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STRATIGRAPHY AND PALAEOENVIRONMENTS OF THE TANQUE BASIN, SOUTHEASTERN BRAZIL

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ABSTRACT – Stratigraphic and paleopalynological studies in Cenozoic deposits of the eastern region of the state of São Paulo led to the identification of two sedimentary episodes during the Paleogene and Neogene times. The analyses also permitted the reconstruction of the predominant climatic and paleoenvironmental conditions during the time of deposition. The first sedimentation phase developed during the Late Eocene, under humid and subtropical climatic conditions, with cold and dry winters. The second episode occurred during the Late Miocene – Pliocene probably under a subtropical to temperate climate, with well-defined seasons. The findings of this study permit us to suggest that these sediments as well as their ages are strongly correlated to the adjacent deposits of the São Paulo and Taubaté sedimentary basins belonging to the continental rift system of southeastern Brazil.

Key words: Paleogene, Neogene, paleopalynology, stratigraphy, paleoenvironments, southeastern Brazil.

RESUMO – Estudos estratigráficos e palinológicos de depósitos cenozóicos da região leste do Estado de São Paulo revelararam duas seqüências sedimentares: Paleógeno e Neógeno. Esses estudos permitiram a reconstrução das condições paleoambientais e do clima predominante durante sua deposição. O primeiro episódio deposicional, durante o final do Eoceno, teria se desenvolvido em condições de clima subtropical úmido, com verões quentes e úmidos e invernos secos. O segundo teria ocorrido durante o Mioceno Superior a Plioceno, provavelmente sob condições de clima subtropical a temperado, com alternância bem definida de estações. Este estudo possibilitou estabelecer que tanto os sedimentos quanto as idades são perfeitamente correlacionáveis aos depósitos adjacentes das bacias sedimentares de São Paulo e Taubaté, que fazem parte do Sistema de Rift Continental do Sudeste Brasileiro.

Palavras-chave: Paleógeno, Neógeno, paleopalinologia, estratigrafia, paleambientes, Sudeste do Brasil.

INTRODUCTION

The presence of discontinuous and punctual Cenozoic sedimentary deposits in eastern São Paulo State, Brazil, was reported by Penalva (1971), Melo & Ponçano (1983) and Fulfaro *et al.* (1985), among others. These authors attribute ages to these deposits which have been controversial, ranging from the Tertiary to Pleistocene, mainly due to the absence of absolute or relative ages. Up to the present, the only fossils discovered in these sediments have been plant megafossils (e.g., leaves) suggesting a Cenozoic age (Mezzalira, 1989).

Bistrichi (2001), Garcia *et al.*, (2004) and Bistrichi *et al.* (2008) studied the deposits located in the area encompassing the regions of Itatiba and Nazaré Paulista in the south and Bragança Paulista and Joanópolis in the north, and they grouped these deposits under the denomination of Tanque Basin, because they constitute facies associations within chronocorrelated depositional systems.

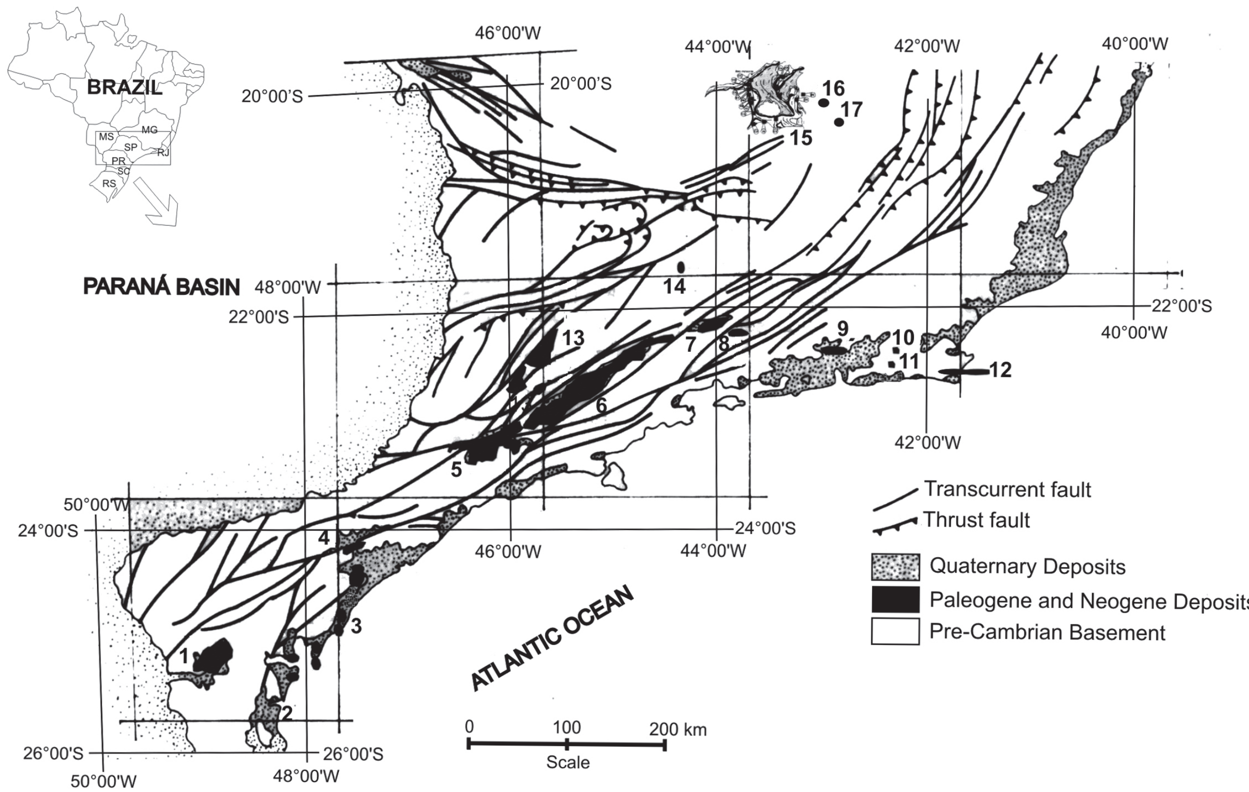

Figure 1. Schematic map of the rift basins of southeastern Brazil: **1**, Curitiba Basin; **2**, Alexandra Formation and Graben of Guaraqueçaba; **3**, Pariquera-Açu Formation; **4**, Graben of Sete Barras; **5**, São Paulo Basin; **6**, Taubaté-Bonfim Basins; **7**, Resende Basin; **8**, Volta Redonda Basin; **9**, Graben of Guanabara; **10**, Macacu Basin; **17**, São José de Itaboraí Basin; **12**, Graben of Barra de São João; **13**, Tanque Basin; **14**, Aiuruoca Basin; **15**, Paleogene/Neogene deposits of Belo Horizonte; **16**, Gandarela Basin; **17**, Fonseca Basin (mod. from Almeida & Hasui, 1984).

In the present study, we conducted a pollen analysis of nine stratigraphical profiles from eight different localities of the Tanque Basin in order to establish a sedimentation model, the age of these processes, and a possible correlation to the paleoenvironmental histories of other rift basins of southeastern Brazil as well (Almeida, 1976**;** Riccomini, 1989), especially that of the São Paulo and the Taubaté basins (Campanha, 1994; Yamamoto, 1995; Sant'Anna, 1999 and Riccomini *et al*., 2004). In this paper we used the concept of geologic time scale of Gibbard *et al*. (2005).

GEOLOGY AND GEOMORPHOLOGY OF THE TANQUE BASIN

The Tanque Basin, located in the eastern section of São Paulo State, includes the localities of Nazaré Paulista, Piracaia, Bom Jesus dos Perdões, Atibaia, Bragança Paulista and Pinhalzinho (Figure 1). This region is part of the central portion of the Mantiqueira Structural Province, which is composed mainly of metamorphic and igneous rocks of various ages, ranging from Archean-Proterozoic to the Cambrian-Ordovician (Hasui & Oliveira, 1984). In addition to these sequences, there are more limited occurrences of Mesozoic units in the form of dykes of basic and alkaline rocks; alkaline *stocks* and batholites and Cenozoic sediments (Almeida *et al*., 1981).

In the Mantiqueira Province, the presence of NE-SW Pre-Cambrian shear zones is notable and defines a set of aligned structures, conditioning the elongated forms of the metamorphic units and granitoid bodies. Cenozoic sedimentary deposits of the rift system of southeastern Brazil, shown in Figure 1 (ns. 1-17), are delimited by these regional tectonic structures which were reactivated during Cenozoic times (Hasui, 1990; Bistrichi, 2001). Geomorphologically, the eastern portion of São Paulo State is characterized by plateaus topographically unleveled, as defined by Almeida (1964) and redefined by Ponçano *et al.* (1981). Recent studies (i.e., Bistrichi, 2001) indicate that these plateau compartments make up morphotectonic units, referred to as Lindóia, Jundiaí, Jandiuvira, Middle Paraíba do Sul river valley and Paraitinga, as shown in Figure 2. The Tanque Basin is located within the Jundiaí block, where the distribution of Cenozoic deposits can be observed.

METHODS AND TECHNIQUES

Stratigraphic analysis

The stratigraphic analysis was based on the characteristics of the sedimentary deposits which were evaluated in the field by means of establishing stratigraphical columns followed by detailed descriptions such as sedimentary structures, grain size analysis, texture, external geometry, color and presence of fossils. The objective of these parameters was to identify and to characterize the main lithofacies as well as facies associations present in the Tanque Basin.

Paleopalynology

A total of 63 samples, collected in different locations of the area studied for pollen analysis, were obtained from outcrops and cleaned to remove possible modern contaminants. Subsamples containing 20 g of sediments were chemically treated following the procedure described by Uesugui (1979) with modifications, *i.e.*, silicate removal with HF (hydrofluoric acid) digestion, followed by hot HCl (hydrochloric acid), sieving with a 10 µm mesh, and mounting on glass slides with Entelan medium. Identification of the palynomorphs was carried out with an Olympus BX-51 light microscope with an attached conventional camera for photomicrography. Pollen diagrams were made using Tilia and Tilia/Graph software (Grimm, 1987, 1990).

We compared the palynomorphs with those described for Paleogene/Neogene basins of southeastern Brazil (Figure 1) such as Macacu (Lima *et al*., 1996), Itaboraí (Lima & Cunha, 1986), Volta Redonda (Lima *et al*., 1994), Resende (Lima & Amador, 1985; Lima & Melo, 1994; Yamamoto, 1995), Bonfim (Lima & Dino, 1984), Taubaté (Lima *et al*., 1985a, 1985 b; Yamamoto, 1995), São Paulo (Lima *et al*., 1991; Yamamoto, 1995), and Gandarela and Fonseca (Lima & Salard-Cheboldaeff, 1981; Pinto & Regali, 1990; Maizatto, 2001), as well as with those from the Alexandra Formation (Lima & Angulo, 1990) in northern Brazil (Carvalho, 1996; Leite, 1997, 2004, 2006) and the coastal basins of the Brazilian continental shelf (Regali *et al*., 1974a, b). In addition, we used palynostratigraphical zonations and various palynological studies conducted in other countries of South America (Van der Hammen,1956a, 1956 b; Van der Hammen & Wijmstra, 1964; Germeraad *et al*., 1968; Dueñas, 1980; Lorente,1986; Muller *et al*., 1987, Colmenares & Teran,1993; Hoorn,1993, 1994a, 1994 b; Barreda, 1993, 1997a, 1997 b, 1997c, 1997d; Barreda & Caccavari, 1992; Anzotegui & Cuadrado, 1996; Jaramillo & Dilcher, 2001. Some studies on the African paleogene/neogene sediments were also examined: Adegoke & Jan Du Chêne (1978); Salard-Cheboldaeff (1979, 1990); and El Beialy *et al.* (2005). The European studies on Paleogene and Neogene palynology were those of Nagy (1969), Ziembinska-Tworzydlo (1974), Ziembinska-Tworzydlo *et al.* (1994 a, 1994b), and Ashraf & Mosbrugger (1996). We also checked our palynomorphs against the palynological catalogues of Jansonius & Hills (1976, 1985, 1987 and 1990).

A total of 10 microscope glass slides, used for counting, were prepared for each sedimentary sample. These slides were scanned and all the palynomorphs present were counted.

RESULTS AND DISCUSSION

Pollen analysis

Of the 63 samples analyzed only 11 proved to contain palynomorphs. These sediment samples, with the exception of the Pinhalzinho locality, were poor in palynomorphs and the pollen sum in these samples was less than 100 grains. However, the assemblages contained important palynostratigraphic taxa, which permitted us to establish relative ages for the sediments. In order to remove bias in the percentages caused by the low pollen sum, the results are given in terms of grains counted per sample.

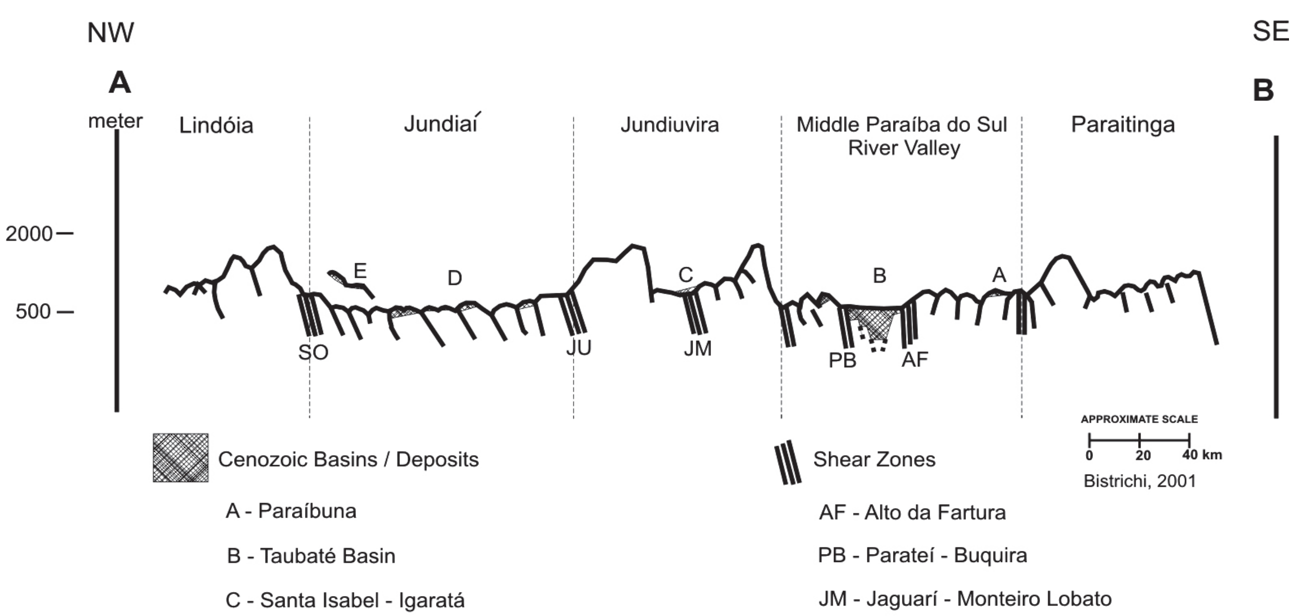

Figure 2. Schematic geomorphological cross-section of morpho-tectonic compartments in eastern São Paulo State, Brazil (mod. from Bistrichi, 2001).

