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RESEARCH PAPER

Late Holocene palynological record and landscape change from the Piraquê-Açu and Piraquê-Mirím estuarine system, Espírito Santo, Brazil

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Abstract

The Piraquê-Açu and Piraquê-Mirim estuarine system (PAPMES) is located next to the Aracruz City (19° 57' S and 40° 9' W), Espírito Santo State, Brazil. Palynological analyses were conducted based on two sediment cores (PA20 and PM1). The main purpose of the present study was to recognize and interpret the vegetation dynamics in the region around the collection site in the last 2000 cal yrs BP. The sediment cores were subsampled at each 10 cm depth. The samples were submitted to standard palynological processes. The PA20 sediment core obtained the oldest age of 1758±68 cal yrs BP at a depth of approximately 105-cm. However, the PM1 sediment core obtained the oldest age of ≈2071±82 cal yrs BP at a depth of 95-cm. The comparative record of the sediment cores demonstrated that palynomorphs deposition were directly influenced by local water circulation. Pollen analysis indicated the striking presence of mangrove vegetation, which is mainly characterised by the *Rhizophora* pollen type. The other vegetation communities underwent little variation over the studied period. The top sediment layers of both sediment cores are characterized by the presence of exotic pollen grains of *Eucalyptus*, introduced by humans, and by the decrease of the original vegetation.

Keywords: Holocene. estuarine sediments. palynological analysis. Vegetation. environmental evolution.

1. Introduction

The estuarine environment can be characterized as a system of drowned valleys towards the sea that receives sediments of marine and river sources. Being highly complex environments, estuaries are influenced by the current circulation, water column mixing and stratification, tidal and wind. From these characteristics, estuaries can be classified based on their geomorphology, saline stratification and dynamic processes (Allee et al., 2000).

Among the landscapes that are found in coastal areas, estuaries emerge as sites that have been heavily impacted by anthropic action. These regions are considered ideal locations for economic development because of the abundant amount of available fresh water as these regions are coastal areas that serve to shelter commercial and tourist vessels (Barbier et al., 2011). The past knowledge and current assessment of the use of these coastal areas become important tools for the management of the surrounding ecosystems. Through pollen analysis, it is possible to recognize changes in the landscape caused by climatic or anthropogenic factors (Flantua et al., 2015).

Palynological analysis can provide a regional overview of the different vegetation gradients that are found throughout estuary locations (Brush and Brush, 1994). These studies play an important role in understanding the dynamics of the vegetation along the Holocene to the coastal regions that are under the influence of both rivers and sea (Miranda et al., 2002). In Brazil, there are few studies of palynological approach-developed estuaries, the most concentrated being in the North (Behling et al., 2004; Cohen et al., 2005; Vedel et al., 2006; Rodrigues and Senna, 2011). Some studies have focused on the Northeastern (Behling and Costa, 1997), Southeastern (Belem, 1985; Amaral et al., 2006; Barth et al., 2006) and Southern regions (Medeanic, 2006). Therefore, a larger number of studies are required for a systematic integration of this environment (Miranda et al., 2002).

Studies of paleoenvironmental reconstruction in different Espírito Santo State localities have been developed over the last years. The present studies have focused on the Delta of Rio Doce (Cohen et al., 2014; França et al., 2015) and at a lagoon located 40 km on the northern coast (Buso Júnior et al., 2013a, 2013b; Lorente et al., 2014). Freitas et al. (2015) used palynological analysis of a sediment core obtained in the lower Piraquê-Açu river, in order to understand the dynamic of the surrounding vegetation. This river, joining together the Piraquê-Mirim river, builds a very large estuary (Piraquê-Açu and Piraquê-Mirim estuarine system, PAPMES). Rhizophora was the main representative of the outstanding mangrove vegetation during the last 1700 cal. yrs BP.

The present study aims to recognize, interpret and compare two sediment cores through the dynamic of the surrounding vegetation in the Piraquê-Açu and Piraquê-Mirim drainage basin located in the Espírito Santo State in order to contribute to its understanding and providing insight for future studies and management.

1.1. Study site

The Piraquê-Açu and Piraquê-Mirim estuarine system (PAPMES) is located at 40°09'W and 19°57'S, near the Santa Cruz district, in the Aracruz municipality, 83 km from the capital Vitória, Espírito Santo State (ES), Brazil. This estuary has a water surface area of approximately 5.1 km². Around this estuary lays the largest mangrove area in Espírito Santo State with approximately 12.3 km² (Barroso, 2004). The geomorphology of this estuary contains a Y shape, where the Piraquê-Açu and Piraquê-Mirim rivers meet together and jointly flow to the sea.

The studied region is characterised by a tropical coastal climate, with dry winters and very wet summers, which have pronounced annually rainfall, approximately 1250 mm (Mello et al., 2012). The geomorphological structure of Espírito Santo State presents a crystalline basement that is covered by coastal strip sandstone from Barreiras Formation, originated in the Neogene (Dominguez, 2009). In the region between Riacho (Aracruz) and Ponta do Tubarão (Vitória), where the PAPMES is located, there is a weak development of the Quaternary sediments at the Barreiras Formation base. The fluvial-marine deposits are more pronounced along the river valleys, such as the Piraquê-Açu and Piraquê-Mirim, Reis Magos and Santa Maria da Vitória rivers (Martin et al., 1996).

The Espírito Santo vegetation is extremely diverse and caught the attention of naturalists in the early nineteenth century (Saint-Hilaire, 1974). Throughout the state, different biomes (Ruschi, 1950) are observed. The Restinga vegetation and Ombrophilous Forest are among the most studied formations (Thomaz, 2010; Valadares et al., 2011). Other studies have focused on the mangrove region in the Anchieta (Petri et al., 2011) and the São Mateus municipalities (Silva et al., 2004), and few studies have focused on an upstate floristic survey (Rolim et al., 2006; Paula et al., 2009; Paula and Soares, 2011).

