Anais da Academia Brasileira de Ciências (2010) 82(3): 731-745
(Annals of the Brazilian Academy of Sciences)
ISSN 0001-3765
www.scielo.br/aabc

Palynological analysis of a late Holocene core from Santo Antônio da Patrulha, Rio Grande do Sul, Southern Brazil

RENATO B. MACEDO[1], PAULO A. SOUZA[1],
SORAIA G. BAUERMANN[2] and SÉRGIO A.L. BORDIGNON[2]

[1]Laboratório de Palinologia, Departamento de Paleontologia e Estratigrafia, Instituto de Geociências
Universidade Federal do Rio Grande do Sul, Av. Bento Gonçalves, 9500, 91540-900 Porto Alegre, RS, Brasil
[2]Laboratório de Palinologia, Universidade Luterana do Brasil, Av. Farroupilha, 8001, 92425-900 Canoas, RS, Brasil

Manuscript received on June 19, 2009; accepted for publication on December 8, 2009

ABSTRACT

A sedimentar core collected at Santo Antônio da Patrulha, Rio Grande do Sul State, southmost Brazil, was submitted to pollen analysis to provide the vegetational history of this region, and the paleoecological and paleoclimatic changes. A total of 98 taxa of palynomorphs was identified from 35 subsamples. Three radiocarbonic datings were obtained along a section of 115 cm depth, including the basal age of 4730 $\pm$ 50 yr BP. Pollen diagrams and cluster analysis were performed based on palynomorphs frequencies, demonstrating five distinct phases (SAP-I to SAP-V), which reflected different paleoecological conditions. The predominance of plants associated with grasslands in the phase SAP-I suggests warm and dry climate conditions. A gradual increasing of humidity conditions was observed mainly from the beginning of the phase SAP-III, when the vegetation set a mosaic of grasslands and Atlantic rainforest. Furthermore, the presence of some forest taxa (*Acacia*-type, *Daphnopsis racemosa*, *Erythrina*-type and *Parapiptadenia rigida*-type), from the phase SAP-IV, is interpreted as an influence of the seasonal semideciduous forest in the study region. From the phase SAP-V (ca. 4000 yrs BP), the vegetation became similar to the modern one (extant Atlantic rainforest Biome), especially after 2000 yrs BP (calibrated age).

Key words: Palynology, Paleoecology, Paleoclimatology, Atlantic rainforest, late Holocene, Rio Grande do Sul State.

INTRODUCTION

The vegetation of Rio Grande do Sul State (RS), Southern Brazil, is composed by grassland-forest mosaic as a result of paleoenvironmental changes, mainly characterized by climate variations during the Quaternary (Marchiori 2004). These grassland-forest mosaics were previously studied by pioneer naturalists at the end of the XIX century. Lindman (1906) observed that forests could expand over the grassland vegetation under dry paleoclimate conditions. Based on phytogeographic evidence, Rambo (1956, 1961) and Klein (1975) interpreted that the grasslands were the first plants constituents of the RS; therefore, advances of the forests is a recent answer to the humid climatic conditions.

Correspondence to: Renato Backes Macedo
E-mail: macedorb@yahoo.com

The palynology is an important tool for the understanding of vegetation dynamics and paleoclimate reconstructions. Several studies based on pollen analysis have contributed in solving questions on the vegetacional succession during the late Quaternary in Southern Brazil, as summarized by Behling (2002), Lorscheitter (2003), De Oliveira et al. (2005) and Leal and Lorscheitter (2007). Palynological results showed that, during the latest Pleistocene, the landscape in these regions was characterized by the dominance of grasslands due to the cold and dry climate associated with glacial times. During the early to middle Holocene, the vegetation related to these grasslands prevailed in lowlands and highlands of the Southern region due to warm and dry climatic condictions after the glacial period. Pollen analysis of the late Holocene in Rio Grande do Sul Coastal Plain (RSCP) and adjacent areas showed that forests had expanded from 3500 yrs BP, especially after 2000 yrs BP, due to higher humidity.

This paper presents interpretations about the vegetational succession of the Atlantic rainforest and seasonal semideciduous forest, as well as paleoclimates related to them, based on palynological data obtained from a core in Santo Antônio da Patrulha, RS, southmost Brazil. The results were compared with other palynological studies previously conducted in South Brazil.

STUDY AREA

The present study was made from a peat bog located in Santo Antônio da Patrulha municipality (coordinates 29°44′45″S, 50°32′56″W, high 37 m), far about 76 km from Porto Alegre and ca. 48 km from the Atlantic Ocean. The access to this site from Porto Alegre is through the highway RS-474, followed by a secondary road (Figs. 1a-b). According to Fortes (1959), this area is part of the physiographic region of the Lower Northeast Slopes of Serra Geral, RS.

The peat bog sediments from Santo Antônio da Patrulha were deposited on sandstones of the Botucatu Formation, Jurassic/Cretaceous of Paraná Basin, which constitutes the basement of the analyzed core.

The presence of a grassland-forest mosaic characterizes the phytophisiognomy of the landscape. The forest comprises a mixture of floristic elements of Atlantic rainforest and seasonal semideciduous forest (Rambo 1956, Teixeira et al. 1986, Reitz et al. 1988, Leite and Klein 1990).

The climate of Southern Brazil is influenced by the South Atlantic Anticyclone, a semi-permanent high pressure system that transports moist tropical air masses over the continent from easterly and north-easterly directions during the whole year. Disturbances are related to polar cold fronts, when it meets the tropical air masses and produces strong rainfall in Southern Brazil (Nimer 1989). This region is characterized by subtropical humid (*Cfa*) in the Koppen classification (Moreno 1961), with regularly distributed rainfalls during the year and hot summers. The mean precipitation is around 1676.5 mm.a^{-1}, and the average annual temperature is 19.8°C; the average temperature of the hottest month is 24.4°C, while the coolest months are 15.4°C (data from Osório and Tramandaí meteorological station, IPAGRO 1979).

MATERIALS AND METHODS

The core was taken from the deepest portion near the center of the peat bog using a *Russian corer* sampler, whose maximum depth reached 115 cm. Sections of 50 cm length were extruded *in situ*, wrapped in plastic film and aluminum foils. The section was transported to the Laboratory and stored in special conditions (ca. +4°C) before sampling. Three sediment subsamples of 3 cm thickness were taken from the core and dated by the Accelerator Mass Spectrometry (AMS) in the CAIS Laboratory of the University of Georgia (USA). The calibration of radiocarbon datings was carried out after CALPAL (Weninger et al. 2004). Ages were also calculated for each interpolated pollen subsample and pollen phase.

For pollen and charcoal analysis, 35 subsamples (1 cm^3 volume) were taken at 3 cm intervals along the 115 cm cored. All subsamples were processed by standard pollen analytical methods (Faegri and Iversen 1989), using HF, HCl, KOH, acetolysis, followed by filtering through a 250 μm net. The slides were prepared in glycerol-jelly. Pollen preparation included the addition of exotic *Lycopodium clavatum* L. spores to determine pollen concentration (grains/cm^3) and accumulation rates (grains/cm^2/year), in agreement with Stockmarr (1971).

