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Paleoenvironmental evolution of the coastal plain of Southern Brazil: palynological data from a Holocene core in Santa Catarina State

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ABSTRACT

This paper presents a paleoenvironmental reconstruction from palynological analyses of a sedimentary core of Holocene age, drilled at municipality of Garopaba (Santa Catarina), Southern Brazil. A total of 46 samples was collected for palynological analyses in the 450 cm-long core PCSC-3, as also three samples for radiocarbon dating and granulometric analyses. The palynological content includes 84 taxa related to pollen grains of angiosperms (38) and gimnosperm (3), spores of pteridophyta (16) and bryophyta (2), spores of fungi (8), algae (3), acritarchs (3), dinoflagellate cysts (2) and microforaminiferal linings (1). Three specimens of acritarchs are described and illustrated in detail. Three palynological phases were defined based on changes in assemblages: Phase I, Phase II and Phase III. The Phase I is characterized as a lagoonal paleoenvironment with marine influence from the beginning of the sedimentation (5390 cal yr BP), based on occurrences of acritarchs, dinoflagellate cysts and microforaminiferal linings. The Phase II (3032 yr BP until 858 cal yr BP) also is characterized by a lagoonal paleoenvironment, however, presented decrease in percentage of marine elements and increase in freshwater algae record, suggesting less marine influence in the lagoonal body. In Phase III (last 856 years), underwater sedimentation prevailed, under swamp-like conditions.

Key words: coastal plain, environmental evolution, Holocene, palynology, Santa Catarina.

INTRODUCTION

The paleoclimatic variations and the sea level oscillations modelled the coastal areas worldwide in the Quaternary, resulting in significant sedimentary changes on the Southern Coastal Plain of Brazil. The sedimentary deposits formed during this time span comprise coastal plain important records on the evolution of Southern of Brazil, providing data set for local and regional analysis of the geological and vegetational history. In recent years, the Coastal Plain of Santa Catarina has shown an intense human occupation, resulting in negative impacts on the natural scenery, especialy near the coastline (Strohaecker 2008).

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Several palynological studies in Southern and southeastern Brazil based on palynomorph analysis have demonstrated the coastal environmental changes in response to Holocene sea-level variation (de Oliveira et al. 2005). However, little is known about the paleoenvironmental history of Santa Catarina Coastal Plain (e.g., Slompo 1997, Behling and Negrelle 2001, Amaral et al. 2012), when compared to nearby areas, especially Rio Grande do Sul (see summary in Bauermann et al. 2009) and Rio de Janeiro States (e.g., Luz et al. 2006, Freitas and Carvalho 2012, Souza et al. 2016).

Palynological data constitute an important tool for paleoclimatical, paleoecological and paleoenvironmental analysis because microfossil assemblages present high potential of preservation. Microfossils are generaly abundant in pelitic deposits, and are distributed in a wide variety of habits and habitats, within marine and transitional to continental basins. Thus, the record of certain marine palynomorphs and the analysis of their frequency and relative abundance in comparison with continental palynomorphs are commonly used as proxies for the delimitation of transgressive and regressive sea level events. This has been done for Brazilian (e.g., Cordeiro and Lorscheitter 1994, Behling and Negrelle 2001, de Oliveira et al. 2005, Meyer et al. 2005a, b), Southern South American (e.g., Vilanova et al. 2006, Borremei and Quattrocchio 2007, Quattrocchio et al. 2008, Mourelle et al. 2015) and other continents (e.g., de Vernal and Giroux 1991, de Vernal 2009, Mudie et al. 2011, Richards et al. 2014), in most cases integrated with other tools of analysis, such as the sedimentology and geochronological calibration.

This study presents the results of a palynological analysis performed from the 450 cm-long core PCSC-3 collected in the Coastal Plain of Santa Catarina. A paleoenvironmental model is proposed for the last 5390 cal yr BP, based on the palynological associations, mainly taxa of spore-pollen, algae cysts, dinoflagellate cysts, microforaminiferal linings and acritarchs.

STUDY AREA

This study was performed on a peat deposit (PCSC-3) located in Garopaba (coordinates 28°02'11.95"S; 48°37'41.73"W), Santa Catarina State, Southern Brazil, about 70 km from the state capital and ca. 2 km from the Atlantic Ocean coastline (Figure 1).

The Coastal Plain of Santa Catarina has two main geological units: the Basement (Precambrian, Paleozoic and Mesozoic units) to the west, and the Pelotas and Santos sedimentary marginal basins (Cretaceous to Quaternary) to the east. The municipality of Garopaba is in the onshore portion of the Pelotas Basin. The basement is composed of Precambrian rocks of the Catarinense Shield, and Paleozoic and Mesozoic sedimentary rocks, including Jurassic/Cretaceous magmatic rocks of the Serra Geral Formation (Diehl and Horn Filho 1996) of the Paraná Basin. The marginal sedimentary deposits comprise continental systems, corresponding to colluvial deposits, alluvial and fluvial fans, in the higher portions. The coastal system has the barrier-lagoon system, and comprises Pleistocene and Holocene deposits associated with the relative sea level variations developed during the Quaternary (Horn Filho 2003).

The climate of Santa Catarina State, similar to the entire Southern Brazil, is influenced by the South Atlantic Anticyclone and the Polar Migratory Anticyclone. The South Atlantic Anticyclone produces the tropical warm and humid air masses, which predominate during spring and summer, while the Polar Migratory Anticyclone is more active during the autumn and winter, producing the Atlantic polar mass, which is characterized by low temperatures (Nimer 1990). The climate of Coastal Plain of Santa Catarina is tropical humid (Cfa) in the Köppen classification, with maximum average temperature of more than 22ºC, minimum average between -3 and 18ºC, and rains distributed evenly along the year (Alvares et al. 2013).

