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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

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ABSTRACT

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

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

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

The palynology is an important tool for the
standing of vegetation dynamics and paleoclimate
structions. Several studies based on pollen analys
contributed in solving questions on the vegetacion
cession during the late Quaternary in Southern Br
summarized by Behling (2002), Lorscheitter (200
Oliveira et al. (2005) and Leal and Lorscheitter (
Palynological results showed that, during the lates
tocene, the landscape in these regions was charac
by the dominance of grasslands due to the cold a
climate associated with glacial times. During the e
middle Holocene, the vegetation related to these
lands prevailed in lowlands and highlands of the

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).

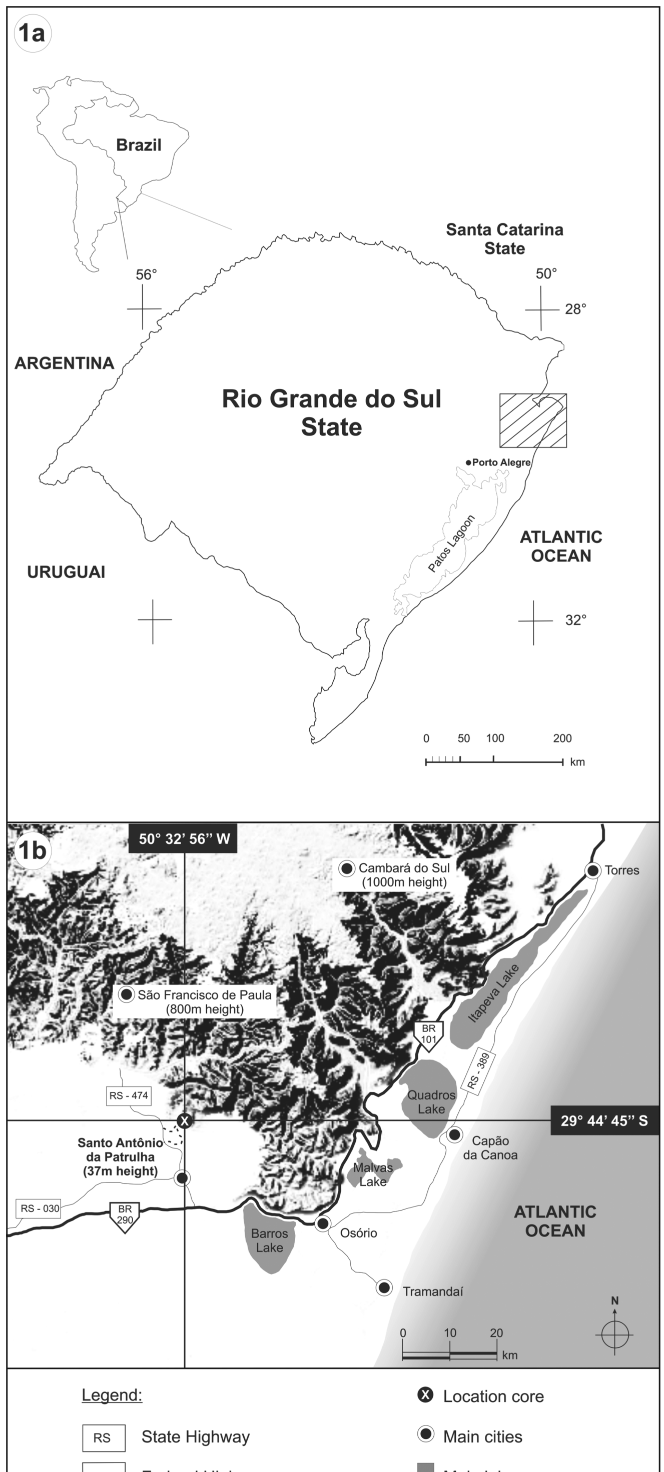
The climate of Southern Brazil is influenced by the South Atlantic Anticyclone, a semi-permanent high pressure system that transports moist tropical air masses over the continent from easterly and north-easterly directions during the whole year. Disturbances are related to polar cold fronts, when it 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

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 pa-


1a
Brazil
Santa Catarina State
56°
50°
28°
ARGENTINA
Rio Grande do Sul State
Porto Alegre
Patos Lagoon
ATLANTIC OCEAN
URUGUAI
32°
0 50 100 200 km
1b
50° 32' 56'' W
Cambará do Sul (1000m height)
Torres
São Francisco de Paula (800m height)
Itapeva Lake
BR 101
RS - 389
RS - 474
Quadros Lake
29° 44' 45'' S
Santo Antônio da Patrulha (37m height)
Capão da Canoa
Malvas Lake
RS - 030
BR 290
Barros Lake
Osório
ATLANTIC OCEAN
Tramandaí
N
0 10 20 km
Legend:
Location core
RS
State Highway
Main cities

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.