A minimum of 300 pollen grains were counted for each subsample. This pollen sum includes trees, shrubs and herbs. Aquatic, ferns and mosses spores, algae taxa, fungal spores and animal remains, as well as carbonized particles (5-150 μm), were also counted, constituting a separated list expressed as the percentage of the total pollen sum. Calculations of concentration were also made for the carbonized particles (particles/cm^3), as well as for accumulation rates (particles/cm^2/year). Pollen identification was based on catalogues of published palynomorphs, as well as on pollen reference colections of Brazil Lutheran University (ULBRA). The word "type" was used when an accurate identification was impossible. Taxonomic descriptions and illustrations of the identified palynomorphs was an additional contribution (Macedo et al. 2009) and constitute the basis for the palynological analysis. Softwares TILIA, TGVIEW and CONISS version 2.0.2. (Grimm 1987) were used for plotting the pollen data, calculations and cluster analy-

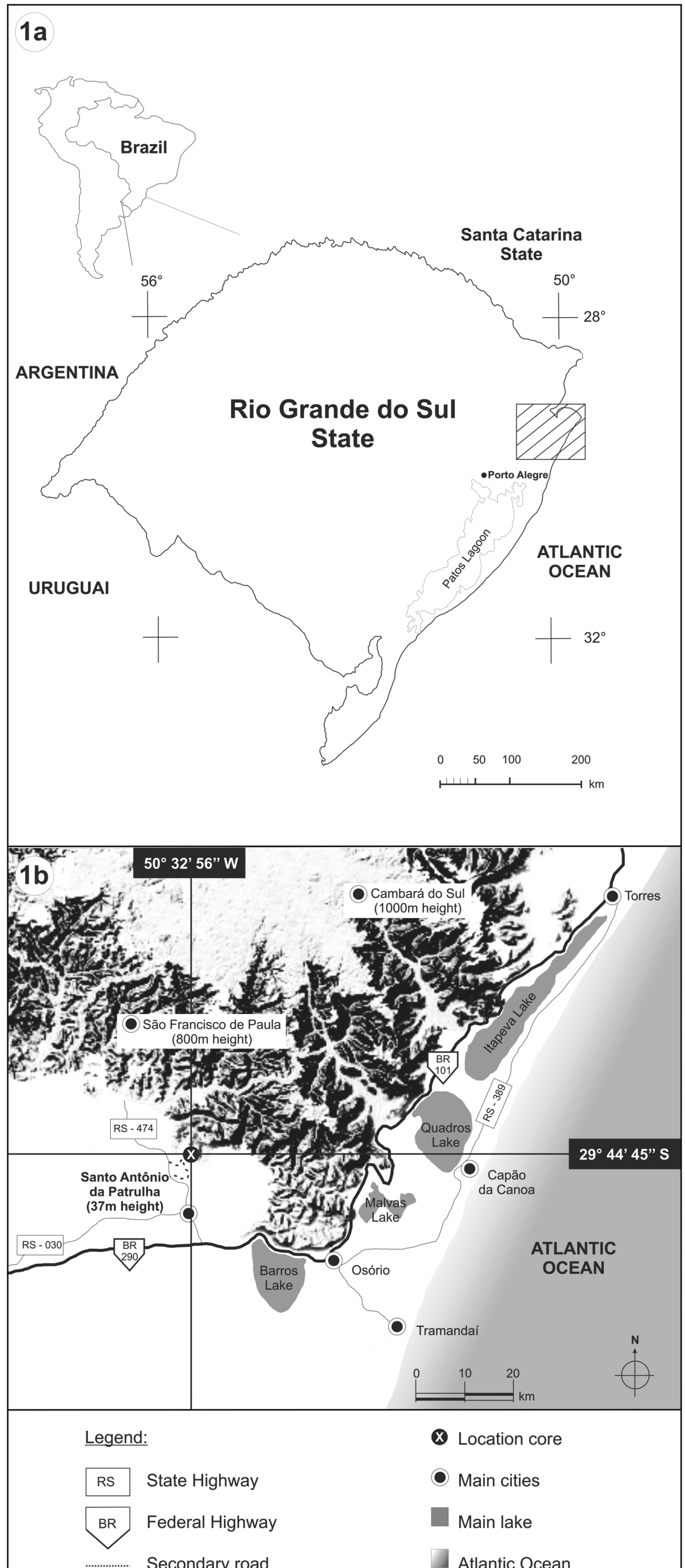


Fig. 1 – Location map showing the general situation **(a)** and position of the Santo Antônio da Patrulha core **(b)**.

sis. The pollen diagrams include individual records of the taxa and records of the groups: grasslands, forest, indeterminate, aquatics, ferns, mosses, algae, fungi and concentration and influx of the pollen and charcoal particles, and a cluster analysis. The phases of the pollen record (*sensu* Salgado-Labouriau 2007 p. 335-336) were established from changes in the pollen assemblages and from cluster analysis.

Ordination by Principal Coordinates Analysis (PCoA) was used for a synthetic view of community compositional changes (Orlóci et al. 2002). PCoA was based on pairwise Euclidean distances among subsamples (Legendre and Legendre 1998, Podani 2000). Distances were computed from squares root transforming pollen percentages in order to reduce the excessive weight of dominant pollen taxa. Algae, spores, indeterminate palynomorphs and Cyperaceae taxa were not included on multivariate analysis, as well as subsamples that did not present pollen grains (phase SAP-II). The significance of ordination axes was evaluated by bootstrap according to Pillar (1999). The multivariate analysis PCoA was calculated using software MULTIV (Pillar 2008).

In order to assist the interpretation regarding the vegetation succession, a rapid survey of the flora was made near the point of collection of the core.

RESULTS

LITHOLOGY

The core retrieves a section of 115 cm of unconsolited sediments. Between 115 to 90 cm depth, sediments are mainly characterized by brown sandstones with decomposed organic matter. From 90 to 50 cm depth, sediments comprise dark mudstones/siltstones with organic material completely decomposed, including few root remains. Between 50 to 13 cm, sediments are constituted by brown-dark sandstones and a mixture of decomposed organic matter with abundant roots and plant remains. From 13 cm depth to the top of the core, the sediments are highy weathered, constituting the regolith, which was not palynologically analyzed.

RADIOCARBON DATING

The results of the AMS radiocarbon datings are presented in Table I. Based on these data, we considered the deposition of the studied core entirely positioned along the late Holocene. However, sedimentation was not continuous. Three datings were obtained. The basal dating corresponds to 4730 $\pm$ 50 ^{14}C yr BP (calibrated age 5461 yr BP), while the sample at 55 cm depth was dated as 4225 $\pm$ 25 ^{14}C yr BP. It suggests a rapid rate of sedimentation between this interval (115 to 55 cm depth). The sample at 13 cm core depth indicates modern age (Anno Domini 1850). The results between 55 and 13 cm core depth suggest a slow sedimentation, envolving the vegetation history of the last 4200 yrs BP.