The Ombrophilous Forest has historically been the major area of vegetable coverage in the state. Naturalist reports have recorded the great diversity and preservation of this ecosystem (Saint-Hilaire, 1974). However, due to intense anthropogenic activities through the last century, this vegetal formation has been extensively deforested for monocultures farming (Gibbs et al., 2010). The areas surrounding the PAPMES were modified to raise animals and for agricultural expansion (Perota, 1974). At the end of 1960s, areas that were previously owned by the indigenous Tupi-Guarani underwent the intense large-scale cultivation of *Eucalyptus* sp. by the pulp cellulose industry (Loureiro, 2006).

2. Material and methods

Two sediment cores collected in the PAPMES area were analysed. The Piraquê-Açu (PA20) core 110 cm long, was collected at the coordinates 19°56'13.63"S and 40°10'29.50"W (Fig. 1) and 2.7 m water depth, and the Piraquê-Mirim (PM1) core, 100 cm long, at the coordinates

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19°56'10.36"S and 40°13'54.89"W (Fig. 1) and 6.6 m water depth. The gathering of cores was conducted by the Department of Oceanography and Ecology of the Universidade Federal do Espírito Santo (UFES), led by Prof. Dr. Alex Cardoso Bastos.

Palynological data published by Freitas et al. (2015) in the lower Piraquê-Açu river are reanalysed in the present study in comparison with lithological data. In the other hand, these obtained data are compared with the new obtained sediment core (PM1) as lithology and the results of palynological data.

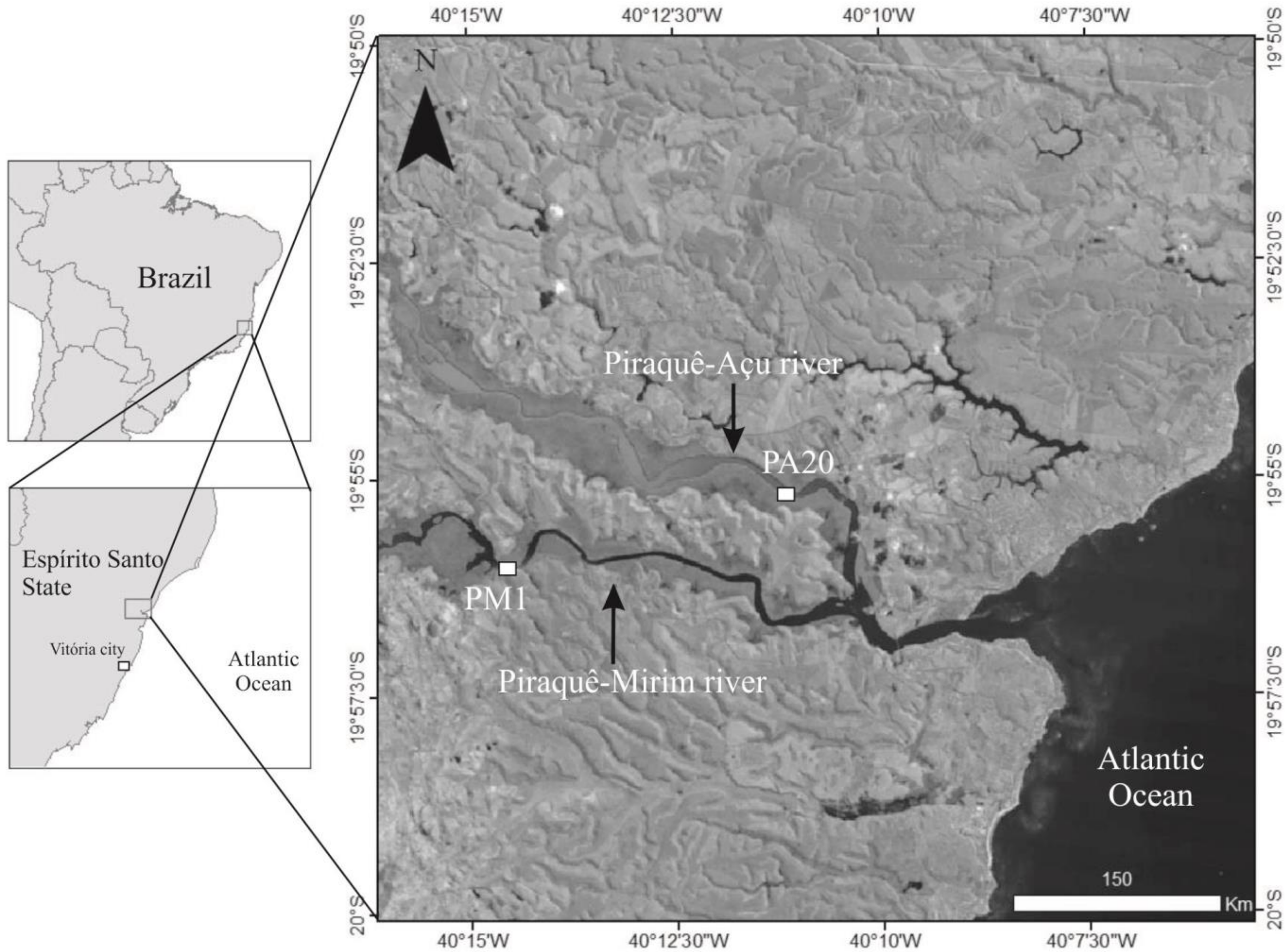

Fig. 1. Location map of the collected sediment cores at PAPMES.

The sediments were described according to the routine methodology for the research group LaboGeo/UFES (Universidade Federal do Espírito Santo). Four samples of the PA20 sediment core and three of the PM1 core were selected for dating by the AMS method (Tab. 1) in the geochronological laboratory at Arizona University (USA). Subsequently the ^{14}C ages were calibrated using the Calib 7.0 program, making use of the IntCal 13 (Stuiver et al., 2014) curve for the two studied cores using 2-sigma.

For palynologycal analyses, two grams of sediment collected every 10 cm, in both cores. Samples used in palynologycal analyses received chemical treatment specific for quaternary sediments as was proposed by Ybert et al. (1992). This methodology includes chemical treatment with 10% HCL to eliminate carbonates, 40% HF to eliminate silicates, acetolysis and palynomorphs were recovered using a Cl2Zn n gradient (density=2). In PA20 core were studied the palynologycal content in 12 samples and in PM1 core 10 samples.

