

## ANALYSIS OF PARTICULATE ORGANIC MATTER IN HOLOCENE SEDIMENTS OF COASTAL PLAIN FROM PERO BEACH, CABO FRIO, RIO DE JANEIRO, BRAZIL

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### Abstract

The study of palynofacies along a core drilled on the coastal plain of Cabo Frio, State of Rio de Janeiro, was carried out in order to contribute to the knowledge of the paleoenvironmental evolution of the Pero Beach region. The ages obtained from <sup>14</sup>C datings allowed to verify that the studied core records the past 6761 ± 130 yrs cal BP. Thirty samples were prepared by standard methodology for palynofacies. About three hundred particles of the particulate organic material was classified and recorded for each sample. Statistical methods were employed for the associations of particulate organic matter (R-mode cluster analysis) and levels (samples; Q-mode cluster analysis) analyzed along the core. Furthermore, the ratio Phytoclast - Total Organic Carbon (Phy-TOC) was used to verify the

proximity of the source area. The three major groups of particulate organic matter found along the studied core are Phytoclasts, Amorphous Organic Matter (AOM) and Palynomorphs. The samples showed in general, a predominance of phytoclasts (73.2%), followed by AOM (18.6%) and Palynomorphs (8.2%). Supported by statistical analysis, it was possible to deduce that the study area evolved since the middle Holocene from a marine environment to a paleolagoon.

Keywords: Palynofacies. Paleoenvironmental reconstruction. Holocene. Coastal region.

### 1. Introduction

The study of particulate organic matter in sediments at coastal areas has been widely used for the recognition of sedimentary evolutionary history of the coastline in different

regions of Brazil (Zocatelli et al., 2012; Amaral et al., 2012; Hermany et al., 2013; Lorente et al., 2014; Gadens-Marcon et al., 2014a, b). According to Tyson (1995), the study of

organic matter in sediments and rocks provides important information about palaeoenvironments as well as about displacement, maturity, source area of organic matter detachment. Thus, the use of technical qualification and quantification of particulate organic matter (palynofacies) is a good method to determine the magnitude and location of terrigenous deposits in proximal and distal areas. Results of this method provides information leading to the recognition of regressive and transgressive events associated with geological processes related to eustatic sea level (Traverse, 1994; Meyer et al., 2005; Lorente et al., 2014).

Transgressive and regressive events can be observed from palynological markers (e.g., dinoflagellate cysts, pollen and spores) and palynofacies. Sea level fluctuations can be deduced from the sedimentary record of sets of palynomorphs and particulate organic matter of terrigenous and marine origin (Meyer et al., 2005; Traverse, 2008; Amaral et al., 2012).

However, few works in Brazil used the study of palynofacies to reconstruct the Quaternary paleoenvironmental evolution in coastal environments (Medeane and Silva, 2010; Meyer et al., 2010; Lorente et al., 2014). Thus, the main objective of this work is to contribute to the knowledge of the Holocene evolution of North Fluminense coastal plain. It was based on the analysis of the amount of continental and marine sedimentary organic material along a sedimentary core (with 2.50 m) collected in Pero Beach, Cabo Frio, Rio de Janeiro, Brazil.

## 2. Study area

The Pero dune field is located at the city of Cabo Frio, north of the State of Rio de Janeiro. The Pero Beach with approximately 6.0 km long and NE-SW orientation is located between the latitudes 22° 49' S and 22° 52' S and longitudes 41° 58' W and 41° 59' W (Fig. 1).

The region is composed of sandy beaches, marshes, infilled lagoons and oblique dune fields. According to Dourado and Silva (2005) and Fernandez and Rocha (2015), the region of Pero Beach is formed by a sandy spit with a maximum width of 1300 meters and an arc of beach with about 4800 meters long and NE-SW orientation. The area has a range of about 600 meters between the crest of the beach and dune area with underbrush. After this zone there is an exposed area with notorious wind movement which is partially colonized by salt marsh vegetation.

Quaternary sediments were deposited under the influence of waves and winds with enough power to suspend fine-grained sands and fine particles of the region. There are two sectors in dune field: an area where the sediment is exposed with notorious wind movement, and another colonized with vegetation (Dourado and Silva, 2005; Fernandez and Rocha, 2015).

Several authors, such as Martin et al. (1993), Castro et al. (2002, 2014), Castro (2006) and Dias et al. (2010), have suggested that the Pero dune field formation was related to paleoclimatic oscillations associated with sea level change prior to 5100 years BP. According to these authors, these conditions originated two lagoons, one internal and another external, isolated from the Atlantic Ocean by two barrier islands called “internal sandbank” and “external sandbank”. Castro et al. (2006) recorded the presence of a coquina deposit found in Taua reserve, located at about 11 km to NW of Pero Beach, with an age ranging between 5034 cal BP and 5730 cal BP. These authors emphasized that the transgressive maximum occurred around 5100 yrs BP, leading to the formation of a paleolagoon. During this event, there was a connection of the paleolagoon with the sea through a paleochannel located at the northeast end of the Pero Beach.

## 3. Material and methods

This study is based on the analysis of a core collected in the coastal plain of the Pero Beach, of Cabo Frio City, State of Rio de Janeiro (at latitude 22°50'15.93"S and longitude 41°59'11.41"W), at about 2.41 meters above the current mean sea level. The core was recovered at 570 meters from the current coastline with the use of a vibracore.