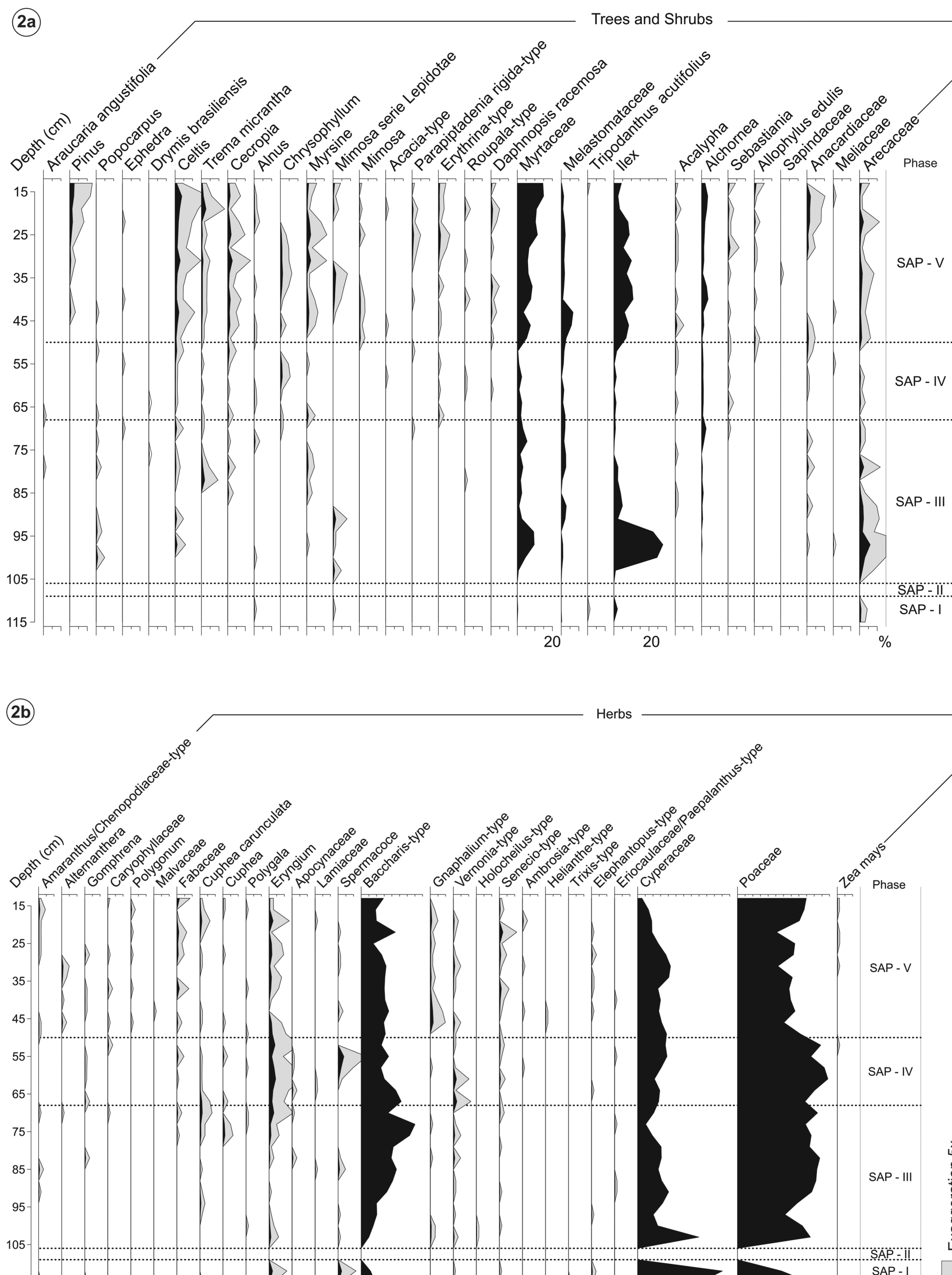
the deposition of the studied core entirely positioned along the late Holocene. However, sedimentation was not continuous. Three datings were obtained. The basal dating corresponds to 4730 ± 50 ^{14}C yr BP (calibrated age 5461 yr BP), while the sample at 55 cm depth was dated as 4225 ± 25 ^{14}C yr 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, involving the vegetation history of the last 4200 yrs BP.