DESCRIPTION OF POLLEN RECORD

A total of 98 taxa of palynomorphs were retrieved and identified along the Santo Antônio da Patrulha core, including taxa of algae, Briophyte, Pteridophytes, Gymnosperms, Angiosperms, as well as fungi and animal remains. The pollen diagram (Figs. 2a-b-c) shows the distribution of the palynomorphs, which were grouped according to their ecological affinities (habit and/or habitat), beyond pollen sum of different botanical groups (Fig. 3). Marked changes in the pollen assemblages, indicated by cluster analysis (CONISS), allow the establishment of five pollen phases: SAP-I, SAP- II, SAP-III, SAP-IV and SAP-V, which are described below (SAP is the abbreviation for Santo Antônio da Patrulha area) in an ascending stratigraphic order.

Phase SAP-I (5461-5443 cal yr BP)

This phase was characterized from the two basal subsamples (115-110 cm of depth), which are dominated by Cyperaceae (40-55%), Poaceae (46-28%), *Baccharis*-type (6-9%), *Eryngium* L., *Spermacoce* L. and other minor herbaceous components (Fig. 2b-3). The group of trees and shrubs presents lower percentages (1-4%), comprising mainly *Ilex* L. and Arecaceae. Other taxa are less than 1% (with Melastomataceae, Myrtaceae and *Mimosa* serie *Lepidotae* Benth., Fig. 2a). Percentages of pollen from aquatic plants (*Ludwigia* L. and *Utricularia* L.) are also less than 1%. Ferns spores are scarce. Mosses spores are abundant in higher samples (27%), which are mainly represented by *Phaeoceros laevis* (L.) Prosk. (Fig. 2c). Algae taxa show lower proportions. Concentration and accumulation rates of the charcoal particles are relatively high in this phase (Fig. 3).

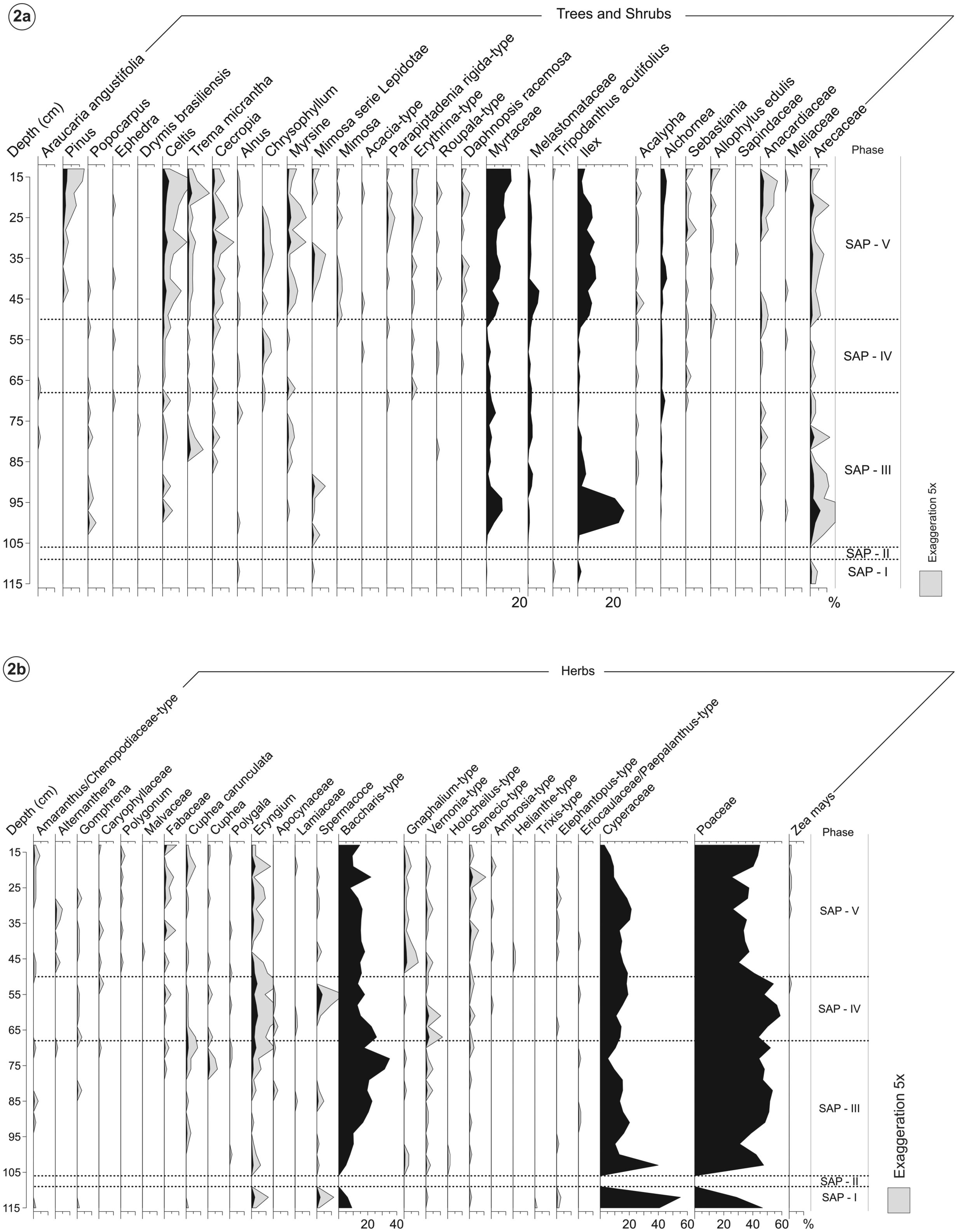


Fig. 2 – Pollen diagram percentages of Trees and Shrubs **(a)**, Herbs **(b)**.