The Atlantic Forest biome covers the entire Santa Catarina State, and forms fragments of dense ombrophylous forest and a mixed ombrophylous forest (Araucaria forest), integrating the Atlantic Forest. This forest is composed of areas of deciduous forest, steppe (altitude fields) and pioneering formations, such as mangroves and "restingas" (MMA/SBF - Ministério do Meio Ambiente/ Secretaria de Biodiversidade e Florestas 2010). In the most internal portion, the dense ombrophylous forest dominates in Santa Catarina, characterized by an ombrophilous climate with no dry period during the year and average temperatures between 22ºC and 25ºC (IBGE - Instituto Brasileiro de Geografia e Estatística 2004). A "restinga" ecosystem lies along the coast, in the river plains and around alluvial depressions (marshes, lakes and lagoons). This vegetation is conditioned by edaphic factors of first occupation character, where the soils are renewed by successive deposition of marine sand (IBGE 2012).

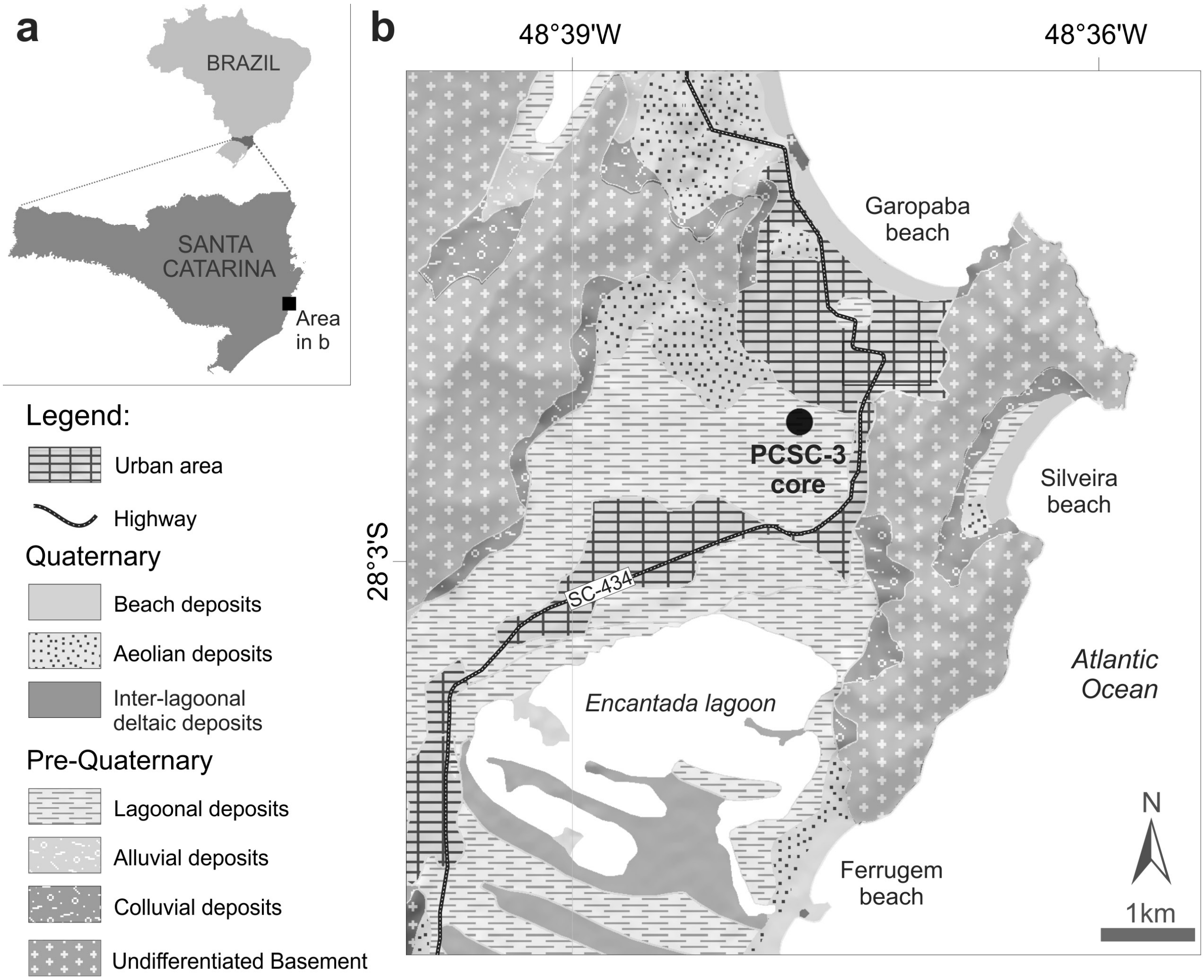

Figure 1 - General location of Santa Catarina in Brazil (**a**), the PCSC-3 core (Garopaba municipality) (**b**), including the main Quaternary and pre-Quaternary deposits (modified from Horn Filho et al. 2012).

MATERIALS AND METHODS

SAMPLING AND PALYNOLOGICAL PREPARATION

The 450 cm-long core PCSC-3 was collected using a Russian Peat Borer. The core was wrapped in plastic and aluminum film, taken to the laboratory and stored under refrigeration. All processing techniques were performed in the Laboratório de Palinologia Marleni Marques Toigo, Instituto de Geociências, Universidade Federal do Rio Grande do Sul (LPMMT/IG/UFRGS). Sampling of the core was at 10 cm spacing, totalling 46 samples of 1 cm^3 each. The samples were submitted to the standard techniques of preparation for pollen analyses of Quaternary sediments (Ybert et al. 1992), modified by using sequentially HF, HCl, KOH, acetolysis, and followed by filtering through a 250 µm mesh sieve. One tablet containing spores of *Lycopodium clavatum* L. (18.584 ± 371 spores) was added to each sample to control processing and pollen concentration (Stockmarr 1971). Four permanent slides of each sample were prepared using Entellan, presently housed in the stratigraphical slide collection of the LPPMT/IG/UFRGS under code "MP-P".