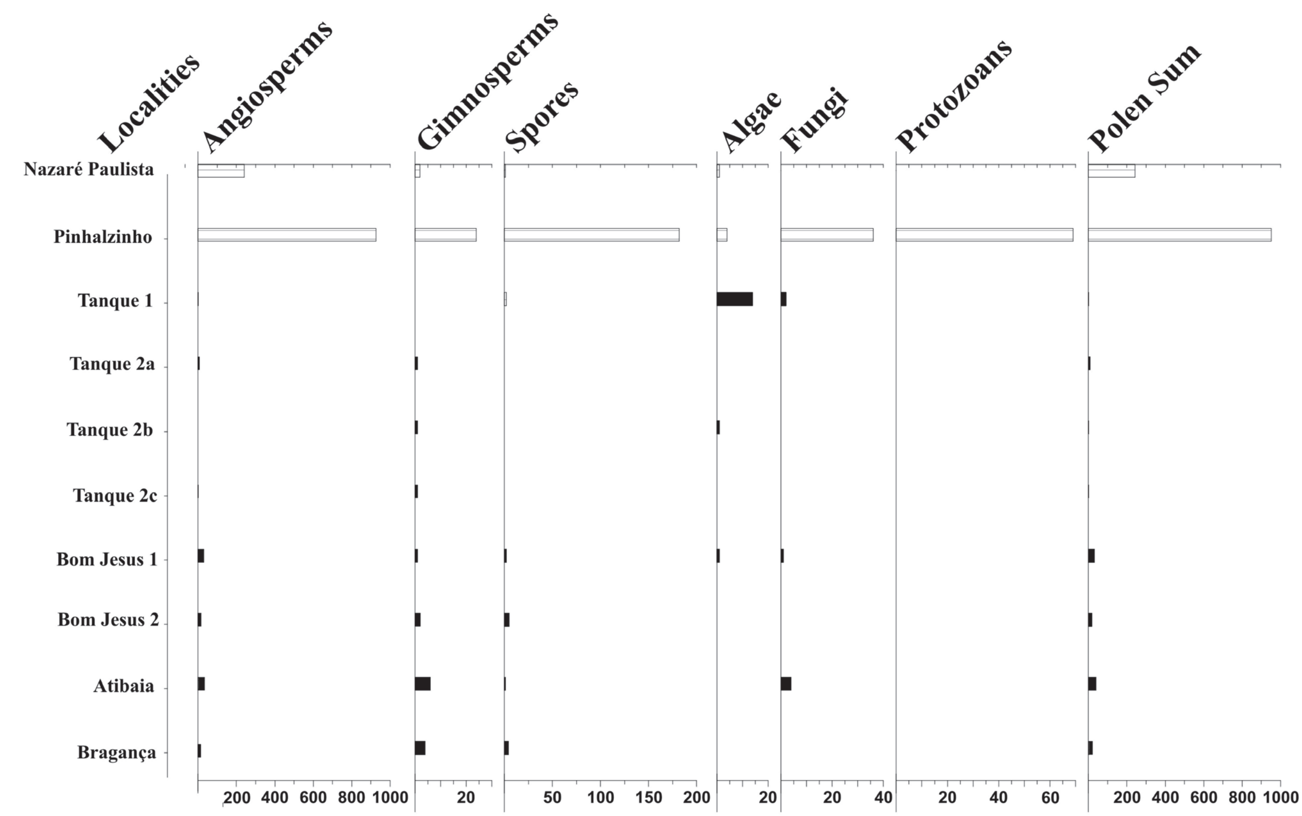

Figure 3 -Total qualitative and quantitative palynodiagram (sum).

Figure 3 shows the distribution of palynomorph categories found in the samples. The distribution of spores and gymnosperm and angiosperm pollen grains in the samples are shown in Figures 4 and 5, respectively. Photomicrographs of palynomorphs of this study are shown in Figures 6, 7 and 8. The complete list of palynomorphs, sample localities, and possible botanical affinities of the taxa found is shown in Appendix 1.

The palynological analyses indicate the presence of Paleogene assemblages in the Tanque Basin (Bom Jesus dos Perdões, Atibaia, Tanque and Bragança Paulista localities) and Neogene assemblages in the Pinhalzinho and Nazaré Paulista localities (Figure 9).

Paleogene flora

The Paleogene assemblage contained 56 taxa, of which 3 were fungi, 2 were algae, 4 were bryophytes/pteridophytes, 8 were gymnosperms, and 39 were angiosperms (Figures 6, 7 and 8). This assemblage was composed of a few spores such as *Biretisporites* sp.3, *Cicatricosisporites* sp. 1 and *Punctatisporites* sp.1. The gymnosperm pollen flora was composed of *Cedripites lusaticus*, *Pityosporites labdacus*, *Pityosporites* sp.2, *Podocarpidites embryonalis*, and *Podocarpidites* sp.1, *P.* sp.2, *P.* sp.3. The angiosperm pollen taxa found were: *Retimonocolpites* sp.2, *Psilamonocolpites* sp.2, *Retitetracolpites* sp.2, *Retitriporites dubiosus*, *Graminidites, Momipites* sp.1, *Miocaenipollis* sp.5, *Psilastephanoporites* sp.2, *Echiperiporites akanthos*, *Scabraperiporites asymmetricus*, *Scabraperiporites* sp.1, *Ulmoideipites krempii*, *Psilastephanocolporites laevigatus*, *Perisyncolporites pokornyi*, *Perfotricolpites digitatus*, *Psilatricolpites papilioniformis*, *Tricolpites* (*Retitricolpites*) *clarensis*, *Tricolpites* sp.1, *Symplocoipollenites* sp.1, *Compositoipollenites* sp.9, *C.* sp.10, *C.* sp.11, *Margocolporites vanwijhei*, *Psilatricolporites* sp.5, *Psilatricolporites costatus, Rhiopites (Retitricolporites*) *cienaguensis*, *R. guianenesis*, *Retitricolporites finitus*, *Siltaria media* (*Retitricolporites medius)*, *Acaciapollenites myriosporites*, *Polyadopollenites* sp.2, *Quadraplanus* sp.1, *Syncolporites lisamae*, *S. poricostatus*, *S.* sp.3, *Cupaneidites* sp.6, *Plicapollis* sp.1, and *P.* sp.2.

Neogene flora

The Neogene assemblage was very diversified and characterized by the presence of 121 taxa, of which 12 were fungi (Figure 6 B, C), 2 were algae, 26 were pteridophytes/ bryophytes (Figure 6), 11 were gymnosperms (Figure 6), 69 were angiosperms (Figure 7 and 8), and one was a protozoan (Rhizopode, aff. *Assulina* – Figure 6 A). The spore taxa found were *Baculatisporites* sp.1, *Biretisporites crassilabratus*, *Biretisporites* sp.1, *B.* sp.2, *Cyatheacidites annulatus*, *Deltoidoipora* sp.1, *D.* sp.2, *Foveotriletes ornatus*, *Leiotriletes microadriennis*, *L.* sp.1, *Lycopodiumsporites* sp.1, *Lycopodiumsporites austroclavatidites*, *Polypodiaceiosporites* sp.1, *Selaginellisporis echinoides*, *Verrucatotriletes bullatus*, *Aspleniumsporites* sp.1, *A.* sp.2, *A.* sp.3, *A.* sp.4, *A.* sp.5, *A.* sp.6, *Laevigatosporites ovatus*, *Laevigatosporites* sp.1, *Punctatosporites* sp.1,

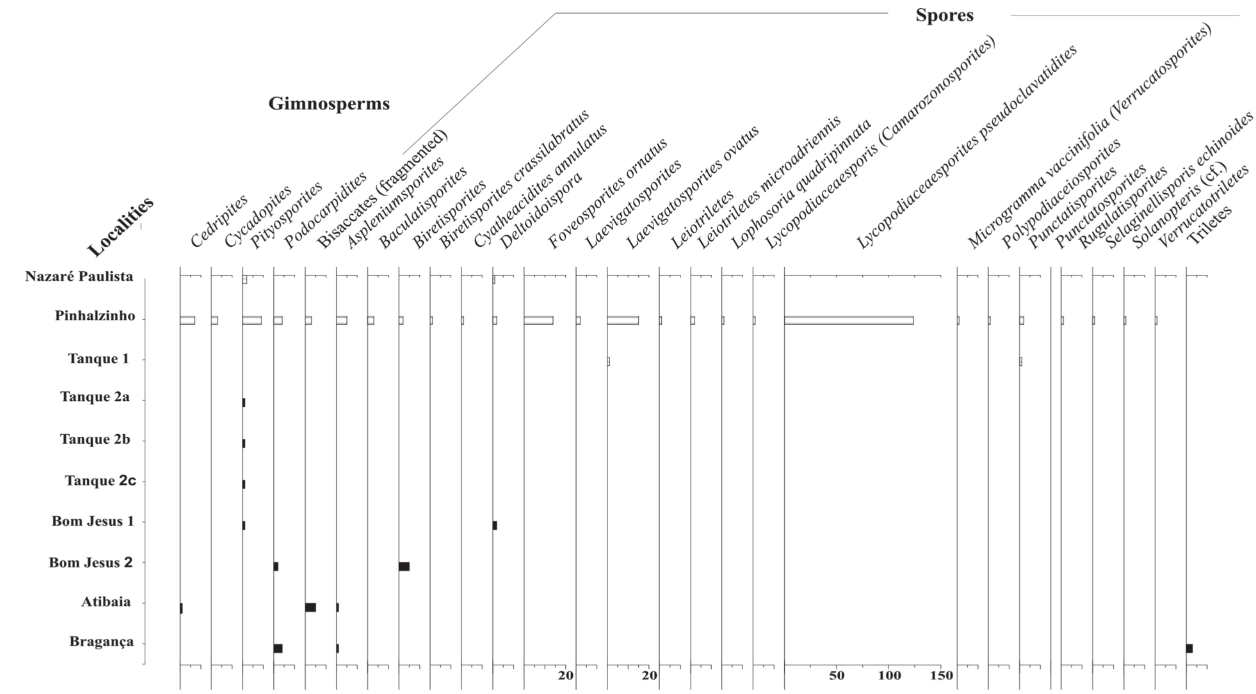

Figure 4. Qualitative and quantitative palynodiagram of gymnosperm pollen grains and spores of pteridophytes and bryophytes.

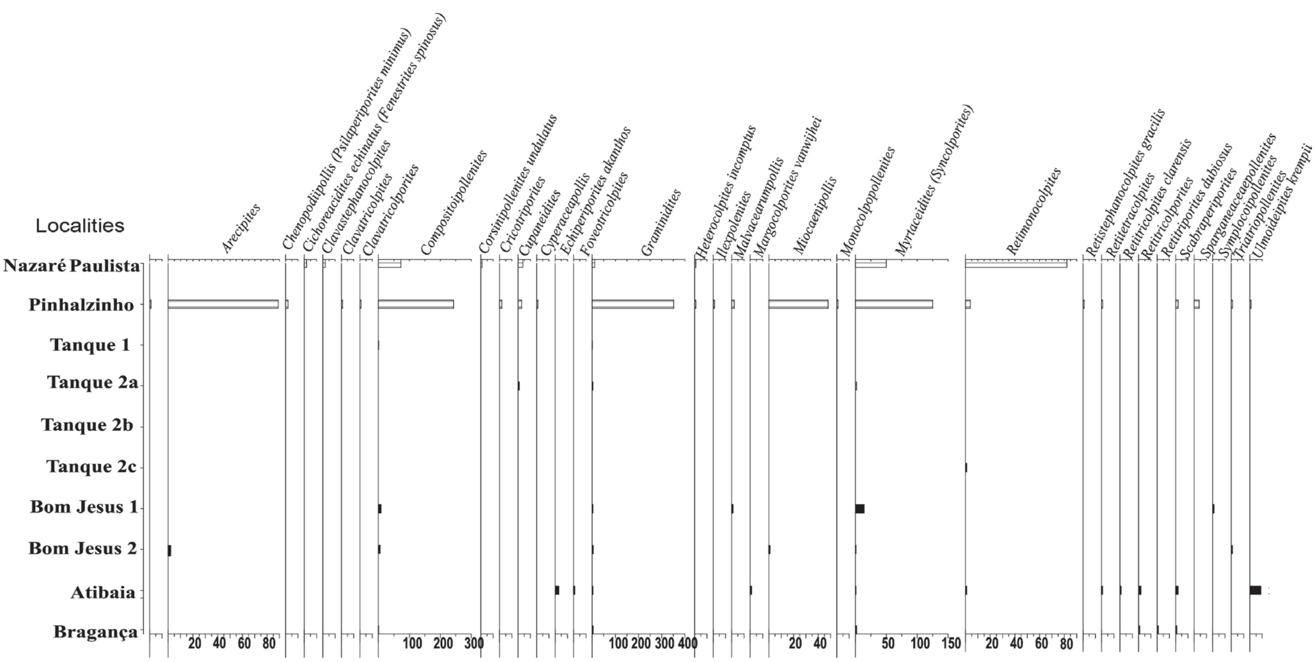

Figure 5 - Qualitative and quantitative palynodiagram of arboreal elements.