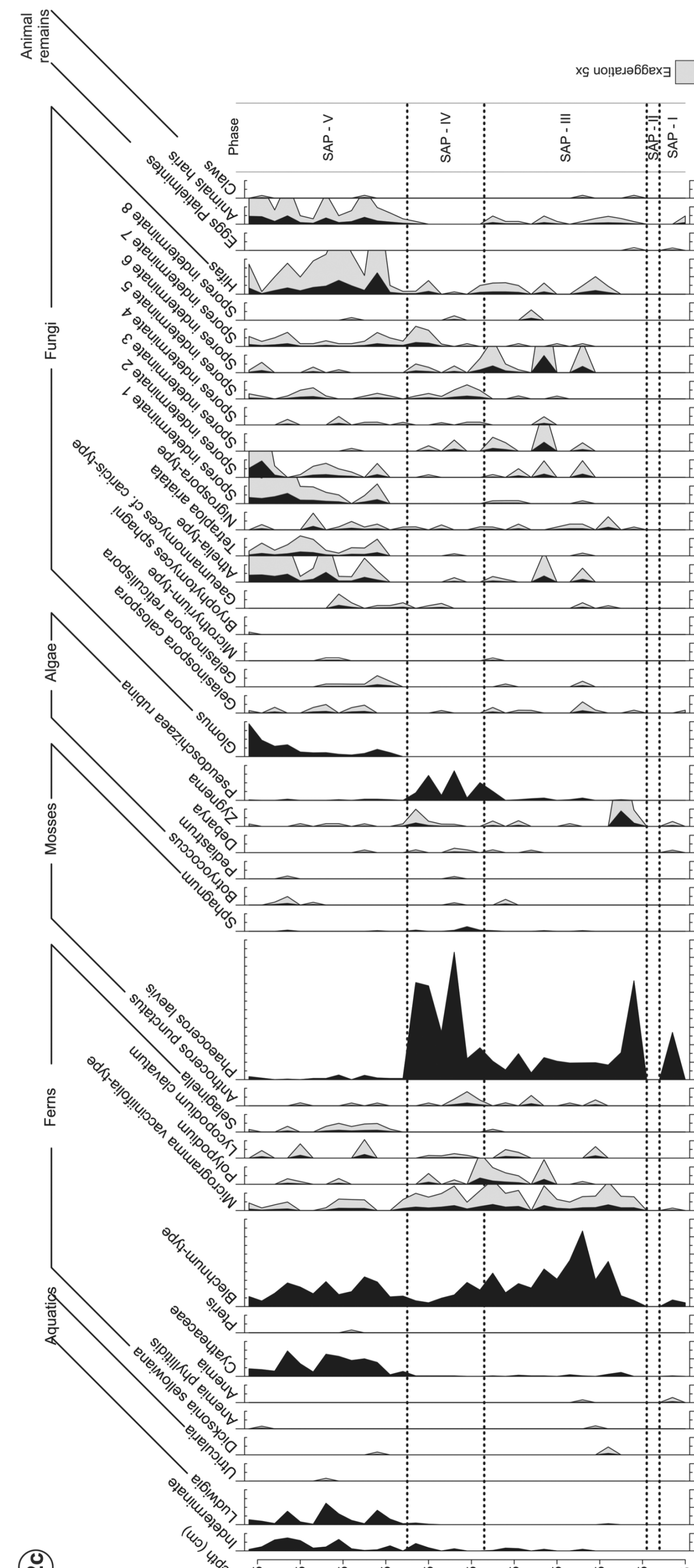


Fig. 2 – **(c)** Pollen diagram percentages of Aquatics, Ferns, Mosses, Algae, Fungi and Animal remains.

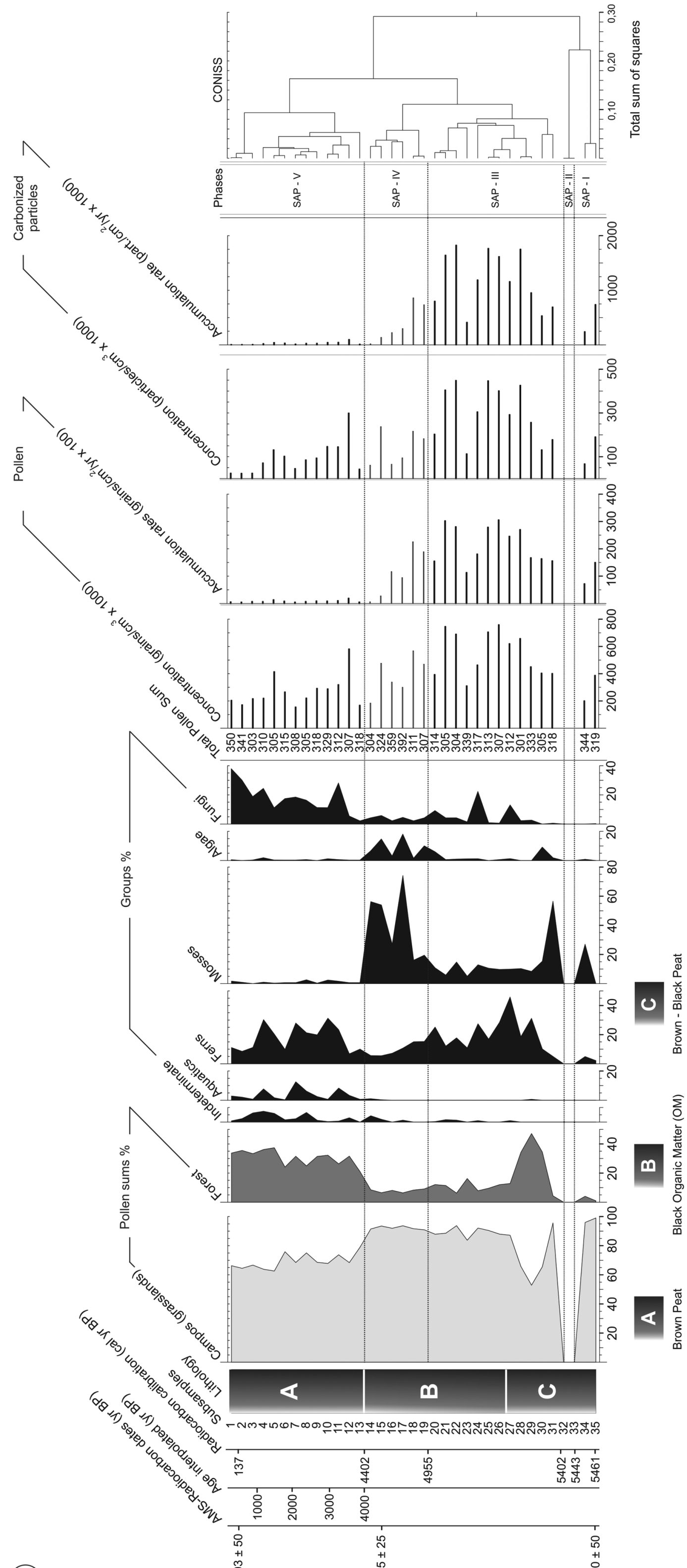


Fig. 3 – Pollen diagram summary showing the AMS radiocarbon dates, calibrated ages, interpolated ages, lithology, ecological groups, sum of pollen, pollen and charcoal concentration and accumulation records, pollen phases and the cluster analysis (CONISS).

TABLE I
Radiocarbonic and calibrated ages.

Lab. number	Depth (cm)	^{14}C yr BP	^{13}C Ratio	Calibrated age (cal yr BP)
SAP-03252	13	107.03 ± 50	–24.2	137 (AD 1850)
SAP-03492	55	4245 ± 25	–19.3	4839
SAP-01964	115	4730 ± 50	–19.2	5461

Phase SAP-II (5443-5402 cal yr BP)

The interval at 110-105 cm depth (two subsamples) is characterized by the non-preservation of pollen grains. Few ferns and mosses spores, as well as algae taxa, were poorly preserved.

