Bonito Formation and a continuous unit in Rio Grande do Sul State (Schneider *et al.*, 1974), this correlation suggests that the Quitéria outcrop could carry the youngest rocks of the Rio Bonito Formation in Rio Grande do Sul State.

Several index species of the *Vittatina costabilis* Zone (VcZ) were recorded in the material studied, such as *Vittatina costabilis*, *V. subsaccata* and *V. vittifera* (Tab. 2). The presence of *Protohaploxypinus limpidus* and *Stellapollenites talchirensis* and the abundance of *Granulatisporites austroamericanus* and *Converrucosisporites confluens* suggest a correspondence with the *Protohaploxypinus goraiensis* Subzone (PgSz), lower portion of VcZ. However, a specimen of *Striatopodocarpites pantii* and cf. *Weylandites* sp. were recorded respectively in levels Q6 and Q9; as these taxa are typical of the overlying *Lueckisporites virkkiae* Zone (LvZ), these are considered their first appearances. Besides, no diagnostic species of the *Hamiapollenites karrooensis* Subzone (HkSz) was recovered.

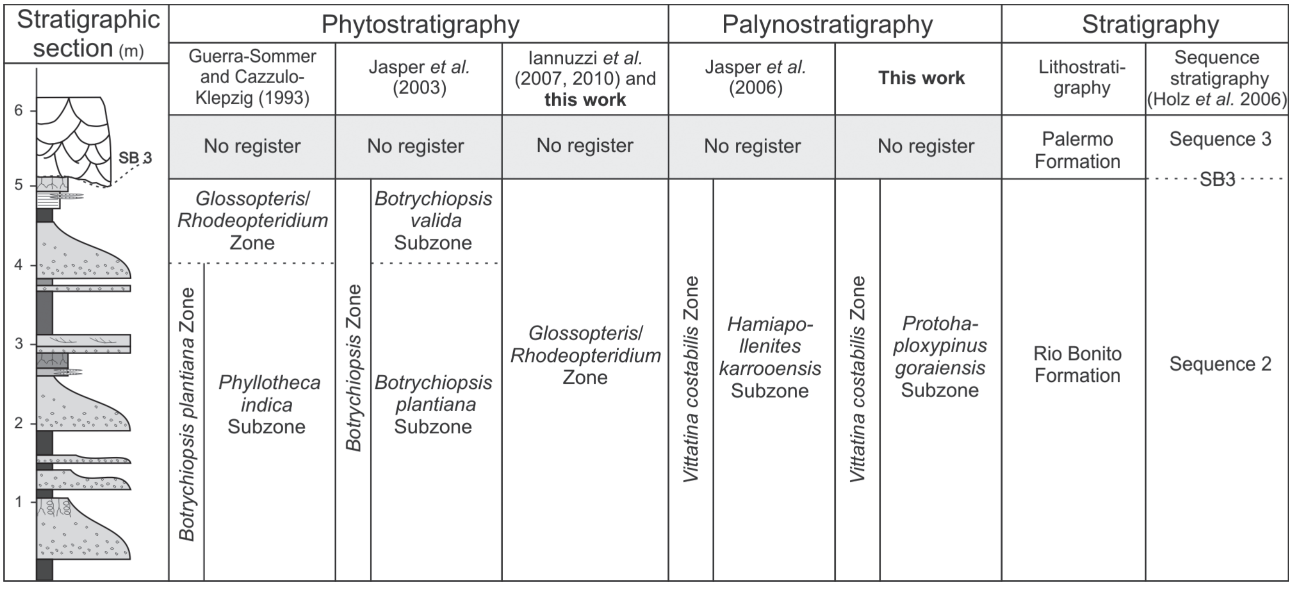

Figure 7. Comparison of various proposals for the stratigraphic position of the rocks exposed at the Quitéria outcrop/ *Comparación de las diversas propuestas para la posición estratigráfica de las rocas aflorantes en el afloramiento Quitéria.*