GRANULOMETRY AND RADIOCARBON DATING

Granulometrical analyses were made of 16 samples selected along the core, using the Laser Scattering Particle Size Distribution Analyzer LA-950, of the Centro de Estudos Costeiros e Oceânicos (CECO/IGeo/UFRGS). Radiocarbon dating of three selected samples were done at the CAIS Laboratory of the University of Georgia (USA), using Accelerator Mass Spectrometry (AMS). Calibration of radiocarbon dating used the program CALIB Radiocarbon Calibration version 7.1 (Stuiver et al. 2016), considering the "The Southern Hemisphere SHCal13 radiocarbon calibration curve" (Hogg et al. 2013). Interpolated ages were calculated using linear interpolation on Tilia software version 1.7.16.

PALYNOLOGICAL ANALYSIS

A minimum of 300 pollen grains were counted for each sample, whenever possible. When not possible, quantitative analysis was finalized after reaching the count of 300 spores of *L. clavatum*. Levels with less than 300 pollen grains were also considered for the percentage and cluster analyses. The taxonomic determinations of palynomorphs retrieved were performed by comparison with modern equivalents in pollen reference colections ("MP-Pr" slides of the LPMMT/IGeo/UFRGS) and by comparison with specialized literature of Quaternary palynology, mainly those from South America (e.g., Hooghiemstra 1984, Neves and Lorscheitter 1992, Herrera and Urrego 1996, Lorscheitter et al. 1998, Colinvaux et al. 1999, Borel and Gómez 2006, Leal and Lorscheitter 2006, Macedo et al. 2009, Cancelli et al. 2012).

Percentage diagram and cluster analyses were constructed using the Tilia versions 1.7.16 (Grimm 2011). The low concentration of pollen grains did not allow the plot of percentages of "pollen sum". Thus, a total sum of palynomorphs (100%) was calculated for each level, including pollen grains, spores of bryophyta and pteridophyta, fungi, algae, acritarchs, dinoflagellate cysts and microforaminiferal linings. The calculation of the percentage of each group was performed using the total sum of palynomorphs. The results of analyses of palynomorphs are presented in percentage diagrams.

RESULTS

SEDIMENTOLOGY AND RADIOCARBON DATA

The studied core consists of unconsolited sediments composed by intercalations of fine silt and fine sand layers, of variable thickness (Figure 2), rich in organic matter. Between 450 and 275 cm, the sediments are predominatly grey, and between 275 and 125 cm they are dark. Completely decomposed organic material occurs from the base to 125 cm of depth, while between 125 and 40 cm, sediments are dark brown with a mixture of decomposed organic matter and roots. The uppermost 40 cm are composed of dark brown sediments with abundant plant debris, mainly modern roots.

Three radiocarbon dates from the 450 cm-long core yield chronological control. The results of the AMS radiocarbon dating are presented in Table I, showing that the deposition of the studied core occurred entirely in the late middle Holocene. The lowermost level (430 cm) has the age 5390 cal yr BP, while the sample at 360 cm depth was dated at 3756 cal yr BP. The uppermost level (80 cm depth) revealed an age of 858 cal yr BP. Figure 2 shows the detailed grain size variation and the location of samples extracted for palynological analyses and radicarbon dating.

FOSSIL POLLEN RECORD

Among the 46 samples, only three (samples 1, 2 and 43) were considered barren in palynomorphs, and thus discarded for analysis. A total of 84 distinct palynomorphs was identified from the other samples, including taxa of angiosperms (38), gimnosperms (3), spores of pteridophytes (8),

TABLE I
Radiocarbonic and calibrated ages of selected samples from the PCSC-3 core.

Sample number*	Depth (cm)	Age (^{14}C yr BP)	Calibrated age (cal yr BP) probability avarage
UGAMS#26651 (38)	80	1010 ± 26	858
UGAMS#26650 (10)	360	3520 ± 25	3756
UGAMS#26539r (3)	430	4650 ± 25	5390

*Serial number of CAIS Laboratory of University of Georgia and our number control (in parenthesis).