Phase SAP-III (5402-4955 cal yr BP)

This phase comprises 12 subsamples within the interval between 105-69 cm core depth. It is marked by the abundance of herb pollens (52-95%), which are represented by Poaceae (31-53%), Cyperaceae (5-40%) and *Baccharis*-type (5-35%), as well as other less frequent taxa, like *Eryngium*, *Cuphea carunculata* Koehne, *Cuphea* Koehne, *Vernonia*-type, *Spermacoce*, *Gnaphalium*-type, *Polygala* L., *Senecio*-type, *Holocheilus*-type, *Amaranthus*/Chenopodiaceae-type and *Elephantopus*-type. Sums of forest taxa are better represented (between 4-48%) due to the increasing of *Ilex*, which reaches up to 28%. Other forest taxa, such as Arecaceae, Myrtaceae, Melastomataceae, *Alchornea* Sw., *Celtis* L., *Trema micrantha* (L.) Blume., Anacardiaceae and *Podocarpus* L' Hér. ex Pers., also increased their proportions during this phase. Pollen grains from *Araucaria angustifolia* (Bertol.) Kuntze and *Drymis brasiliensis* Miers. occur respectively at 79-76 cm depth (Fig. 2a). Fern spores also increase in this phase, mainly *Blechnum*-type, *Microgramma vacciniifolia*-type and *Polypodium* L. Spores from *Dicksonia sellowiana* Hook were found at 97 cm depth (Fig. 2c). Moss spores from *Phaeoceros laevis* decrease during this phase. The concentration and accumulation rates of the charcoal particles and pollen grains were the highest ones in the core.

Phase SAP-IV (4955-4402 cal yr BP)

This phase comprises six subsamples, between 69-51 cm depth. In this phase, taxa related to grasslands continue to be dominant (91-93%). Pollen sum of forest taxa decreases (6-12%). However, at the beginning of this phase, there are the first records of *Chrysophyllum* L., *Ephedra tweediana* C.A. Meyer, *Acacia*-type, *Parapiptadenia rigida*-type, *Erythrina*-type, *Daphnopsis racemosa* and *Sebastiania* Spreng. Pollen from aquatics plants, such as *Ludwigia*, is less than 1%. Ferns spores decrease in this phase. Spores of mosses reached the highest percentages (16-74%), which are mainly dominated by *Phaeoceros laevis* (12-72%), while *Sphagnum* (Dill.) Hedw and *Anthoceros punctatus* L. occur in lower proportions. Algae taxa were mainly represented by *Pseudoschizaea rubina* Rossignol ex Christopher (17%). The concentration and accumulation rates of the charcoal particles and pollen grains were lower than in the previous phase.

Phase SAP-V (4402-137 cal yr BP)

The highest stratigraphic phase comprises 13 subsamples within the interval between 51-13 cm depth. This phase is characterized by a significant increasing of pollen sum of forest taxa (21-37%) and by the decreasing of herb pollens (62-78%). In general, all taxa related to forest were better represented in this phase than in the previous one. On the other hand, *Podocarpus* decreases in frequency. In the transition between phases SAP-IV and SAP-V, there is the first record of *Zea mays* L. and *Pinus* L., which were found in mostly subsamples of this last phase. Aquatic taxa were also better represented in this phase, mainly by *Ludwigia*, which reached up to 12%. Spores of ferns increased their percentages (6-31%), while spores of mosses and algae taxa decreased them. Spores of fungi also increased (*Glomus* Tus. & C. Tus., *Gelasinospora calospora* (Mouton) C. Moreau & M. Moreau and *Gelasinospora reticulispora* (Greis & Greis-Dengler) C. Moreau & M. Moreau, *Gaeumannomyces* cf. *caricis*-type, *Athelia*-type and *Tetraploa aristata* Berk. & Br.). The concentration of the charcoal particles and pollen grains were higher than in the previous phase, while accumulation rates of the charcoal particles and pollen grains were lower.

Multivariate Analysis

The multivariate analysis (PCoA) shows a synthesis of the changes in the pollen composition since 5461 cal yr BP until present 137 cal yr BP (Anno Domini 1850). The two dimensional ordination diagram accounts for 61% of the total variation in the data set, with 53 taxa in 33 subsamples (Figs. 4a-b). Pollen composition dynamics depicted by the ordination analysis shows phases of random, non-directional changes and periods in which the changes were directional toward more abundant forest taxa. Directional jumps, characterizing transitions of phases, were most evident from 5386 to 5314 cal yr BP, 5206 to 5189 cal yr BP, and 4402 to 3991 cal yr BP. Multivariate analysis of phase SAP-I shows the dominance of grasslands up to 5386 cal yr BP, which are represented by Poaceae and *Baccharis*-type. At ca. 5314 cal yr BP (phase SAP-III), ordination diagrams suggest important vegetational changes by the appearance of forest taxa, such as Myrtaceae, *Ilex*, Arecaceae and *Podocarpus*. After 5058 cal yr BP, within the SAP-III/IV transition, grassland taxa diversified, including *Holocheilus*-type, *Trixis*-type, *Spermacoce*, *Senecio*-type, *Vernonia*-type, Lamiaceae, *Gomphrena* L., *Eryngium*, Melastomataceae and *Cuphea*. The phase SAP-V is evidenced in the PCoA diagrams by the increasing and diversity of trees and shrubs components, such as Anacardiaceae, *Sebastiania*, *Chrysophyllum*, *Alchornea*, *Trema micrantha*, *Myrsine* L., *Daphnopsis racemosa*, *Mimosa* L., *Celtis* and *Erytrina*-type.

Botanical Data

The main components of the modern flora around the peat bog are listed in the Figure 5, according to their type, physiognomy, habit and habitat, and including the taxonomic basis for genera and species.

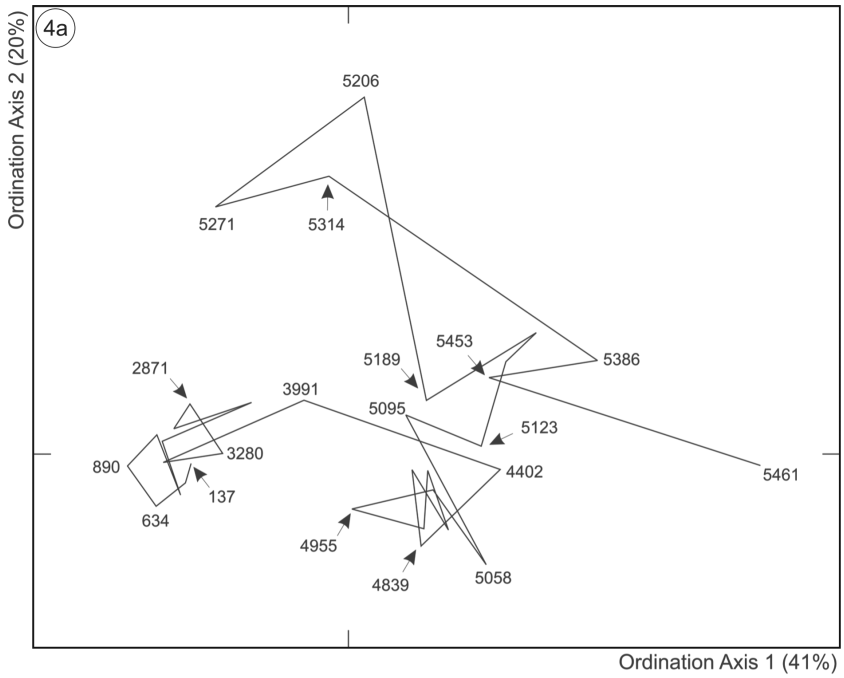
DISCUSSION

The results obtained from the pollen analysis of Santo Antônio da Patrulha core revealed changes in the vegetational composition during the last millennia on the Lower Slopes of Serra Geral, RS. These vegetational successions reflected paleoenvironmental variations, which are described below.

