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RESEARCH PAPER

LATE HOLOCENE EVOLUTION OF THE NORTHEAST INTERTIDAL REGION OF SEPETIBA BAY, RIO DE JANEIRO (BRAZIL)

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Abstract

This work is based on the study of the core T1 collected in the Guaratiba Mangrove, located on the northeastern margin of Sepetiba Bay. Few studies dealing with the application of benthic foraminifera to study sea level changes during the Holocene have been conducted in Sepetiba Bay, State of Rio de Janeiro, Brazil. In order to fill this gap, the core T1 was studied using textural, geochemical (carbonate, total organic carbon, total sulfur and stable isotopes evaluated in *Ammonia tepida*) and microfaunal (benthic foraminifera) data, unveiling paleoecological relationships of these organisms and the evolutionary scenario of Guaratiba Mangrove.
Radiocarbon results indicate an estimated age of about 2400 yrs cal BP for the core base. Textural, geochemical and benthic foraminifera data suggest that the study area changed significantly during the last 2400 yrs cal BP. It experienced coastal waves action and shoreface processes in the period between ≈2.400-1.400 yrs cal BP; then, this phase gave place to a shallow marine environment similar to that found currently in internal and protected areas of Sepetiba Bay, between ≈1.400-350 yrs cal BP. Thenceforth, the study area evolved to the present mangrove environment. Factors related to climatic oscillations and the formation, evolution and events of rupture of Marambaia sand ridge influenced the late Holocene evolution of the northeast intertidal area of Sepetiba Bay.

Keywords: Foraminifera. Stable isotope. Late Holocene. Guaratiba Mangrove. Environmental Evolution

1. Introduction

Sea level changes over geological time occurred in very different time and space scales (Milne et al., 2009; Church et al., 2010). Such modifications consist of the temporary result of complex interactions between continental surface and sea (Suguio, 1999; Church et al., 2011). Volume changes of ocean basins (tectono-eustasy) and variations in volume of water in the oceans (glacioeustasy) cause effects on a global scale (IPCC, 2014). On the other hand, alterations of the continents elevation (tectonics and isostasy) and modifications in the geoid form (geoidal eustasy) operate in local or regional scales (IPCC, 2014).

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The reconstruction of ancient sea levels is directly related to the determination of indicators that can provide the relative position of the past mean sea level, or paleo shoreline, at a certain place and a certain period (Suguio et al., 2005). The indicators of sea level change can be grouped into three main categories: i) geological records, such as geomorphological features related to marine terraces, marine abrasion, beach rocks, paleo beach ridges, among others; ii) biological records, represented by animal and marine plant remains, fossils and microfossils and paleo mangroves and; iii) pre-historical and archaeological records (Martin et al., 1997). More recently, other indicators have been incorporated, such as records of tide gauges and series of satellite radar altimeters, which are contributing to estimate the global mean sea level in short temporal scales.

The marine terraces are deposits of coastal sediments characterized by topographical levels related to sea level fluctuations. According to Suguio et al. (2005), marine terraces are examples of paleo sea levels above the current. The marine abrasion terraces represent erosional surfaces on older basement rocks. These erosional features arising from the wave action above the current sea level, are also indications of past sea level oscillations. For Bhatt and Bhonde (2006), marine notches are concave cavities created on the rocky shores and cliffs by wave action. In the coastal plain of Rio Grande do Sul, for example, the sea level rise due to the last deglaciation gave way to the barrier island system (Suguio and Martin, 1978).

Biological indicators – for example, carbonized tree trunks, urchin marks, mollusk remains, paleo barnacles – have indicated sudden changes of sea level in the landscape along the Brazilian coast (Angulo, 1993; Angulo and Suguio, 1995; Angulo and Lessa, 1997; Angulo et al., 1999; Andrade and Dominguez, 2003; Fernandes et al., 2002).

Urchin marks are important indicators of sea level variations, since such perforations are found in the intertidal areas (Fernandes et al., 2002). Such information is very important for the regional understanding of possible sea level oscillations, particularly those that occurred during the Quaternary.

Considering the occurrence and state of preservation, bivalve shells are seen to be good indicators of sea level changes. According to Angulo (1993), the species *Anomalocardia flexuosa* (Linnaeus, 1767), refereed as *Anomalocardia brasiliana* (Gmelin, 1791), lives below the low tide level to a few meters deep. When there is no much reworking by other organisms, these shells banks serve to indicate at least the low tide level at the period in which these bivalves lived. Based on these criteria and knowing the range of the paleo tide in the area, these indicators can unveil the paleo sea level.

Paleo barnacles have also been useful in studies on sea level changes during the Holocene. Barnacles are crustaceans that live in the intertidal zone of rocky shores environments. Marks left on the rocks by paleo barnacles can be windows onto estimating the sea level change (Pirazzoli et al., 1985).

Vermetid are gastropods with tube-shaped shells that live attached to bedrocks. The genera *Petaloconchus* Lea, 1843 and *Dendropoma* Mörch, 1861 are the most common on the Brazilian coast. Angulo et al. (1999) developed a variation curve of sea level for the coast of Paraná State using the species *Petaloconchus varians* (d'Orbigny, 1839). According to Laborel (1986), the accuracy in the evaluation of sea level range from vermetids can range from +0.1 m and +1.0 m, depending on the exposure to waves and amplitude of the tides.

Benthic foraminifera provide excellent paleoecological and paleoenvironmental proxies which can be applied to studies of sea level rise (e.g. Leckie and Olson, 2003; Carson et al., 2008; Li et al., 2013; Romahn et al., 2015). Thus, their faunal assemblages shed light on the environmental evolution along a time scale and provide important parameters for the identification of Holocene sea-level change (Horton et al., 2007; Strachan et al., 2014).

1.1 Holocene studies of sea level change in Brazil

In the coastal region of Brazil, notable evidences of the alteration of the shoreline position and in the sea level changes during the Holocene are known (Suguio and Martin, 1978). There are many studies dealing with the variations of mean sea level, during the Holocene. They were based on sedimentary/stratigraphic, geomorphological and paleontological records in Brazilian coastal areas (Castro et al., 2014 and references herein). Fluctuations in the sea level during the Holocene were important in the construction and evolution of Brazilian coastal plains (Martin et al., 1997). Factors influencing the evolution of these coastal plains were investigated by for instance Roncarati and Neves (1976), Martin et al. (1984, 1985), Suguio and Tessler (1984), Flexor et al. (1984), Suguio et al. (1985), Villwock (1994), Angulo and Lessa (1997), Turcq et al. (1999), Suguio (1999, 2003a, b) and Castro and Suguio (2010).

These studies improved the knowledge on ancient sea levels, as well as they proposed models and curves of variation of mean sea level for certain coastal regions (e.g.

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Angulo and Suguio, 1995; Angulo and Lessa, 1997; Martin et al., 1997; Angulo et al., 1999; Castro et al., 2009).

However, the used evidences do not always show very accurately the height reached by sea level. There are records that indicate that the sea level rose during the Holocene for 3 to 4 m above the current in northeastern Brazil coast (e.g., Suguio et al., 1985; Martin et al., 1986; Bezerra et al., 2003), while other studies indicate increases of less than 1 m for the same period (e.g., Angulo and Lessa 1997; Lessa and Angulo 1998; Angulo et al., 2006).

Differences in sea level detected among several locations in Brazil have been related to the influence of tectonics (Martin et al., 1986; Angulo and Suguio, 1995). In fact, an increasing number of studies have demonstrated the significance of tectonics in the development of sedimentary Quaternary successions in Brazil (Bezerra and Vita-Finzi, 2000; Costa et al., 2001; Bezerra et al., 2003; Rossetti et al., 2008a, b). Some studies have also suggested that episodes of eustatic increases along the South American plate during the Quaternary, were reinforced by subsidence due to post-rifting tectonic reactivations (Moraes-Neto and Alkmin, 2001; Bezerra et al., 2001; Barreto et al., 2002).