According to Souza and Marques-Toigo (2003, 2005), taeniate and polyplicate pollen grains are more abundant in the base of the LvZ, where spores are less frequent, as observed in several boreholes through the stratigraphic units of the two zones (Picarelli, 1986; Picarelli *et al.*, 1987). These first occurrences of index species of the LvZ were also observed by Mori and Souza (2010) in the transition between Rio Bonito and Palermo formations, in the southern part of the basin (Candiota Region, RS). Also, they confirmed the presence of typical species of the VcZ within the levels containing LvZ, as previously reported by Daemon and Quadros (1970).

These apparent dicrepancies require analyzing anew the continuous sections in order to detect whether the previously considered stratigraphically restricted ranges of some taxa are instead longer. According to Souza and Marques-Toigo (2003, 2005), *Protohaploxypinus goraiensis* is restricted to the VcZ. However, Mori and Souza (2010) recorded this taxon within levels referred to the base of the underlying LvZ. According to Mori (2010), the interval between the top of the Rio Bonito Formation and the base of the Palermo Formation in boreholes HN-05-RS and HN-25-RS presents "transitional" biostratigraphic characteristics, such as the persistence of index-species from the VcZ in levels assigned to the LvZ, whereas the first appearances of certain taxa from the LvZ occur in topmost levels of the VcZ. This stratigraphic distribution was observed also by Beri *et al.* (2004) in the adjacent area of the basin in Uruguay (Souza *et al.*, 2007). This problematic situation was discussed by Mori (2010), who suggested a new biostratigraphic subdivision for this sector of the basin.

Jasper *et al.* (2006) assigned the palynological assemblages to the HkSz based on the occurrence of *Striatopodocarpites fusus*, which appears restricted to this subzone according to Souza and Marques-Toigo (2005). However, Dias (1993) had recorded this species in the Itararé Subgroup, preventing the use of this taxon as an indicator of the HkSz.

Thus, the assignment of the beds exposed at the Quitéria outcrop to the PgSz (Fig. 7) is based on the presence of a large number of taxa typical of this unit —some of them stratigraphically restricted— as well as on the absence of diagnostic species of the HkSz and rare occurrences of guide-species from the LvZ.

Chronostratigraphy

Although the number of absolute datings of the Paleozoic deposits has increased over the last decade, there is no work specifically dealing with the section exposed at the Quitéria outcrop. Datings of the Rio Bonito Formation are still very controversial due to the different radiometric methods used and results are often conflicting.

Two typical localities where coal seams are exposed in Rio Grande do Sul provided information on absolute datings. Different ages were obtained at Mina de Candiota, based on two levels of *tonstein* at the top of the section (Matos *et al.*, 2001; Guerra-Sommer *et al.*, 2005, 2008b, d; Rocha-Campos *et al.*, 2006, 2007); results vary from 267.1±3.4 My (Matos *et al.*, 2001) to 296.9±1.65 My (Guerra-Sommer *et al.*, 2008b). The *tonstein* found in the Mina do Faxinal, at Arroio dos Ratos, was dated as 288.76±1.4 My, according to a combined approach using radiometric and palynostratigraphic data of Guerra-Sommer *et al.* (2008c). Later, Guerra-Sommer *et al.* (2008d) correlated the *tonstein* at Mina de Candiota with that from Mina de Faxinal and inferred that they belonged to the same volcanic event, estimating an average age of 290.6±1.5 My for these volcanic ashes. Mori and Souza (2010) had already mentioned such works frequently, but included no detailed paleobotanical or palynological data. This prevented any meaningful discussion about the stratigraphic sequence or an adequade biostratigraphic analysis of the deposits.