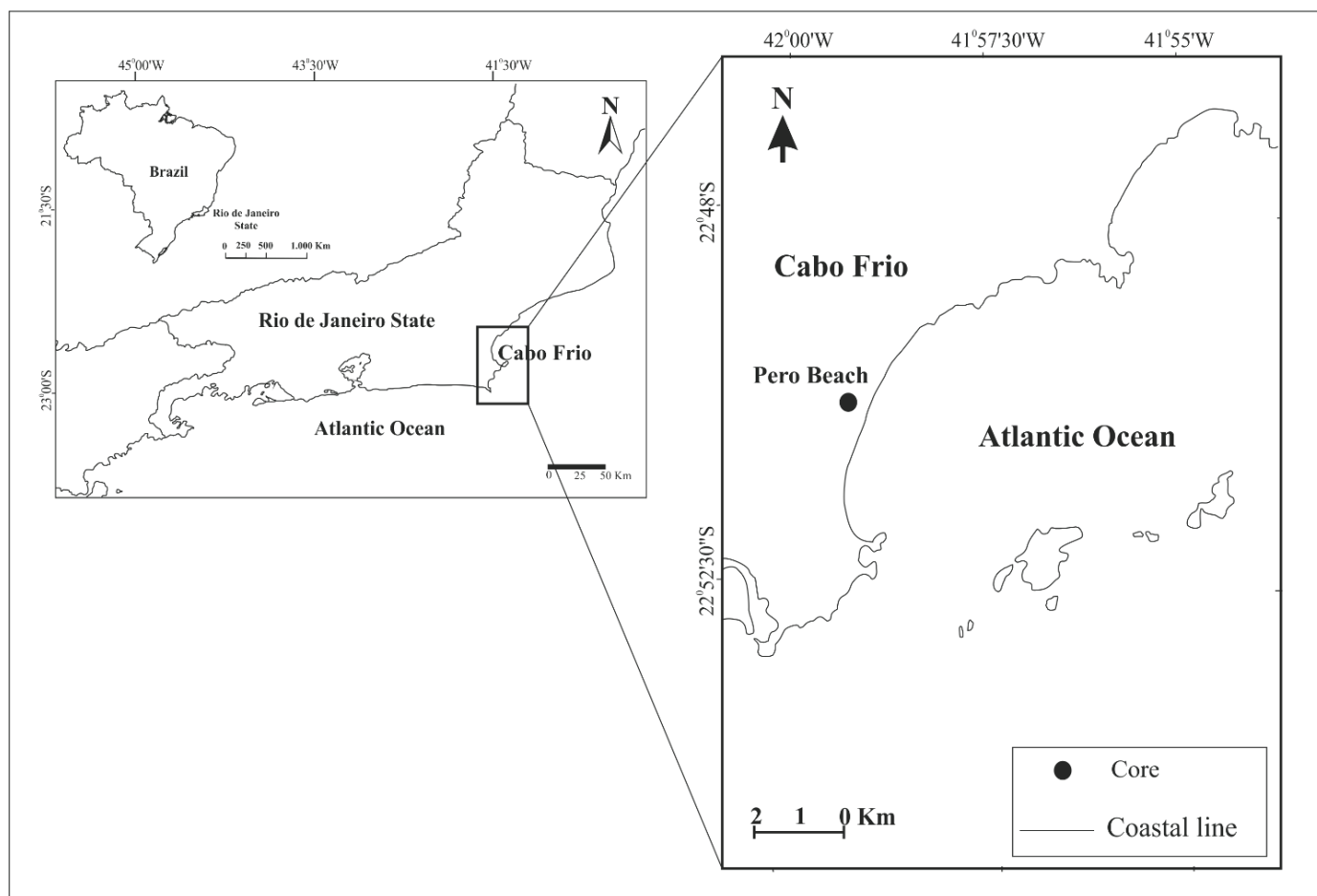
The lithological and radiocarbon datings used in this work were obtained in earlier studies performed by Dias et al. (2009, 2010) and Castro et al. (2014).

### 3.1 Granulometric analysis

The granulometric analysis were performed in the Department of Geology (Sedimentology Laboratory), of the Universidade Federal do Rio de Janeiro (UFRJ), where the samples were washed, oven dried and sieved following the methodology described by Folk (1974).

### 3.2 Total Organic Carbon analysis

Samples were decarbonised and analyzed on a LECO WR-12 equipment, consisting of an induction furnace coupled to an infrared reader to determine the TOC values.



**Fig. 1.** Core localization at Pero Beach, Cabo Frio City – Rio de Janeiro state.

The TOC values are given in percentage by weight of organic carbon, which is based on a comparison with a reference standard.

### 3.3 Preparation and analysis of palynofacies

Preparation of material for analysis followed palynofacies non oxidative process protocol described by Tyson (1995) and Mendonça-Filho et al. (2002). This methodology consists of the acid etching of the material using hydrochloric and hydrofluoric acids for removal of carbonate and mineral fractions. Subsequently zinc chloride ( $ZnCl_2$ ) was used in order to perform the separation and concentration of the organic matter.

The palynofacies analysis included qualitative and quantitative analysis of organic matter of three main groups:

Amorphous Organic Matter (AOM), Phytoclasts and Palynomorphs.