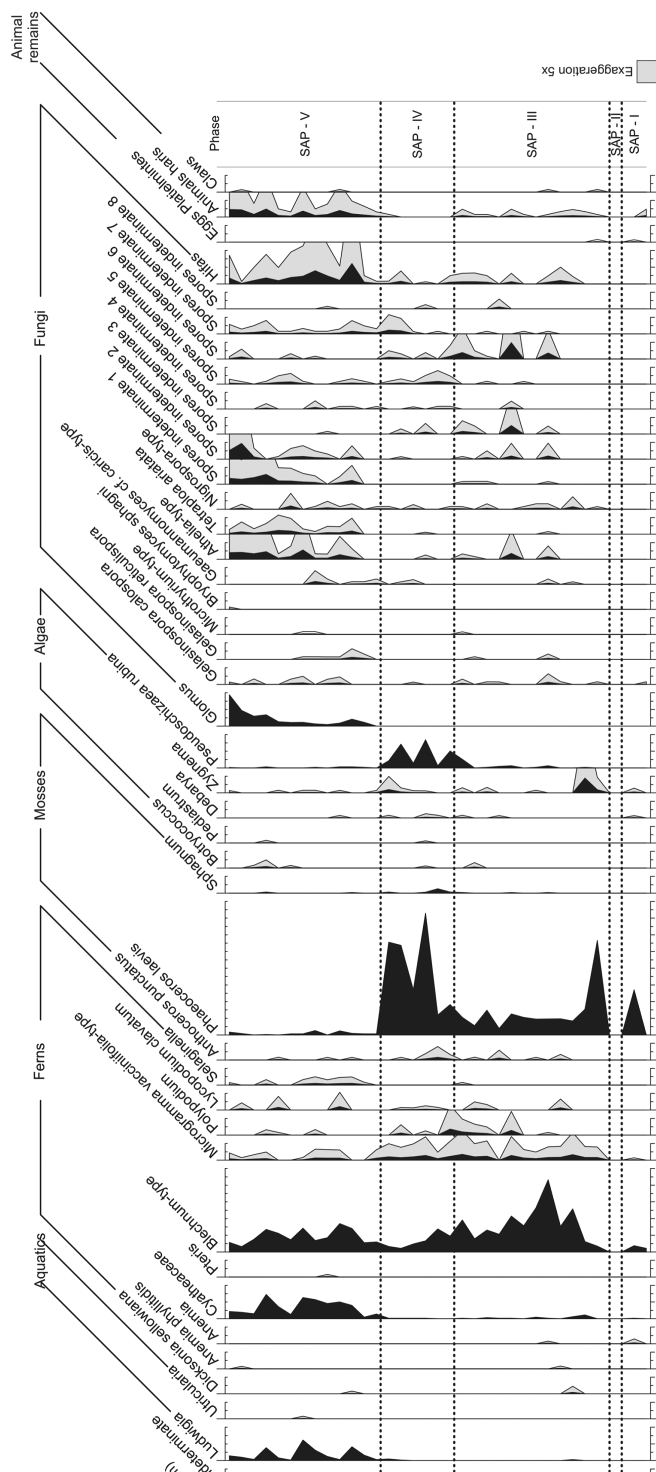
DESCRIPTION OF POLLEN RECORD

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.)


2a
Trees and Shrubs
Depth (cm)
Araucaria angustifolia
Pinus
Popocarpus
Ephedra
Drymis brasiliensis
Celtis
Trema micrantha
Cecropia
Alnus
Chrysophyllum
Myrsine
Mimosa serie Lepidotae
Mimosa
Acacia-type
Parapiptadenia rigida-type
Erythrina-type
Roupala-type
Daphnopsis racemosa
Myrtaceae
Melastomataceae
Tripodanthus acutifolius
Ilex
Acalypha
Alchornea
Sebastiania
Allophylus edulis
Sapindaceae
Anacardiaceae
Meliaceae
Arecaceae
Phase
SAP - V
SAP - IV
SAP - III
SAP - II
SAP - I
20
20
%
2b
Herbs
Depth (cm)
Amaranthus/Chenopodiaceae-type
Alternanthera
Gomphrena
Caryophyllaceae
Polygonum
Malvaceae
Fabaceae
Cuphea carunculata
Cuphea
Polygala
Eryngium
Apocynaceae
Lamiaceae
Spermacoce
Baccharis-type
Gnaphalium-type
Vernonia-type
Holocheilus-type
Senecio-type
Ambrosia-type
Helianthe-type
Trixis-type
Elephantopus-type
Eriocaulaceae/Paepalanthus-type
Cyperaceae
Poaceae
Zea mays
Phase
SAP - V
SAP - IV
SAP - III
SAP - II
SAP - I