Moreover, despite the significant volume of studies focusing on the Holocene sea level changes, this remains a topic of great debate. No consensus even on the magnitude of the fluctuations or on the chronology of transgressive-regressive events was still reached. So the reconstruction of the history of sea level along the Brazilian coast is a matter still under consideration.

1.2. The main goal of this study

This work aims to contribute for the knowledge of sea level influence at the SE Brazilian coastal area during the late Holocene. It analyses textural, geochemical (TOC, sulfur, $CaCO_3$ and stable isotopes data) and microfaunal (benthic foraminifera) data along the core T1 (480 cm long). This core was collected at the northeast region of Sepetiba Bay, in the Guaratiba Mangrove (State of Rio de Janeiro coast). Thus, this study aims to reconstruct the paleoenvironmental evolution of Guaratiba Mangrove in the last ≈2400 yrs cal BP.

Only a small number of works aiming to study the ecology of benthic foraminifera were performed in the Guaratiba Mangrove. Zaninetti et al. (1976, 1977) conducted the first ecological study based on foraminifera in this area. These authors partitioned the mangrove into five regions, based on the diversity index of Fisher et al. (1943).

Brönnimann et al. (1981 a, b) using environmental parameters (e.g. pH, salinity, temperature and suspended material) studied several stations in tidal channels. These authors verified that species of the order Textulariida dominate the benthic foraminifera assemblages in those environments.

Laut et al. (2006, 2009, 2012) and Laut and Rodrigues (2011) established different faunal assemblages in the study area through studies of samples collected in channels and in Guaratiba Mangrove and Sepetiba Bay. These authors proposed a new division of Guaratiba Mangrove.

1.3. Study area

The Guaratiba Mangrove is situated in the northeastern region of Sepetiba Bay (southeastern Brazil coast, State of Rio de Janeiro). Mangroves are transitional ecosystems between the marine and terrestrial environments, developed on low energy intertidal zones, at sub-tropical and tropical regions (Pereira et al., 2007).

The study area is part of the Guaratiba/Sepetiba coastal complex and is bordered by the latitudes 23°00'S-23°03'S and longitudes 43°40'W-43°37'W. It is situated between the mouths of Piraquê and Piracão rivers (Figure 1). However, several other rivers flow to Sepetiba Bay such as the Guandu, Flecha and Guarda rivers.

Vast areas of Guaratiba Mangrove substrate consist of sandy sediments with abundant plant and animals (mainly mollusks and crustaceans) debris (Pereira et al., 2007, 2009). This environment should correspond to a transgressive sedimentary sequence related to the sea level rise since the last glaciation (Figueiredo Jr. et al., 1989).

The lithology around the Sepetiba Bay is essentially composed by Neoproterozoic rocks with intrusions of alkaline Cenozoic rocks and Quaternary sediments of fluvial-marine origin scattered throughout the area (SEMA, ZEE-RJ, 1996). Among the Neoproterozoic units there are tonalite, granodiorite, granite and foliated gabbro associated with the Rio Negro Complex (Tupinambá et al., 2000; Heilbron and Machado, 2003) and the Turvo River Granitoid (Machado et al., 1996). The rivers that flow toward Sepetiba Bay cross these rocks and discharge sediments resultant of the erosion of the aforementioned rocks in these coastal systems.

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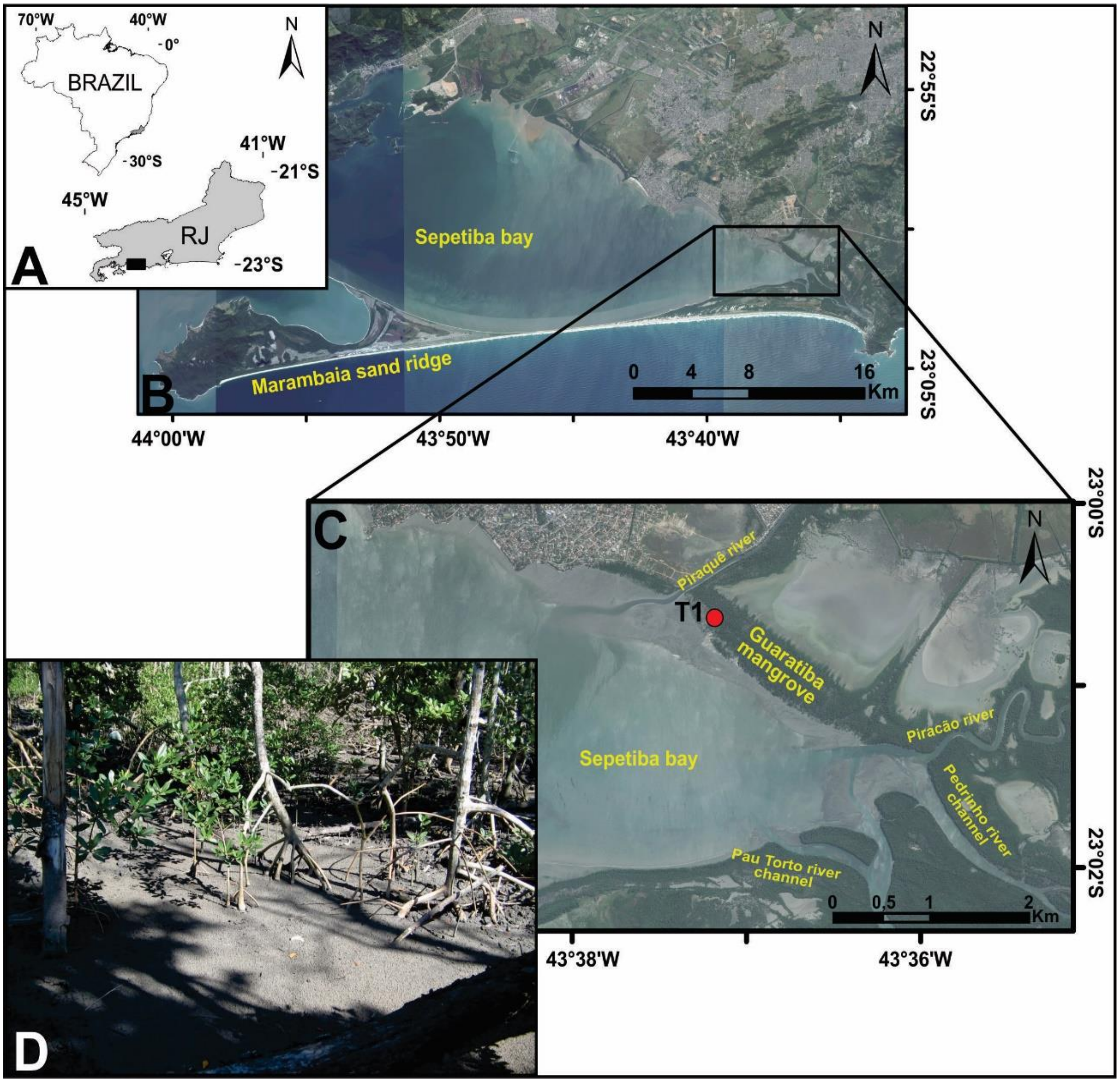

Fig. 1. A: Localization of Sepetiba Bay in the State of Rio de Janeiro (Brazil); B: Sepetiba Bay, Marambaia sand ridge and the Guaratiba tidal plain/mangrove (highlighted by the retangle with black contourn); C: Place of core T1 sampling; D: General aspects (soil, vegetation) of the sampling site.

2. MATERIALS AND METHODS

2.1. Core sampling

This work analyzes the sediments obtained along the core T1 (latitude 23°00'33.0"S, longitude 43°37'09.7"W), collected in the tidal plain of Guaratiba mangrove during low tidal conditions (Figure 2). For coring was used a Russian corer, a manual use sampler that allows the collection of successive sections of 50 cm. It was possible to acquire a core with 490 cm, divided into nine sections of 50 cm. However, considering that among each section there was loss of sediment (the length of the sampler probe), the recovered sedimentary column reached in fact 480 cm.