One tablet of exotic spores of *Lycopodium clavatum* (Stockmarr, 1971) was introduced into each sample in order to obtain the absolute concentration of palynomorphs per

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gram of sediment. At least 300 pollen grains per sample were counted and analysed using photonic light microscopy. The reference catalogues of Roubik and Moreno (1991), Colinvaux et al. (1999), Luz and Barth (2000), Luz and Barth (2002), Barreto et al. (2013) were used to identify pollen grains. Diagrams of pollen grain percentages and concentration were obtained using the TILIA and CONISS programs (1987, 1992).

3. Results

The ^{14}C results showed that the PA20 sediment core presented its oldest age of 2071±82 cal yrs BP (2102±35 BP non-calibrated years) at 95 cm of depth. The other sediment core (PM1) presented its oldest age of 2071±82 cal yrs BP (2102±35 BP non-calibrated years) at 95 cm of depth (Table 1).

Tab. 1. Data on the ^{14}C and calibrated ages from the Piraquê-Açu (PA20) and Piraquê-Mirim (PM1) cores.

Sediment cores	Laboratory code*	Sample (cm/depth)	^{14}C non-calibrated age yrs BP	^{14}C calibrated age yrs BP
PA20	AA93437	39-40	1304±34	1255±37
	AA93435	58-59	1531±37	1436±88
	-	86-87	1723±34	1632±75
	AA93433	105	1816±35	1758±68
PM1	AA93436	54-57	994±34	930±36
	-	85-84	1982±37	1933±70
	AA93439	93-95	2102±35	2071±82

* Arizona AMS Laboratory

The sediments description does not show particle size variation and the analysed sediments presented a homogeneous muddy lithology. Bioturbation, bivalve shells and vegetal fragments were observed throughout both cores. However, the PM1 core presented a sandy facies near the top (Tab. 2).

It was possible to identify and group the pollen types into three major vegetation types (Mangrove, Alluvial Community and Ombrophilous Forest) in both cores. The pollen types that occurred in more than one vegetal formation were grouped into "Wide Distribution", and those of introduced plant species into "Exotic" (Tab. 3).

3.1. PA20 core

Pollen analysis of this core allows distinguishing three main core sections (I, II and III) (Figs. 2, 3).

Section 1: 110-95 cm. This core section is characterised by a high pollen grains concentration at its base (205.824 palynomorphs/g), followed by a significant decrease (123.453 palynomorphs/g) towards the top. This decrease in palynomorph accumulation is more significant of pollen grains of the Mangrove vegetation (85.649 – 30.250 palynomorphs/g) and of fern spores (87.641 – 18.395 palynomorphs/g) (Fig. 2).

Mangrove elements have the highest percentage values, especially of *Rhizophora* (36%), along with the pollen types of the Ombrophilous Forest (*Alchornea*, Arecaceae, *Celtis*, Combretaceae, Melastomataceae, *Tetrapterys*, *Trema*) (38%) and fern spores (43%) at the base of this section. The herbaceous/shrub pollen types from the Alluvial Community are mainly represented by Cyperaceae and Poaceae, whose values remain around 18% (Fig. 3).

At the core depth of ≈100-cm there is a decrease of the mangrove pollen types (42-24%) and fern spores (43-15%), followed by an increase in the frequency of Ombrophilous Forest taxa (26-38%) caused mainly by the *Phoradendron*, *Alchornea*, Arecaceae, *Cecropia*, *Celtis*, *Sebastiania* and *Tetrapterys* pollen types along with a small increase in the Alluvial Community (18-22%) (Fig. 2). However, there is a decrease in the mangrove vegetation and fern spores towards the top of this core section, while the Ombrophilous Forest showed a small increase in these percentages (26-38%). There is no increase in the algae or marine elements (2-9%) (Fig. 3).

Section II: 95-35 cm. The total pollen grains concentration from section II is similar to those observed on top of the previous section with a significant decrease (123.453-60.339 palynomorphs/g) at depth of 60 cm (Fig. 3). The Mangrove pollen type (*Rhizophora*) showed the highest percentage throughout the entire section (36.4-38%) with a slight decrease near the top (27%). The Ombrophilous

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Forest elements remain constant throughout this section (26-25%) (Fig. 3).

The same pattern can be observed in the Alluvial Community. However, a small increase of plant taxa is observed at an approximately 70 cm depth (17-26%), mainly due to increase Cyperaceae, Poaceae and *Myrcia* pollen types, which are related to an herbaceous/shrub vegetation. The values of fern spores and marine elements are similar to the previous section (Fig. 3). However, it is worth noting the first occurrence of *Botryococcus* (Algae).

Section III: 35-0 cml, top of the core. A sharp decrease of the total pollen grain concentration at a depth of ≈10 cm can be observed in this section, followed by a tendency to increase all the vegetal groups. The highest *Botryococcus* concentration at the core (73 palynomorphs/g) and an increase in the marine elements towards the top (Fig. 2) is identified.

The Mangrove vegetation shows a small expansion (31-36%) similar to that of the Alluvial Community. The increased frequency in the Alluvial Community is characterized by Cyperaceae, *Gomphrena*, *Machaerium* and Poaceae pollen types.

A small decrease in the Ombrophilous Forest (27-19%) is also observed after 10 cm depth. On top of this section, a low frequency (3%) of the *Eucalyptus* pollen type is recorded at the onset (Fig. 3).

Tab. 2. Lithological description of sediment cores that were collected from the Piraquê-Açu (PA20) and Piraquê-Mirim (PM1) rivers.

Sediment cores	Depth (cm)	Lithological description
PA20	0-30	Fluid mud 5YR 2/1 5GY 4/1
	30-55	Mud 5Y 3/2 with vegetal fragments
	55-70	Mud 5Y 3/2 with shell fragments and bioturbation
	85-110	Mud 5GY 4/1 with bivalve shell and bioturbation
PM1	0-7	Vegetal fragments
	7-8	Top layer with mud presence 5YR 2/1 and sand
	8-34	Mud layer 5YR 2/1 with bioturbation presence between 24-31 cm
	47	Sand layer
	48-49	Mud layer
	76-77	Mud layer and shell presence at 77 cm
	80-86	Shell and vegetal fragments
	86-87	Mud 5YR 2/1 with shell fragment and well preserved shell
	93	Well preserved shell

3.2. PM1 core

Pollen analysis allows establishing three main core sections (I, II and III) with one subsection (Figs. 4, 5).