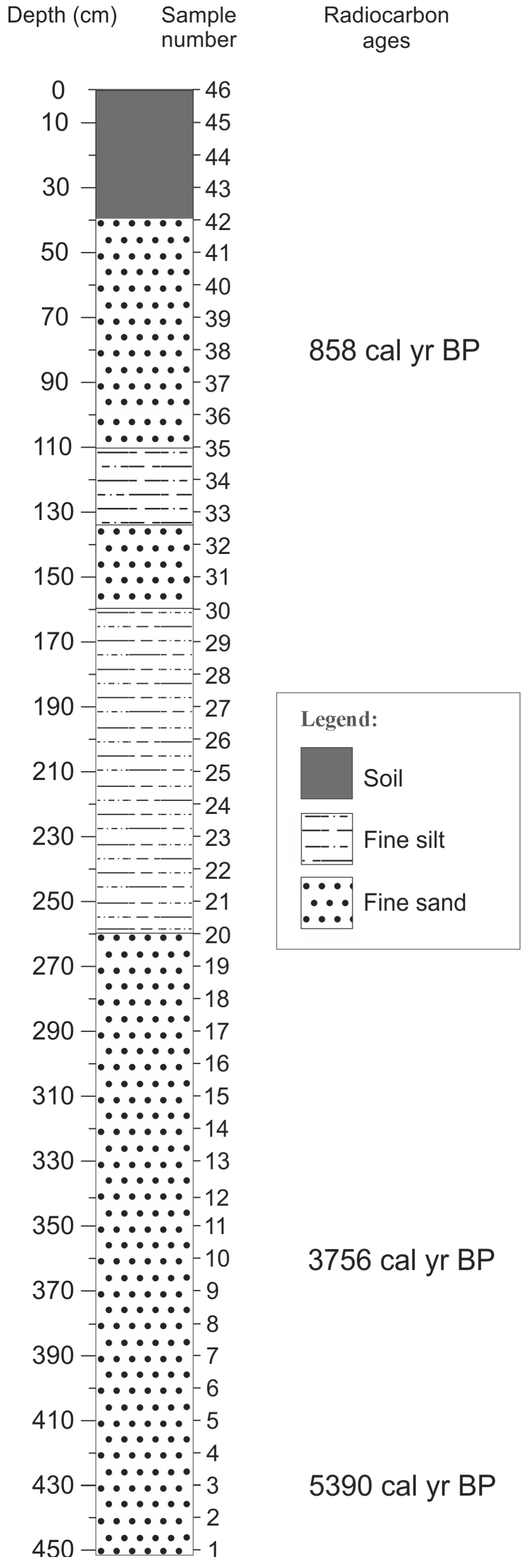

Figure 2 - Schematic sedimentar column of the PCSC-3 core showing the grain size variation, location of samples extracted for palynological analyses.

bryophytes (2) and fungi (8), algae (3), acritarchs (3), dinoflagellate cysts (2), microforaminiferal linings (1), as well as 16 unknown types of spores and pollen grains (Table II).

Along the core, the palynological diagrams show the distribution of palynomorphs, grouped according to their ecological affinities (habit or habitat). Three palynological phases are defined (Figure 3) from changes in the palynomorph assemblages: Phase I, Phase II and Phase III. These are described in sequence in ascending stratigraphical order. The main criteria for the establishment of the phases are the relationship between terrestrial, aquatic and marine elements (Figure 4). Three taxa are referred to as open nomenclature among the acritarchs as described and illustrated herein (Figure 4a-e) due to their importance for paleoenvironmental interpretations and comparisons with other palynological assemblages.

Phase I (5390 cal yr BP- 3135 yr BP)

This phase is the basal portion of the core, including samples 3 to 16 (430 to 295 cm of depth). Aquatic macrophytes are present (0.6%) with only one taxa (*Myriophyllum aquaticum*). The pollen record of herbs represents 0.4 to 16.5% of the total palynomorphs, highlighting *Amaranthus*/Chenopodiaceae, Poaceae, Oxalidaceae *Asteraceae* subf. Cichorioideae, *Asteraceae* subf. Asteroideae. Trees and shrubs have a varied occurrence (0.2-29.7%), especially *Ilex*, Arecaceae, *Alchornea* and Myrtaceae, followed by *Sebastiania*, *Celtis*, Proteaceae, *Trema micrantha*, *Mimosa* serie Lepidotae, including species with only one occurrence: *Allophylus*, *Dodonaea viscosa*, *Faramea*, *Lithraea* and *Matayba.* Regional (1.3%) and extraregional flora (0.4%) are present at this phase, with occurrence of *Araucaria angustifolia* (Bertol.) Kuntze, *Ephedra tweediana* C.A. Mey., *Alnus* Mill. and *Nothofagus* Blume. Spores of mosses have low frequency (<1.3%); spores of fern are more frequent (0.5-21.1%), comprising Polypodiaceae, *Blechnum, Cyathea* and *Dicksonia*. A high percentage of algae is observed (between 8.3-95.5%), especially dominated by *Botryococcus*. Fungi spores are also abundant in this phase (2.1-51.9%). Marine palynomorphs are represented by microforaminiferal linings, dinoflagellate cysts (*Operculodinium* sp. and *Spiniferites* sp.) and acritarchs (*Micrhystridium* sp., *Acritarch* sp. 1 and *Acritarch* sp. 2) which are well recorded, especially in samples 8 and 12 (380 and 340 cm of depth), reaching up to 18%.

Phase II (3032 yr BP- 858 cal yr BP)

This phase comprises 21 samples (295 to 85 cm of depth). Percentages of pollen from aquatic plants are also low, with the occurrence of only one species (*Myriophyllum*). This phase is characterized by decrease of herb pollen (0.8-11.5%) and by a relative increase of pollen sum of forest taxa (0.5-46.1%), when compared to the Phase I. Herbs pollen are represented mainly by Poaceae, *Asteraceae* subf. Asteroideae*, Asteraceae* subf. Cichorioideae, *Amaranthus*/Chenopodiaceae, as well as other less frequent taxa, such as Apiaceae, Cyperaceae, *Gomphrena*, Oxalidaceae and others with only one occurrence: *Cuphea*, Rubiaceae and *Utricularia*. Tree and shrub pollen are mainly recorded by *Ilex*, Myrtaceae, Arecaceae, *Sebastiania*, *Alchornea* and other less representative taxa, such as *Celtis*, *Lithraea*, *Mimosa* serie Lepidoteae, *Myrsine*, *T. micrantha* and others with first appearance in the core: Ericaceae, Mimosoideae, *Podocarpus* and *Sapium*. Regional (*A. angustifolia* and *E. tweediana*) and extraregional (*Alnus*) flora taxa are also present, reaching up to 0.9 and 0.2%, respectively. Epiphyte pollen are recorded, despite the low occurrence (<4.2%). Although the record of spore mosses increases in the section (1.5%), they have a irrelevant account. Spores of pteridophytes reach up to 1.3-14%. Polypodiaceae, *Blechnum*, *Cyathea* and *Dicksonia* were also recorded and other ones occurred for the first time in the core (*Huperzia* and Pteridaceae). The high percentage of algae (12.7-94.4%) and fungi (0.7-46.5%) persists in this phase. Marine elements decrease (<3.3%), represented by all taxa recorded in the Phase I.