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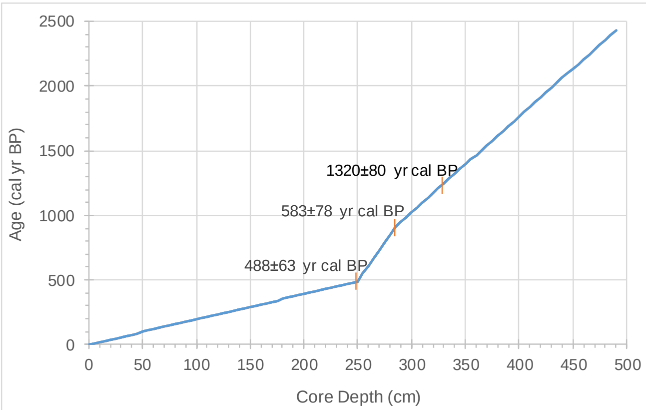

Fig. 2. Age model for core T1, obtained by linear interpolation of radiocarbon data (presented in this plot) along the core.

Each section was wrapped in plastic wrap to prevent drying and unpacked in Micropaleontology Laboratory of Universidade do Estado do Rio de Janeiro (UERJ). The core was then photographed, macroscopically described (color, texture, sedimentary structures and biogenic content) and sub-sampled in 5 cm intervals at each 10 cm. The sediments of each interval was subdivided for subsequent geochemical, particle size and foraminifera analyses.

2.2. Geochemical and textural analyzes

The samples for particle size analysis were weighted and divided into two parts: > 1.4 mm and <1.4 mm by screening. The sediment fraction <1.4 mm was submitted to analysis in the laser granulometer MasterSizer2000 mode, at Laboratory of Geological Oceanography of UERJ. This equipment uses the laser diffraction answer for determining particle sizes. The textural classification of sediments was based on Folk and Ward (Folk and Ward, 1957).

About 250 mg of each sample was submitted to total organic carbon (TOC) and total sulfur (S) analyses in the Laboratory of Chemostratigraphy and Organic Geochemistry (LGQM-UERJ), with the LECO SC-444 analyzer, which directly provided the percentage of TOC and S.

2.3. Radiocarbon dating

Mollusk shells recovered from three layers were used for radiocarbon dating. The radiocarbon analyses were performed in the Beta Analytics laboratory (Miami, Florida). This work uses the 2-sigma calibrated before present (BP) ages, based on Marine 13 database (Reimer et al., 2013; Talma and Vogel, 1993).

2.4. Foraminifera

The samples were spited in aliquots of 10 ml of sediment. The sediment fraction 500-63 µm was separated by wet sieving according to the methodology described by Schröder et al. (1987). The sediments fractions >500 µm and <63 µm were discarded.

After washing, the samples were dried in an oven at ≈50°C. In the dry material was added Trichloroethylene (C_2HCl_3), which resulted in the separation of foraminifera tests by flotation, due to their lower density than most part of terrigenous particles (Scott et al., 2001). The supernatant material was recovered in a filter paper. Foraminiferal tests were separated from the sediment, identified and counted under a binocular microscope and fixed in microslides (Uehara et al., 2007). All the specimens found were identified and counted in each sample (10 ml). So foraminifera density is the number of specimens per species per 10 ml of sediment. The species richness (the number of species) was determined for each sample.

The species identification was based on several references, such as Cushman and Brönnimmann (1948 a, b), Tinoco (1965), Loeblich and Tappan (1988), Debenay et al. (1998), Semensatto-Jr. and Dias-Brito (2004), Murray (2006) and Laut et al. (2012). The suprageneric classification follows the World Register of Marine Species (WoRMS: http://www.marinespecies.org/index.php; accessed on 03.01.2016).

2.5. Carbon and oxygen isotopes ($\delta^{13}C$ and $\delta^{18}O$)

The stable isotopes were obtained in 10 to 15 specimens of *Ammonia tepida*. Data were held in LGQM-UERJ. *Ammonia tepida* was chosen since it is the most common calcareous species along the core and in the study area (Brönnimmann et al., 1981 a, b).

The specimens for isotopic analysis were first washed in ultrasound with distilled water to remove impurities and milled. The carbonated powder was stored in a glass container. Each sample was placed to react with orthophosphoric acid to 100%, at 25°C during 12 hours. The CO_2 released during the reaction was extracted in a high vacuum line using cryogenic purification by following the method proposed by Craig (1957).

The "Kiel IV Carbonate Devise" equipment and "Delta V Plus - Isotope Ratio MS" analyzer (Thermo Scientific) were used for isotopic analysis. The obtained results are

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compared with a standard carbonate, the Pee Dee Belemnite (PDB). Data from carbon and oxygen isotopes are shown by the δ parameter defined by: δ (‰) = [R_{sample} - $R_{standard}$ /$R_{standard}$) × 1000. In this parameter, R values correspond to C^{13}/C^{12} and O^{18}/O^{16}. The accuracy of the analysis is 0.030 ‰.

2.6. Statistical analysis

Only the most abundant and frequent species of benthic foraminifera along the core were considered in statistical analysis. Before to be submitted to statistical analysis, data were logarithmically transformed [log (x+1)]. This work analyses Pearson correlations. Correlations are significant for p>0.05. Selected data also were submitted to Principal Components Analysis (PCA) to assess the relationship between selected variables. These analyzes were conducted in the software Statistica 12.0.

3. RESULTS

3.1 The core age model of the core T1

Table 1 presents the results of the radiocarbon dating. The radiocarbon results provide ages from 550 to 425 yr cal BP (400±30 yr cal BP), from 660 to 505 yr cal BP (540±30 yr cal BP) and from 1400 to 1240 yr cal BP (1310±30 yr cal BP) for the depths 250 cm, 285 cm and 340 cm, respectively. The estimated mean sedimentation rates were determined (ranging from 0.10 cm/yr and 0.51 cm/yr) and presented in Table 1.

The model ages for the core T1 was obtained through linear interpolation of the results of radiocarbon data (Fig. 2). This age model suggests an age of ≈2400 yr cal BP for the core base.

3.2. Particle size of the core T1

Supplementary material 1 (SM1) presents data of sediment granulometry, namely percentage of coarse (1000-500 μm), medium (500-250 μm), fine (250-125 μm) and very fine sand (125-63 μm), as well as very coarse (63-31 μm), coarse (31-16 μm), medium (16-8 μm), fine (8-4 μm), very fine silt (4-2 μm) and clay (<2 μm) fractions.

Figure 3 represents the stratigraphic column of the core T1. It shows that this core consists essentially of fine sand. It contains bioclasts (fragments of mollusk shells and entire valves) in its middle section. Oxidized plant fragments also were identified from 160 cm to the core top.

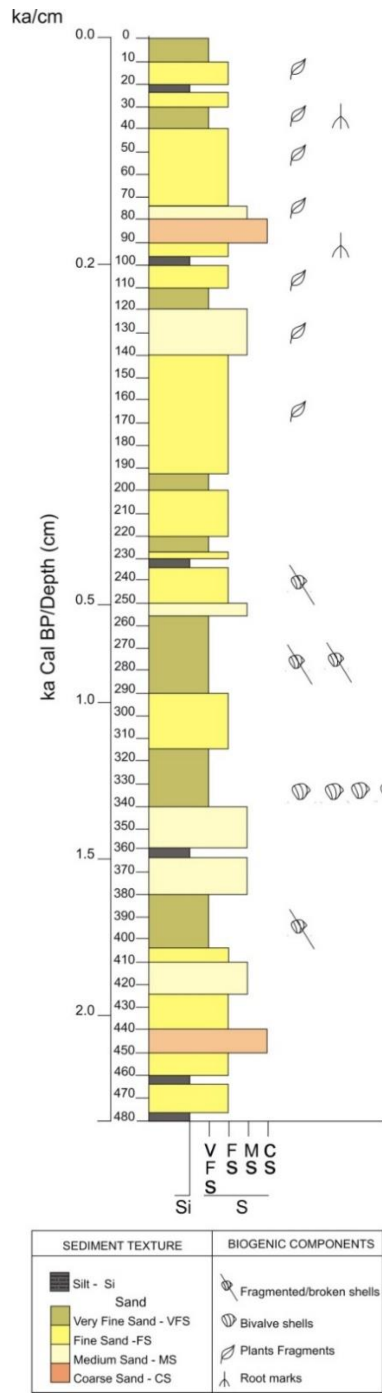

Fig. 3. Textural description of core T1. A depth (cm) and an age scales (ka cal BP) are presented.