Section I: 100-80 cm. This section is characterised by its low total pollen grains concentration at the base, decreasing sharply toward the top (266.784-159.241 palynomorphs/g) (Fig. 4).

Mangrove elements have the highest percentage values of all of the vegetal formations (Fig. 5). The *Rhizophora* pollen type shows a high percentage (66%) compared to that of the *Avicennia* pollen type (0.7%). The herbaceous/shrub Alluvial Community (Asteraceae, Cyperaceae, *Myrcia*) is also well represented based on this section having the highest percentage of the Poaceae pollen type of this group (6.6%). Later, a small drop in the Alluvial Community (Fig. 5) can be observed generated by a decrease in the *Amaranthus*/Chenopodiaceae, Asteraceae, Cyperaceae and *Myrcia* pollen types.

The Ombrophilous Forest is significantly represented by the Arecaceae, *Alchornea* and *Piper* pollen types (7%). Starting at the section I base (90 cm of depth), there is a vegetation decrease in the *Alchornea*, *Arrabidaea*, *Cecropia*, *Celtis*, *Hedyosmum*, *Lecythis*, Myrtaceae, *Piper*, *Sebastiania*, *Tabebuia* and *Tapirira* pollen types (Fig. 5).

Section II: 80-30 cm. This section is subdivided into subsections IIa and IIb. The subsection IIa starts at 80 cm of depth and is characterized by the significant increase of all

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the vegetal formations and fern spores (Fig. 5). A high value of total pollen grains concentration (4.735.441 palynomorphs/g) is found at 70 cm of depth. After this step, the total concentration of all vegetal formations tend to decrease significantly, such as the Mangrove (412.428 – 177.821 palynomorphs/g), Alluvial Community (101.974 – 38.835 palynomorphs/g) and Ombrophilous Forest (11.557 – 45.988 palynomorphs/g). The fern spores also show a considerable variation in their concentrations (38.523 – 15.329 palynomorphs/g) (Fig. 4). This subsection does not present significant percentage differences in its vegetal formations.

Tab. 3. Botanically taxa identified using pollen morphology and the vegetal classification present in the PAPMES.

Mangrove	*Rhizophora*, *Avicennia*
Alluvial community	*Alternanthera*, *Amaranthus*/Chenopodiaceae, Asteraceae, *Bernardia*, *Borreria*, *Brassica*, *Cleome*, *Cordia*, Cyperaceae, Cucurbitaceae, *Dalbergia*, *Desmodium*, *Eringyum*, *Gomphrena*, *Machaerium*, *Myrcia*, Poaceae.
Ombrophilous Forest	*Phoradendron*, *Cassia*, *Alchornea*, *Anadenanthera*, Arecaceae, *Arrabidaea*, *Bauhinia*, Bignoniaceae, Bombacaceae, *Casearia*, *Cecropia*, *Celtis*, *Cedrela*, Combretaceae, *Cupania*, *Citrus*, *Dendropanax*, *Didymopanax*, *Hedyosmun*, *Ilex*, Lauraceae, *Lecythis*, *Mabea*, Malvaceae, Melastomataceae, *Myrsine*, Myrtaceae, *Pera*, *Piper*, *Pachira aquatica*, *Paullinia*, *Phyllantus*, Polygonaceae, *Pouteria*, *Protium*, *Pseudobombax*, *Psychotria*, *Sebastiania*, *Tabebuia*, *Tapirira*, *Tetrapterys*, *Trema*, *Trichilia*.
Exotic	*Eucalyptus*
Wide distribution	Anacardiaceae, Boraginaceae, Caesalpiniaceae, *Cassia*, Euphorbiaceae, Fabaceae, Malpiguiaceae, Mimosaceae, Moraceae, Rubiaceae, Sapindaceae, Solanaceae.

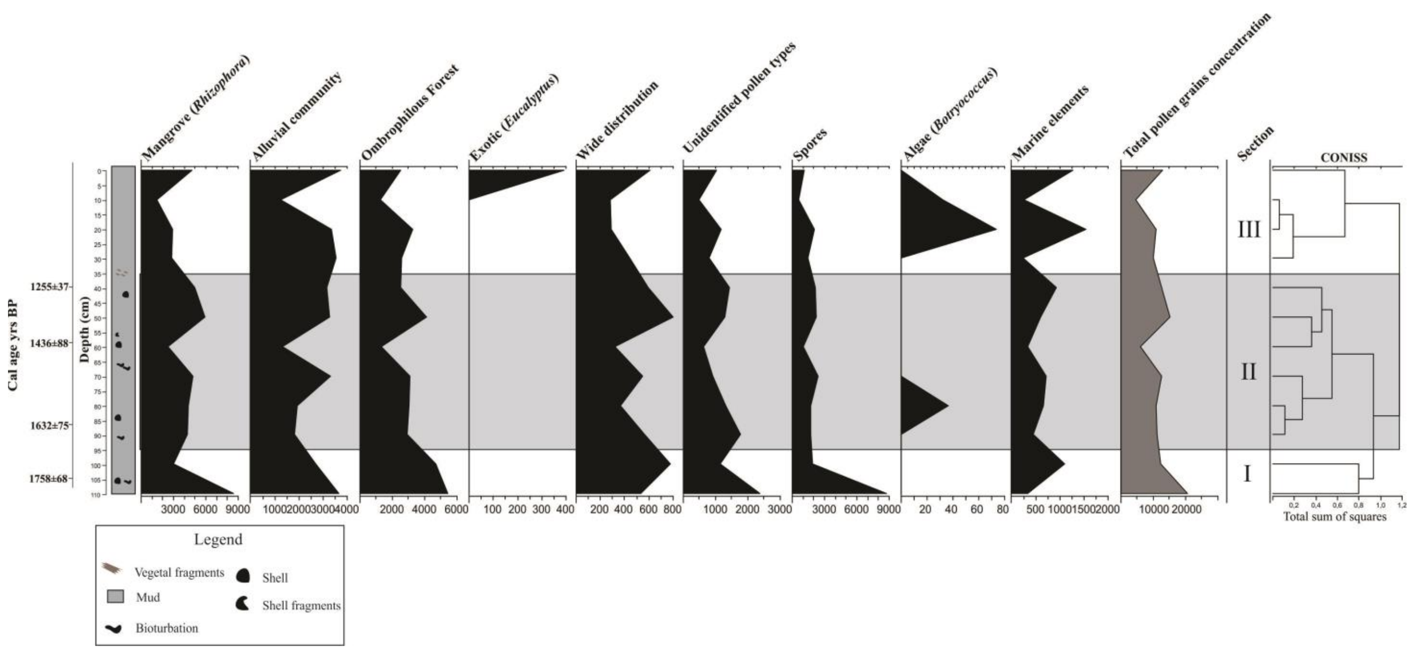

Fig. 2. Concentration diagram of the vegetation forms identified in the PA20 core.