The classification of particulate organic matter was held with microscopy using transmitted white light and fluorescent radiation and with magnifications of 200x and 400x. The raw data obtained from the classification and counting of particles were transformed into percentage values for the groups and subgroups of organic matter.

### 3.4 Radiocarbon datings

The chronological analysis was obtained by radiocarbon dates ( $^{14}C$ ) of samples taken from two stratigraphic levels: *Anomalocardia brasiliensis* (Gaertn, 1807) (Combretaceae) shells and a carbonized trunk of *Anomalocardia brasiliensis* (Gmelin, 1791) (Bivalvia, Veneridae), found in the core at 80 cm and 250 cm levels, respectively. The dates were held in the Head of Radiation Monitoring Hygienic Laboratory, located in

Kiev, Ukraine. The ages were calibrated by Calib 4.1.2 software using the method SHCal04 for not marine samples and Marine04 option for marine samples.

### 3.5 Statistical analysis

The results were subjected to Q-mode cluster analysis, to observe similarities between samples, and R-mode to check similarity between organic components. For this purpose the Statistic Basic program, version 6.0 (Valentin, 2000) was used.

## 4. Results

### 4.1 Core description

The studied core is a sandy sequence composed mainly by fine sand varying from well selected to moderately selected sedimentary particles. In two stratigraphic levels have been identified biogenic materials: a carbonized trunk of the species *L. racemosa*, in the basal part of the core (250-240 cm); and a level of mollusk shells, belonging mostly to the species *A. brasiliiana* (at a depth of 80 cm). Paleosol levels were also found in the core top.

### 4.2 Radiocarbon dating

The results of radiocarbon dating levels were included in Tab. 1. An age of  $6761 \pm 130$  yrs cal BP was estimated for the layer 250 cm and of  $3187 \pm 186$  yrs cal BP for the layer 80 cm. The model age based on the radiocarbon dates is presented in Fig. 2. Results of radiocarbon allows to estimate an accumulation rate of about 53.3 cm/1000 yrs for the core base (250-80 cm) and of about 39.8 cm/1000 yrs for the first 80 cm of the studied core. These results indicate a reduction in the sediments accumulation rate in the core top.

### 4.3 Total Organic Carbon

The sediments of the analyzed core have very low TOC content ranging from 0.08 to 0.03% (Tab. 2). However, it was possible to establish a ratio between the TOC content and opaque phytoclasts (Phy-TOC) ranging from 0.1 to 0.04%. The description of the TOC and Phy-TOC ratio is detailed in the item 4.5.

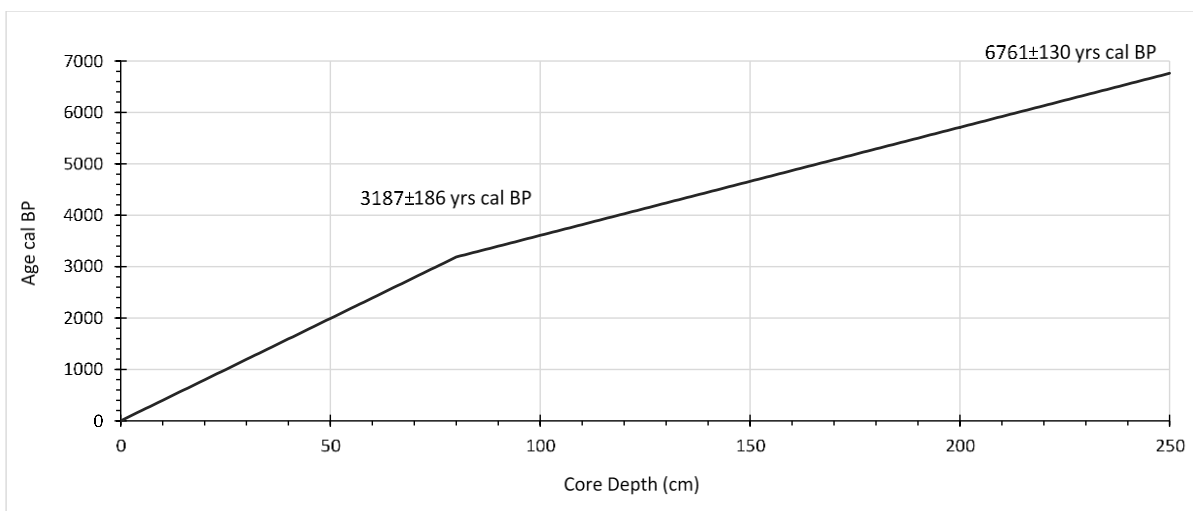
### 4.4 Palynofacies Analysis

The results of palynomorphous analysis are included in Tab. 2 (examples in Plate 1). The studied core clearly shows a predominance of components of the Phytoclast Group. This group achieved an overall average of 73.2% of Particulate Organic Matter (POM), followed by the groups Amorphous Organic Matter (18.6%) and Palynomorphs (8.2%). The Phytoclast Group is dominated by particles of non-opaque components (non-biostructured and structured; 20.3% of POM). The second most abundant component is the opaque equidimensional phytoclast group, which reaches 19.3% of POM. This last component (opaque equidimensional phytoclasts) is often fragmented, reflecting an effective transport. The other components like membranes and cuticles are subordinated to the two most abundant components. In the Amorphous Organic Matter Group (AOM) the following components were recorded: AOM, resin and pseudomorphs. The higher frequency is made by AOM mainly characterized by a light brown to dark colored material with aggregate palynomorphs.