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Tab. 1. Measured, conventional and calibrated Before Present (BP) and Ano Domine (AD) radiocarbon ages for the analyzed core levels. Evaluated mean sedimentation rate (cm/yr) are also presented.

Depth (cm)	Measured Radiocabon Age (BP)	$\delta^{13}C$ (‰)	Conventional Radiocarbon Age (yr cal BP)	Calibrated Age Before Present (yr cal BP)	Calibrated Age *Ano Domine* (yr cal AD)	Mean Sedimentarion rate (cm/yr)
250	400 ± 30	0.1	810 ± 30	550 to 425 (488±63)	1400 to 1525 (1463±63)	0.51
285	540 ± 30	0.8	940 ± 30	660 to 505 (583±78)	1290 to 1445 (1368±78)	0.10
340	1310 ± 30	0.9	1710 ± 30	1400 to 1240 (1320±80)	550 to 710 (630±80)	0.13

In the SM2 are presented the results of sedimentary mean grain size (SMGS, µm), the particle size modes, as well as sorting (σ), skewness (ϕ), kurtosis (K) and sediment textural classification. Figure 4 includes depth plots of sediment mean grain size (SMGS, µm), coarse + medium sand fractions (%) and fine fraction (<63 µm, %). The values of sorting (σ), skewness (ϕ) and kurtosis (K) are also included in this figure. These plots show that the values of SMGS (ranging from 31 µm to 598 µm, average 185 µm) increase cyclically, such as between 450-400 cm, 370-340 cm, 255-240 cm, 175-115 cm and 90-60 cm. These sections with coarser grain size are characterized mainly by the increase of total coarse + medium sand fractions (1000-250 µm).

The sediments of the core T1 are composed mainly by sand fraction (>63 µm; 94-24%, average 69 %). The fine fraction (<63 µm) content varies between 69-6% (average 30%). The most abundant fine fraction is coarse silt (63-31 µm), ranging from 29% to 1% (average 15%; SM1). Among the fine fractions, clay fraction (<2 µm) is the less abundant (<7%; SM1). The sediments grain sizes of this core are in general composed by two modes of particle size. The average values of mode 1 is ≈380 µm and of mode 2 is ≈243 µm. In the coarser sections, the sediments only display one granulometric mode, which can also be observed in the finest core layers.

Sorting (σ) values ranged from 5.94 to 2.04, at 480 cm and 440 cm, respectively (average 3.46, SM2). Thus, the core T1 is composed mostly of poorly sorted fine and very fine sand (SM1). Sediment skewness (ϕ, or symmetry) varies between 0.16 and -0.67 (average -0.18). The sediments are mostly symetrical to very fine skewed. Skewness values become much more negative in layers with coarser sediments, between 440-425 cm (-0.48 to -0.37), 370-340 cm (-0.61 to -0.54), and 85 cm (-0.64). The most positive values of skewness were identified in the layers of 315 cm (0.12), 275 cm (0.13), 195 cm (0.15) and 65 cm (0.13), all containing predominantly very fine sand. The kurtosis values oscillate in turn of a medium value (1.01) along the core, with predominance of mesokurtic sediments.

3.3. Geochemistry

The SM1 presents the results of total organic carbon (TOC, %), total sulfur (S, %), calcium carbonate ($CaCO_3$, %). In Figure 5, the depth plot of sediment mean grain size (SMGS, µm) is compared with TOC (%), $CaCO_3$ (%) and S (%). TOC content ranges from 0.62% to 7.03%. TOC values below the average (1.85%) were recorded in the section 480-130 cm. In the upper 250 cm, there is a tendency to the TOC content increasing (R^2 = 0.66; Fig. 5).

Calcium carbonate content varied between 10% and 23% (average 16%). An upward increasing trend of this variable values is observed (R^2 = 0.63, Fig. 5). The S content ranged from 0.12% to 1.13% (average 0.63%). In general, lower S contents were registered in the sections 350-120 cm and 40-0 cm. Between 350 and 120 cm, there are relatively low TOC concentrations. The highest values of TOC of core T1 were recorded in the section 40-0 cm.

Stable isotope data were obtained in the section 340-185 cm, due to the presence of enough calcareous foraminifera. In that section, $_{A.tepida}\,\delta^{18}O$ values ranged from -4.769 ‰ to -1.201 ‰ and of $_{A.tepida}\delta^{13}C$ between -4.598 ‰ and -1.851 ‰ (Table 2). Figure 6 presents the depth plots of $_{A.tepida}\,\delta^{18}O$ and $_{A.tepida}\,\delta^{13}C$. These depth plots evidence that these data varied cyclially. Simultaneous increases of $_{A.tepida}\delta^{18}O$ and $_{A.tepida}\delta^{13}C$ values are observed.

Tab. 2. Values of $_{A.tepida}\delta^{18}O$ (‰) and $_{A.tepida}\delta^{13}C$ (‰) in the section 340-185 cm of core T1.

Depth (cm)	$_{A.tepida}\delta^{18}O$ (‰)	$_{A.tepida}\delta^{13}C$ (‰)
185	-1.201	-1.851
195	-1.397	-2.237
205	-1.434	-2.487
220	-1.470	-2.675
230	-1.528	-2.490
240	-1.532	-1.583
250	-1.625	-2.395
260	-1.808	-2.753
275	-1.869	-2.610
285	-2.184	-3.096
295	-2.438	-2.492
305	-2.879	-3.574
315	-4.409	-4.437
340	-4.769	-4.598

3.4. Benthic foraminifera

The amount of 31 species of benthic foraminifera was identified, 15 calcareous and 16 agglutinated (SM3). The results of foraminifera density (nº/10 ml) and species richness (SR, number of species per sample) can be observed in SM1. Foraminifera density along the core ranged from 0 to 325 specimens/10 ml. Foraminifera are rare or absent between 480-350 cm, at 130 cm, between 95-75 cm and between 55-30 cm. The highest foraminifera density was observed between 340-165 cm, at 110 cm, at 65 cm and in the first 20 cm of the core.

In the section 340-165 cm, foraminifera assemblages are composed mostly of calcareous species. Instead, at 110 cm, 65 cm and in the first 20 cm of the core, these assemblages include mostly agglutinated foraminifera. Between 195-175 cm, the assemblages contain both calcareous and agglutinated foraminifera.

Specific richness (SR) varied between 0-11 species per sample, reaching the highest values in the sections with higher foraminifera density. Foraminifera density and SR reach the highest values in the section 315-260 cm, where the highest values of $_{A.tepida}\delta^{18}O$ and $_{A.tepida}\delta^{13}C$ are recorded (Fig. 6). A reduction of $_{A.tepida}\delta^{13}C$ values seems to occur in the section 230-185 cm followed by a general reduction of foraminifera density and SR (Fig. 6). This trend is less clear for $_{A.tepida}\delta^{18}O$.

The list of species identified along the core T1 is presented in SM3 and the species density (nº/10 ml) in SM4. The most abundant and common species along the core are *Ammonia parkinsoniana*, *Ammonia tepida*, *Ammonia* sp., *Arenoparrella mexicana*, *Cribroelphidium excavatum*, *Cribroelphidium poeyanum*, *Elphidium gunteri*, *Elphidium* sp., *Entzia macrescens*, *Haynesina germanica* and *Trochammina inflata*.