Section IIb starts at 45 cm of depth. This subsection is marked by a sharp decrease in the vegetal formations concentration (Mangrove, Alluvial Community and Ombrophilous Forest), with the lowest value presented throughout the core (61.061 palynomorphs/g) (Fig. 5). Total pollen grains concentration increased at the 30 cm depth (475.398 palynomorphs/g) (Fig. 5). However, a sharp decrease in the percentage values that are characteristic of

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the mangrove pollen types can be observed at 40 cm depth (57-28%) with a small increase in the Alluvial Community (10-25%) and Ombrophilous Forest (11-22%) (Fig. 5).

Section III: 30-0 cml, top of the core. No palynomorph preservation occur in 20 - cm of depth, due to the presence of a coarser sediments grain size. However, this record was not featured in the macroscopic core description. In 10 cm of depth occurs high palynomorphs concentration (226.704-459.537 palynomorphs/g), evidenced by the high mangrove concentration (386.128 palynomorphs/g) (Fig. 4).

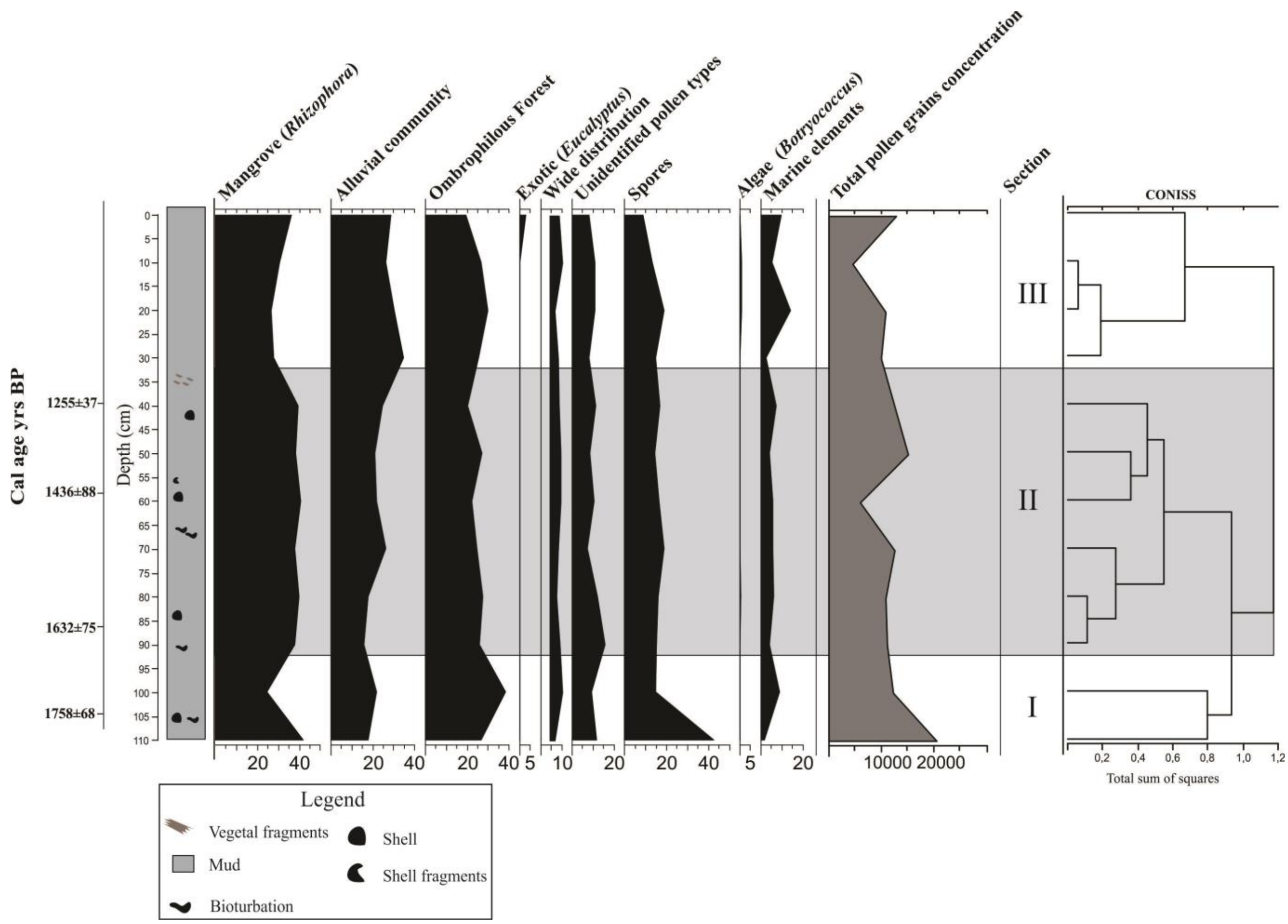

Fig. 3. Percentage diagram of the vegetation forms identified in the PA20 core.

Between 10 cm depth and the core top, the Mangrove vegetation dominate. This dominance is characterized by high frequency of *Rhizophora* pollen type (72-84%) (Fig. 5). However, Alluvial Community slightly decreases (8-5%) due to the lower frequency of Asteraceae, Cyperaceae, Poaceae and *Myrcia*.