In the Palynomorph Group, the terrestrial origin (spores, fungi, pollen and freshwater algae) are conspicuously more abundant than those of marine origin (microforaminiferal linings and dinoflagellate cysts). The curve for this group remains relatively uniform along the core. However, in the top core section a peak of palynomorphs of continental origin is recorded (e.g., spores and pollen). The dendrogram obtained by cluster analysis revealed five R-mode palynofacies (Fig. 3). The classification agrees with the highest degree of similarity of the components of organic matter in relation to the "origin criteria". Six depositional sections were obtained by Q-mode cluster analysis (Fig. 4) as the similarity between samples.

### 4.5 Characterization of the sections defined by cluster analysis Q-mode (Fig. 4)

The section 1 (240-230 cm, in turn of  $6761 \pm 130$  cal years BP; Tab. 1) is characterized by the palynofacies 4 and 5 (Fig. 3), where the marine component (dinoflagellates and microforaminiferal linings) was found. In this section, the mean value of marine components is 2.8 % of the total fraction of palynomorphs and of AOM with fluorescence is 27.1 %. The phytoclasts has the mean value of 70.1 % of the total POM present in this section. In this section, the average value of TOC and Phy-TOC ratio is 0.06 % and 0.04 respectively.



**Fig. 2.** Age model based on radiocarbon dates.

**Tab. 1.** Radiocarbon data obtained in the studied core.

Depth (cm)	Analysed Material	Age Years BP	Calibrated Age BP
250	Charcoal ( <i>Laguncularia racemosa</i> )	5.910 ± 55	6.890 – 6.631
80	Shells ( <i>Anomalocardia brasiliiana</i> )	3.350 ± 70	3.373 – 3.000

Section 2 (230-170 cm; ≈6300-5000 yrs cal BP) is marked by the presence of Palynofacies 5, where the greater presence of AOM (35.2 %) was found. Associated with the increased AOM component the smaller amount of phytoclasts (57.6%) is found. In this section, the values of TOC and Phy-TOC is 0.03 % and 0.02, respectively.

Section 3 (170-150 cm; ≈5000-4650 yrs cal BP) is characterized by Palynofacies 4. In this section, there is a significant fall of the amorphous organic matter (7.1 %), together with the considerable increase in phytoclasts (87.2%) from the previous section. The presence of marine elements, represented by the occurrence of dinoflagellate cysts was observed. The average TOC content is 0.08 %. These values indicate that the highest TOC value of this section, is related to the increasing of the phytoclasts component. The value of Phy-TOC ratio (0.1) is the highest of this section.

In the Section 4 (150-125 cm; ≈4650-4130 yrs cal BP), the remarkable presence of Palynofacies 3 was observed. In this section the Palynofacies 2 is an accessory assemblage (Fig. 3). In this interval, the smaller amount of AOM was

recorded (3% of total organic matter). Else the AOM present in this interval showed no fluorescence. The phytoclasts reached the highest values of the studied core (92.2 % of POM; Fig. 4). Opaque equidimensional phytoclasts were the most representative assemblage, reaching 39.9 % of POM. The continental palynomorph component showed an average of 4.8 % of POM. The occasional presence of dinoflagellate cysts are observed in this section. The TOC content and Phy-TOC ratio mean values is 0.03 % and 0.02, respectively.

Section 5 (125-90 cm; ≈4130-4000 yrs cal BP) records in general, a small decrease in the phytoclasts number in relation to the previous one (80.9 %). Among the phytoclasts, the dominance of opaque equidimensional particles is observed (Fig. 4).

The curve of AOM without fluorescence present a rising trend compared to the previous section. The average abundance of palynomorphs, with continental origin, is 7.5 % (spores of pollen grains). In this section, the mean TOC content and Phy-TOC ratio values is 0.03% and 0.02, respectively (Fig. 4).



**Tab. 2:** Results of the analysis of Particulate Organic Matter along the core collected in Pero Beach, Cabo Frio, Rio de Janeiro, Brazil. Radiocarbon calibrated ages and TOC content values are also presented.