Rugulatisporites sp.1, and *Verrucatosporites* sp.1. The gymnosperm taxa were *Cedripites lusaticus*, *Cedripites miocaenicus*, *Pityosporites labdacus*, *Pityosporites* cf. *P. zaklinskaiana*, *P.* sp.1, *Podocarpidites* cf.. *P. ellipticus*, *Podocarpidites* cf. *P. sellowiformis*, *P. macrophylliformis, Cycadopites miocaenica*, and *C.* sp.1. The angiosperm pollen grains were *Cyperaceapollis* sp.1, *Graminidites*, *Sparganeaceapollenites* sp.1, *S.* sp.2, *Arecipites* sp.1, *A.* sp.2, *A.* sp.3, *A.* sp.4, *Proxapertites tertiaria*, *Psilamonocolpites* sp.1, *Retimonocolpites noremi*, *Retimonocolpites* sp.1, *Monocolpopollenites* sp.1, *Alangiopollenites barghoomianum*, *Retistephanocolpites gracillis*, *Retitetracolpites* sp.1, *Heterocolpites incomptus*, *Nothofagidites* sp.1, *Corsinipollenites undulatus, Cricotriporites* sp.1, *Psilatriporites* sp.1, *Proteacidites rectomarginatus*, *Momipites quietus*, *Miocaenipollis* sp.1, *M.* sp.2, *M.* sp.3, *M.* sp.4, *Psilastephanoporites* sp.1, *Malvacearumpollis* (*Echiperiporites*) *estelae*, *Persicariopollis* sp.1, *Psilaperiporites minimus*, *Scabraperiporites nativensis*, *S. asymmetricus*, *Ulmoideipites krempii*, *Fenestrites spinosus*, *Psilastephanocolporites fissilis*, *Perisyncolporites pokornyi*, *Clavatricolpites* sp.1, *Psilatricolpites* sp.1, *P*. sp.2, *Araliaceoipollenites edmundi*, *Clavatricolpites* sp.1, *Echitricolporites mcneillyi*, *Echitricolporites spinosus*, *Compositoipollenites sentis*, *Compositoipollenites* sp.2, *C*. sp.3, *C*. sp.4, *C*. sp.5, *C*. sp.6, *C*. sp.7, *C*. sp.12, *Ilexpollenites* sp.1, *Psilatricolporites* sp.1, *P*. sp.2, *P*. sp.3, *Psilatricolporites costatus*, *Polyadopollenites* sp.1, *Syncolporites incomptus*, *S. lisamae*, *S. poricostatus*, *S*. sp.1, *S*. sp.2, *Cupaneidites* sp.1, *C*.sp.2, *C*. sp.3, *C*. sp.4, and *C*. sp.5.

Age comparisons and similarities with other palynofloras

Some of the taxa identified in these two assemblages are of biostratigraphic importance, and therefore, we correlated them in Figure 10, according to the palynostratigraphic zonations proposed by Van der Hammen & Wjimstra (1964) for Guyana, Germeraad *et al.* (1968) for tropical areas, Wjimstra (1971 apud Hoorn, 1993) for Surinam and French Guyana, Regali *et al.* (1974 b) for Brazilian coastal basins, Muller *et al.* (1987) for northern South America, Lorente (1986) for Venezuela, and Hoorn (1993) for Amazonia.

We compared our results with the Brazilian studies of Regali *et al*. (1974 b), Lima & Salard-Cheboldaeff (1981), Lima & Dino (1984), Lima & Amador (1985), Lima & Cunha (1986), Hoorn (1994a, 1994b), Lima *et al*. (1985a, 1985b,1991,1994,1996), Pinto & Regali (1990), Lima & Melo (1994), Yamamoto (1995), Carvalho (1996), Maizatto (2001), Hoorn (1993, 1994 a, 1994b), (Leite, 2004, 2006) and those proposed for other regions of South America by Van der Hammen (1956 a, 1956b), Van der Hammen & García de Murtis (1965), González-Gusmán (1967), Quattrocchio (1978), Dueñas (1980), Anzotegui & Cuadrado (1996), Prámparo *et al.* (1996), Barreda (1997a, 1997b, 1997c, 1997d), Ottone *et al.* (1998) and Jaramillo & Dilcher (2001).

We also compared our results to those studies conducted in Africa by Sah (1967), Adegoke & Jan Du Chêne (1978), Salard-Cheboldaeff (1979,1981,1990), and El Beialy *et al.* (2005), in Australia and New Zealand by Cooper (1960), Mc Intyrer (1968),Partridge (1978), Pocknall (1982,1985), Stover & Partridge (1973), Stover & Evans (1973), Truswell *et al.* (1985) and Bruch & Mosbrugger (2002) for Slovenia.

Late Eocene palynofloras

In order to define the Late Eocene ages, the following palynomorphs were used (some of which are well-established palynostratigraphical markers): *Retitriporites dubiosus, Psilastephanocolporites* cf. *P. laevigatus, Margocolporites vanwijhei, Tricolpites clarensis, Perfotricolpites digitatus*, *Psilatricolpites papilioniformis, Siltaria media, Rhiopites cienaguensis, R. guinanensis, Retitricolporites finitus, Acaciapollenites myriosporites, Quadraplanus* sp., *Syncolporites lisamae, Syncolporites poricostatus, Scabraperiporites asymmetricus, Psilatricolporites costatus,* and *Perisyncolporites pokornyi,* including a large abundance of *Ulmoideipites krempii* and *Echiperiporites akanthos*.

The biostratigraphical distribution of some of these palynomorphs is wide. In addition, some of them show a controversial vertical range among different authors (for example, *Margocolporites vanwijhei* and *Perfotricolpites digitatus*). Jaramillo & Dilcher (2001) found these taxa in the Lower Eocene in central Colombia (Regadera section). On the other hand, Germeraad *et al*. (1968), in tropical areas (Caribbean area, Nigeria and Borneo) and Muller *et al.* (1987), in northern South America, consider them indicative of ages spanning from the Eocene to the Recent. Lorente (1986) described them for the Maracaibo Basin (Venezuela) and considered *Margocolporites vanwijhei* a taxon occurring from the Oligocene to the Present, whereas *Perfotricolpites digitatus* was found from the Early Eocene to Pleistocene. In Argentina, Barreda (1997b) encountered *Margocolporites vanwijhei* in the Chenque, Chubut and Santa Cruz Formations (Late Oligocene-Miocene).

In Egypt, El Beialy *et al*. (2005) described *Margocolporites vanwijhei* in association with *Perfotricolpites digitatus* and *Striatopollis catatumbus* in Rudeis and Kareem formations together with other palynomorphs that characterized the Lower-Middle Miocene, such as *Fenestrites spinosus.* However, *Margocolporites vanwijhei,* is also recorded in the Late Oligocene and *Perfotricolpites digitatus* in the Early-Middle Oligocene age of New Zealand (Pocknall, 1982), in the Late Neogene west coastal of Africa (Partridge, 1978), and in southern Australia from the Early to Middle Oligocene (Truswell *et al*., 1985), in Sudan from the Late Eocene-Oligocene (Kaska, 1989). On the other hand, Regali *et al.* (1974 a, 1974b) suggest that *Margocolporites vanwijhei* characterizes the Late Eocene in the Brazilian coastal basins and *Perfotricolpites digitatus* the Middle Eocene-Oligocene. In the Brazilian continental basins, however, this taxon has been considered indicative of the Late Eocene by Lima & Salard-Cheboldaeff (1981), Pinto & Regali (1990) and Maizatto (2001) in the Gandarela and Fonseca basins, as well as by Lima & Amador (1985) for the Resende Formation (Resende Basin), and (Lima *et al*. 1994) for Volta Redonda Basin (Graben Casa de Pedra), and by Lima & Dino (1984) for the Bonfim Basin. According to Lima *et al*. (1991), *Margocolporites vanwijhei* could indicate that the range of this taxon can encompass the Oligocene in the São Paulo Basin (Itaquaquecetuba and São Paulo Formations) or can be the result of reworked sediments from the Late Eocene into Oligocene age. Yamamoto (1995) found this taxon in the São Paulo Formation, (Taubaté Basin), Resende Formation (Resende Basin) and in the Itaquaquecetuba Formation (São Paulo Basin), thus suggesting an Oligocene age for these microfloras. Hoorn (1993, 1994a, 1994 b) found *Margocolporites vanwijhei* in Miocene sediments of the Solimões Basin, NW Amazonia. In addition, Carvalho (1996) suggests that the presence of this taxon in Plio-Pleistocene sediments of the Foz do Rio Amazonas Basin as a consequence of its reworking. Garcia *et al*. (2008) suggest that these taxa were controlled by climate, and therefore, they do show a uniform and synchronous geographic distribution on the South American continent.

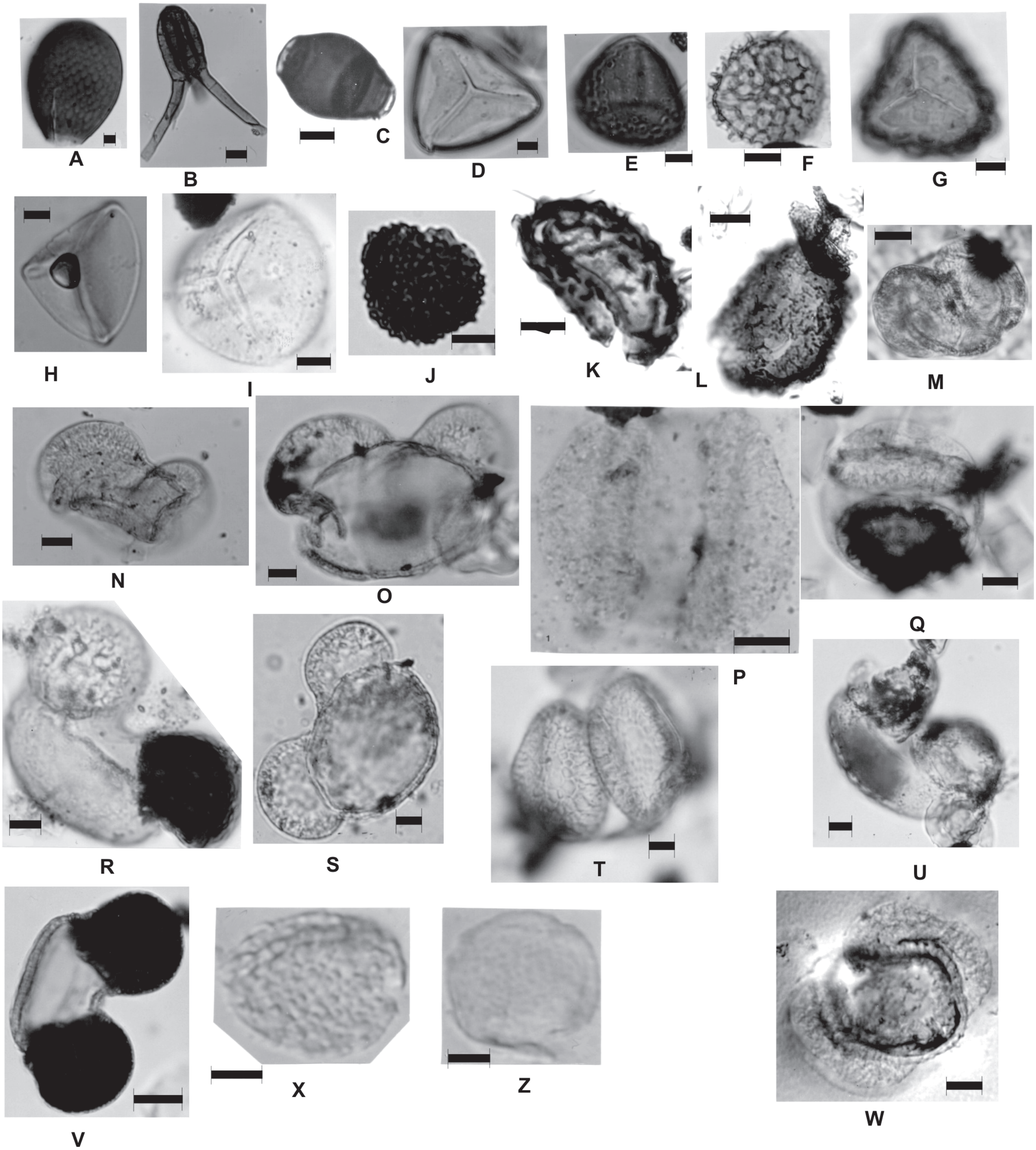

Figure 6. A, aff. *Assulina seminulum;* **B**,*Tetraploa aristata*; **C**, *Brachysporium* sp.; **D**, *Cyatheacidites annulatus* Cookson, 1947; **E**, *Foveotriletes ornatus* Regali, Uesugui & Santos, 1974; **F**, *Lycopodiumsporites austroclavatidites* (Cookson) Potonié, 1956; **G**, *Verrucatotriletes bullatus* Van Hoeken-Klinkenberg, 1964; **H**, *Biretisporites crassilabratus* Archangelsky, 1972; **I**, *Punctatisporites* sp. 1; **J**, *Selaginellisporis echinoides* Krutzsch & Pacltova, 1963; **K**, *Aspleniumsporites* sp. 1; **L**, *Aspleniumsporites* sp. 2; **M**, *Podocarpidites* sp.1; **N,** *Podocarpidites ellipticus* Cookson, 1947; **O**, *Cedripites miocaenicus* Krutzsch, 1971; **P,Q**, *Cedripites lusaticus* Krutzsch, 1971; **R,S**, *Pityosporites labdacus reticulatus* (Doktorawicz-Hrebnicka,1960) Krutzsch, 1971; **T**, *Pityosporites labdacus* (Potonié, 1931) Thomson & Pfug, 1953; **U**, *Pityosporites* cf. *P. zaklinskaiana* Nagy, 1996; **V**, *Podocarpidites macrophylliformis* Nagy, 1969; **W**, *Podocarpidites* cf. *P. embryonalis* Krutzsch,1971; **X**, *Echiperiporites akanthos* Van der Hammen & Wijmstra, 1964; **Z**, *Ulmoideipites krempii* Anderson, 1960. Scale bars= 10 µm.