Phase III (858 cal yr BP until the present)

This phase was recognized from eight samples between 85 cm of depth to the top of the core. The aquatic macrophytes have only one taxa in the register (*Polygonum*). This phase is marked by the increase of herb pollen (5.9-22.7%), represented by *Asteraceae* subf. Asteroideae, *Asteraceae* subf. Cichorioideae, Poaceae other less frequent taxa, such as Apiaceae, Cyperaceae, *Amaranthus*/Chenopodiaceae, *Gomphrena* and Malvaceae. Tree and shrub pollen are also recorded in high percentages (reaching 44.8% in the sample from the top of the core), mainly represented by *Ilex*, Ericaceae, Myrtaceae, Arecaceae and *Myrsine*. Other forest taxa, such as *Drimys brasiliensis*, *Alchornea*, Mimosoideae, *Podocarpus*, *Sebastiania,* Proteaceae and *Sapium* also occur in lower proportions. Epiphytic taxa reach 26.9%, with the occurrence of Cucurbitaceae. Moss spores increase (<9.1%), with the presence of *Sphagnum* and *Phaeoceros*, as well as fern spores (1.2-26.9%), mainly represented by Polypodiaceae and *Blechnum*; *Dicksonia*, *Osmunda* and *Cyathea*. Algae taxa show a marked decrease at this phase (<15.8%), while fungi spores present high percentage (13.5-71%); marine palynomorphs were not detected.

TABLE II
Palynomorphs identified in the PCSC-3 core according to their habitat and habit.

	Habitat our habit of groups	**Taxa**
	Macrophytes aquatic	*Myriophyllum aquaticum* (Vell.) Verd., *Polygonum* L.
Terrestrial palynomorphs	Herbs	*Amaranthus*/Chenopodiaceae, Apiaceae, Asteraceae subf. Asteroideae, Asteraceae subf. Cichorioideae, *Cuphea* P. Browne, Cyperaceae, *Gomphrena* L., Lamiaceae, Malvaceae, Oxalidaceae, Poaceae, Rubiaceae, *Utricularia* L.
	Trees and shrubs	*Alchornea* Sw., *Allophylus* L., Arecaceae, *Celtis* L., *Dodonaea viscosa* Jacq., *Drimys brasiliensis* Miers., Ericaceae, *Faramea* Aubl., *Ilex* L., *Lithraea* Miers ex Hook. & Arn., *Matayba* Aubl., Mimosaideae, *Mimosa* serie Lepidotae Benth., *Myrsine* L., Myrtaceae, *Podocarpus* L´ Hér. ex Pers., Proteaceae, *Sapium* Jacq., *Sebastiania* Spreng., *Trema micrantha* (L.) Blume.
	Epiphytes	Cucurbitaceae, *Tripodanthus acutifolius* (Ruiz & Pav.) Tiegh.
	Bryophytes and Pteridophytes	*Phaeoceros* Prosk., *Sphagnum* L., Aspleniaceae/Dryopteridaceae, *Blechnum* L., *Cyathea* J. Sm., *Dicksonia* L' Hér, *Huperzia* Bernh., *Osmunda* L., Polypodiaceae, Pteridaceae.

TABLE II (continuation)

	Habitat our habit of groups	Taxa
Freshwater palynomorphs	Algae	*Botryococcus* Kütz., *Pseudoschizaea rubina* Rossignol ex Christopher, *Spirogyra* Link.
Marine palynomorphs	Acritarchs, dinoflagellate cysts and microforaminiferal linings	*Operculodinium* Wall, 1967, *Spiniferites* Mantell, 1850, *Micrhystridium* (Deflandre) emend. Serjeant & Stancliffe 1994, *Acritarch* sp. 1, *Acritarch* sp. 2, Microforaminiferal linings.