Depth.	<sup>14</sup> C (Cal Years BP)	Amorphous group		Phytoclast Group										Palynomorphs Group						Total	TOC (%)	
				Opaque Phytoclasts				Non-Opaque Phytoclasts						Terrestrial				Marine				
		AOM	Resin	Oblong	Equidimensional	Corroded	Pseudoamorph	Striped	Striated	Banded	Perforated	No Biostructured	Cuticles	Membrane	Spore	Fungal spore	Polen	Botryococcus	Dinoflagellate			Microforaminiferal linings
75	3373	2	3	30	31	44	6	18	1	0	4	17	15	16	40	42	25	6	0	0	295	0.00
85		15	1	9	15	53	3	10	1	8	8	21	24	19	31	40	20	22	0	0	284	0.00
90	6361	21	8	12	134	0	0	2	5	5	5	25	20	14	27	0	3	0	0	0	252	0.00
95		33	0	30	70	46	10	4	7	8	3	6	12	43	21	7	0	0	0	0	267	0.00
100		38	4	18	156	0	0	6	3	6	5	20	8	16	14	0	6	0	0	0	258	0.00
105		9	3	22	91	0	0	7	8	13	4	19	6	14	5	1	0	0	0	0	190	0.02
110		22	0	40	91	58	6	8	9	1	9	6	12	26	11	0	1	0	0	0	278	0.05
115		5	1	4	6	0	0	1	0	1	0	6	0	1	2	0	1	0	0	0	22	0.04
125		16	1	26	54	50	8	6	8	19	12	27	5	20	13	2	4	0	0	0	254	0.02
130		10	3	44	155	0	0	8	8	10	8	14	17	18	0	0	0	0	0	0	282	0.05
135		4	0	41	182	0	0	3	11	13	1	8	10	15	11	0	1	0	0	0	296	0.03
140		0	0	41	80	65	8	15	10	13	17	4	7	16	14	0	10	0	1	0	301	0.05
150		7	0	38	90	0	0	6	28	13	3	18	49	35	13	0	0	0	1	0	294	0.07
155		23	0	19	29	14	2	8	20	21	3	17	29	83	21	10	1	0	2	0	279	0.07
160		8	0	4	25	1	0	6	11	18	5	76	54	85	2	0	5	0	0	0	292	0.10
165		47	0	6	47	0	0	0	16	18	2	36	67	48	9	0	3	0	0	1	253	0.07
170		21	1	4	12	13	14	24	13	44	4	20	54	59	16	1	0	0	0	0	278	0.00
175		12	0	3	30	7	0	0	2	6	2	16	26	22	5	1	1	0	0	0	121	0.05
180		129	2	15	45	1	1	0	5	6	0	15	9	50	10	12	0	0	0	0	169	0.00
185		150	0	9	16	30	14	10	0	8	0	11	14	18		14	6	0	0	0	150	0.03
195		51	1	14	29	1		9	17	8	5	13	11	31	9	6	2	0	0	0	155	0.04
200		79	2	6	18	22	12	18	7	14	1	30	44	26	11	1	8	0	0	1	219	0.05
205		4	0	0	0	0	0	1	1	0	0	0	0	4	1	0	0	0	0	0	7	0.05
210		31	0	4	14	15	2	0	0	1	0	0	5	8	8	1	0	0	0	0	59	0.04
215		109	1	14	42	3	0	21	3	8	8	12	21	40	18	0	0	0	0	0	190	0.05
220		157	5	18	27	0	0	1	6	6	2	9	20	41	7	0	1	0	0	0	138	0.03
225		107	0	10	15	25	6	20	17	9	6	20	20	21	15	0	4	0	0	0	193	0.00
230		74	0	8	11	3	0	24	22	26	8	27	62	33	2	0	0	0	0	0	226	0.03
235		40	0	15	19	3	4	23	27	43	6	23	30	53	14	0	0	0	0	0	260	0.05
240	6361	132	0	2	2	7	0	22	19	12	5	25	41	28	2	2	0	1	3	1	172	0.10

Section 6 (90-75 cm; ≈4000-3000 yrs cal BP) is characterized by the occurrence of Palynofacies 1. It is composed mostly by continental palynomorphs (37.7 % of POM; Fig. 4). The continental palynomorph component, such as spores and pollen grains, reach 25.5% and 7.5% of

POM, respectively. The continental nature is also confirmed by the presence of the algae *Botryococcus braunii* (Kützing, 1849) representing 4.7% of the palynomorphs. The Palynofacies 2 is characterized by the strong presence of corroded elements that may indicate effective transport of

organic material. In this section, it was not possible to obtain results of TOC (and Phy-TOC ratio) due to the too much low percentage of organic matter.

The sediments were reworked in the first 75 cm of the studied core. So the samples of this section were not considered.

## 5. Discussion

### 5.1 Total Organic Carbon

The values of TOC and Phy-TOC ratio are low throughout the studied core when compared to other studies conducted in other coastal regions of Brazil (Zocatelli et al., 2012; Boussafir et al., 2012; Lorente et al., 2014; Gadens-Marcon et al., 2014a). However, Amaral et al. (2012) analyzed three coastal cores, collected in the State of Santa Catarina, also observing low TOC values. In this work, we can associate the low values of TOC, absence of amorphous organic matter (or low frequency) and high occurrence of opaque equidimensional phytoclasts, to the sediments grain size, which indicate a high-energy environment.

### 5.2 Palynofacies Analysis

The strong presence of marine elements (mainly the dinoflagellate's cysts), at about  $6761 \pm 130$  yrs cal BP in the studied core indicates that the Pero Beach region was influenced by marine water at that time. According to some authors (e.g. Suguio et al., 1985; Martin et al., 1997; Angulo and Lessa, 1997) the middle Holocene sea level was 4 meters above the current (Transgressive event). This event possibly contributed to the deposition of marine palynomorphs. According to Castro et al. (2014) and Dias et al. (2010), this record may be associated with beach ridges which should have isolated and formed a paleolagoon in Pero Beach region due to the relative rise of sea level. Further evidence of higher sea level was suggested by Scheel-Ybert (2000). This author found mangrove records on the banks of Itajuru Canal, Cabo Frio, which were established during the highest Holocene sea level. The same situation was observed at about 7000 - 6000 yrs. BP in several zones along the Brazilian coast.