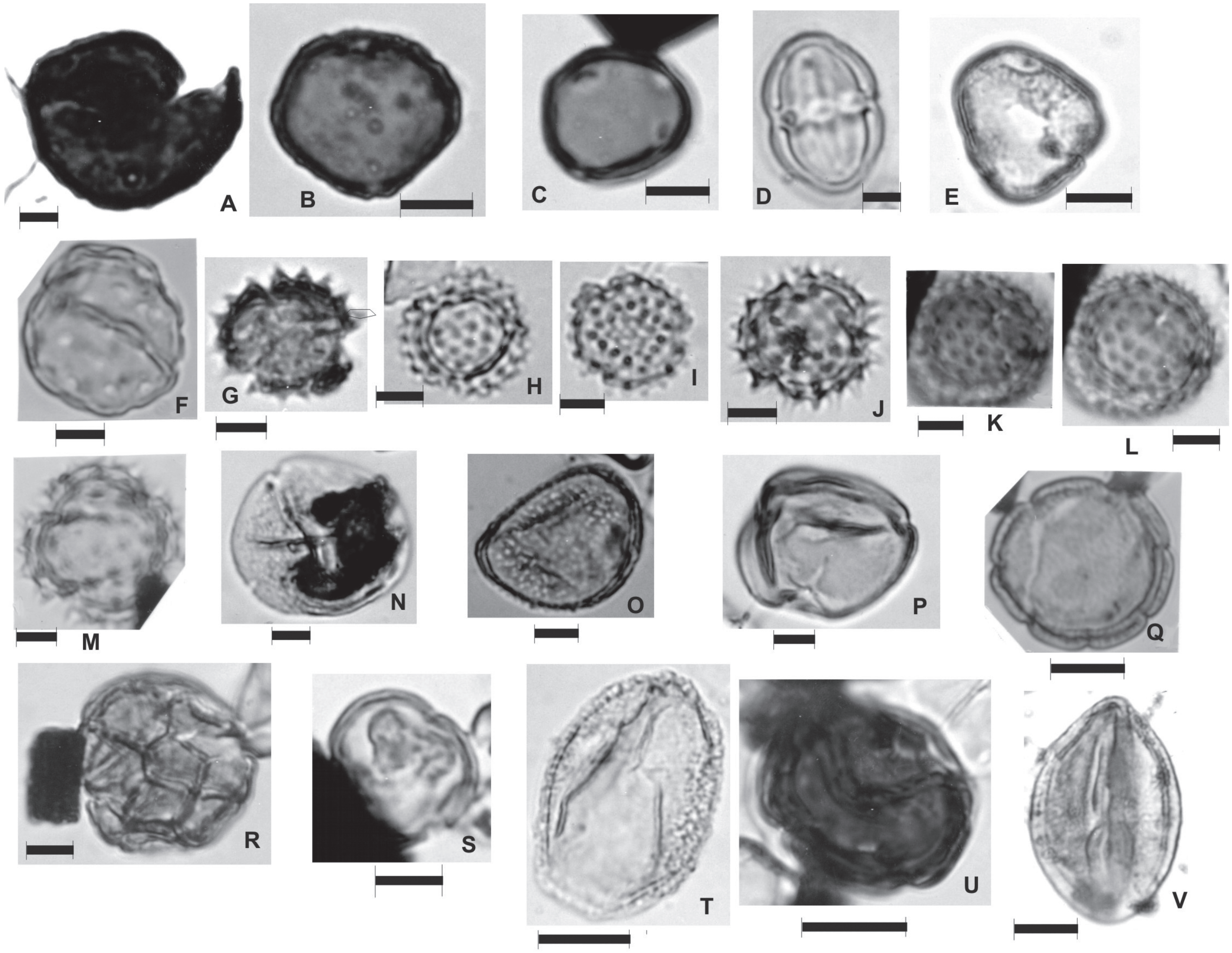

Figure 7. A, *Scabraperiporites asymmetricus* Duenas, 1980; **B**, *Scabraperiporites nativensis* Regali, Uesugui & Santos,1974; **C**, *Miocaenipollis* sp.3; **D**, *Psilastephanocolporites fissilis* Regali Uesugui & Santos, 1974; **E**, *Cyperaceapollis* sp.1; **F**, *Psilaperiporites minimus* Regali, Uesugui & Santos, 1974; **G**, *Compositoipollenites sentis* Sah, 1967; **H**, *Compositoipollenites* sp.5 (*Tubulifloridites ambrosiinae*); **I**, *Compositoipollenites* sp.1 (*Echtricolporites mcneillyi* Van der Hammnen ex Germeraad, Hopping & Muller, 1968); **J**, *Compositoipollenites* sp.8 (*Echitricolporites spinosus* Van der Hammen ex Germeraad, Hopping & Muller, 1968); **K**-**L**, *Compositoipollenites* sp.7 (*Tubulifloridites granulosus*); **M**, *Compositoipollenites* sp.6; **N**, *Retitetracolpites* sp.1; **O**, *Sparganiacaepollenites* sp.2; **P**, *Psilatricolporites* sp.2; **Q**, *Retistephanocolpites gracilis* Regali,Uesugui & Santos, 1974; **R**, *Acaciapollenites myriosporites* (Cookson, 1959) Midenhall, 1972; S, Psilatricolpites sp.2; T, Clavatricolpites sp.1; U, *Perisyncolporites pokornyi* Germeraad, Hopping & Muller, 1968; **V**, *Retitricolporites finitus* González-Guzmán, 1967. Scale bars = 10 µm.

Because the taxa *Margocolporites vanwijhei, Perfotricolpites digitatus, Striatopollis catatumbus* are typically found in Eocene sediments, we conclude that their occurrence in various basins of southeastern Brazil together with low percentages of gymnosperm pollen are indicative of a Late Eocene palynoflora. A remarkable difference between Late Eocene and Oligocene microfloras in the southeastern Brazilian basins is due to the overwhelming diversification of bisaccate pollen grains and the abundance of *Dacrydiumites florinii*, which are characteristic of the Oligocene.

By comparison with palynofloras from the Late Paleocene to Late Eocene of central Colombia, Jaramillo & Dilcher (2001) found some palynomorphs present in our analyses, such as *Margocolporites vanwijhei, Perfotricolpites digitatus, Perisyncolporites pokornyi, Momipites, Ulmoideipites krempii, Tricolpites clarensis, Rhiopites cienagensis, Siltaria media (Retitricolporites medius), Syncolporites lisamae,* and *Foveotricolpites perforatus,* along with a good representation of the Poaceae *Graminidites (Monoporopollenites annulatus).* It is noteworthy that this palynoflora is very similar to our pollen and spore fossil assemblages, especially in relation to the substantial representation of Poaceae.

Late Miocene-Pliocene palynofloras

The second association (Neogene), already described above, contains some important palynostratigraphical markers for the Late Miocene-Pliocene such as *Cyatheacidites annulatus*, *Foveotriletes ornatus*, *Chenopodiipollis (Psilaperiporites minimus)*, *Compositoipollenites* (*Echitricolporites*) *spinosus*, *Compositoipollenites (Echitricolporites) mcneilly*, *Fenestrites spinosus*,

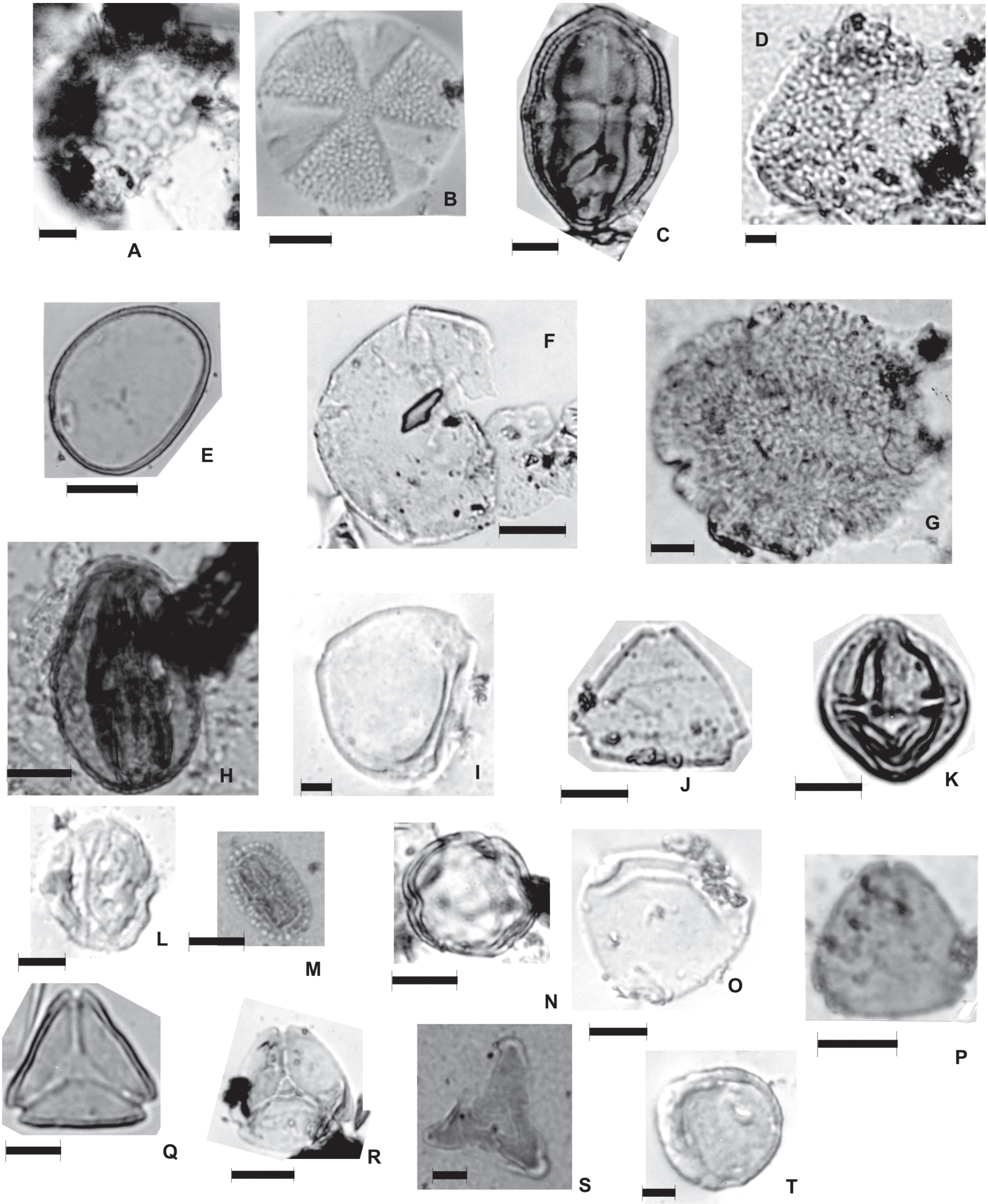

Figure 8. A, *Persicariopollis* sp.1; **B**, *Margocolporites vanwijhei* Germeraad, Hopping & Muller, 1968; **C**, *Araliaceoipollenites edmundi* (Potonié, 1951) ex Potonié, 1960; **D**, *Proxapertites tertiaria* Van der Hammen & Garcia de Mutis, 1966; **E**, *Graminidites* sp.1; **F**, *Nothofagidites* sp.1; **G**, *Alangiopollenites barghoomianum* (Traverse, 1955) W. Krutzsch, 1962; **H**, *Rhiopites guianensis* Van der Hammen & Wymstra, 1964 n. comb. Jaramillo & Dilcher, 2001; **I**, *Triatripollenites* sp.1; **J**, *Proteacidites rectomarginatus* Cookson, 1950; **K**, *Psilatricolporites costatus* Dueñas, 1980; **L**, *Foveotricolpites* sp.1; **M**, *Ilexpollenites* sp.1; **N**, *Heterocolpites incomptus* Van der Hammen, 1956 ex Hoorn, 1993; **O**, *Symplocoipollenites* sp.1; **P**, **R**, *Syncolporites lisamae* Van der Hammen, 1954; **Q**, *Syncolporites incomptus* Van Hoeken-Klinkemberg, 1964; **S**, *Anacolosidites* sp.1; **T**, *Scabraperiporites* sp.1. Scale bars = 10 μm.

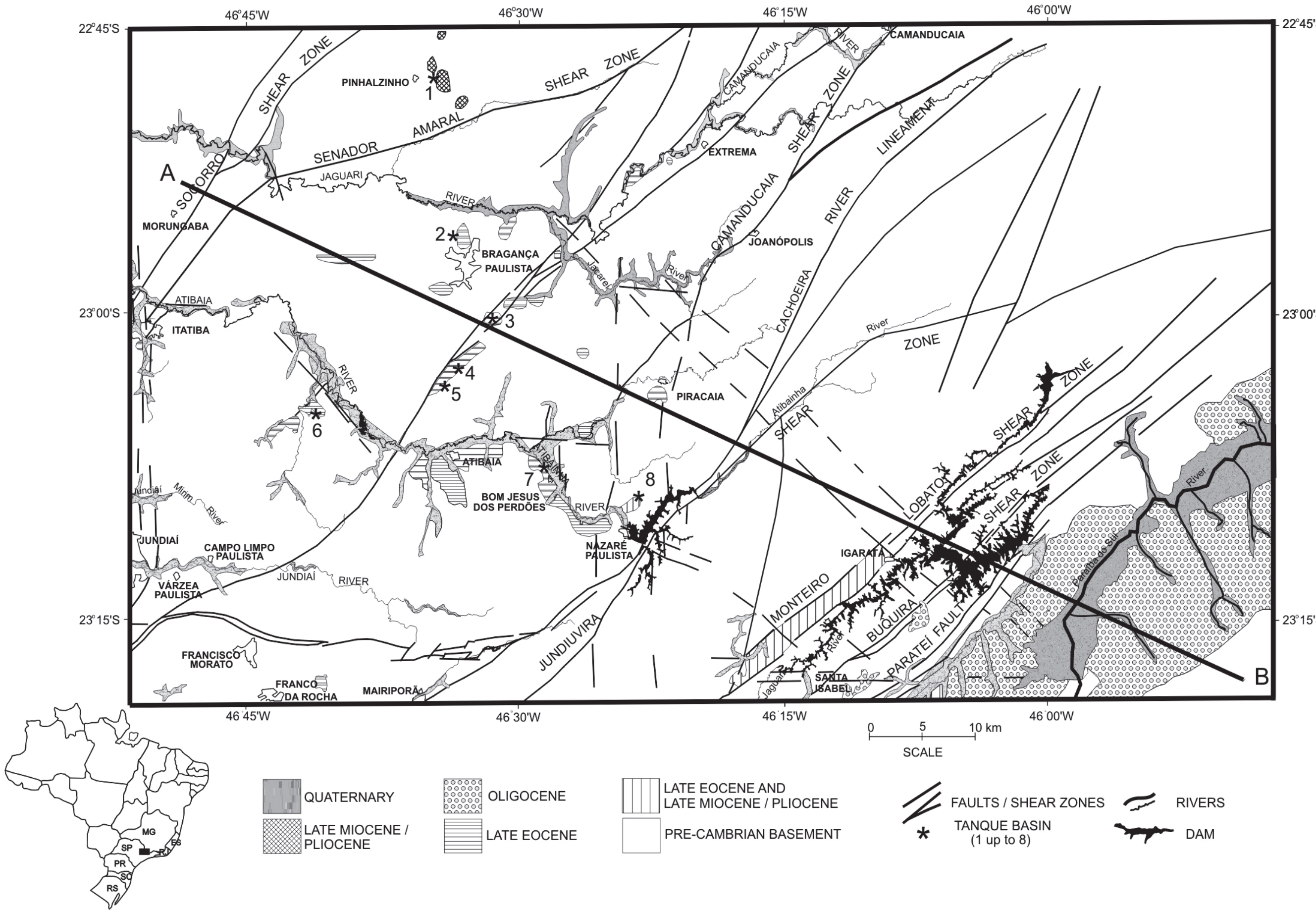

Figure 9. Geological map of the distribution of Cenozoic deposits in relation to the sites studied. Localities: **1**, Pinhalzinho; **2**, Bragança Paulista; **3**, Tanque; **4**, Tanque; **5**, Tanque; **6**, Atibaia; **7**, Bom Jesus dos Perdões; **8**, Nazaré Paulista.

Retistephanocolpites gracilis, Proxapertites tertiaria, *Heterocolpites incomptus, Cyperaceapollis, Ilexpollenites, Persicariopollis* sp., *Polygalacidites* sp and *Verrucatotriletes* cf. *V. bullatus*.