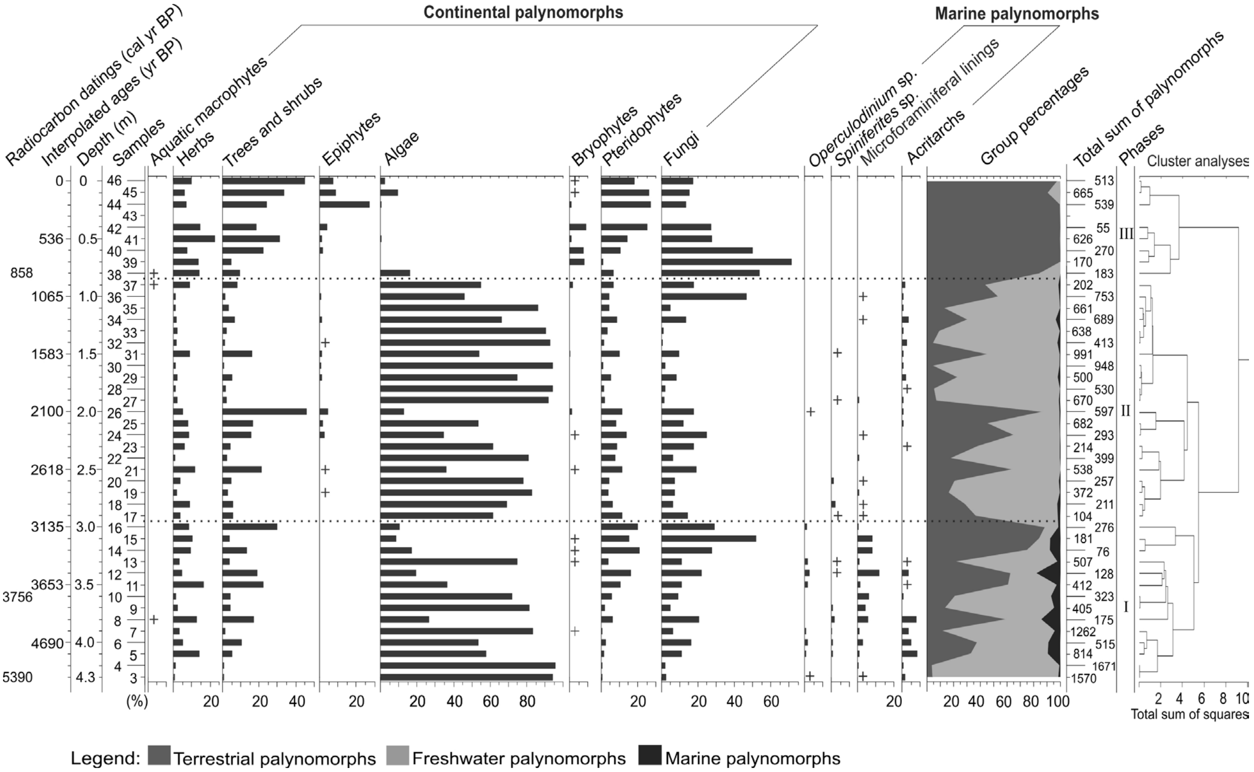

Figure 3 - Percentage diagram of the palynomorphs grouped according to their ecological affinities (habit or habitat) from the PCSC-3 core, as well as the identified phases and cluster analyses. The symbol (+) represents an occurrence of palynomorphs.

SYSTEMATIC PALYNOLOGY

Group ACRITARCHA Evitt, 1963

Genera ***Micrhystridium*** (Deflandre) emend. Serjeant & Stancliffe 1994

Micrhystridium sp.

(Figure 4a and 4b)

Description (20 specimens measured): Hyaline and spheroidal palynomorphs; overall diameter: 10-14 μm, exine thickness: 1 μm, spines: 1 μm of height. Some specimens show small openings in the form of a straight breach.

Comparisons: Cancelli et al. (2012) identified specimes assigned to the genera *Michrystridium*

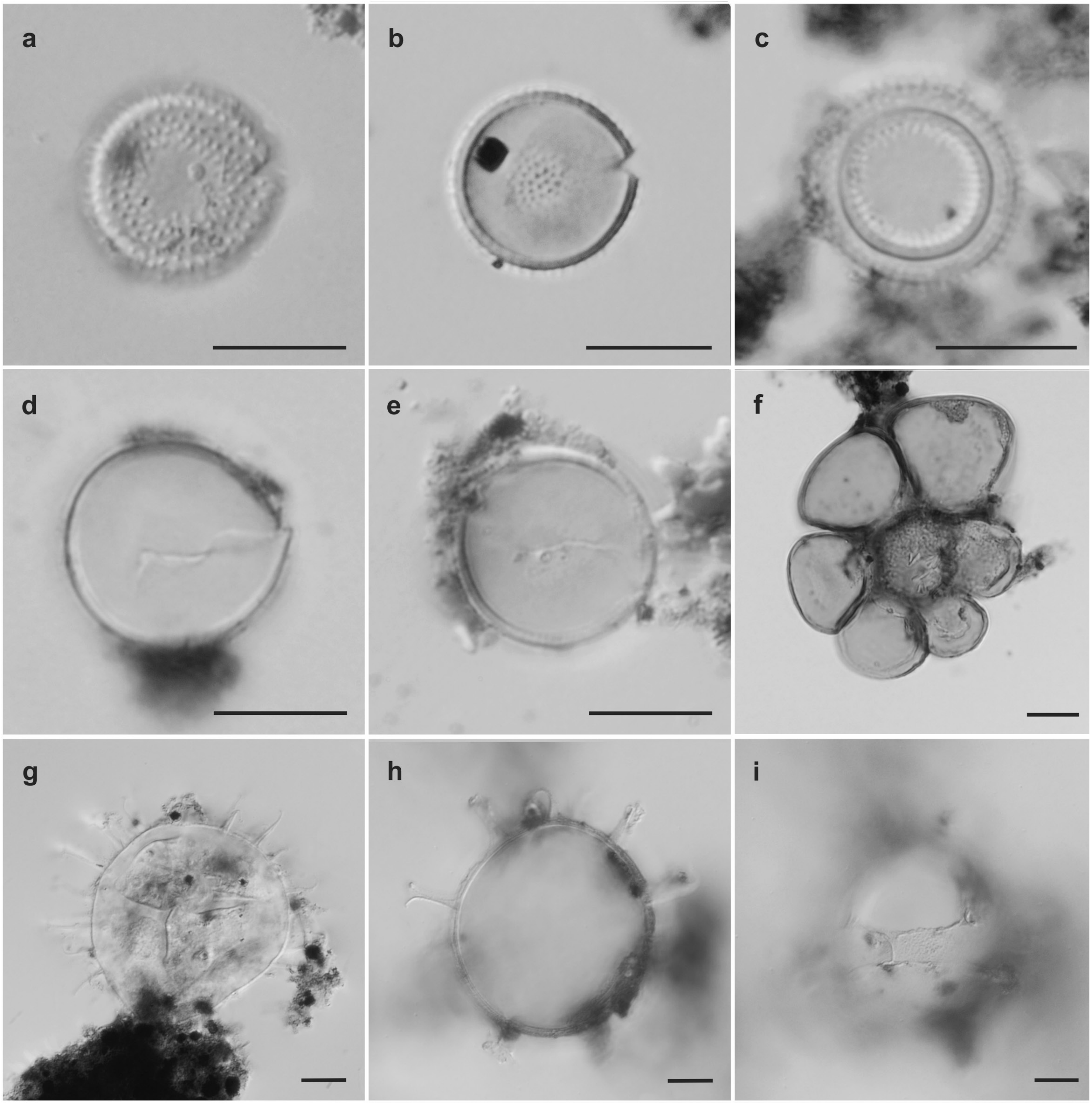

Figure 4 - Photomicrographs of marine palynomorphs retrieved from the PCSC-3 core. **a-b**: *Micrhystridium* sp. (Slide MPP-9981, England Finder coordinate N41-1); (**a**: high focus, **b**: intermediate focus); **c**: *Acritarch* sp. 1 (MPP-9937, T51-2); **d-e**: *Acritarch* sp. 2 (MPP-9981, U39-3 and D44-1); **f**: Microforaminiferal linings (MPP-9976, U43); **g**: *Operculodinium* sp. (MPP-9972, F65); **h-i**: *Spiniferites* sp. (MPP-9982, P38-4); (**h**: intermediate focus and **i**: high focus). Scale = 10 µm.