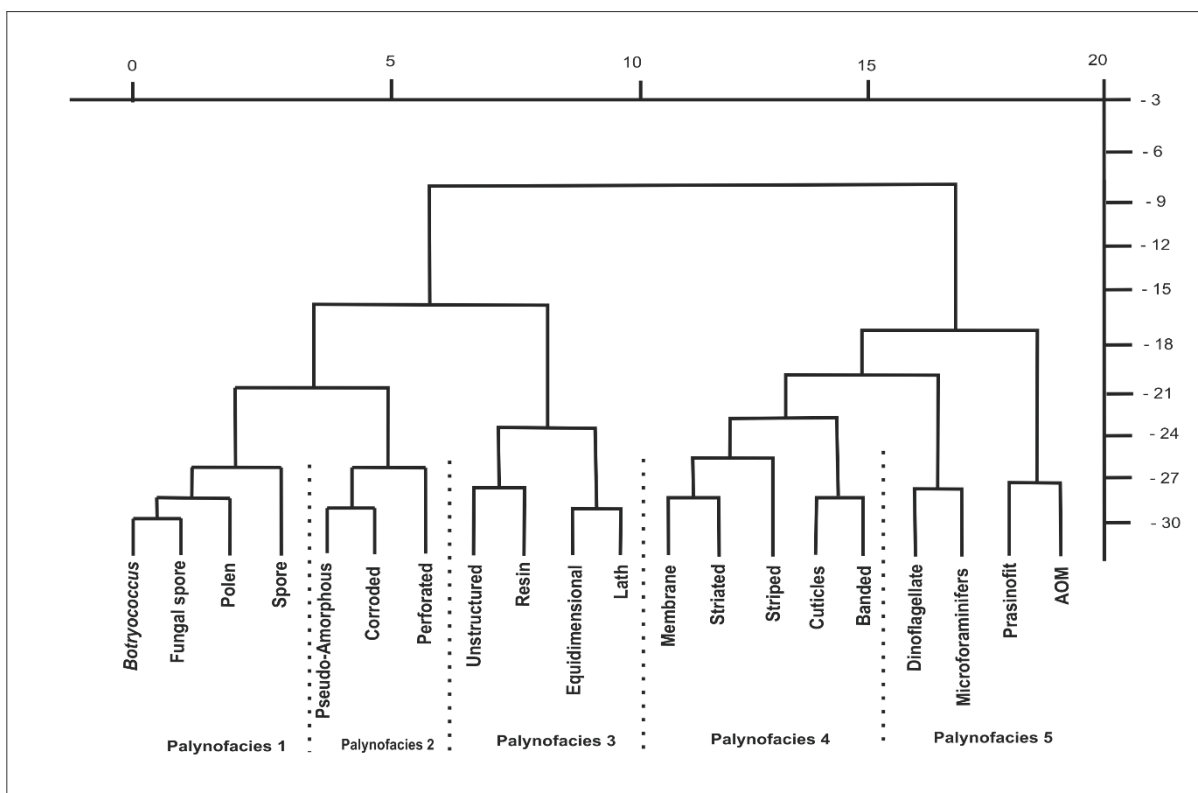
The presence of marine elements associated with the amorphous organic matter in a quantity greater than the mean for the studied core (Fig. 4), suggests a slight

confinement of the study area, which would allow their preservation. However, terrigenous inputs are pronounced in this environment with continental palynomorphs (pollens and spores).

The marine influence was most evident at about 6300-5000 yrs cal BP in the studied site (Section 2), associated with a greater presence of AOM (Palynofacies 5) and a lower frequency of non-opaque phytoclasts that is interpreted as a greater distance and / or lower terrigenous input in the paleolagoon (Tyson, 1995; Menezes et al., 2008; Silva et al., 2010). In the sea level curve proposed by Castro et al. (2014) the sea level was rising steadily.

Similarly to the previous section, the paleoenvironment in the studied site was probably characterized by the presence of a paleolagoon associated with mangrove vegetation, but with less influence of continental elements (Fig. 4). The significant decrease of the amorphous organic matter (AOM) since  $\approx 5000$  yrs cal BP, suggests that its preservation was hampered by strong terrigenous contribution in the lagoon (Palynofacies 4) indicating the start of the lagoon desiccation process (Section 3). In this period, the high values of TOC and Phy-TOC indicated possible proximity to the source area. In addition, the conspicuous presence of non-opaque phytoclasts allows us to suggest that at that time began a greater continental influence. The occurrence of non-opaque phytoclasts was observed by Boussafir et al. (2012) in a pond located in the Northeast of Brazil. According to this author, the presence of this type of phytoclasts could indicate a long exposure to subaerial environment or remobilization of organic matter from the soil or rocks. Lorente et al. (2014) analyzing sediments of a lake in southeastern Brazil highlighted the occurrence of non-opaque phytoclasts and correlated them to a greater continental input driven by fluvial influence.