Figure 7 presents the depth plots of absolute abundance (nº/ 10 ml) of the main taxa and species groups of benthic foraminifera of the core T1. *Ammonia parkinsoniana*, *A. tepida, Criboelphidium/Elphidium* spp. and *H. germanica* are the most abundant species in the section 340-165 cm. In addition, the species *Bolivina striatula* and *Buliminella elegantissima* have also significant occurrences between 350-175 cm. Instead, in the upper 150 cm, where foraminifera assemblages are composed only by agglutinated foraminifera, the most abundant species is *A. mexicana*. Other species were also observed, such as, *E. macrescens*, *Haplophragmoides manilaensis*, *Haplophragmoides wilberti*, *Miliammina fusca* and *T. inflata*.

3.5 Statistical results

In SM5 are presented the Pearson's correlations obtained for all analyzed layers of the core T1 considering the following variables: SMGS (μm), very fine sand fraction (63-125 μm, %), TOC (%), S (%), foraminifera density (nº/ 10 ml). The abundance (nº/ 10 ml) of the following species was also considered: *A. parkinsoniana, A. tepida, A. mexicana, B. striatula, B. elegantissima, C. excavatum, C. poeyanum, Cribroelphidium vadescens, Elphidium discoidale, E. gunteri, Elphidium* sp., *E. macrescens, H. germanica* and *T. inflata*.

The SM5 shows that: i) very fine sand fraction (63-125 μm) has significant positive correlations with foraminifera density and SR; ii) TOC has significant positive correlations with $CaCO_3$, *A. mexicana*, *T. inflata* and *E. macrescens* and negative one with most of the calcareous species such as *A. parkinsoniana*, *A. tepida*, *B. striatula*, *B. elegantissima*, *C. excavatum*, *C. poeyanum*, *E. discoidale*, *E. gunteri* and *H. germanica*; iii) the main calcareous species have significant positive correlations with each other; iv) *A. tepida* has significant positive correlation with *B. elegantissima*; v) *A. parkinsoniana* displays significant positive correlation with *B. striatula*; and vi) S has significant negative correlations with $CaCO_3$, SR, foraminifera density and several calcareous species, such as *A. parkinsoniana*, *A. tepida*, *A. mexicana*, *C. excavatum*, *C. poeyanum*, *T. inflata* and *E. macrescens*.

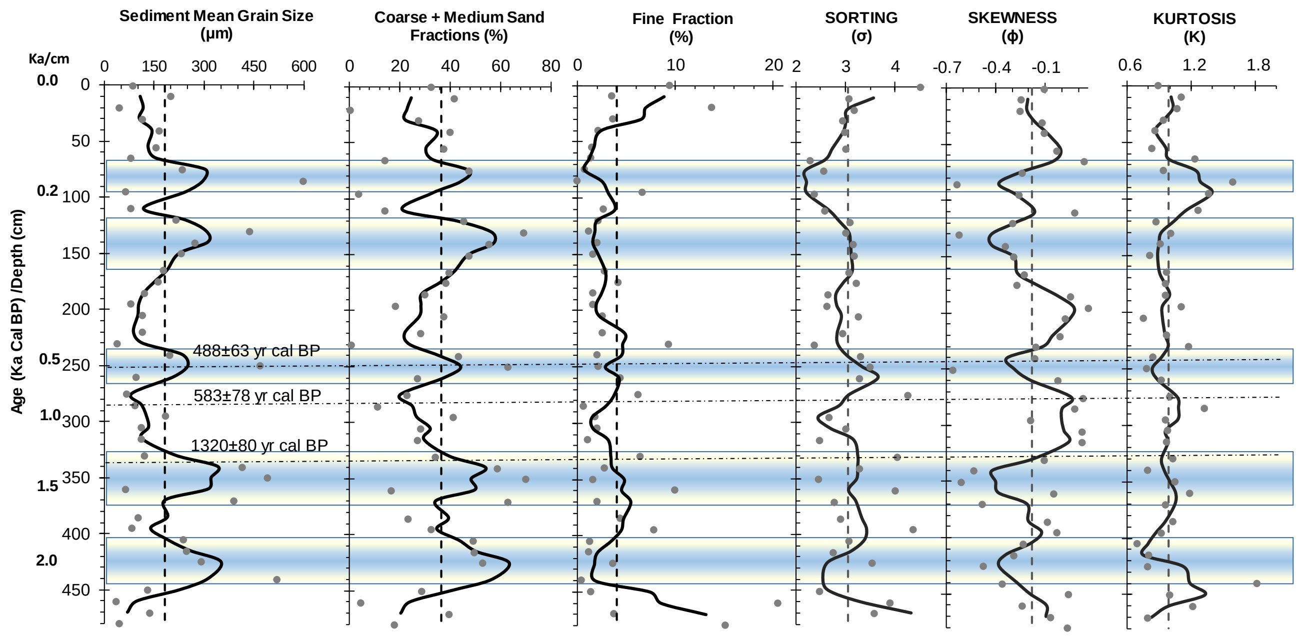

Fig. 4. Depth plots of sediment mean grain size (SMGS; µm), coarse + medium sand fractions (%) and fine fraction (%). The values of sorting (σ), skewness (ϕ) and kurtosis (K) are also included in this figure. The values of each variable are represented by points, the mean of the values in black dotted line, and the moving mean average with the black solid line. An age scale based on estimated yr cal BP are represented as well as the radiocarbon results of the dated levels.

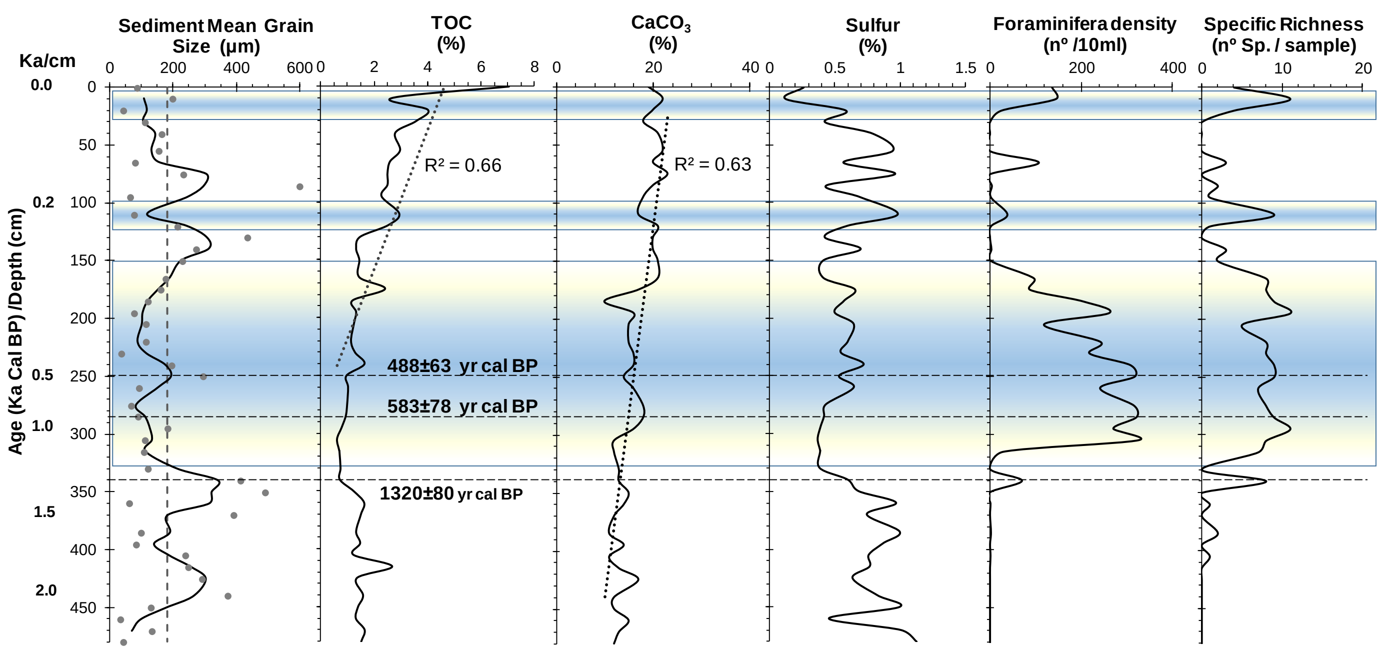

Fig. 5. Depth plots of sediment mean grain size (SMGS; µm), TOC (%), $CaCO_3$ (%) and S (%) and biotic parameters - foraminifera density (nº/10 ml) and species richness. In the depth plot data are represented by points, the mean of the values in grey dotted line and the moving mean average with the black solid line. An age scale based on estimated yr cal BP are represented as well as the radiocarbon results of the dated levels.