from Holocene sediments of the Southern coast of Santa Catarina, described with the same shape and ornamentation; however, those taxa show slightly larger size (ca. 18 µm of diameter). In Rio Grande do Sul, Neves and Bauermann (2003) described certain specimens of *Michrystridium* as having globular cysts, hyaline and with tiny spines, but the specimens also present differences in the range of overal diameter (18 to 22 µm). Several studies from the Coastal Plain of Rio Grande do Sul record the genera *Micrhystridium* from Holocene deposits. However, the available descriptions are illustrated in some cases but are insufficient for a deeper comparison (e.g., Cordeiro and Lorscheitter 1994, Medeanic et al. 2001, 2007, 2009, 2010, Medeanic 2006a, b, Neves and Bauermann 2001, Weschenfelder et al. 2008).

The genus *Michrystridium* has been also found in Holocene sediments in Uruguay (Mourelle et al. 2015) and in Argentina (Borel and Gómez 2006, Borel 2007). Borel and Gómez (2006) described a taxon with the same characteristics as found in our material, named as *Michrystridium* sp., with 0.5-1 µm of exine thickness, spines of 1-2 µm of height and 9-19 µm of overal diameter, as well as openings in tear forms in some species.

Acritarch sp. 1
(Figure 4c)

Description (six specimens measured): Hyaline, thick walled and spheroidal palynomorphs; overal diameter: 12-15 µm, exine thickness: 1.5-2 µm, spine: 1 µm of height.

Comparisons: Medeanic et al. (2010) identified similar specimens to this species from a Holocene deposit in Rio Grande do Sul, named as *Michrystridium*. However, a more precise analysis is limited due to the absence of description and the poor quality of the photomicrograph.

Acritarch sp. 2
(Figure 4d and 4e*)*

Description (20 specimens measured): Hyaline, psilate ornamentation and spheroidal palynomorphs; overall diameter: 10-14 µm, exine thickness: 1 µm, spine: 1 µm of height. Some specimens show small openings in the form of straight tear.

Comparisons: Specimens similar to *Acritarch* sp. 2 were recorded by Borel and Gómez (2006) and Borel (2007) from Holocene sediments in Argentina. These similar specimens were identified as *Acritarch* sp. F, described as spheroidal, thick-walled palynomorphs, psilate, with some species showing tear-shaped openings. According to Borel and Gómez (2006), in their life cycle, some species (*Pyramimonas*) of freshwater algae or tidal environments form small benthic spores with morphology similar to these acritarchs.

DISCUSSION

The results obtained from the palynological analysis of the core indicate paleoenvironmental changes during the late Middle Holocene to the Recent, represented by three phases. Phase I (5390 cal yr BP – 3135 yr BP) is marked by the presence of marine palynomorphs, suggesting the proximity to marine water. High percentages of freshwater algae reveal an input of freshwater in the environment.

In Phase I, the algae of genera *Botryococcus* dominate the palynological association (Figure 3). Percentage of spores of fungi vary throughout this phase. Pteridophytes spores show a relative increase towards the top of the phase. Pollen grains (herbs, shrubs and trees) have low percentage. Aquatic macrophytes have isolated occurrences. In this phase, the marine palynomorphs reach the highest percentage in relation to the subsequent phases.

High percentage of algae of genera *Botryococcus* indicate an input of freshwater in the depositional site. The occurrence of spores of pteridophytes reinforces the interpretation of the presence of fresh water, because these elements depend on water for their reproductive cycle. The low abundance of pollen grains suggests a long distance between the source area and depositional site.

The occurrence of the acritarchs (*Michrystridium* sp., *Acritarch* sp. 1 and *Acritarch* sp. 2), dinoflagellate cysts (*Operculodinium* sp. and *Spniferites* sp.), as well as microforaminiferal linings, indicates the influence of marine water. The *Acritarch* sp. 2, similar to specimens of the

Sphaeromorphitae subgroup, and the specimes assigned to the genera *Michrystridium* are characteristic of shallow coastal water associations (Montenari and Leppig 2003, Félix and Souza 2012). The genera of dinoflagellate cysts *Spiniferites* and *Operculodinium* correspond to gonyaulacoids forms, which have a cosmopolitan character, being recorded in a wide range of environments, from internal neritic to open ocean, revealing tolerance to a large range of salinity, luminosity, nutrients and temperature (de Vernal et al. 2001, Marret and Zonneveld 2003). Microforaminiferal linings are abundant in estuarine marshes of variable salinity (Batten 1996).

The high percentage of *Botryococcus* added whit the presence of marine elements indicates that the sedimentation environment was lagoonal. The occurrence of spores of fungi throughout this phase can be explained by the erosion of the river banks that transported organic matter to the lagoonal body, in agreement with Muller (1959) taking into account Recent sediments from Orinoco river. The frequent herbs taxa, mainly represented by *Amaranthus*/Chenopodiaceae and Poaceae, can be related to dry sandy soils (including halophytes taxa), as also interpreted by Lorscheitter (2003) from Holocene samples of Serra Velha and Guaíba. The beginning of sedimentation of Phase I coincides with the last sea-level maximum documented for the Brazilian coast between 5000 and 5800 cal yr BP (Angulo et al. 2006). Two samples in the middle of this phase (380 and 340 cm of depth), close to 3756 cal yr BP, presented higher percentage of marine palynomorphs, these data suggest that the depositional site had marine influence. Others works in Santa Catarina State demonstrated which between 3000 yr BP and 3800 yr BP the sea level was above the present sea level (Suguio et al. 1985, Angulo et al. 1999).