The continental influence was becoming increasingly evident from 4650 yrs cal BP (sections 4 and 5). This is suggested mainly by the high frequency of non-opaque phytoclasts in relation to the declining of the AOM values, and the strong presence of continental palynomorphs (pollen and spores). The phytoclasts present high frequency at about 4130 yrs cal BP (Section 5), along with a small decrease of the AOM without fluorescence and plenty of continental palynomorphs. According to some authors, the beginning of a drying of the entire lagoon complex in the region occurred in this period, in coincidence with the replacing of the lagoon areas by wetlands (Suguio et al., 1985; Martin et al., 1997; Castro et al., 2014). Castro et al. (2014) noted the beginning of a decline in sea level in the region at that time.



**Fig. 3.** Dendrogram (R-Mode cluster analysis) for the groups and subgroups of organic matter components.

The total silting of the lagoon and the transformation of its surrounding region in wet areas should have occurred at about 3373 yrs cal BP (Section 6). This may be indicated by a strong presence of strictly continental palynomorphs (Palynofacies 1).

The continental influence was also confirmed by the presence of *Botryococcus braunii* algae. It should be noted that the occurrence of corroded elements in Palynofacies 2 indicate effective transport (Fig. 4).

These results suggest that this period may be interpreted as a high energy environment with low AOM preservation and small abundance of opaque phytoclasts. These characteristics may indicate a higher fluvial distance, an exposed area of sediment to oxidative processes or reworking by transport agents.

## 6. Conclusion

This study provides important palynofacies data for paleoenvironmental reconstruction of the coastal plain of

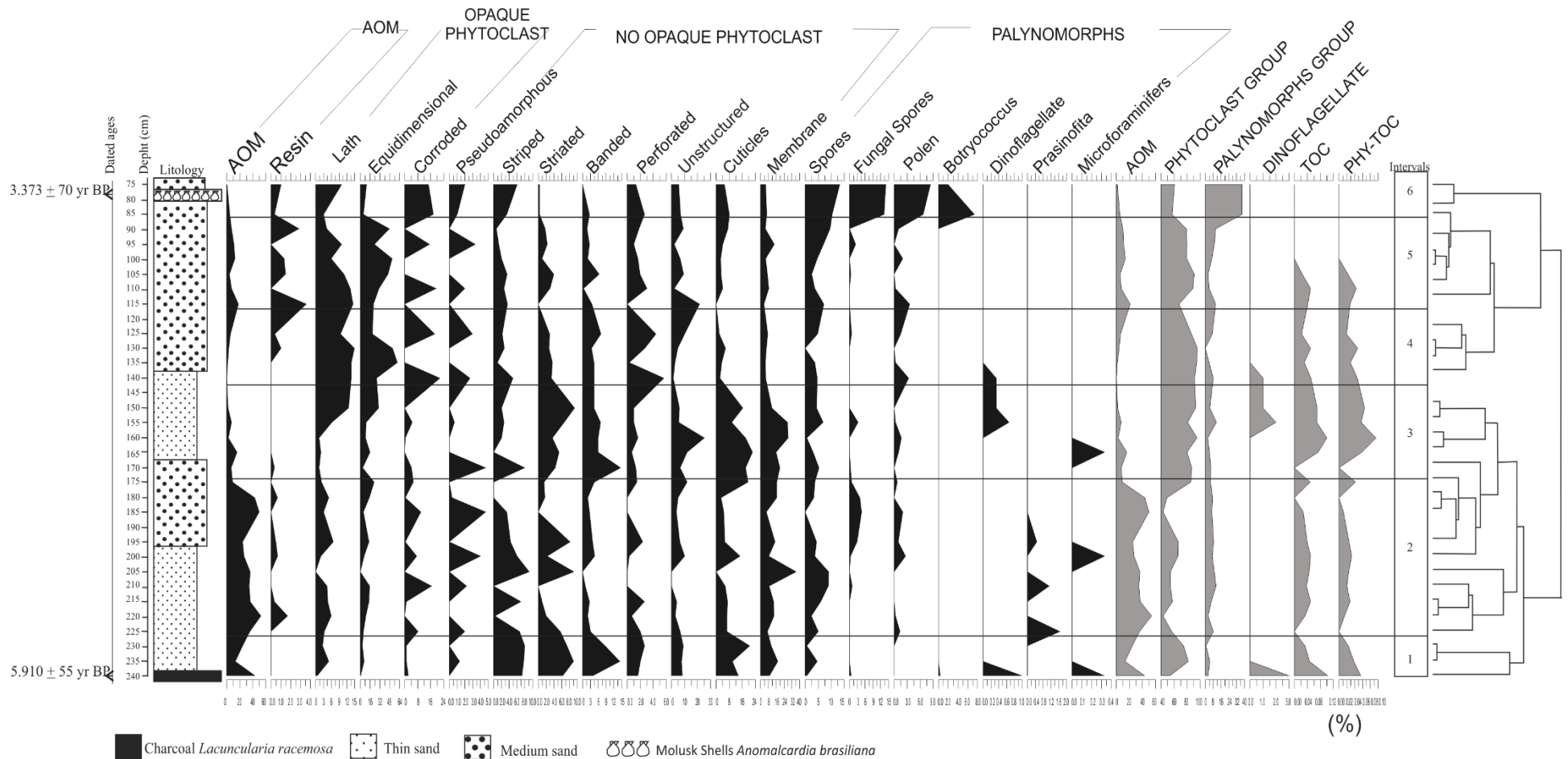
Pero Beach. Particulate organic matter from sediments presented characteristics in its abundance, color and structures that might be associated with environmental changes in the study area.