Animal remains
Fungi
Algae
Mosses
Ferns
Aquatics
Exaggeration 5x
Phase
SAP - V
SAP - IV
SAP - III
SAP - II
SAP - I
%
Claws
Animals hairs
Eggs Platelmintes
Hifas
Glomus
Pseudoschizaea rubina
Zygnema
Debarya
Pediastrum
Botryococcus
Sphagnum
Phaeoceros laevis
Anthoceros punctatus
Selaginella
Lycopodium clavatum
Polypodium
Microgramma vacciniifolia-type
Blechnum-type
Pteris
Cyatheaceae
Anemia phyllitidis
Dicksonia sellowiana
Ludwigia

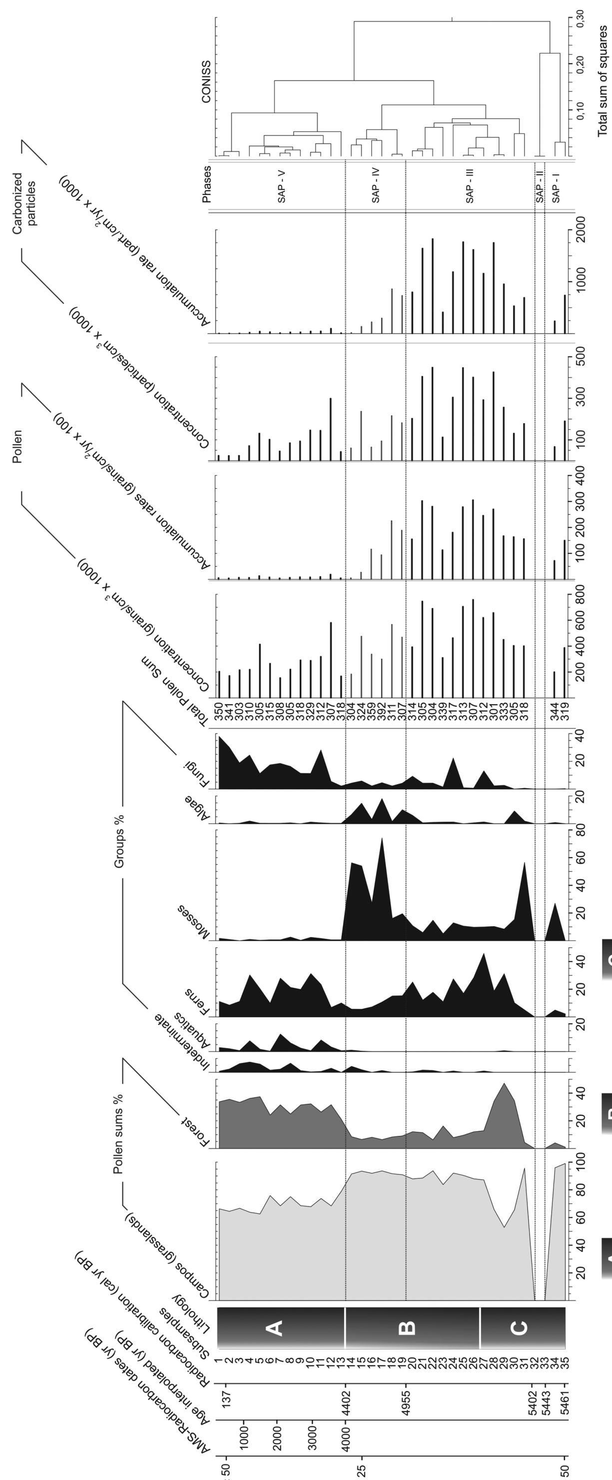

AMS-Radiocarbon dates (yr BP)
Age interpolated (yr BP)
Radiocarbon calibration (cal yr BP)
Subsamples
Lithology
Campos (grasslands)
Forest
Pollen sums %
Indeterminate
Aquatics
Ferns
Mosses
Algae
Fungi
Groups %
Total Pollen Sum
Concentration (grains/cm³ x 1000)
Accumulation rates (grains/cm²/yr x 100)
Pollen
Concentration (particles/cm³ x 1000)
Accumulation rate (part./cm²/yr x 1000)
Carbonized particles
Phases
SAP - V
SAP - IV
SAP - III
SAP - II
SAP - I
CONISS
Total sum of squares
A Brown Peat
B Black Organic Matter (OM)
C Brown - Black Peat
137
4402
4955
5402
5443
5461