Cyatheacidites annulatus has a wide distribution range. In Venezuela, for example, it occurs from the Late Miocene to Pleistocene (the Asteraceae to the *Alnipollenites* zones of Lorente, 1986). According to Muller *et al*. (1987), in northern South America, this taxon occurs in the *Echitricolporites spinosus* to the *Echitricolporites mcneillyi* zones, in agreement with the opinion of Germeraad *et al*. (1968). However, in Argentina, Barreda (1997a) recorded *Cyatheacidites annulatus* in the Oligocene of the San Julian Formation, associated with Poaceae (Gramineae) and Asteraceae (Compositeae) and from the Oligocene?-Miocene age in the Chenque, Chubut and Santa Cruz Formations (Barreda, 1993,1997b), also associated with Asteraceae (*Echitricolporites spinosus, Echitricolporites mcneillyi) Echiperiporites estelae,* Mimosaceae and Polygonaceae. Leanza *et al*. (2002) reported *Cyatheacidites annulatus* in the Late Oligocene–Early Miocene sediments in the Lileo Formation; while Rossello *et al*. (2004) described it in Tierra del Fuego in the Late Eocene to Early Oligocene sediments. In the Brazilian continental shelf basins, Regali *et al*. (1974a, 1974 b), reported *Cyatheacidites annulatus* from the *Echitriletes muelleri* to the *Echitricolporites spinosus* superzones (Early Miocene to Pliocene). This taxon is also present in the top of the Lower to Middle Miocene sediments from Alexandra Formation (Lima & Angulo 1990). In the Gandarela and Fonseca basins. Maizatto (2001) found it in the Early Miocene while Yamamoto (1995) reported it only in the Itaquaquecetuba Formation (São Paulo Basin), of Early Miocene age. Finally, Hoorn (1994a, 1994 b) found it in the Miocene of northwestern Amazonia. We therefore conclude that *Cyatheacidites annulatus* has a wide chronostratigraphic distribution in South America (Late Eocene to Recent); however, it has been used as a Miocene marker in Brazil.

Cyperaceapollis can be a good genus marker for Miocene age. It has been reported in Venezuela (Lorente, 1986) only in the Maracaibo Basin in the *Psiladiporites* to the *Grimsdalea* zones (the top of Middle Miocene). Hoorn (1994 a, 1994 b) also found it in the Miocene in northwestern Amazonia.

Compositoipollenites (*Echitricolporites) spinosus* has a wide chronostratigraphical range (Oligocene to Pleistocene), because it was reported from the Oligocene to Miocene by Germeraad *et al.* (1968) in tropical areas

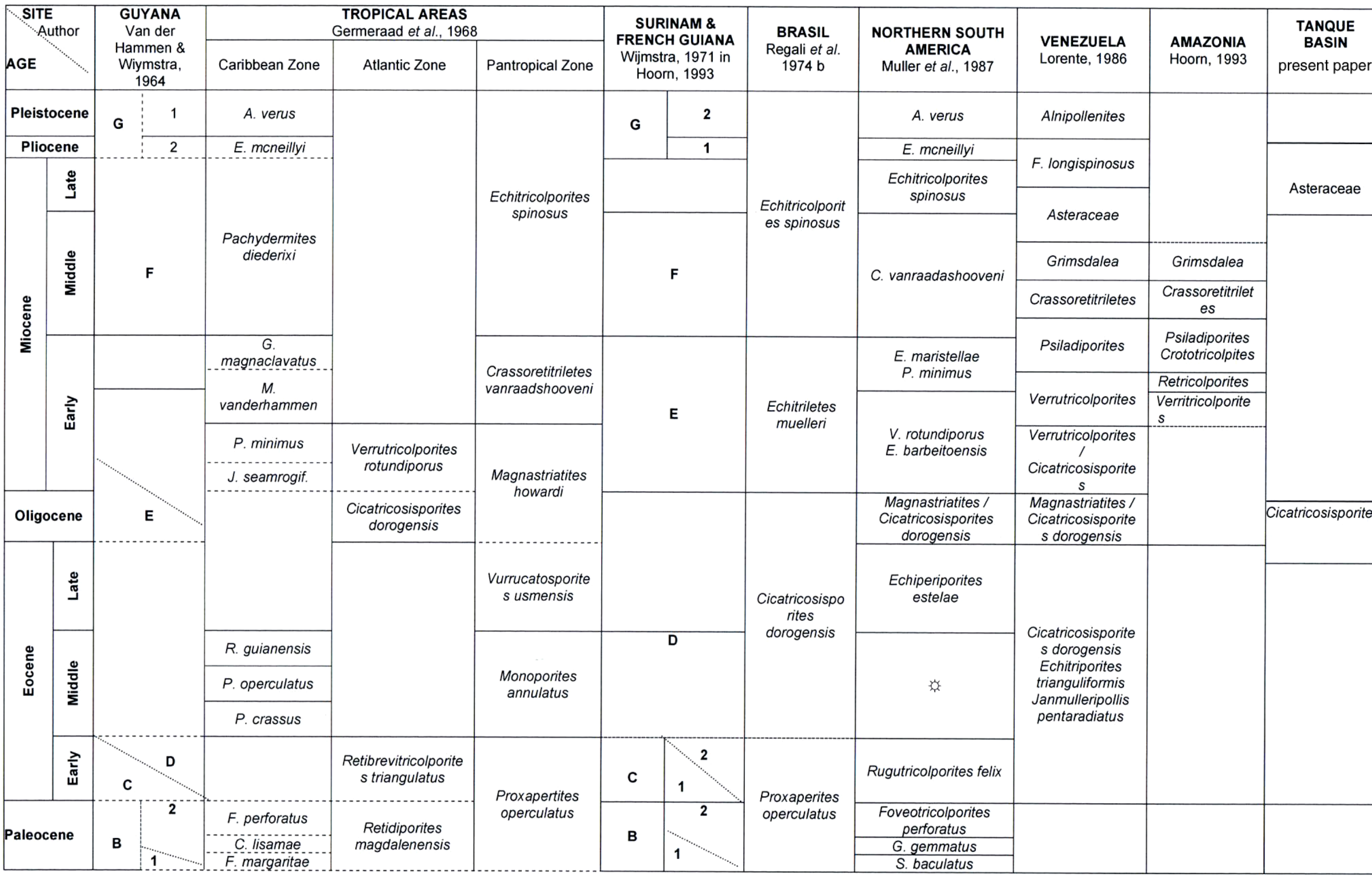

Figure 10. Correlation of diferent palinozones with the present study (Tanque Basin).

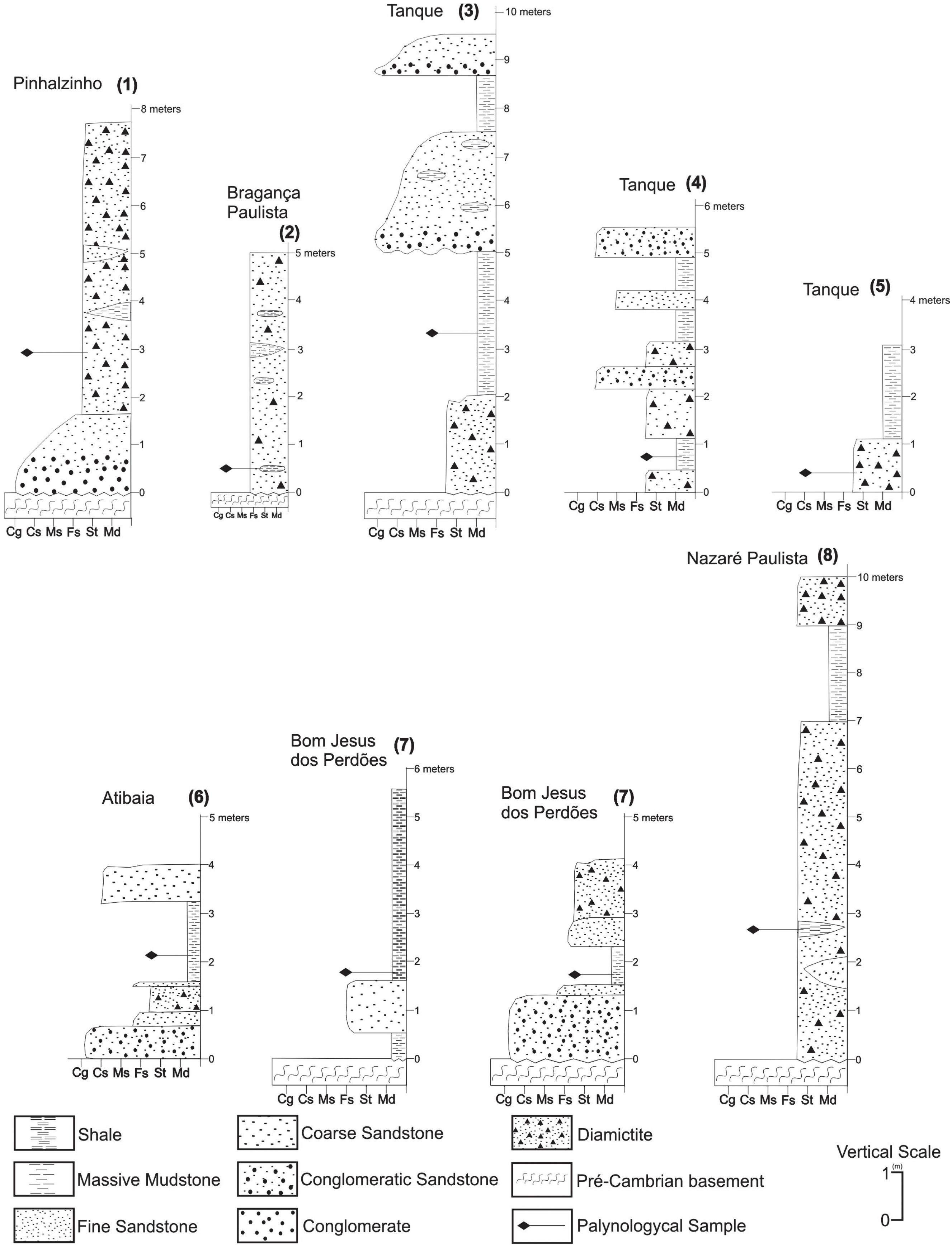

Figure 11. Column stratigraphic sections related to the sites studied.

and by Barreda (1993) in Argentina, and because Lima & Melo (1994) reported it in the Itatiaia Formation (Oligocene). In Venezuela, Lorente (1986) reported it in the Asteraceae to the *Alnipollenites* zones (top of the Middle Miocene to Pleistocene), and in northern South America, Muller *et al*., (1987) found this taxon in sediments of the Late Miocene to Pleistocene age. In the Brazilian continental shelf basins, Regali *et al*. (1974a, 1974 b) reported it in the *Echitriletes muelleri* to the *Echitricolporites spinosus* superzones (Early Miocene to Pliocene), whereas Hoorn (1993, 1994a, 1994 b) found it in the Miocene in northwestern Amazonia.

Germeraad *et al*. (1968) reported the first occurrence of *Fenestrites spinosus* in tropical areas in tropical areas from the Early to Middle Miocene, whereas Lima & Angulo (1990) described it for the Early to Middle Miocene of the Alexandra Formation, in southern Brazil. This taxon has been reported by Regali *et al.* (1974a, 1974 b), in the Brazilian continental shelf basins, from the *Echitriletes muelleri* to the *Echitricolporites spinosus* superzones (Miocene to Pliocene). According to Williams (1975), Partridge (1978), Stover & Partridge (1973), and El Beialy *et al*. (2005), *Fenestrites spinosus* becomes abundant in the Late Miocene. According to Leopold (1969), the occurrence of this Miocene pollen type of the Liguliflorae (Asteraceae) is questionable when extended to Oligocene ages.

Foveotriletes ornatus has been used in Brazil as a good marker for the Early- Late Miocene to Pliocene (Regali *et al*., 1974a, 1974 b; Lima & Angulo, 1990; Carvalho, 1996), but in Venezuela, Lorente (1986), reported it for the Eocene to Pleistocene.

According to Germeraad *et al.* (1968) and Muller *et al.* (1987), *Echitricolporites mcneillyi* is present in tropical areas and northern South America, from the Pliocene to Pleistocene. In Venezuela, Lorente (1986) reported it in the *Fenestrites longispinosus* to the *Alnipollenites* zones (Late Miocene to Pliocene), but in Argentina, Barreda (1993) found it in the Chenque Formation (Late Oligocene?- Miocene). However, the presence of the *Echitricolporites mcneillyi* in the present study suggests Pliocene age because, during the Late Miocene, there is an increase in the diversification of the *Compositoipollenites* pollen type (*aff.* Asteraceae), including the group of fenestrate grains, as observed in our samples from Nazaré Paulista and Pinhalzinho, which, in our opinion, is more indicative of a Late Miocene to Pliocene age.

Cenozoic sediments

The classification of lithofacies of the Paleogene and Neogene sequences of the Tanque Basin is summarized in Table 1, and the schematic representation of the vertical stratigraphical columns is shown in Figure 11 (Bistrichi *et al.,* 2008). The Paleogene sediments, represented by siltstones and argillites, also contain plant megafossils (leaves), fish remains, ichnofossils and undetermined bone molds. The Neogene sediments, on the other hand, are characterized by mudstones containing only palynomorphs.

The depositional system of the Paleogene **(**Late Eocene) sequence is characterized by alluvial fan and lacustrine sediments, with sporadic occurrence of turbidite deposits. The Neogene (Miocene and Pliocene) stratigraphic sequence is composed of only alluvial fan deposits with proximal and distal facies.

Table 1. Stratigraphical classification of Paleogene and Neogene facies. For numbers 1 - 7 see Figure 9.