Marine influence was also observed in Volta Velha, northern Santa Catarina, due to the presence of microforaminiferal linings between 6720 to 4330 yr BP (Behling and Negrelli 2001). Amaral et al. (2012) also registered marine influence in the Jaguaruna region, South-central portion of the Coastal Plain of Santa Catarina, between approximately 5000 to 2580 yr BP, based on diatoms and isotopes. Several palynological studies (e.g., Cordeiro and Lorscheitter 1994, Lorscheitter and Dillenburg 1998, Medeanic et al. 2001, Meyer et al. 2005a) recorded the transgressive event (at approximately 5000 yr BP) in the Coastal Plain of Rio Grande do Sul by means of palynological indicators, as dinoflagellate cysts (*Spiniferites* and *Operculodinium*), microforaminiferal linings and acritarchs (*Michrystridium*).

In studies of Holocene sediments in Argentina (Bahía Blanca and Arroyo La Ballanera) and Uruguay (Río de La Plata northeastern coast), marine input was identified from associations of acritarchs with the dinoflagellate cysts *Spiniferites* and *Operculodinium* (Borel and Gómez 2006, Borel 2007, Mourelle et al. 2015). Borel and Gómez (2006) and Borel et al. (2007) identified, in addition to *Michrystridium* sp., an acritarch named *Acritarch* sp. F. This form is very similar to *Acritarch* sp. 2 (Figure 4d and 4e), described herein, because it has psilate, spheroidal and hyaline wall, of small size.

In the Phase II, *Botryococcus* continues to dominate the palynological association, with a more homogeneous distribution. Spores of pteridophytes and fungi show a small decline in their percentages. Pollen grains (herbs, shrubs and trees) continue to have low representation in the palynological association; epiphytes make their first appearance at this phase. Marine palynomorphs decrease compared to the previous phase.

The continuous high percentages of algae of genera *Botryococcus* indicate that input of fresh water was not interrupted between Phase I and Phase II. The presence of taxa that are water-dependent for their reproductive cycle, spores of pteridophytes and fungi, suggests the presence of fresh water in the environment. The low abundance of pollen grains indicates that the vegetation was not close to the depositional site. However, the first appearance of epiphytes (little expression) indicates the presence of forest fragments developed in adjacent areas. The record of marine elements indicates marine water influence. However, the decrease of these elements in relation to Phase I suggests a reduction in the saline water supply.

The high percentage of *Botryococcus* added to the presence of marine elements indicates that the sedimentation environment was still a lagoonal body. Nevertheless, the low occurrence of marine palynomorphs, with the dominance of acritarchs in the assemblage (with a few specific occurrences of dinoflagellate cysts and microforaminiferal linings), reveals that the connection to the sea was already closed, limiting the seawater input. The decrease of *Amaranthus*/Chenopodiaceae throughout this phase may reflect the desalination of the soil contiguous to the body of water. Predominance of silt layers indicates a decrease in the energy of the sedimentary environment, corresponding to diminishing marine influence in the lagoonal body. The Phase II is characterized by a transitional paleoenvironment between the Phase I and Phase III.

Phase III corresponds to the last 858 cal yr BP, when algae abruptly decrease and fungi and arboral taxa increase. The drastic decline of algae indicates a depletion in the water column in the depositional site and the absence of marine palynomorphs reveals the end of seawater input.

The high percentage of fungi in the first samples of this phase indicates the beginning of soil development, since the abundance of fungal fragments is indicative of aerobic biodegradation of plant remains (Sebag et al. 2006). Dominance of pollen of herbs and spores of bryophytes (*Sphagnum* and *Phaeoceros*) indicates the beginning of vegetation colonization. Both spores of bryophytes and fungi at the lower portion of this phase reflect wet conditions.

The progressive increase of pteridophytes, epiphytes and arboreal taxa (Arecaceae, Ericaceae, *Ilex*, *Myrsine* and Myrtaceae), added to the appearance of new taxa (*Drimys brasiliensis*), reveals the beginning of the development of the Atlantic Forest in the site. However, low richness of the arboreal taxa can be related to the early stage of evolution of this forest in the site.

The lowering and stabilization of relative sea level led to the desalination of the coastal plain lands. These ancient coastal lagoonal and fluvial plains were gradually colonised by the Atlantic Forest. The forest development after coastal regression was also identified in other palynological studies in the Santa Catarina (Behling and Negrelli 2001, Amaral et al. 2012) and Rio Grande do Sul coastal plains (Cordeiro and Lorscheitter 1994, Neves and Lorscheitter 1992, Meyer et al. 2005a, b, Medeanic 2006a, Macedo et al. 2007, Medeanic et al. 2009).

CONCLUSIONS

The palynological analyses of the 450 cm-long core PCSC-3 in Santa Catarina State (Garopaba) led to the recognition of three phases from 5390 cal yr BP (late Middle Holocene) to close to modern days. These phases are characterized by the presence and the relative frequency of marine (dinoflagellates, acritarchs and microforaminiferal linings), freshwater (*Botryococcus*) versus continental palynomorphs (spore-pollen taxa, fungi).

Records of marine and freshwater elements indicate that during Phase I and the Phase II the environment comprised a lagoonal body. Phase I reveals higher marine influence, while Phase II presents decrease of percentage of marine elements and increase of freshwater algae record, suggesting less marine influence into the lagoonal body. Phase III is marked by the closing of the connection of the lagoon with the sea, with prevalence of subaerial sedimentation, under swamp-like conditions, by means of the vegetation colonization in the locality for the last 856 yr BP. Our conclusions are in agreement with other paleoenvironmental reconstrutions for the sea level oscilations of certain portions of the coastal plain of Brazil, in particular to the Santa Catarina State.

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