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)

est 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, *Gaeumanno-*

vious 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

The Phase SAP-I (5461-5443 cal yr BP) s
the predominance of plants associated with
lands, mainly represented by Poaceae and *Bac*
type (Figs. 2b-3). Furthermore, few records of tr
shrubs, ferns spores and algae taxa, as well as hi
quency of mosses spores (*Phaeoceros laevis*), s
warm and dry climate conditions, in agreement w
interpretations of Behling (2002) to South and
east regions of Brazil. According to this autho
precipitations and a long annual dry season, pr
of three months, should have limited the expan
trees taxa during the middle Holocene in So
Brazil. Perhaps these paleoclimates conditions
lated to changes in the trajectory of Polar cold fr
the Atlantic Ocean, similar to modern events of *L*
which causes drought in Southern Brazil. Othe
nological studies performed in RSCP and adjacen
also showed similar results (Bauermann 2003, M
et al. 2007, Leal and Lorscheitter 2007).

Poor preserved palynomorphs occur in Phas
II (5443-5402 cal yr BP), in low frequency, prev
vegetational and paleoclimatic interpretations to
terval. These results can be related to taphonom
tations, though no sedimentological and lithologi
ferent evidences are observed. This limitation w
recorded by Bauermann (2003) from the inter
tween ca. 6000 cal yr BP to 3163 ± 29 ^{14}C yr BP
a core recovered from Barrocadas, RSCP.

The Phase SAP-III (5402-4955 cal yr BP) re
pollen changes in the grasslands vegetation clearl
lighted by the multivariate analysis of PCoA, taki
account the gradual increasing of *Baccharis*-typ
ceae and other herbaceous components, such as *C*
Eryngium, *Gomphrena*, *Holocheilus*-type, Lam
Melastomataceae, *Polygala*, *Senecio*-type, *Sperm*
Trixis-type and *Vernonia*-type (Figs. 4a-b). This
is also marked by the increase of pioneers taxa
Atlantic rainforest, such as *Alchornea*, Anacard
Arecaceae, *Cecropia* Loefl., *Celtis*, *Chrysophyllu*
Melastomataceae, Myrtaceae, *Myrsine*, *Podocarp*
bastiania and *Trema micrantha* (Figs. 2a-3).
pollen records suggest the beginning of the gra
forest mosaics. These Atlantic rainforest comp