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The correlations between these variables are expressed in the results of the two first factors, of PCA presented in Figure 8A. The biplot of Factor 1 against Factor 2 (which explains 58% of data variability) allow us to distinguish four main groups of variables. These groups are composed of the following variables: I - TOC and S; II – SR, foraminifera density, very fine sand fraction (63-125 µm), *A. parkinsoniana, A. tepida, B. elegantissima, B. striatula, C. excavatum, C. poeyanum, C. vadescens, E. discidale, E. gunteri* and *H. germanica*; and III-TOC, $CaCO_3$, *A. mexicana, E. macrescens* and *T. inflata*; IV – S.

Total organic carbon is the only variable with significant positive correlation ($p > 0.50$) with the Factor 1, which explains 0.40 of data variability (Table 3). This factor has significant negative correlations with several variables, such as: SR, foraminifera density, *A. parkinsoniana, A. tepida, B. striatula, C. excavatum, C. poeyanum, C. vadescens, E. discidale, E. gunteri, Elphidium* sp. and *H. germanica*. Factor 2 (which explains 0.18 of data variability) has significant positive correlation ($p > 0.50$) with TOC, *E. macrescens, T. inflata* and *A. mexicana*.

Figure 9 includes the depth plots of the Factor Score 1 and 2 along the core T1 of the PCA of Figure 8A, in comparison with foraminifera density, abundance of agglutinated species and the values of C/S ratio. The values of Factor Score 1 decrease significantly in turn of ≈340 cm and in the section 330-165 cm in coincidence with foraminifera density increase. Factor Score 2 increases mostly at 195 cm, 110 cm, 65 cm and in the first 20 cm. The rise of Factor Score 2 values corresponds to the rises of agglutinated foraminifera abundance. The values of C/S ratio increase slightly between 175-30 cm and have a very sharp rise from 20 cm to the core top.

In the section 185-340 cm, stable isotopic data (obtained in *A. tepida* tests) were confronted through the Pearson's correlations (SM6) with selected variables (SR, foraminifera density, species abundance and abiotic parameters). The values of $_{A.tepida}\delta^{18}O$ and $_{A.tepida}\delta^{13}C$ have significant positive correlations with each other and with SR, foraminifera density, *A. mexicana, B. elegantissima* and *B. striatula*. The values of $_{A.tepida}\delta^{18}O$ also are positively correlated with TOC content.

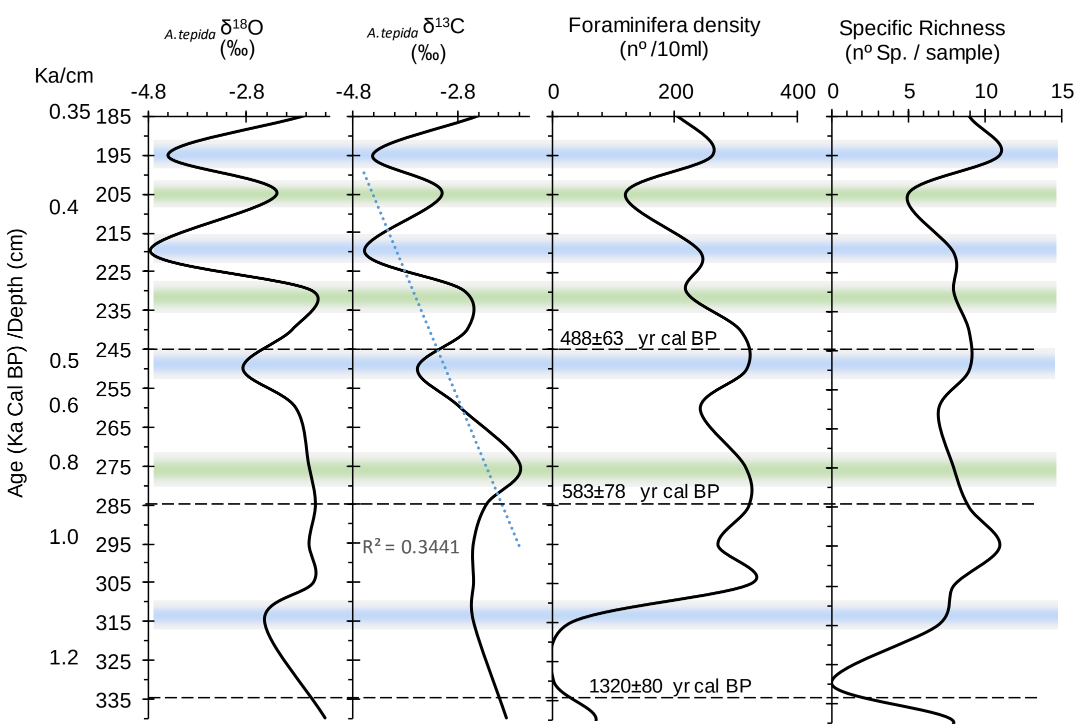

Fig. 6. Isotopic values of $_{A.tepida}\delta^{13}C$ and $_{A.tepida}\delta^{18}O$, foraminifera density (nº/10 ml) and SR (number of species per sample) between 340-185 cm on the core T1. An age scale based on estimated yrs cal BP are represented as well as the evaluated radiocarbon dates.

Tab. 3. The variables with significant correlations (*p*> 0.50) with Factors 1 and 2, which explains 58% of data variability, of PCA analysis (Fig. 8). Significant correlations are marked in bold.

Variables / Factors	Factor 1	Factor 2
Sediment mean grain size (µm)	0.18	-0.25
Very fine sand fraction (%)	-0.35	0.21
Total organic carbon (%)	**0.50**	**0.58**
Total Sulfur (%)	0.40	-0.43
Calcium carbonate (%)	0.13	0.41
Species Richness (nº species /sample)	**-0.84**	0.37
Foraminifera Density (nº/10 ml)	**-0.89**	0.35
Ammonia parkinsoniana (nº/10 ml)	**-0.91**	-0.06
Ammonia tepida (nº/10 ml)	**-0.96**	-0.10
Arenoparrella mexicana (nº/10 ml)	0.06	**0.90**
Bolivina striatula (nº/10 ml)	**-0.70**	0.08
Buliminella elegantissima (nº/10 ml)	-0.43	0.30
Cribroelphidium poeyanum (nº/10 ml)	**-0.90**	-0.23
Cribroelphidium vadescens (nº/10 ml)	**-0.57**	0.13
Elphidium discoidale (nº/10 ml)	**-0.51**	-0.22
Cribroelphidium excavatum (nº/10 ml)	**-0.92**	-0.22
Elphidium gunteri (nº/10 ml)	**-0.76**	-0.23
Elphidium sp. (nº/10 ml)	**-0.62**	-0.10
Haynesina germanica (nº/10 ml)	**-0.83**	0.06
Trochammina inflata (nº/10 ml)	-0.02	**0.88**
Entzia macrescens (nº/10 ml)	-0.10	**0.86**
Explained variability	0.40	0.18

These correlations are expressed in the groups established by the PCA of Figure 8B. In the biplot of the two first factors of this PCA (which explain 51% of data variability), we can highlight the group II (which is related to finer grained sediments since it is in opposition to group I, composed by medium to coarse sand fractions) and is composed of the following variables: $_{A.tepida}\delta^{18}O$ and $_{A.tepida}\delta^{13}C$, TOC, SR, foraminifera density, $CaCO_3$, *A. parkinsoniana, A. tepida, H. germanica, C. poeyanum* and *C. vadescens*.