The Phase SAP-I (5461-5443 cal yr BP) showed the predominance of plants associated with grasslands, mainly represented by Poaceae and *Baccharis*-type (Figs. 2b-3). Furthermore, few records of trees and shrubs, ferns spores and algae taxa, as well as high frequency of mosses spores (*Phaeoceros laevis*), suggest warm and dry climate conditions, in agreement with the interpretations of Behling (2002) to South and Southeast regions of Brazil. According to this author, low precipitations and a long annual dry season, probably of three months, should have limited the expansion of trees taxa during the middle Holocene in Southern Brazil. Perhaps these paleoclimates conditions are related to changes in the trajectory of Polar cold fronts to the Atlantic Ocean, similar to modern events of *La Niña*, which causes drought in Southern Brazil. Other palynological studies performed in RSCP and adjacent areas also showed similar results (Bauermann 2003, Macedo et al. 2007, Leal and Lorscheitter 2007).

Poor preserved palynomorphs occur in Phase SAP-II (5443-5402 cal yr BP), in low frequency, preventing vegetational and paleoclimatic interpretations to this interval. These results can be related to taphonomic limitations, though no sedimentological and lithological different evidences are observed. This limitation was also recorded by Bauermann (2003) from the interval between ca. 6000 cal yr BP to 3163 ± 29 ^{14}C yr BP within a core recovered from Barrocadas, RSCP.

The Phase SAP-III (5402-4955 cal yr BP) revealed pollen changes in the grasslands vegetation clearly highlighted by the multivariate analysis of PCoA, taking into account the gradual increasing of *Baccharis*-type, Poaceae and other herbaceous components, such as *Cuphea*, *Eryngium*, *Gomphrena*, *Holocheilus*-type, Lamiaceae, Melastomataceae, *Polygala*, *Senecio*-type, *Spermacoce*, *Trixis*-type and *Vernonia*-type (Figs. 4a-b). This phase is also marked by the increase of pioneers taxa of the Atlantic rainforest, such as *Alchornea*, Anacardiaceae, Arecaceae, *Cecropia* Loefl., *Celtis*, *Chrysophyllum*, *Ilex*, Melastomataceae, Myrtaceae, *Myrsine*, *Podocarpus*, *Sebastiania* and *Trema micrantha* (Figs. 2a-3). These pollen records suggest the beginning of the grassland-forest mosaics. These Atlantic rainforest components could possibly be distributed in areas of higher humidity, such as borders of rivers, forming the gallery forest. Furthermore, they could have been dispersed in small



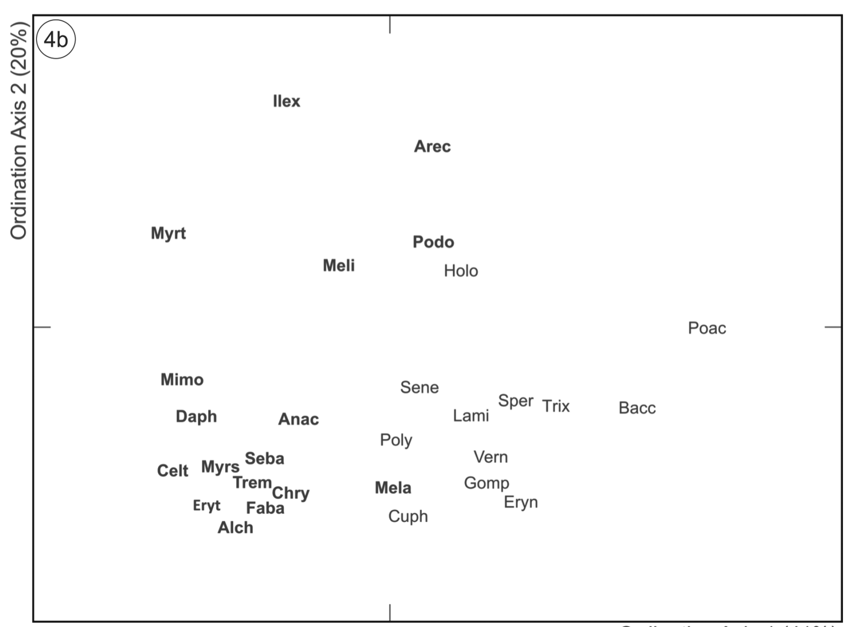


Fig. 4 – The diagram map of the vegetation trajectory for the last 5461 cal yr BP in **(a)** and **(b)**. Calibrated years BP (i.e. before AD 1950) are indicated for some points. Arboreal (in bold) and herb taxa are shown in positions that are proportional to their correlation level with the ordination axis (only taxa with the highest correlations are indicated); the corresponding overlapped diagrams would form biplots. The tick marks on the axes indicate the origin coordinates. Taxa abbreviations: Alch = *Alchornea*, Anac = Anacardiaceae, Arec = Arecaceae, Bacc = *Baccharis*-type, Celt = *Celtis*, Chry = *Chrysophyllum*, Cuph = *Cuphea*, Daph = *Daphnopsis racemosa*, Eryn = *Eryngium*, Eryt = *Erythrina*-type, Faba = Fabaceae, Gomp = *Gomphrena*, Holo = *Holocheilus*-type, Ilex = *Ilex*, Lami = Lamiaceae, Mela = Melastomataceae, Meli = Meliaceae, Mimo = *Mimosa* serie *Lepidotae*, Myrs = *Myrsine*, Myrt = Myrtaceae, Poac = Poaceae, Podo = *Podocarpus*, Poly = *Polygala*, Seba = *Sebastiania*, Sene = *Senecio*-type, Sper = *Spermacoce*, Trem = *Trema micrantha*, Trix = *Trixis*-type, Vern = *Vernonia*-type.