	LOCALITY NUMBERS	FACIES	SEDIMENTARY STRUCTURES	DEPOSITIONAL SYSTEM
NEOGENE	Nazaré Paulista (2) Pinhalzinho (1)	Massive mudstone	—	ALLUVIAL FAN
		Muddy, massive diamictite	Microfossils	
		Fine to medium, stratified sandstone	Parallel lamination	
		Matrix-supoorted, massive conglomerate	Weak grading	
		Clastic-supported, massive conglomerate	Weak grading	
PALEOGENE	Nazaré Paulista (2) Piracaia (3) Bom Jesus dos Perdões (4) Atibaia (5) Tanque (6, 7) Bragança Paulista (8)	Rhytmite (sandastone/siltstone)	Parallel lamination, Fossils	LACUSTRINE
		Massive siltstone/argillite and shale	Fossils	
		Fine, massive sandstone	Weak grading	
		Medium to coarse, stratified sandstone	Trough cross-bedding	ALLUVIAL FAN
		Matrix-supported, stratified conglomerate	Trough/tangential cross-bedding	
		Clastic-supported, massive conglomerate	Weak grading	

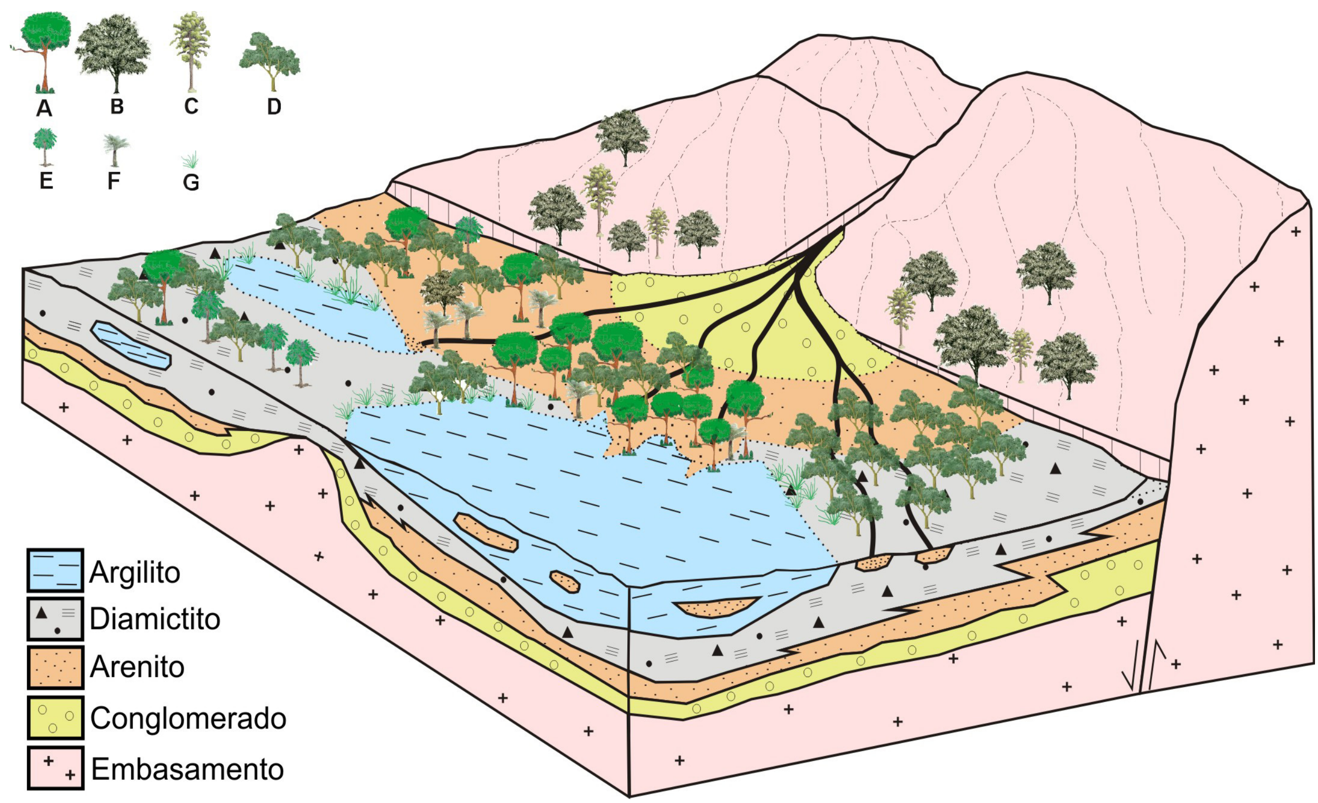

Figure 12. Hypothetical schematic representation of a generalized Late Eocene landscape based on palynology and lithology of the sites studied. **Legend: A**, Proteaceae, Myrtaceae, Melastomataceae; **B**, Arecaceae; **C**, Podocarpaceae, Fagaceae; **D**, Leguminosae, Sapindaceae; **E**, Euphorbiaceae, Bombacaceae, Symplocaceae; **F**, Malpighiaceae, Myricaceae, Annonaceae, Malvaceae and Ulmaceae; **G**, Pteridophyta; **H**, Aquatic angiosperms (Cyperaceae, Polygonaceae, Onagraceae; **I**, Poaceae, Asteraceae, Rubiaceae and Amaranthaceae-Chenopodiaceae.

PALEOENVIRONMENT, PALEOCLIMATE AND PALEOGEOGRAPHY

The Late Eocene

The present palynological analysis indicates a complete absence of marine microplankton, confirming the continental origin of the samples studied, thus in accordance with the stratigraphic interpretation. The samples containing the association of palynomorphs, indicative of a Late Eocene age, were probably deposited in bodies of water that were relatively shallow. The presence of poorly preserved palynomorphs, together with the rarity of fungi, suggests an oxidizing environment. Plant remains are represented by dicotyledoneous leaves, pinnules of Marattiales, Cyatheaceae and Aspleniaceae, leaf fragments of Typhaceae, Liliopsida, Equisetales and Malvales, and a gymnosperm strobilus (Bernardes de Oliveira, 2000 *personal communication*) as well. These fossils suggest a shallow lacustrine environment where Typhaceae and Equisetales occupied areas near the shore. The presence of megafossil taxa with affinity to Cyatheaceae, Aspleniaceae, Marattiales and Malvales is suggestive of a nearby forest, represented schematically in Figure 12. This interpretation based on plant megafossil data is supported by the presence of a pollen flora represented by *Syncolporites* (*aff.* Myrtaceae), *Symplocoipollenites* (*aff.* Symplocaceae), *Psilastephanocolporites laevigatus* (*aff.* Meliaceae), *Margocolporites vanwijhei* (*aff.* Caesalpiniaceae), *Ulmoideipites krempii* (Ulmaceae), *Acaciapollenites myriosporites* (*aff. Acacia*), *Quadraplanus* sp (*aff.* Mimosaceae), *Psilamonocolpites* (*aff.* Arecaceae), *Perisyncolporites pokornyi*, *Scabraperiporites asymmetricus* and *Miocaenipollis* sp (*aff.* Malpighiaceae), *Cedripites lusaticus* (*aff. Cedrus*), *Pityosporites* (*aff. Abies*? *Pinus*?), *Podocarpidites* sp.1, sp.2 and sp.3, and *Podocarpidites embryonalis* (*aff. Podocarpus*).

Together, the palynological and paleobotanical data indicate a wet subtropical climate with relatively cold and dry winters, an interpretation which is especially attested by the presence of gymnosperm pollen taxa such as *Pityosporites, Podocarpidites* and *Cedripites*. We used here Köppen´s definition of wet subtropical climate, i.e., a climate that is characterized by a pronounced continentality, warm and rainy summers with temperatures usually above 22^{o}C, and lack of a defined dry season although generally with one drier month. This palaeoclimatic interpretation finds support in the Late Eocene paleogeographical reconstruction (40 million years) of Smith & Briden (1977). As can be observed in Figure 13, the area studied was located at that time period approximately at 32°S, thus likely under a subtropical climatic condition. This climatic shift corresponds to a latitudinal displacement of ca. 10°S, which is equivalent to the modern border of Brazil and Uruguay.

The Late Miocene-Pliocene

The abundance of pteridophyte spores, especially *Lycopodiumsporites austroclavatidites*, followed by *Foveosporites ornatus*, among others, suggests that these plants may have occupied the edges of the lakes, rivers, and wetlands, where the rhizopod *Assulina* may also have lived. The rarity of the fungi and algal spores may be attributed to dry seasonal climatic conditions, with little availability of decomposing organic material.

The palynoflora, here interpreted as belonging to an understory vegetation, consists of abundant *Graminidites* (*aff*. Poaceae), *Compositoipollenites* and *Fenestrites* (*aff*. Asteraceae) pollen, associated with the rare occurrence of *Chenopodipollis* (*aff*. Chenopodiaceae-Amaranthaceae) and *Retistephanocolpites gracilis* (*aff*. Rubiaceae). These taxa probably occupied hillsides and fields, while Poaceae (Gramineae) plants may also have inhabited the edges of lakes, fluvial margins, floodplains, associated here with the presence of *Cyperaceapollis* (*aff*. Cyperaceae), *Persicariopollis* (*aff*. Polygonaceae), *Polygalacidites* (*aff*. Polygalaceae) and *Sparganeaceaepollenites* (*aff*. Typhaceae/ Sparganiaceae).

Significant numbers of bisaccate grains (gymnosperms) such as *Podocarpidites*, *Cedripites* and *Pityosporites*, in association with *Nothofagidites* (*aff*. Fagaceae), suggest, according to Lima & Angulo (1990), dry and cold climates and well-drained areas of highlands.

The arboreal angiosperm palynoflora consisting of *Syncolporites* (aff. Myrtaceae), *Cupaneidites* (*aff*. Sapindaceae), *Ulmoideipites krempii* (*aff*. Ulmaceae), *Arecipites* (*aff*. Arecaceae), *Heterocolpites incomptus* (*aff*. Melastomataceae), *Malvacearumpollis estelae* (*aff*. Malvaceae), *Polyadopollenites* (aff. *Acacia*), *Proteacidites rectomarginatus* (*aff*. Proteaceae), *Proxapertites tertiaria* (*aff*. Annonaceae), and *Perisyncolporites pokornyi*, *Scabraperiporites asymmetricus* and *Miocaenipollis* sp (*aff*. Malpighiaceae), suggest the existence of a rainforest, which is represented schematically in Figure 14.

The samples here dated and assigned to the Late Miocene- Pliocene, because of their palynological association, may have been deposited in small bodies of water within

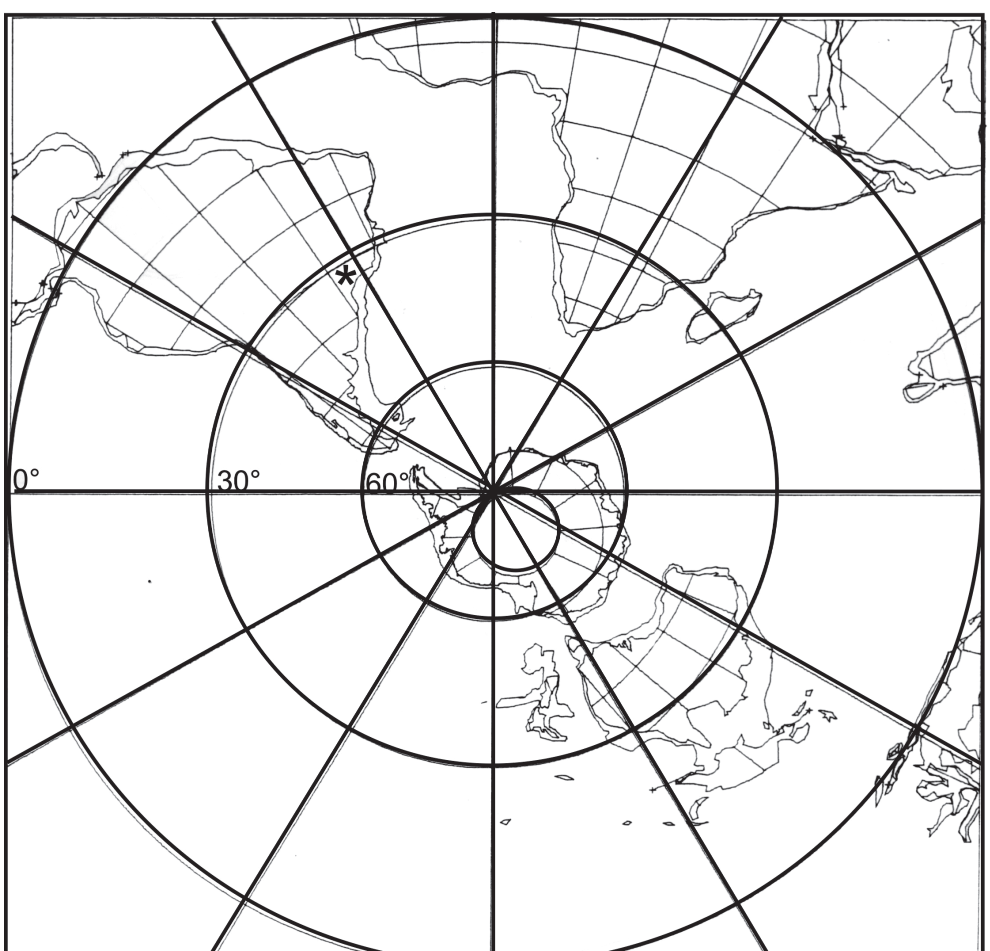

Figure 13. Paleocontinental map of Late Eocene from Smith and Briden (1977) with the location of the area studied (asterisk).

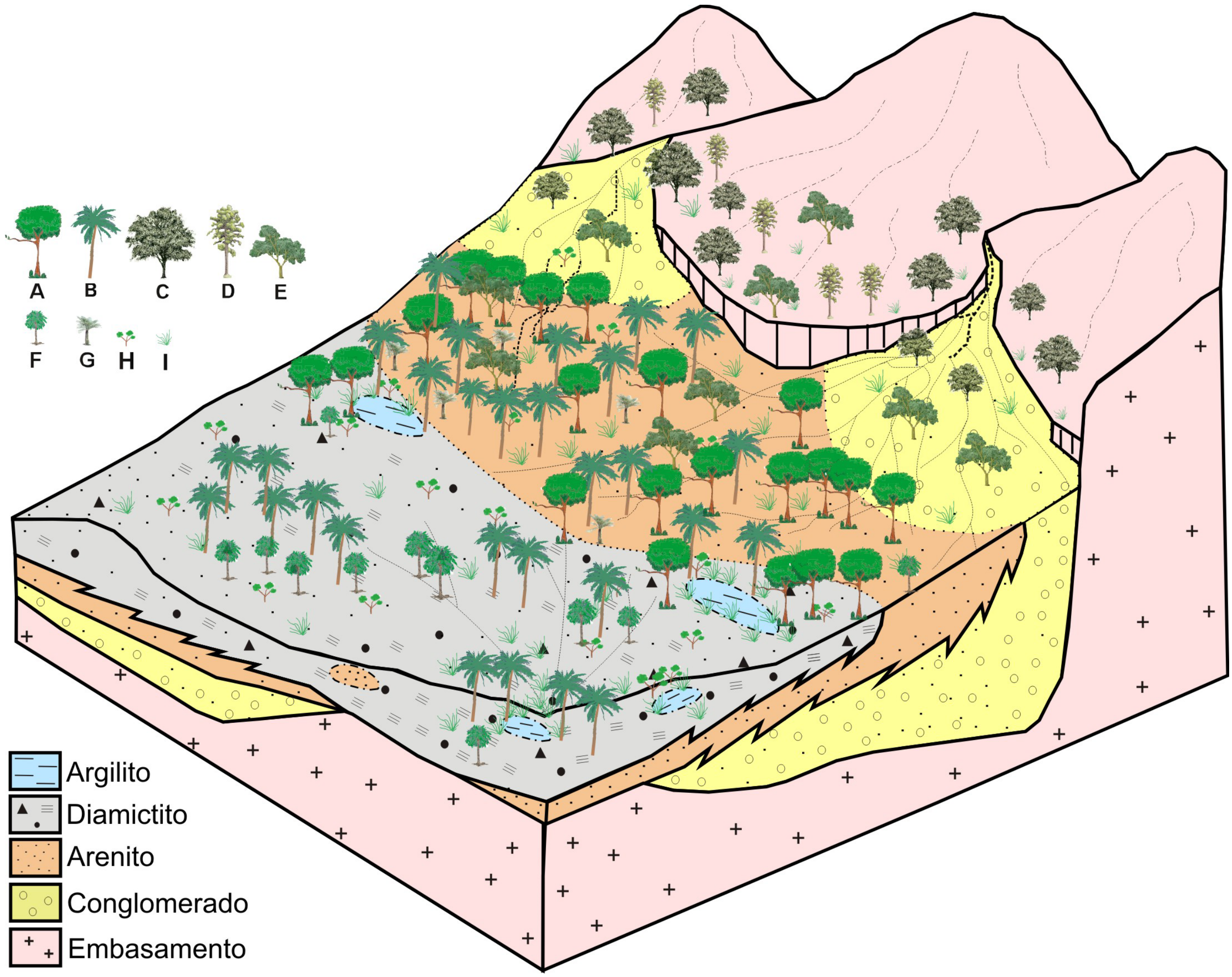

Figure 14. Hypothetical schematic representation of a generalized Late Miocene-Pliocene landscape based on palynological and lithological data from the sites studied.

alluvial fans, probably under subtropical to temperate climates with well-defined seasons.