In the period between 6761 - 5000 yrs cal BP, the sand bar of the study area was under strong influence of marine waters due to the Holocene Transgressive Event, evidenced by the abundance of dinoflagellate cysts. After this period, the records suggested a progressive increase of the continental influence, based on high frequency of non-opaque phytoclasts indicated by the decreasing of the AOM values, and by the high presence of continental palynomorphs (pollen and spores).

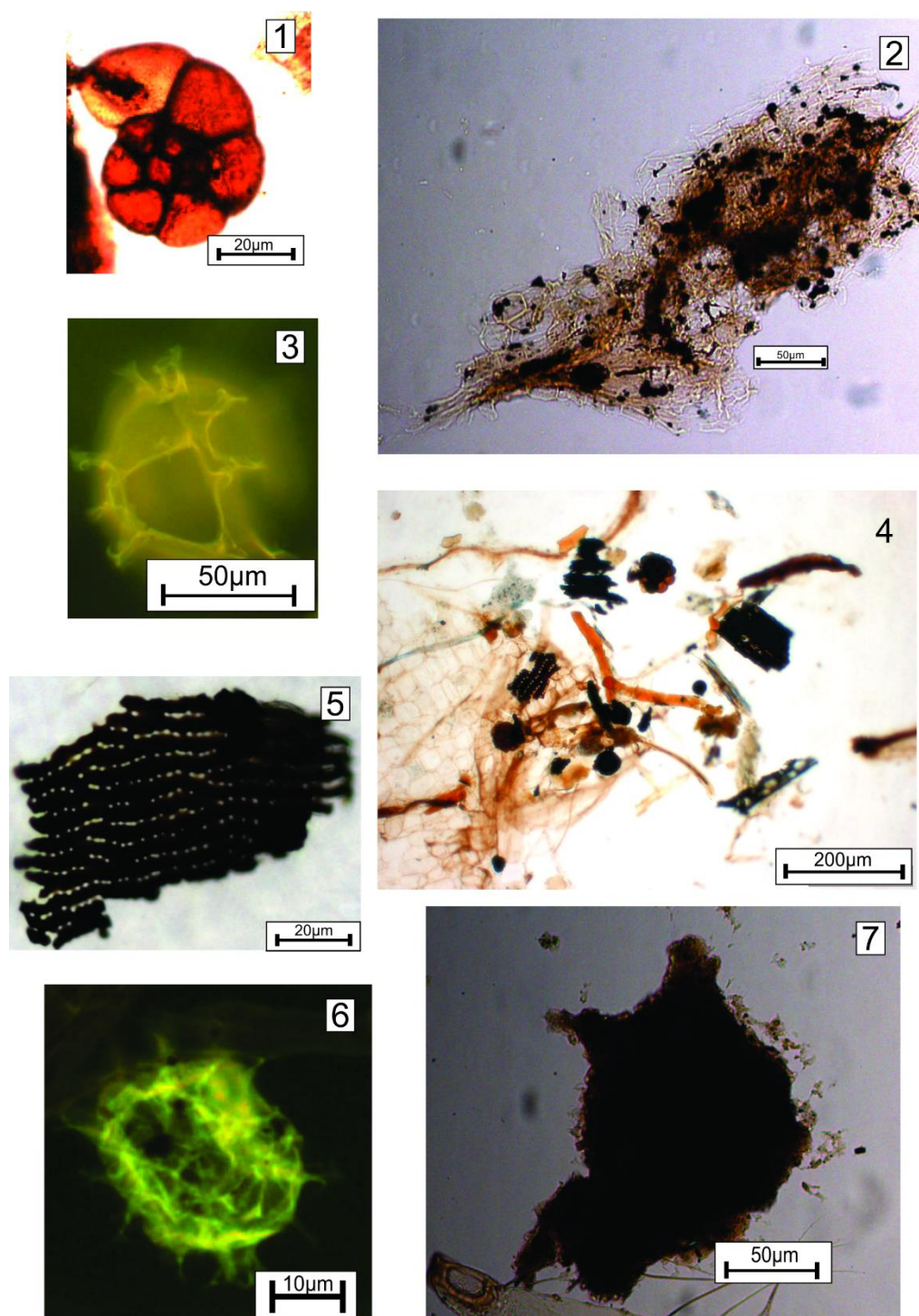
Since 3373 yrs cal BP, the high presence of strictly continental palynomorphs indicated the probable silting of the lagoon and signed the evolution for the present situation.

Thus, the application of the palynofacies study the coastal sediments is a valuable method for paleoenvironmental and paleoclimatic reconstruction, contributing to a better understanding of the evolution of coastal environments.





**Fig. 4.** Dispersion peak of particulate organic matter throughout the core. Gray peaks of large groups of organic matter, highlighting the dinoflagellates peaks. Percentage TOC and TOC-Phy ratio. Dendrogram R-mode presenting association samples throughout the core.



**Plate 1** – Photomicrographs of the Particulate Organic Matter found along the studied core: 1. Microforaminifera; 2. Cuticle; 3. *Spiniferites delicatus*; 4. Association of opaque phytoclasts and non-opaque phytoclasts, microforaminifera and pollen; 5. Perforated phytoclast non-opaque; 6. *Spiniferites* sp.; 7. Amorphous organic matter.

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