Vegetation type/ physiognomy	Important species
Forest	**Trees**: *Alchornea triplinervia* (Spreng.) Müll. Arg. (Euphorbiaceae), *Allophylus edulis* Radlk. ex Warm. (Sapindaceae), *Campomanesia xanthocarpa* O. Berg. (Myrtaceae), *Casearia sylvestris* Sw. (Flacourtiaceae), *Celtis* L. (Ulmaceae), *Cupania vernalis* Cambess. (Sapindaceae), *Daphnopsis racemosa* Griseb. (Thymelaeaceae), *Dodonaea viscosa* Jacq. (Sapindaceae), *Erythrina crista-galli* L. (Fabaceae), *Erythroxylum argentinum* O. E. Schulz. (Erythroxylaceae), *Eugenia uniflora* L. (Myrtaceae), *Ilex dumosa* Reiss., *I. pseudobuxus* Reiss. (Aquifoliaceae), *Lithraea brasiliensis* March. (Anacardiaceae), *Myrsine lorentziana* (Mez) Arechav., *M. ferruginea* (R. & P.) Mez. (Myrsinaceae), *Parapiptadenia rigida* (Benth.) Brenan. (Mimosaceae), *Sebastiania commersoniana* (Baill.) L. B. Smith & R. J. Downs., *S. serrata* (Müll. Arg.), *S. brasiliensis* Spreng. (Euphorbiaceae), *Syagrus romanzoffiana* Cham. (Arecaceae), *Symplocos* Jacq. (Symplocaceae), *Tabebuia* Gomes ex DC. (Bignoniaceae), *Trema micrantha* (L.) Blume (Ulmaceae), *Verbenoxylum reitzii* (Mold.) Tronc. (Verbenaceae). **Epiphytes**: *Antiacantha* Bertol., *Tillandsia* L. (Bromeliaceae). **Herbs and Shrubs**: *Chiococca alba* Hitchc.(Rubiaceae), *Peperomia* Ruiz & Pav. (Piperaceae), *Psychotria carthagenensis* Jacq. (Rubiaceae). **Ferns**: *Anemia phyllitidis* (L.) Sw (Schizaeaceae), *Microgramma* C. Presl. (Polypodiaceae), *Selaginella* P. Beauv (Selaginellaceae).
Border forest	**Herbs and Shrubs**: *Baccharis* L. (Asteraceae), *Calea serrata* Less. (Asteraceae), *Cuphea* P. Browne (Lythraceae), *Diodia alata* Ness & Mart. (Rubiaceae), *Elephantopus mollis* H. B. & K., *Erechtites hieracifolia* (L.) Rafin., *Eupatorium inulaefolium* H. B. & K., *E. tweedianum* Hook & Arn. (Asteraceae), *Eryngium pandanifolium* Cham. & Schultdl. (Apiaceae), *Hypericum* L. (Clusiaceae), *Hyptis mutabilis* Briq. (Lamiaceae), *Lantana camara* L. (Verbenaceae), *Leandra australis* Cong. (Melastomataceae), *Miconia cinerascens* Miq., *M. hyemalis* A. St. Hill & Naud., *M. sellowiana* Naud. (Melastomataceae), *Mikania* sp. Willd, *M. micrantha* H. B. & K. (Asteraceae), *Mimosa bimucronata* (DC.) Kuntze., *M. pilulifera* Benth. (Mimosaceae), *Passiflora suberosa* L. (Passifloraceae), *Paullinia trigonia* Vell. (Sapindaceae), *Randia armata* (Sw.) DC. (Rubiaceae), *Phyllanthus* L. (Phylanthaceae), *Smilax* L. (Smilacaceae), *Tibouchina* Aubl (Melastomataceae), *Triunffeta semitriloba* Jacq. (Malvaceae), *Vernonia tweedieana* Baker. (Asteraceae) and *Xyris* L. (Xyridaceae). **Ferns**: *Blechnum* L. (Blechnaceae), *Doryopteris* J. Sm. (Adiantaceae).
Grasslands	**Herbs:** *Aspilia montevidensis* (Spreng.) Kuntze, *Baccharis* L. (Asteraceae), Cyperaceae, *Eryngium pandanifolium* Cham. & Schltdl. (Apiaceae), *Glechon* Spreng. (Lamiaceae), *Ludwigia* L. (Onagraceae), *Oxalis* L. (Oxalidaceae), *Panicum prionitis* Nees (Poaceae), *Pterocaulon* Elliotti, *Senecio bonariensis* Hook. & Arn., *Vernonia flexuosa* Sims (Asteraceae).

Fig. 5 – Extant species of the forest and grasslands in Santo Antônio da Patrulha, RS, Brazil.

populations under waterlogged soil, forming swamp forests. In this interval, the initial and gradual appearance of certain taxa of the Araucaria forest (*Araucaria angustifolia* and *Drymis brasiliensis*) was observed, as well as some ferns spores (*Dicksonia sellowiana*) developed on valleys and areas associated with the Serra Geral Plateau (Behling et al. 2004, Leonhardt and Lorscheitter 2010). These components are no more observed in the study area. We interpret that they were transported and subsequently incorporated within the analyzed sediments.

The beginning of the expansion of the Atlantic rainforest reflects changes to climatic conditions with higher temperature and humidity. High frequencies in records of ferns spores (*Blechnum*-type, Cyatheaceae, *Microgramma vacciniifolia*-type and *Polypodium*), algae (*Zygnema* C.A. Agardh) and fungi spores corroborate this humidity conditions (Figs. 2c-3). According to Martin et al. (1993), the constant rainfalls during the last 5000 yrs BP is probably due to *El Niño* events, which caused strong storms in South Brazil.

The increasing in temperature and humidity also coincides with the last maximum transgressive marine event marked in the lowlands RSCP at ca. 5000 yrs BP (Villwock et al. 1986, Villwock and Tomazelli 1995).

These paleoenvironmental interpretations are also compatible with the records of human occupation associated with the Umbu tradition (pre-ceramic period) observed by Dias (2003) and Dias and Jacobus (2003) in the arqueologic site "RS-S-327" located about 2 km of this study area. In addition, mammalian fossils of small size, related to grassland vegetation (*Thylamys* Grey, *Clyomys* sp. nov. and *Dicolpomys* fossor Winge) and others typical of forests (*Gracilinanus microtarsus* Wagner and *Phyllomys* sp.), were found in the archaeological site above mentioned at stratigraphical levels corresponding to this phase. It confirms the grassland-forest mosaics hypothesis (Rodrigues 2008) to this region.

An important theme to be reanalyzed concerns the rates of concentration and accumulation of carbonized particles, which are the highest in this phase. It was expected that, by the increasing of humidity conditions as reflex of the entrance of Atlantic rainforest elements, natural events of fire could be less expressive. Human origin to these highest rates of carbonized particles is discarded. In those times, arqueological record of fire seem to be restricted to rock shelter, related to hunt of human Umbu tradition (Dias 2003). These carbonized particles are relatively well preserved, demonstrating that this site of deposition received most contributions from the nearest area, with a strong influence of organic matter. It is reinforced by the lithological data and by the highest sedimentation rate of the core (Fig. 3).

The Phase SAP-IV (4955-4402 cal yr BP) is very similar to the previous one, with a well-represented grasslands vegetation in the studied region. However, pioneer components of the Atlantic rainforest (Arecaceae, *Ilex*, Myrtaceae, *Myrsine* and *Celtis*) showed a slightly reduction in their frequencies, as also verified by other authors (Lorscheitter 2003, De Oliveira et al. 2005). This reduction is attributed to the marine transgression above mentioned (ca. 5000 yrs BP) that controlled the Atlantic rainforest expansion, mainly at the Rio Grande do Sul Northern Coastal Plain with indirect reflexes in the studied area.