Group III of this PCA also group *B. striatula, B. elegantissima, A. mexicana, E. macrescens* and *T. inflata* with TOC. These results evidences that the most positive stable isotopic values are related to the rise of TOC, foraminifera density, due to the expansion of several calcareous species, and diversity. They also show that in an environment characterized by relatively low concentrations of TOC, the increase of this variable determine a proliferation of *B. striatula, B. elegantissima* and of the reported agglutinated species.

4. DISCUSSION

4.1. Sedimentological characteristics of core T1

The sediments of the core T1 are composed essentially of lithogenic materials including mostly quartz. It also displays in the middle section of the core (between 340-150 cm) abundant carbonated biogenic particles (mollusk shells and foraminifera tests). Terrestrial plant remains are observed in the first 150 cm.

This core is composed mostly of poorly sorted fine and very fine sand with a coarser constituent (composed of medium to coarse sand) that increases cyclically (such as at 450-400 cm, 370-340 cm, 255-240 cm, 175-115 cm and 90-60 cm). These characteristics reveal that the hydrodynamism related to transport and deposition of the sediments changed from moderate to relatively high during the last 2400 yrs cal BP, in the study area.

The occurrence of stronger hydrodynamic conditions occurred at a centennial scale, around for instance: ≈2000 yrs cal BP, ≈1500 yrs cal BP, ≈500 yrs cal BP, ≈250 yrs cal BP and ≈100 yrs cal BP.

On the other hand, in the section 340-165 cm, the sediments tend to be in general finer and to have lower values of sorting and skewness and intermediate values of kurtosis. These results suggest that the sediments deposited between ≈1300 yrs cal BP and ≈300 yrs cal BP tended to be better sorted, coarser skewed and more platykurtic, except around 500 yrs cal BP. These textural characteristics indicate a longer prevalence of relatively weak and less variable conditions which were interrupted by stronger hydrodynamic events at about 500 yrs cal BP.

The percentage of TOC and S in the sediments deposited in the period ≈1300-300 yrs cal BP (between 340-165 cm, the middle section of the core) is relatively low, but display well preserved shells and bioclasts of mollusks and relatively high density of calcareous benthic foraminifera.

The sediments tend to be also finer in the upper section of the core, corresponding to the last ≈100 yrs cal BP (the upper 50 cm). In this period, the values of sorting and kurtosis tend to rise, and skewness to decrease. These

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characteristics reveal that the sediments became each more poorly sorted, less coarse skewed and more lepticurtic, which should be related to each more low hydrodynamics but intercalated with phases with more energetic currents.

These reported textural features agree with the current Guaratiba Mangrove setting, which is a low energy intertidal zone (Pereira et al., 2007)

The S content tends to rise in the sections where TOC percentage is relatively high. However, S has the lowest concentrations in the upper core section, where there are the highest TOC concentrations.

These results indicate that the S values should be related essentially to diagenetic reactions arising from organic matter degradation and biogenic formation of pyrite (FeS), in anoxic environments (Saunders et al. 1997; Kohn et al. 1998).

The reduction of S concentrations in the upper 40 cm of this core should be related to less favorable conditions for pyrite formation and preservation, regardless of the highest TOC content (Martins et al., 2015a).

The relatively large spaces between the sandy grains allows the oxygen penetration and the anoxia is established in deep layers of the sedimentary column.

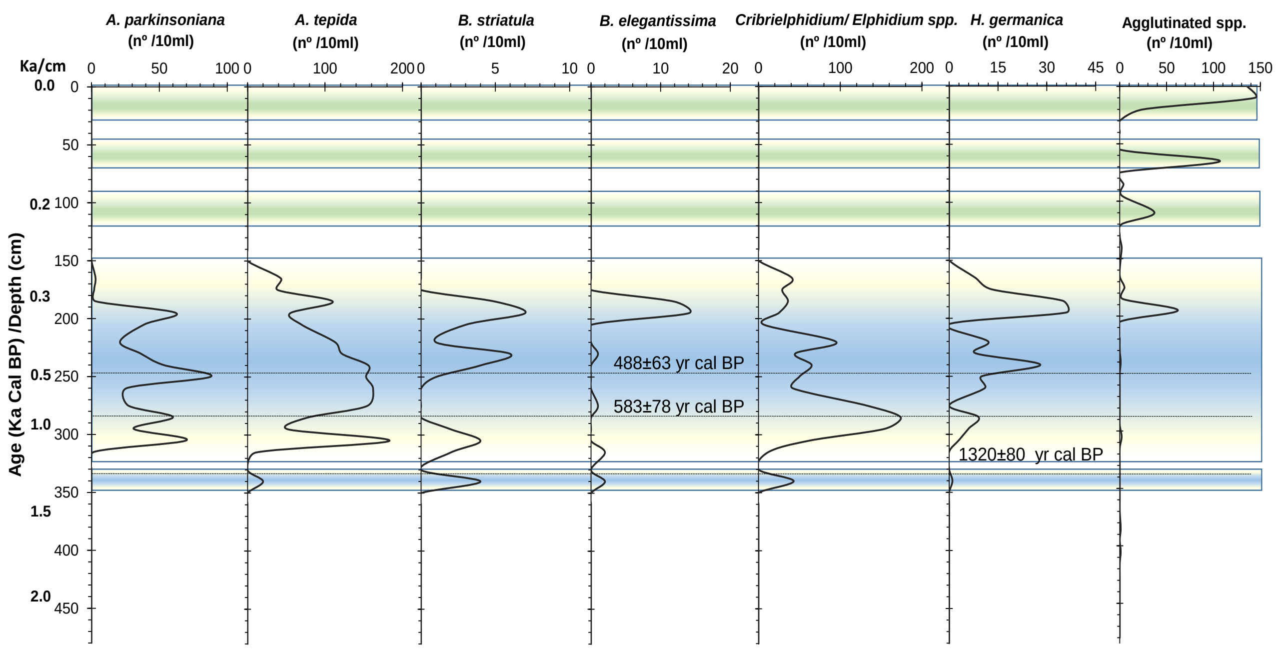

Fig. 7. Presents the depth plots of absolute abundance (nº/10 ml) of the main taxa and species groups of benthic foraminifera from core T1. An age scale based on estimated yrs cal BP is represented as well as the radiocarbon results of the dated levels.

4.2. Foraminifera assemblages composition

The benthic foraminifera assemblages along the core T1 display relatively low species richness, including mostly *A. parkinsoniana, A. tepida, A. mexicana, C. excavatum, C. poeyanum, E. gunteri, Elphidium* sp., *H. germanica, T. inflata* and *E. macrescens*. This kind of species are common in the Guaratiba Mangrove as well as in Sepetiba Bay, as observed by Zaninetti et al. (1976, 1977), Brönnimann et al. (1981a, b), Laut et al. (2006, 2009, 2012, 2014) and Laut and Rodrigues (2011). They are also common in other worldwide transitional systems (Murray 1991, 2006; Coccioni et al., 2009; Frontalini et al., 2009, 2010, 2011; Camacho et al., 2015; Clemente et al., 2015; Laut et al. 2016; Martins et al., 2010, 2011, 2013, 2014, 2015b, c, d, 2016).

The dimension and structure of the benthic foraminifera assemblages present significant changes along the core T1. These variations are partially related to the sediments grain size and composition, as indicated by the results of the PCA shown in Figure 8A and Pearson's correlations (SM5).

The arrangement of Group II of the PCA (Figure 8A) shows that SR and foraminifera density and the abundance of *A. parkinsoniana, A. tepida, B. striatula, B. elegantissima, C. excavatum, C. poeyanum, C. vadescens, E. discidale, E. gunteri* and *H. germanica* are mostly related to the increase in the very fine sand fraction (63-125 µm).