This vegetation decrease is also observed in the Ombrophilous Forest (11-5%) (Fig. 5) due to the lower frequencies of Arecaceae, *Arrabidaea*, Bignoniaceae, Bombacaceae, *Cecropia*, *Hedyosmum*, *Ilex*, *Lecythis*, *Pachira aquatica*, *Piper* and *Trema* pollen types. This section presents a low frequency (1%) of the *Eucalyptus* pollen type (Fig. 5).

4. Discussion

The PA20 core showed a homogeneous lithology consisting of mud and displaying bioturbation in some layers. However, despite the PM1 core being similar to the PA20 lithology, there are two sandy facies (47 and 8 cm

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depths), emphasising the presence of vegetal fragments at the core top and bioturbation.

Areas that are dominated by mangroves favour the organisms' establishment that can cause bioturbation in the sediment (Woodroffe et al., 2015). Likewise, mangrove roots may penetrate up to 2 m into underlying sediments generating youngest sediments remobilization to oldest (Hutchings and Saenger, 1987). The remobilization of sediments can generate an inversion dating but in the analysed cores this fact it was not observed.

This effect also was not observed and in the sediment cores from mangrove area in Zanzibar (Woodroffe et al., 2015). In fact, the records of both cores display a coherent signal and were not apparently affected by bioturbation. This is indeed similar to what was also observed by Woodroffe et al. (2015) in analysed sediments from southeast India.

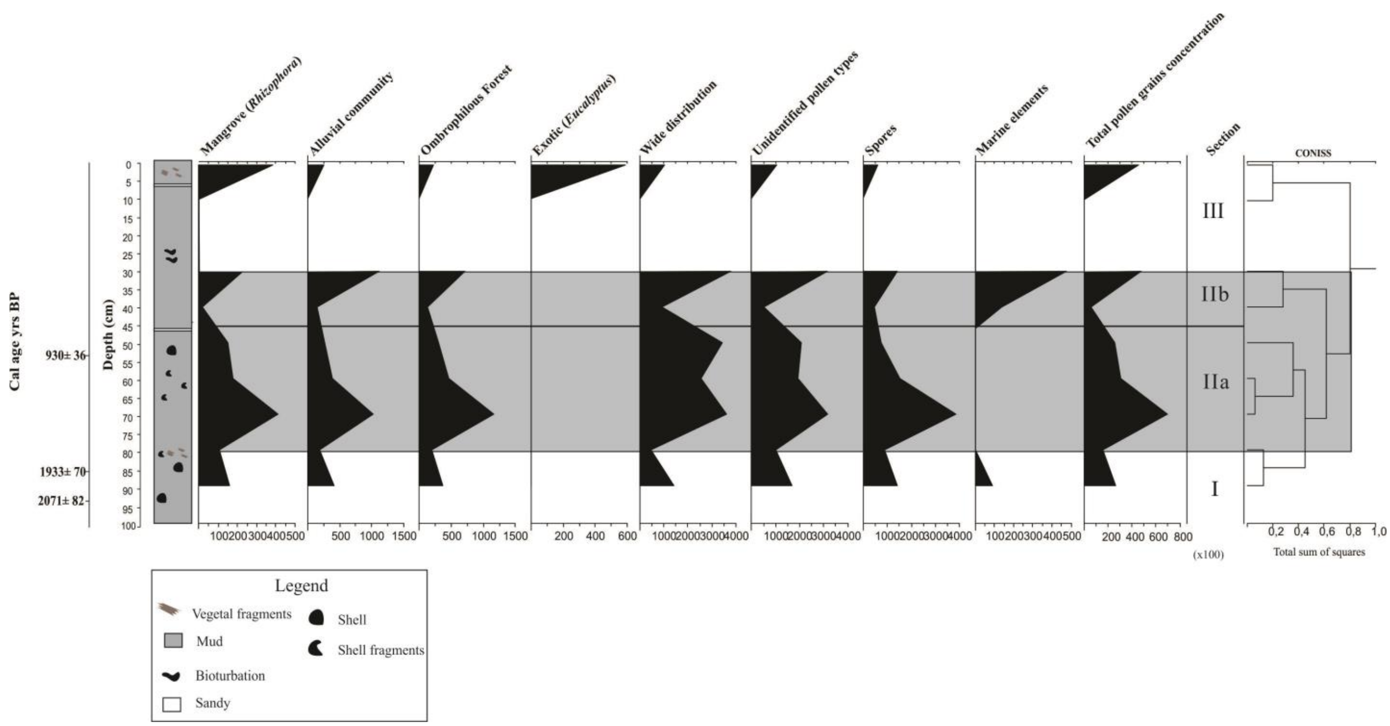

Fig. 4. Concentration diagram of the vegetation forms identified in the PM1 core.

The pollen record of the cores (PA20 and PM1) demonstrated significant differences in the water circulation behaviour of each river that forms PAPMES. The PM1 core showed high values of pollen grain concentration compared to that of the PA20 core. This may be related in addition to the collection point of the PM1 core, located upstream of the Piraquê-Mirim river. The size of the drainage basin of this river, which is approximately 69 km² compared to 379 km² of the Piraquê-Açu river is also significant (Vale and Ferreira, 1998).

The PM1 core only presented marine elements (foraminiferal linings) in two sections (I, IIb). However, this pattern was varied throughout the PA20 core. The foraminiferal linings are the microforaminifera organic part and is always related to the marine conditions (Stancliffe, 1996). This concentration difference between the two cores may be related to different environmental conditions, related for instance to higher salinity at this local or to the high productivity as observed by Pienkowski et al. (2011) in southwestern Canadian Artic Archipelago.

Likewise, there is in the PM1 record the occurrence of *Botryococcus* algae but not in the PA20 core. This algae genus can occur in freshwater as environments with a certain salinity (Traverse, 2008). Pienkowski et al. (2011) found this colonial alga in the Coronation Gulf and associated its occurrence with increasing fluvial input.

The fact that the collection point of the PM1 core, which is located upstream of the Piraquê-Mirim river may have contributed to the lower salinity conditions, favouring algae establishment.