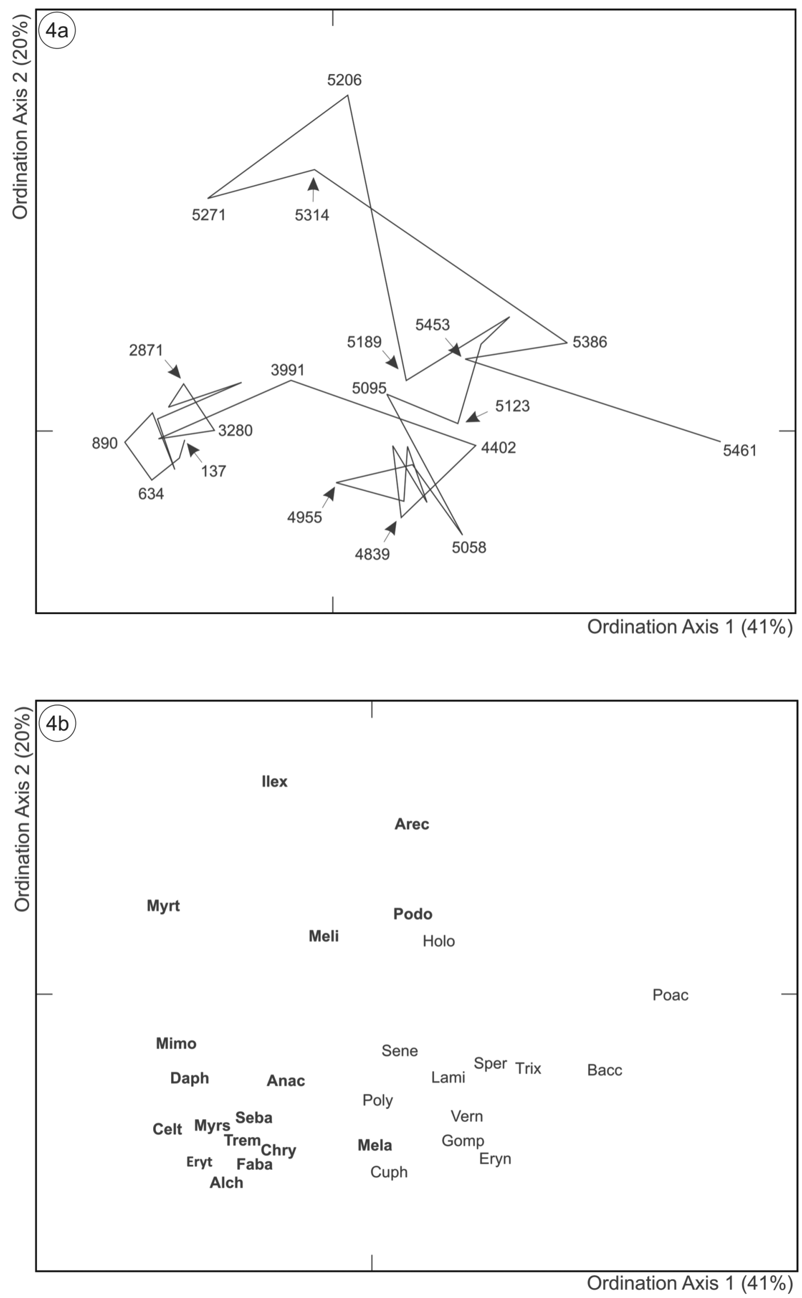


Fig. 4 – The diagram map of the vegetation trajectory for the last 5461 cal yr BP in **(a)** and **(b)**. Calibrated years BP (i.e. before AD 1950) are indicated for some points. Arboreal (in bold) and herb taxa are shown in positions that are proportional to their correlation level with the ordination 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,

Vegetation type/ physiognomy	Important species
Forest	**Trees**: *Alchornea triplinervia* (Spreng.) Müll. Arg. (Euphorbiaceae), *Allophylus eduli* Radlk. ex Warm. (Sapindaceae), *Campomanesia xanthocarpa* O. Berg. (Myrtaceae) *Casearia sylvestris* Sw. (Flacourtiaceae), *Celtis* L. (Ulmaceae), *Cupania vernali* 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), *Ile 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. brasiliensi* 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), *Elephantopu 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* Aub (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

Microgramma vacciniifolia-type and *Polypodiu* gae (*Zygnema* C.A. Agardh) and fungi spores orate this humidity conditions (Figs. 2c-3). Acc to Martin et al. (1993), the constant rainfalls dur last 5000 yrs BP is probably due to *El Niño* which caused strong storms in South Brazil.

The increasing in temperature and humidi coincides with the last maximum transgressive event marked in the lowlands RSCP at ca. 5000 (Villwock et al. 1986, Villwock and Tomazelli 1

These paleoenvironmental interpretations a 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 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 cerning 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-

ca. 4000 cal yrs BP to present, corroborati
vious palynological data obtained in the RS
following the marine regression during th
Holocene times.

(vii) The presence of some pollen taxa, such as
type, *Daphnopsis racemosa*, *Erythrina*-ty
Parapiptadenia rigida-type, is interpreted h
an influence of the seasonal semideciduous
Other authors recorded these taxa from lat
cene cores in southmost Brazil, but they see
included as Atlantic rainforest components.

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RESUMO

Um testemunho de sondagem coletado em Santo Ant
Patrulha, Rio Grande do Sul, Brasil, foi submetido para
polínica a fim de revelar a história vegetacional e m
paleoecológicas e paleoclimáticas. Um total de 98 tá
identificado a partir de 35 subamostras. Três dataçõe
carbônicas foram obtidas ao longo de uma seção de
de profundidade, incluindo a idade basal de 4730 ±
AP. Diagramas polínicos e análises de agrupamento
realizadas com base nas freqüências dos palinomor
monstrando cinco fases distintas (SAP-I a SAP-V),
refletiram diferentes condições paleoecológicas. A p
nância de plantas relacionadas à vegetação campestre
SAP-I sugere condições climáticas quentes e secas.
dual aumento nas condições de umidade foi observad
palmente no início da fase SAP-III, quando a vegetaçã

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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