According to Berggren & Prothero (1992), the development of the Antartic ice cap after the Late Eocene-Oligocene, promoted drastic climatic change in South America due to the strengthening of cold air masses, thus establishing temperate climates. During the Late Miocene (10 million years ago), the area studied was likely located at a 26-28°S latitude (Figure 15), therefore under a subtropical climate, which corresponds presently to the latitudinal position of the border between the states of Santa Catarina and Paraná.

CONCLUSIONS

The two sedimentary sequences identified in the Tanque Basin and deposited during the Late Eocene and Late Miocene/Pliocene correspond to a well-defined period of development of rift basins in southeastern Brazil. These two sequences are made up of clastic sediments, representing facies associations formed by alluvial/lacustrine (Paleogene) and alluvial (Neogene) systems.

The pelitic sediments of the Paleogene sequence were probably deposited in relatively shallow lakes. The presence of poorly preserved palymorphs, together with the rarity of fungi, suggests a somewhat oxidizing environment, but their botanical affinities indicate the presence of wet and subtropical climates with dry and cold winters. Based on data related to this sequence, we suggest the presence of a broad sedimentation scenario which encompasses, besides the present area studied the Macacu, Volta Redonda, Resende, Taubaté, Bonfim, São Paulo, Gandarela and Fonseca basins (Figure 1). This large region would have been characterized by low and relatively flat reliefs, locally with more subsiding and better preserved areas, which permitted greater sediment accumulation.

The fine clastic sediments of the second sequence, palynologically dated as the Late Miocene/ Pliocene, may have been deposited in small and ephemeral bodies of water associated with alluvial fans, probably under subtropical to temperate climatic conditions with well-defined seasons. We suggest this deposition reflects a Middle Miocene tectonic remodeling. Our hypothesis is that this modification

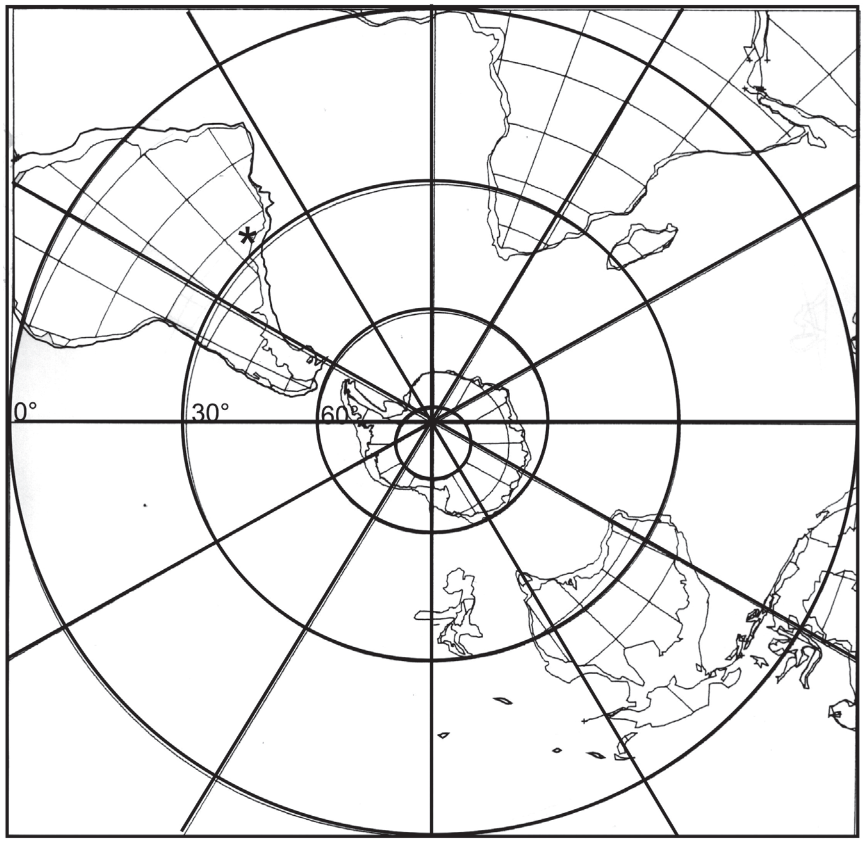

Figure 15. Paleocontinental map of Late Miocene-Pliocene from Smith and Briden (1977) with the location of the studied area (asterisk).

of the geological scenario is probably related to the beginning of the activation of the Nazca plate in western South America (Riccomini, 1989; Hasui, 1990), thus initiating neotectonics activities in southeastern Brazil, which persist to this day.

ACKNOWLEDGMENTS

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Appendix 1. Identified palynomorphs with their respective localities (Loc) and Taxonomic affinity (TA). Conventions for localities: 1, Pinhalzinho; 2, Bragança Paulista; 3, Tanque T2b; 4, Tanque T2a; 5, Tanque T1; 6, Atibaia; 7, Bom Jesus dos Perdões; 8, Nazaré Paulista, 9, Tanque. **Abbreviations: Ama,** Amaryllidaceae**; Amr,** Amaranthaceae**; Ann,** Annonaceae**; Are,** Arecaceae; **Che**, Chenopodiaceae; **Com,** Compositae; **Con,** Convolvulaceae**; Cya**, Cyatheaceae; **Cyc**, Cycadaceae; **Cyp**, Cyperaceae**; Dip**, Dipteridaceae; **Lil**, Liliaceae**; Lop**, Lophosoriaceae; **Lyc**, Lycopodiaceae; **Mal**, Malpighiaceae; **Mel**, Melastomataceae; **Osm**, Osmundaceae; **Pal**, Palmae; **Pin**, Pinaceae; **Pod**, Podocarpaceae; **Pol**, Polypodiaceae; **Pro**, Proteaceae; **Sel**, Selaginellaceae; **Sym**, Symplocaceae.

DIVISION: SPORITES H. Potonié, 1893
CLASS: TRILETES (Reinsch, 1881) Potonié & Kremp,1954
Baculatisporites Thomson & Pflug, 1953
Baculatisporites sp.1 **Loc:**1 **TA:**Osm
Biretisporites Delcourt & Sprumont, 1955 emend. Delcourt, Dettmann & Hughes, 1963
Biretisporites crassilabratus Archangelsky, 1972 (Figure 6H) **Loc:**1 **TA:**Osm
Biretisporites sp.1 **Loc:**1 **TA:**Osm
Biretisporites sp.2 **Loc:**1 **TA:**Osm
Biretisporites sp.3 **Loc:**7 **TA:**Osm
Cicatricosisporites Potonié & Gelletich, 1933
Cicatricosisporites sp.1 **Loc:**4 **TA:**Schiziaceae
Cyatheacidites Cookson, 1947 ex Potonië, 1956
Cyatheacidites annulatus Cookson, 1947 (Figure 6D) **Loc:**1 **TA:**Lop
Deltoidospora Miner, 1935
Deltoidospora sp.1 **Loc:**1 **TA:**Pol? Cya?
Deltoidospora sp.2 **Loc:**8 **TA:**Pol? Cya?
Echitriletes Potonié, 1956
Echitriletes muelleri Regali, Uesugui & Santos, 1974 **Loc:**7 **TA:**Sel?
Foveotriletes Potonië, 1956
Foveotriletes ornatus Regali, Uesugui & Santos, 1974 (Figure 6E) **Loc:**1 **TA:**Lyc
Leotriletes Naumova ex Ishchenko, 1952
Leotriletes microadriennis Krutzch, 1959 **Loc:**1 **TA:**Pteridaceae
Leotriletes sp.1 **Loc:**1 **TA:**Pteridaceae
Lycopodiumsporites Thiegart, 1938
Lycopodiumsporites sp. 1 **Loc:**1 **TA:**Lyc
Lycopodiumsporites austroclavatidites (Cookson) Potonié, 1956 (Figure 6F) **Loc:**1 **TA:***Lycopodium clavatum*
Polypodiaceoisporites Potonié, 1951 ex Potonié, 1956
Polypodiaceoisporites sp.1 **Loc:**1 **TA:**Pteridaceae,? Pol?
Punctatisporites Ibrahim, 1933
Punctatisporites sp.1 **Loc:**4 **TA:**?
Selaginellisporis Wazynska, 1994
Selaginellisporis echinoides Krutzch & Pacltova, 1963, comb. nov. Wazynska, 1994 (Figure 6J) **Loc:**1 **TA:**Sel
Verrucatotriletes Van Hoeken-Klinkenberg, 1964
Verrucatotriletes bullatus Van Hoeken-Klinkenberg, 1964 (Figure 6G) **Loc:**1

CLASS: MONOLETES Ibrahim, 1933
Aspleniumsporites Srivastava, 1987
Aspleniumsporites sp.1 (Figure 6K) **Loc:**1 **TA:***Asplenium*?
Aspleniumsporites sp.2 (Figure 6L) **Loc:**1 **TA:***Asplenium*?
Aspleniumsporites sp.3 **Loc:**1 **TA:***Asplenium*?
Aspleniumsporites sp.4 **Loc:**1 **TA:***Asplenium*?
Aspleniumsporites sp.5 **Loc:**8 **TA:***Asplenium*?
Aspleniumsporites sp.6 **Loc:**8 **TA:***Asplenium*?
Laevigatosporites brahim, 1933
Laevigatosporites ovatus Wilson & Webster, 1946 **Loc:**1 **TA:**Dip? Pol
Laevigatosporites sp.1 **Loc:**1 **TA:**Dip? Pol
Punctatosporites Ibrahim, 1933
Punctatosporites sp.1 **Loc:**1 **TA:**Pol
Rugulatisporites Pflug, 1953
Rugulatisporites sp.1 **Loc:**1 **TA:**Lyc
Verrucatosporites Pflug & Thomson in Thomson & Pflug, 1953

Verrucatosporites sp.1 **Loc:**1 **TA:***Microgramma vaccinifolia*?

DIVISION: POLLENITES R. Potonië,
CLASS: VESICULATAE Iversen & Troels-Smith, 1950
Cedripites Wodehouse, 1933
Cedripites lusaticus Krutzsch, 1971 (Figures 6 P,Q) **Loc:**1, 6 **TA:***Cedrus* (Pin)
Cedripites miocaenicus Krutzsch, 1971 (Figure 6 O) **Loc:**1 **TA:***Cedrus* (Pin)
Pityosporites (Seward, 1914) Potonié & Klaus, 1957
Pityosporites labdacus (Potonié, 1931) Thomson & Pfug, 1953 (Figure 6 T) **Loc:**1, 5, 8 **TA:***Abies, Pinus?* (Pin?/Abietaceae?)
Pityosporites labdacus reticulatus (Doktorawicz-Hrebnicka,1960) Krutzsch, 1971 (Figures 6 R,S) **Loc:**5, 8 **TA:***Abies, Pinus?* (Pin?/Abietaceae?)
Pityosporites cf. *P. zaklinskaiana* Nagy, 1996 (Figure 6 U) **Loc:**1 **TA:***Abies, Pinus?* (Pin?/Abietaceae?)
Pityosporites sp.1 **Loc:**1 **TA:***Abies, Pinus?* (Pin?/Abietaceae?)
Pityosporites sp.2 **Loc:**7 **TA:***Abies, Pinus?* (Pin?/Abietaceae?)
Podocarpidites (Cookson, 1947) ex Couper, 1953) emend. Potonié, 1958
Podocarpidites cf. *P. embryonalis* Krutzsch, 1971 (Figure 6 W) **Loc:**7 **TA:***Podocarpus* (Pod)
Podocarpidites cf. *P. ellipticus* Cookson, 1947 (Figure 6 N) **Loc:**1 **TA:***Podocarpus* (Pod)
Podocarpidites cf. *P. sellowiformis* Zaklinskaya, 1957 **Loc:**1 **TA:***Podocarpus* (Pod)
Podocarpidites macrophylliformis Nagy, 1969 (Figure 6 V) **Loc:**1 **TA:***Podocarpus* (Pod)
Podocarpidites sp.1 (Figure 6 M) **Loc:**4 **TA:***Podocarpus* (Pod)
Podocarpidites sp.2 **Loc:**4 **TA:***Podocarpus* (Pod)
Podocarpidites sp.3 **Loc:**7 **TA:***Podocarpus* (Pod)

CLASS: INAPERTURATAE Iversen & Troels-Smith, 1950
Cyppollis Krutzsch, 1970
Cyppollis sp.1 (Figure 7 E) **Loc:**1 **TA:**Cyp

CLASS: MONOPORATAE Iversen & Troels-Smith, 1950
Graminidites Cookson, 1947 ex Potonie, 1960
Graminidites sp.1 (Figure 8 E) **Loc:**1, 6 **TA:**Poaceae (Gramineae)
Sparganiaceaepollenites Thiergart, 1937
Sparganiaceaepollenites sp.1 **Loc:**1 **TA:**Sparganiaceae? Typhaceae?
Sparganiacaepollenites sp.2 (Figure 7 O) **Loc:**1 **TA:**Sparganiaceae? Typhaceae?