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The analysis of the two cores showed a high pollen grain concentration in the PA20 section I and in the PM1 section IIa. According to Martin et al. (1996), the Espírito Santo coast underwent a marine transgression approximately 1959 cal yr BP, where the shoreline was approximately 1.2±0.5 m above the present shoreline. The relative sea level slightly above the current one could influence the palynomorph deposition, blocking the flow of water from the watershed and hampering the transport of palynomorphs to more distant areas.

The Mangrove vegetation was well represented throughout the studied cores mainly by the occurrence of the *Rhizophora* pollen type. It was well preserved in estuaries and bay regions, and has also been observed by other authors (Behling et al., 2004; Barth et al., 2006; Rodrigues and Senna, 2011) in sediment cores collected in the North, Northeast and Southeast regions of Brazil.

Similar observations also were observed in other regions such as in Venezuela (Muller, 1959) and India (Woodroffe et al., 2015).

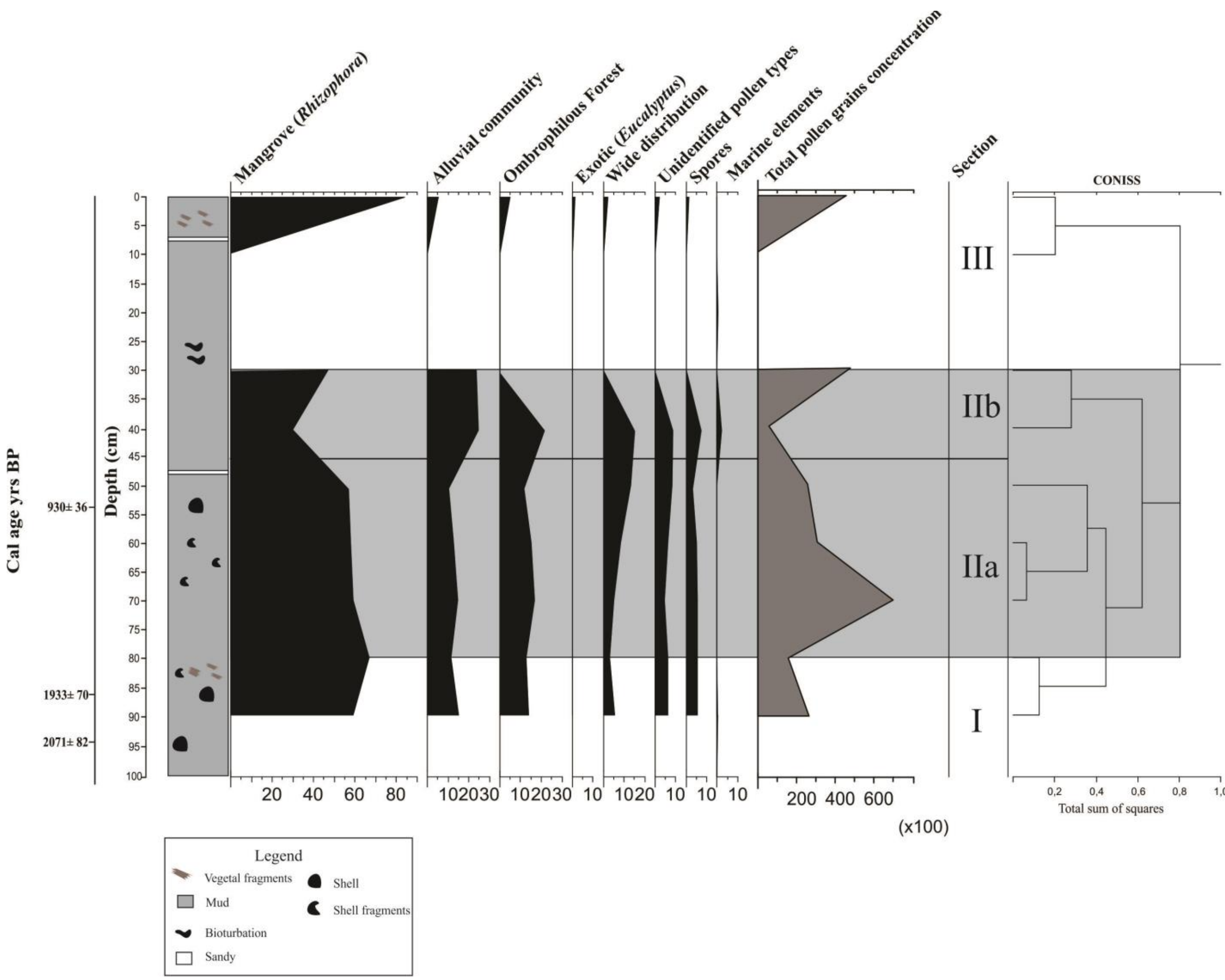

Fig. 5. Percentage diagram of the vegetation forms identified in the PM1 core.

The analysed sediments in the mangroves influence areas in the southeastern region of Brazil and have been found at low frequencies (Belem, 1985; Coelho et al., 1999, Amaral et al., 2006). However, Coelho et al. (1999) emphasised that the analysed pollen in Sepetiba Bay showed damages that may be related to the transport and leaching of the grains through the influence of rivers flowing close to the area of study. Muller (1959) notes that *Rhizophora* sp. have high pollen production and the pollen grains can be transported over long distances by wind due to their small size (Hogarth, 2007).

Buso Júnior et al. (2013a, 2013b) showed a high accumulation from mangrove taxa at a lagoon located at Espírito Santo State. The authors highlights that in the period between 7623 and 3190 cal yrs BP the site location suffered a marine transgression. With the saline water entrance into the study area, the formation of mangrove became possible. In 3190–585 cal yrs BP occurred the paleo-estuary progradation and the disappearance of the mangrove. The environment was transformed from an estuary to a coastal lagoon and it was also observed by Lorente et al. (2014). To the present study, other factors, such as specific characteristics of each studied site, hydrodynamics, wind direction and sedimentation rate, can induce sedimentary particles deposition, accumulation and preservation (Hofmann, 2002).

The data of pollen concentration analysed in both cores were significantly different (Fig. 6). Core PA20 presented ¼ of the total pollen grain concentration of the PM1 core. This fact may be associated with the high energy level of the water flow in these rivers, which possibly hindered the process of palynomorph deposition. Cohen et al. (2014) analyzing sediment cores at the deltaic plain at Rio Doce, Espírito Santo State points out that during the Holocene the vegetation (arboreal/herbaceous) found at the coastal plain supply conditions to the estuarine system development from the balance between the relative sea-level and river sediments.