The first pollen records of Acacia-type, *Daphnopsis racemosa* Griseb., *Erythrina*-type, and *Parapiptadenia rigida*-type are interpreted as seasonal semideciduous forest influence. In addition, probably *Ephedra tweediana* moved from west to east. According to Rambo (1954), this species migrated from the Andes regions and subsequently penetrated in the South of RS from Argentina. Currently *E. tweediana* is restricted in the RSCP, ca. 30° latitude.

The uppermost Phase SAP-V involves the last 4402 cal yr BP, showing a significant expansion of the forest vegetation and constituting the grassland-forest mosaics similar to the modern ones. The increasing of biodiversity of the Atlantic rainforest and seasonal semideciduous forest in the region was synchronous to the marine regression after 4000 yrs BP in RSCP. After this event, processes of desalinization in soils allowed that certain elements replaced the RSCP region and adjacent areas, according to Lorscheitter (2003), De Oliveira et al. (2005) and Leal and Lorscheitter (2007). High percentages of algae taxa (*Pseudoschizaea rubina* Rossignol ex Christopher, *Zygnema*) and mosses spores (*Sphagnum* Dill. Hedw) suggest the permanence of these humidity conditions and intense rainfall in this phase. Ferns spores such as Blechnum-type, Cyatheaceae and *Selaginella* became well represented even as aquatic elements (mainly *Ludwigia*). Spores of fungi mycorrhizal increased in frequency and can be associated with the development of soils. The expansion of the Atlantic rainforest and seasonal semideciduous forest may have minimized the fire frequency, which is also evidenced by the reduction of rates of concentration and accumulation of carbonized particles. According to Pillar (2003) and Overbeck et al. (2005), fire in the grasslands vegetation did not reach the inner part of forest due to the lack of biomass to promote flammability. Finally, the uppermost subsamples (from the 0, 35 m to top) of the core showed the human influence by the marked presence of *Zea mays* L.

The dating performed at 55 cm depth reveals an interesting and exciting aspect about the geological evolution of the analyzed sedimentary interval. According to the obtained datings, the section between 115 and 55 cm had a high sedimentar rate, of about 0,124 cm/year, including a time of ca. 485 years. Otherwise, for the interval between 55 and 13 cm depth, the sedimentation rate is much lower, of ca. 0,01 cm/year. Considering the dating accuracy and the granulometry sustenance, this difference can be explained by changes in the shape of paleotopography. At the beginning, the point of sampling probably corresponded to a more irregular surface on the ground, such as minor depressions or a cavity. The upper section was deposited on a more regular and planar surface, with a lower sedimentation rate. Furthermore, the presence of *Pinus* at the base of Phase V (ca. 50 cm of depth) corresponds to a younger and modern feature concerning the vegetational occupation. This basal record suggests a variability in the sedimentar pattern, with the possibility of having hiatuses from the base, which were not revealed by the lithological descriptions.

CONCLUDING REMARKS

The palynological record obtained from a peat bog at Santo Antônio da Patrulha, RS, southmost Brazil, revelead five phases, named SAP-I to SAP-V. These phases reflect different ecological and environmental conditions, mainly related to the vegetational succession and the paleoclimate variations, as summarized below. The results reinforced the use of pollen and spores assemblages for Quaternary analysis.

(i) A total of 98 taxa of palynomorphs were identified from 35 subsamples recovered from the Santo Antônio da Patrulha core, whose basal radiocarbonic dating (at 115 cm of depth) revealed an age of 4730 ± 50 yr BP (calibrated age 5461 yrs BP).

(ii) Among the five identified phases, only the SAP-II (two subsamples 110 to 105 cm core depth) did not revealed an amount of pollen and spores for paleoecological and paleoclimatic interpretations.

(iii) Taking into account the main tendencies of the vegetational record, it is possible to observe a gradual increasing of humidity, mainly from the beginning of the SAP-III, when the pioneers of the Atlantic rainforest components, fern spores and fungi, became significant. Furthermore, grasslands present more diversity of taxa.

(iv) Grassland components are dominant along the entire core. However from the SAP-V (ca. 4000 cal yrs BP) forest taxa, Atlantic rainforest and seasonal semideciduous forest, present a gradual and significant increasing.

(v) The records and frequency of grasslands and forest taxa from the SAP-III show the beginning of the vegetation as a mosaic, as interpreted by other authors. Mammalian fossils and arqueological data support this idea, especially correlated to the SAP-III.

(vi) The progressive establishment of these forest elements in the region suggests warm condition from ca. 4000 cal yrs BP to present, corroborating previous palynological data obtained in the RSCP and following the marine regression during the latest Holocene times.

(vii) The presence of some pollen taxa, such as *Acacia*-type, *Daphnopsis racemosa*, *Erythrina*-type and *Parapiptadenia rigida*-type, is interpreted herein as an influence of the seasonal semideciduous forest. Other authors recorded these taxa from late Holocene cores in southmost Brazil, but they seem to be included as Atlantic rainforest components.

ACKNOWLEDGMENTS

Radiocarbonic datings were supported in part by Conselho Nacional de Desenvolvimento Científico e Tecnológico (CNPq) through projects conducted by Adriana Schmidt Dias (474630/2004-8) and Rodrigo Rodrigues Cancelli (140924/2008-6). The authors thank to Valério De Patta Pillar for discussions and revision of the multivariate analysis, and to the referees for their important suggestions. This paper is part of the Master's dissertation of the first author, with grants from Coordenação de Aperfeiçoamento de Pessoal de Nível Superior (CAPES).

RESUMO

Um testemunho de sondagem coletado em Santo Antônio da Patrulha, Rio Grande do Sul, Brasil, foi submetido para análise polínica a fim de revelar a história vegetacional e mudanças paleoecológicas e paleoclimáticas. Um total de 98 táxons foi identificado a partir de 35 subamostras. Três datações radiocarbônicas foram obtidas ao longo de uma seção de 115 cm de profundidade, incluindo a idade basal de 4730 ± 50 anos AP. Diagramas polínicos e análises de agrupamentos foram realizadas com base nas freqüências dos palinomorfos, demonstrando cinco fases distintas (SAP-I a SAP-V), as quais refletiram diferentes condições paleoecológicas. A predominância de plantas relacionadas à vegetação campestre na fase SAP-I sugere condições climáticas quentes e secas. Um gradual aumento nas condições de umidade foi observado principalmente no início da fase SAP-III, quando a vegetação conformou um mosaico de Campos e Floresta Atlântica. Além disso, a presença de certos táxons florestais (tipo-*Acacia*, *Daphnopsis racemosa*, tipo *Erythrina* e tipo *Parapiptadenia rigida*), a partir da fase SAP-IV, é interpretada como influência da Floresta Estacional Semidecidual na região de estudo. A partir da fase SAP-V (ca. 4000 anos AP) a vegetação tornou-se similar à moderna (atual Bioma da Floresta Atlântica), especialmente após 2000 anos AP (idade calibrada).

Palavras-chave: Palinologia, Paleoecologia, Paleoclimatologia, Floresta Atlântica, Holoceno tardio, Rio Grande do Sul.

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