CLASS: MONOCOLPATAE Iversen & Troels-Smith, 1950
Arecipites Wodehouse, 1933
Arecipites sp.1 **Loc:**1 **TA:**Pal/Lil/Ama
Arecipites sp.2 **Loc:**1 **TA:**Pal/Lil/Ama
Arecipites sp.3 **Loc:**1 **TA:**Pal/Lil/Ama
Arecipites sp.4 **Loc:**1 **TA:**Pal/Lil/Ama
Cycadopites Wodehouse, 1933
Cycadopites miocaenica Nagy, 1996 **Loc:**1 **TA:***Cyca* (Cyc)
Cycadopites sp.1 **Loc:**1 **TA:***Cyca* (Cyc)
Proxapertites Van der Hammen, 1956
Proxapertites tertiaria Van der Hammen & Garcia de Mutis, 1966 (Figure 8 D) **Loc:**8 **TA:**Ann
Psilamonocolpites Van der Hammen & Garcia de Murtis, 1965
Psilamonocolpites sp.1 **Loc:**1 **TA:**Are
Psilamonocolpites sp.2 **Loc:**7 **TA:**Are
Retimonocolpites Pierce, 1961
Retimonocolpites noremi Jan Du Chene, Adegoke,1978 **Loc:**1 **TA:**Are
Retimonocolpites sp.1 **Loc:**1 **TA:**Are
Retimonocolpites sp.2 **Loc:**6 **TA:**Are
Monocolpopollenites Pflug & Thomson in Thomson & Pfug, 1953
Monocolpopollenites sp.1 **Loc:**1 **TA:**Are?

CLASS: STEPHANOCOLPATAE Iversen & Troels-Smith, 1950
Alangiopollenites (Travers, 1955) W. Krutzsch, 1962
Alangiopollenites barghoomianum (Traverse, 1955) W. Krutzsch, 1962 (Figure 8G) **Loc:**8 **TA:**Are
Retistephanocolpites Leidelmeyer, 1966
Retistephanocolpites gracilis Regali,Uesugui & Santos, 1974 (Figure 7Q) **Loc:**1 **TA:**Rubiaceae
Retitetracolpites (Van der Hammen) Pierce, 1961
Retitetracolpites sp.1 (Figure 7N) **Loc:**1 **TA:**?
Retitetracolpites sp.2 **Loc:**6 **TA:**?

CLASS: HETEROCOLPATAE Iversen & Troels-Smith, 1950
Heterocolpites Van der Hammen, 1956 ex Van der Hammen & Garcia de Murtis, 1965
Heterocolpites incomptus Van der Hammen, 1956 ex Hoorn, 1993 (Figure 8N) **Loc:**1, 8 **TA:**Mel (*Miconia*)
Nothofagidites Erdtman ex Potonié, 1960
Nothofagidites sp.1 (Figure 8 F) **Loc:**1 **TA:**Fagaceae (*Nothofagus*)

CLASS: TRIPORATAE Iversen & Troels-Smith, 1950
Anacolosidites Cookson et Pike, 1954
Anacolosidites sp.1 (Figure 8 S) **Loc:**7 **TA:***Anacolosa?Cathedra?Ptychope-latum?*
Corsinipollenites Nakoman, 1965
Corsinipollenites undulatus (González-Guzmán) Lima & Salard-Cheboldaeff, 1981 **Loc:**8 **TA:**Onagraceae
Cricotriporites Leidelmeyer, 1966
Cricotriporites sp.1 **Loc:**1 **TA:**Rubiaceae
Psilatriporites Van der Hammen ex Pierce, 1961
Psilatriporites sp.1 **Loc:**1 **TA:**?
Proteacidites Cookson, 1950 ex Couper, 1953
Proteacidites rectomarginatus Cookson, 1950 (Figure 8J) **Loc:**8 **TA:**Pro
Retitriporites (Van der Hammen) González Guzmán, 1967
Retitriporites dubiosus González-Guzmán, 1967 **Loc:**2 **TA:**Mal
Momipites Wodehouse, 1933
Momipites quietus (Potonié, 1931) Nichols, 1973 **Loc:**1 **TA:**Myricaceae
Momipites sp.1 **Loc:**7 **TA:**Myricaceae
Triatripollenites (Potonié, 1931)
Triatripollenites sp. 1 (Figure 8 I) **Loc:**6 **TA:**?

CLASS: STEPHANOPORATAE Iversen & Troels-Smith, 1950
Miocaenipollis Krutzsch, 1966
Miocaenipollis sp.1 **Loc:**1 **TA:**Mal
Miocaenipollis sp.2 **Loc:**1 **TA:**Mal
Miocaenipollis sp.3 (Figure 7C) **Loc:**1 **TA:**Mal
Miocaenipollis sp.4 **Loc:**1 **TA:**Mal
Miocaenipollis sp.5 **Loc:**7 **TA:**Mal
Psilastephanoporites Van der Hammen, 1956 ex Regali, Uesugui & Santos, 1974
Psilastephanoporites sp.1 **Loc:**1 **TA:**?
Psilastephanoporites sp.2 **Loc:**7 **TA:**?

CLASS: PERIPORATAE Iversen & Troels-Smith, 1950
Malvacearumpollis Nagy, 1962
(*Echiperiporites* Van der Hammen & Wijmstra, 1964)
Malvacearumpollis estelae (Germeraad, Hopping & Muller, 1968) Hekel, 1972 **Loc:**1 **TA:**Malvaceae
Persicariopollis Krutzsch, 1962
Persicariopollis sp.1 (Figure 8 A) **Loc:**8 **TA:**Polygonaceae (*Polygonum*)
Psilaperiporites Regali, Uesugui & Santos, 1974 (*Chenopodipollis* Krutzsch, 1966)
Psilaperiporites minimus Regali, Uesugui & Santos, 1974 (Figure 7 F) **Loc:**1 **TA:**Amr-Che
Echiperiporites Van der Hammen & Wijmstra, 1964
Echiperiporites akanthos Van der Hammen & Wijmstra, 1964 (Figure 6X) **Loc:**6 **TA:**?
Scabraperiporites Regali, Uesugui & Santos, 1974
Scabraperiporites nativensis Regali, Uesugui & Santos, 1974 (Figure 7B) **Loc:**1 **TA:**Che-Amr
Scabraperiporites asymmetricus Duenas, 1980 (Figure 7 A) **Loc:**1,6 **TA:**Mal
Scabraperiporites sp.1 (Figure 8T) **Loc:**6 **TA:**Sym
Ulmoideipites Anderson, 1960

Ulmoideipites krempii Anderson, 1960 (Figure 6 Z) **Loc:**1, 6 **TA:**Ulmaceae

CLASS: FENESTRATAE Iversen & Troels-Smith, 1950
Fenestrites Van der Hammen, 1956 ex Germeraad, Hopping & Muller, 1968
Fenestrites spinosus Van der Hammen, 1956 **Loc:**8 **TA:**Asteraceae (Com) *Vernonia*

CLASS: STEPHANOCOLPORATAE Iversen & Troels-Smith, 1950
Psilastephanocolporites Leidelmeyer, 1966 (*Polygalacidites* Sah & Dutta, 1966)
Psilastephanocolporites fissilis Leidelmeyer, 1966(Figure 7D) **Loc:**8 **TA:**Polygalaceae
Psilastephanocolporites laevigatus Salard-Cheboldaef, 1978 **Loc:**6 **TA:**Meliaceae

CLASS: PERICOLPORATAE Iversen & Troels-Smith, 1950
Perisyncolporites Germeraad, Hopping & Muller, 1968
Perisyncolporites pokornyi Germeraad, Hopping & Muller, 1968 (Figure 7U) **Loc:**1, 6 **TA:**Mal

CLASS: TRICOLPATAE Iversen & Troels-Smith, 1950
Clavatricolpites Van Hoeken-Klinkenberg, 1964
Clavatricolpites sp.1 (Figure 7T) **Loc:**1 **TA:**?
Foveotricolpites Van der Hammen & Garcia, 1966
Foveotricolpites sp.1 (Figure 8 L) **Loc:**6 **TA:**?
Perfotricolpites González-Guzmán, 1967
Perfotricolpites digitatus González-Guzmán, 1967 **Loc:**6 **TA:***Merremia* (Con)
Psilatricolpites (Van der Hammen) Pierce, 1961
Psilatricolpites papilioniformis Regali, Uesugui & Santos, 1974 **Loc:**6 **TA:**?
Psilatricolpites sp.1 **Loc:**1 **TA:**?
Psilatricolpites sp.2 (Figure 7S) **Loc:**1 **TA:**?
Retitricolpites Van der Hammen, 1956 ex Pierce, 1961
Retitricolpites sp.1 **Loc:**6 **TA:**?
Symplocoipollenites Potonié, 1957
Symplocoipollenites sp.1 (Figure 8O) **Loc:**7 **TA:**Sym
Tricolpites Cookson ex Couper, 1953 emend. Jarzen & Dettmann, 1990
Tricolpites clarensis (González-Gusmán, 1967) n. comb. Jaramillo & Dilcher, 2001**Loc:**6 **TA:**?

CLASS: POLLENITES R. Potonië, 1931
TRICOLPORATAE Iversen & Troels-Smith, 1950
Araliaceoipollenites Potonié, 1951) ex Potonié, 1960
Araliaceoipollenites edmundi (Potonié, 1951) ex Potonié, 1960 (Figure 8C) **Loc:**1 **TA:**?
Clavatricolporites Ramamujam, 1966
Clavatricolporites sp.1 **Loc:**1 **TA:**?
Compositoipollenites (Potonié, 1951) ex Potonié, 1960 (*Echtricolporites* Van der Hammnen ex Germeraad, Hopping &Muller, 1968)
Compositoipollenites sp.1 (Figure 7I) **Loc:**1 **TA:**Asteraceae (Com), *Ambrosia*
Compositoipollenites sp.2 **Loc:**1 **TA:**Asteraceae (Com)
Compositoipollenites sp.3 **Loc:**1 **TA:**Asteraceae (Com)
Compositoipollenites sp.4 **Loc:**1 **TA:**Asteraceae (Com)
Compositoipollenites sp.5 (Figure 7H) **Loc:**1 **TA:**Asteraceae (Com), *Tubulifloridites ambrosiinae*
Compositoipollenites sp.6 (Figure 7M) **Loc:**1 **TA:**Asteraceae (Com)
Compositoipollenites sp.7 (Figures 7K, L) **Loc:**1 **TA:**Asteraceae (Com), *Tubulifloridites ambrosiinae*
Compositoipollenites sp.8 (Figure 7J) **Loc:**1 **TA:**Tubuliflorae
Compositoipollenites sp.9 **Loc:**2 **TA:***Asteraceae (Com)*
Compositoipollenites sp.10 **Loc:**7 **TA:**Asteraceae (Com)
Compositoipollenites sp.11 **Loc:**7 **TA:**Asteraceae (Com)
Compositoipollenites sp.12 **Loc:**8 **TA:**Asteraceae (Com)
Compositoipollenites sentis Sah,1967 (Figure 7G) **Loc:**1
Ilexpollenites Thiergart, 1937 ex Potonié, 1960
Ilexpollenites sp.1 (Figure 8M) **Loc:**7 **TA:***Ilex* (Aquifoliaceae)
Ilexpollenites sp.2 **Loc:**8 **TA:***Ilex* (Aquifoliaceae)
Ilexpollenites sp.3 **Loc:**1 **TA:***Ilex* (Aquifoliaceae)
Margocolporites Rananujam, 1966 ex Srivastava, 1969
Margocolporites vanwijhei Germeraad, Hopping & Muller, 1968(Figure 8B) **Loc:**6 **TA:***Caesalpinia* (CaesalPin)
Psilatricolporites Van der Hammen, 1956 ex Pierce, 1961
Psilatricolporites sp.1 **Loc:**1 **TA:**?
Psilatricolporites sp.2 (Figure 7P) **Loc:**1 **TA:**?
Psilatricolporites sp.3 **Loc:**1 **TA:**?
Psilatricolporites sp.4 **Loc:**1, 2 **TA:**?
Psilatricolporites sp.5 **Loc:**6 **TA:**?
Psilatricolporites costatus Dueñas, 1980 (Figure 8K) **Loc:**1,2 **TA:**?
Rhiopites Wodehouse, 1933
Rhiopites guianensis Van der Hammen & Wymstra, 1964 n. comb. Jaramillo & Dilcher, 2001 (Figure 8H) **Loc:**7 **TA:**Sterculiaceae? Tiliaceae?
Rhiopites cienagensis (Dueñas, 1980) n. comb. Jaramillo & Dilcher, 2001 **Loc:**6 **TA:**?
Retitricolporites Van der Hammen, 1956 ex Van der Hammen & Wijmstra, 1964
Retitricolporites finitus González-Guzmán, 1967 (Figure 7V) **Loc:**2 **TA:**?
Siltaria Traverse, 1955
Siltaria media (González-Gusmán, 1967) comb. nov. Jaramillo & Dilcher, 2001 **Loc:**6 **TA:**?

CLASS: POLYADEAE Iversen & Troels-Smith, 1950
Polyadopollenites Pfug & Thomson, 1953
Polyadopollenites sp.1 **Loc:**1 **TA:**Mimosaceae
Polyadopollenite sp.2**Loc:**6 **TA:**Mimosaceae
Acaciapollenites Cookson, 1959
Acaciapollenites myriosporites (Cookson, 1959) Midenhall, 1972 (Figure 7R) **Loc:**6 **TA:***Acacia* (Mimosaceae)
Quadraplanus Stover (in Stover & Parttridge, 1903)
Quadraplanus sp. 1 **Loc:**6 **TA:**Leguminosae

CLASS: SYNCOLPORATAE Iversen & Troels-Smith, 1950
Syncolporites Van der Hammen, 1954
Syncolporites incomptus Van Hoeken-Klinkemberg, 1964 (Figure 8Q) **Loc:**1 **TA:**Myrtaceae/Loranthaceae
Syncolporites lisamae Van der Hammen, 1954 (Figures 8P, R) **Loc:**1**,** 7, 2 **TA:**Myrtaceae
Syncolporites poricostatus Van Hoeken-Klinkemberg, 1966 **Loc:**1, 7, 5 **TA:**Myrtaceae
Syncolporites sp.1 **Loc:**1 **TA:**Myrtaceae
Syncolporites sp.2 **Loc:**8 **TA:**Myrtaceae
Syncolporites sp.3 **Loc:**6 **TA:**Myrtaceae
Cupanieïdites Cookson & Pike, 1954
Cupanieïdites sp.1 **Loc:**1 **TA:**Sapindaceae
Cupanieïdites p.2 **Loc:**8 **TA:**Sapindaceae
Cupanieïdites sp.3 **Loc:**1 **TA:**Sapindaceae
Cupanieïdites sp.4 **Loc:**1 **TA:**Sapindaceae
Cupanieïdites sp.5 **Loc:**8 **TA:**Sapindaceae
Cupanieïdites sp.6 **Loc:**9 **TA:**Sapindaceae
Plicapollis Pflug, 1953
Plicapollis sp.1 **Loc:**7 **TA:**?
Plicapollis sp.2 **Loc:**3 **TA:**?