This fact also is observed to França et al. (2015) that analysed from one deep sediment core collected at deltaic plain at Rio Doce. In the present study the core location and the greater extent of the drainage basin of the Piraquê-Açu river compared to Piraquê-Mirim (Barroso, 2004), fostering a higher energy environment. With the largest contribution of continental water, transport of lithogenic and organic material found in the river were facilitated and could be transported to higher distant regions from the source area.

At the top of section III from both of the studied cores, there was a tendency to fall the Ombrophilous Forest associated with a slight expansion of the Alluvial Community. This fact can be associated with the arrival of European immigrants, mostly Italians, to the Piraquê-Açu drainage basin area at approximately 1891 AD. These immigrants intended to colonize and establish the first farms (Nagar, 1985). Gibbs et al. (2010) highlights that the Ombrophilous Forest was the primary source for the agriculture in the last century. The anthropogenic activity in the studied region modified deeply the landscapes with the new open areas used for livestock and agricultural expansion (Perota, 1974).

The *Eucalyptus* pollen type was found in samples from both of the core tops. The *Eucalyptus* genus was introduced in Brazil in the late XIX century and for the Espírito Santo state, the *Eucalyptus* sp. record took place from the late 1960 AD in indigenous areas (Loureiro, 2006). The presence of this pollen type at the cores top may indicate the beginning of the cellulose industry's installation in the state. Species of this genus are cultivated in different areas of PAPMES in order to implement its monoculture on a large scale (De Souza and Zanuncio, 1998; Loureiro, 2006) to meet the demand for raw material production for the pulp industry.

5. Conclusion

The core records comparison showed that mangroves have been present since 2071 cal yr BP in the PM1 core and since 1758 cal yr BP in the PA20 core, with a well preserved vegetation, reported by naturalists in the mid nineteenth century (Saint-Hilaire, 1974). Thus, despite physical factors have influenced the deposition of palynomorphs, the vegetation remained stable during the studied period, suffering minor variations at the core top with the anthropogenic influence.

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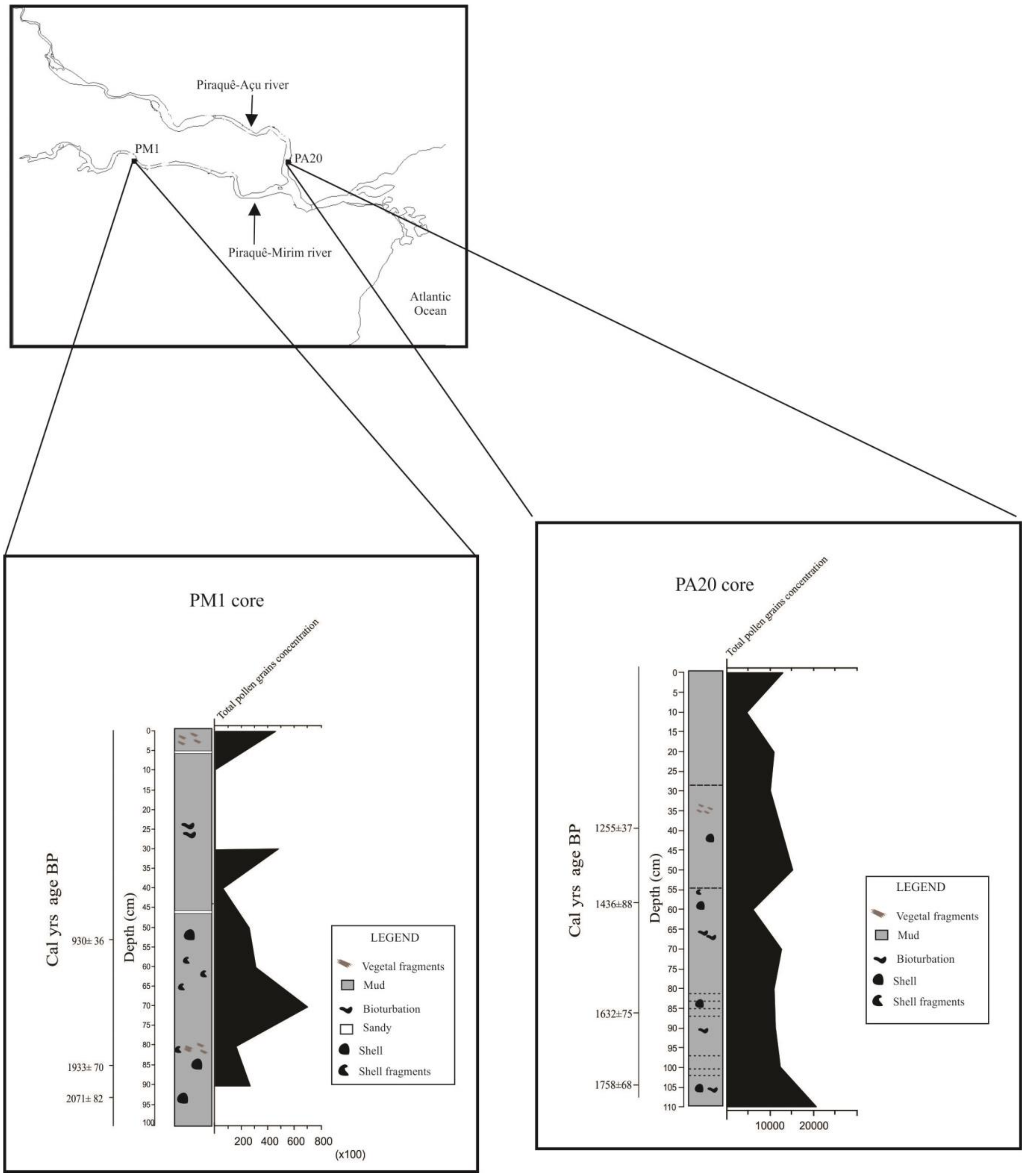

Fig. 6. Comparative scheme of the total pollen grain concentrations from the collected PA20 and PM1 cores at PAPMES.

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