Mori *et al.* (2012) obtained an age of 281.4±3.4 My for a *tonstein* bed occuring at an outcrop of rocks higher up the section than those at Candiota Mine. Mori and Souza (2010) presented a comprehensive palynostratigraphic study of this bed. Erosional surface SB3 (Holz, 1997, 1998; Holz *et al.*, 2006) was recognized at that outcrop, and it can be used to correlate the rocks exposed there with the levels studied herein. Palynozones VcZ and LvZ occur in the interval between the top of the Rio Bonito Formation and the base of the Palermo Formation (Daemon and Quadros, 1970; Souza and Marques-Toigo, 2003, 2005), where a significant erosional surface was identified (SB3). This erosional event might have affected the units in different ways, eroding the continental deposits at the top of the Rio Bonito Formation and/or the marine facies at the base of the Palermo Formation, thus rendering different ages for the levels beneath SB3. Because of this, the levels studied here and lying directly below SB3 and lithostratigraphically within the Rio Bonito Formation are assigned to the PgSz of the VcZ. The material from the Candiota region (Mori and Souza, 2010) displayed palynological assemblages assigned to the LvZ within the Rio Bonito Formation, directly below SB3.

The sequence boundary SB3 is found at the two localities and comparison between the palynological assemblages from

Candiota (Mori and Souza, 2010; Mori *et al.*, 2012) and Quitéria indicates that the section at Quitéria bears slightly older rocks than those from Candiota region. We conclude that the erosive event (SB3) eroded more intensely the Rio Bonito Formation at the Quitéria outcrop than at Candiota. Thus, it reveals that the rocks of the section at the Quitéria outcrop should be considered older than 281.4±3.4 My, an age obtained by Mori *et al.* (2012) for the section in the Candiota region.

CONCLUSIONS

The section at the Quitéria outcrop is considered a relevant one within the deposits of the Rio Bonito Formation, as it carries rich and diversified taxa of plant remains, palynological assemblages retrieved from several levels, and it also contains a regional stratigraphic boundary surface.

The plant association characterizes a typical scenario of roof shale flora. Its taxonomic revision allowed us to confirm the record of 14 fossil species belonging to botanical groups. Lycopsida is the most common one, strongly represented in Quitéria Top within a level where *in situ* casts (*Brasilodendron pedroanum*) are well-preserved. Palynologically, these levels carry a *Lundbladispora*-rich association.

This outcrop yielded plant fossils attributed to taphofloras B and C by Rösler (1978). Taking into account the model of floral succession established for the Paraná Basin by Iannuzzi and Souza (2005), it corresponds to the *Glossopteris-Brasilodendron* Flora, which is well-distributed throughout the Paraná Basin including areas of Argentina and Uruguay (*Glossopteris* Phytozone, Archangelsky *et al.* 1980), and also in other Permian zones in Australia and India (Retallack, 1980; Maheshwari and Bajpai, 2001).

The *Protohaploxypinus goraiensis* Subzone was recognized in this outcrop mainly by the presence of *P. limpidus* and *S. talchirensis* and by the abundance of *G. austroamericanus* and *C. confluens*. This subzone is correlated with the *Cristatisporites inconstans-Vittatina subsaccata* Zone established for the Paraná Basin in Uruguay (Beri *et al.,* 2004), and with the *Potonieisporites-Lundbladispora* Zone of the Chacoparaná Basin in Argentina (Russo *et al.*, 1980; Vergel, 1993), and the *Fusacolpites fusus-Vittatina subsaccata* Zone in central-western Argentina (Césari and Gutiérrez, 2000). However, certain species typical of the overlying palynozone (LvZ) are recorded too. This implies that this section represents the transition between two biozones and/or the first appearance of these guide species.

The erosional surface SB3 occurs in the uppermost levels of the section at the Quitéria outcrop. It represents a geologic event affecting the uppermost portion of the Rio Bonito Formation in the Paraná Basin. We conclude it eroded more intensely the Rio Bonito Formation in the Quitéria region than in the Candiota region. Thus, rocks in the Quitéria section are slightly older than those recorded in the Candiota region, as these have been recently dated as Artinskian (281.4±3.4 My, Mori *et al.*, 2012).

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