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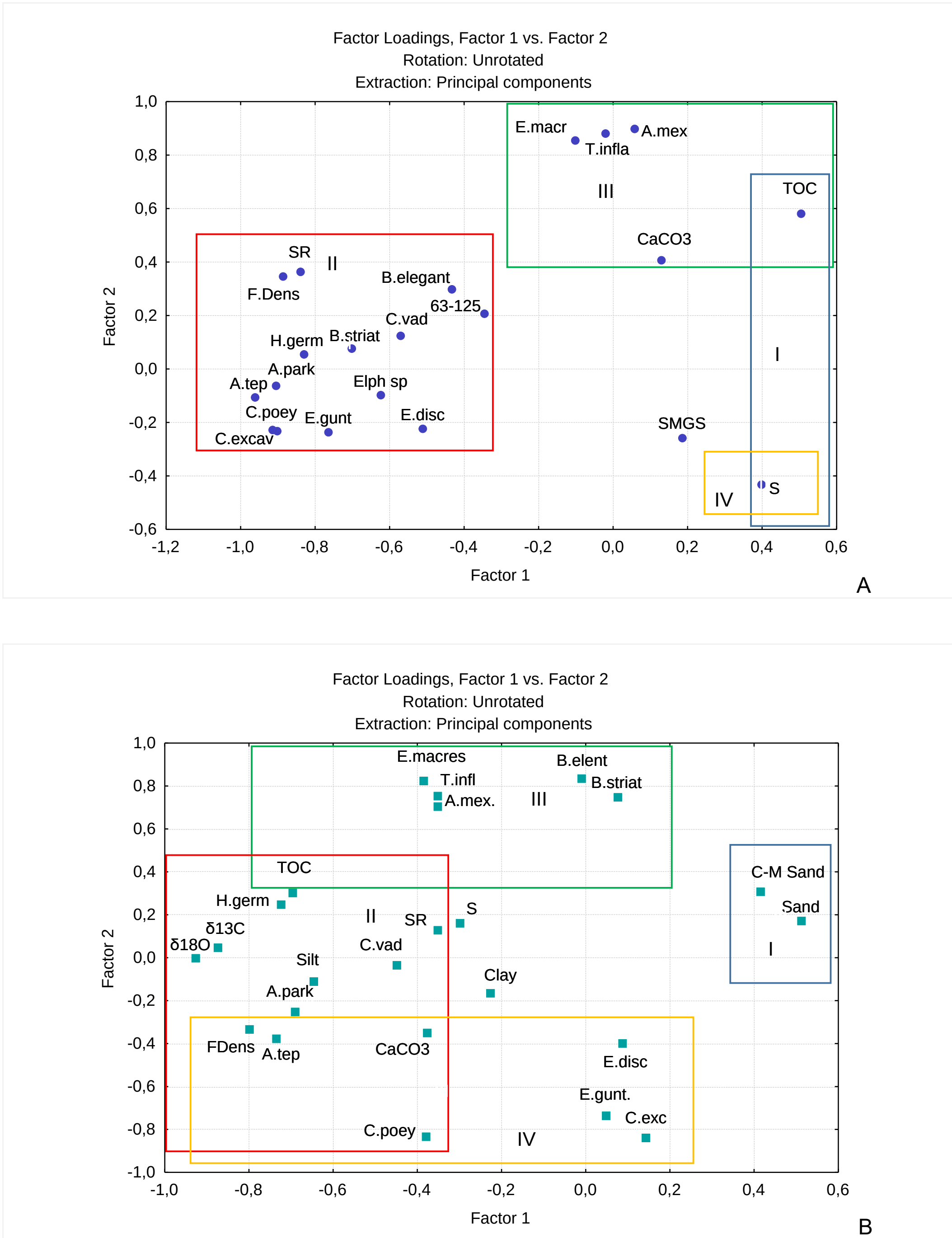

Fig. 8. Principal Components Analysis (PCA) results based on the most significant variables (species abundance and abiotic parameters). A - in all the studied core T1 layers; B - based on the core T1 layers with isotopic data, this is in the section 185-340 cm. Figure legend: SMGS - sediment mean grain size (μm); 63-125 - very fine sand fraction (%); TOC - total organic carbon (%); S- total sulfur (%); $CaCO_3$ - calcium carbonate (%); SR - species richness (nº species /sample); F.Dens - foraminifera density (nº/10 ml); A.park - *Ammonia parkinsoniana* (nº/10 ml); A.tep - *Ammonia tepida* (nº/10 ml); A.mex - *Arenoparrella mexicana* (nº/10 ml); B.striat - *Bolivina striatula* (nº/10 ml); B.elegant - *Buliminella elegantissima* (nº/10 ml); C.poey - *Cribroelphidium poeyanum* (nº/10 ml); C.vad - *Cribroelphidium vadescens* (nº/10 ml); E.disc - *Elphidium discoidale* (nº/10 ml); C.excav - *Cribroelphidium excavatum* (nº/10 ml); E.gunt - *Elphidium gunteri* (nº/10 ml); Elph. sp. - *Elphidium* sp. (nº/10 ml); H.germ - *Haynesina germanica* (nº/10 ml); T.infla - *Trochammina inflata* (nº/10 ml); E.macr - *Entzia macrescens* (nº/10 ml).

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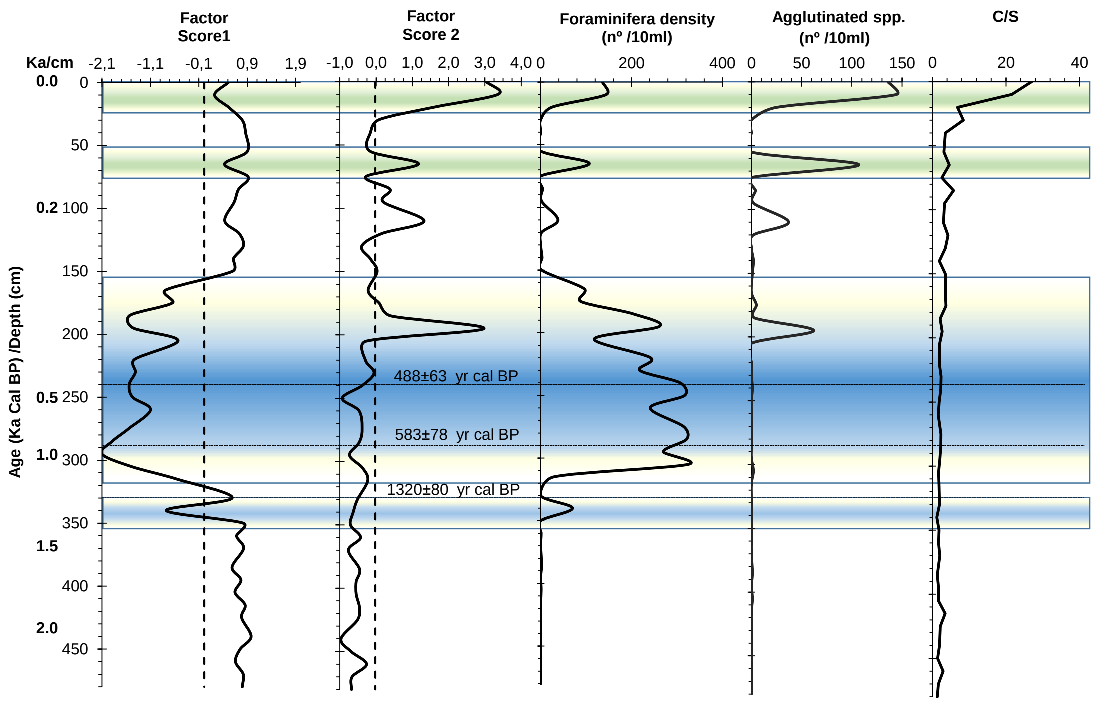

Fig. 9. Depth plot of the factor scores 1 and 2 along the core T1 (in solid black line and the mean of the values for each factor in black dotted line). These graphs are compared with the depth plots of foraminifera density (nº/10 ml), abundance of agglutinated species (nº/10ml) and the values of the C/S ratio. An age scale based on estimated yr cal BP are represented as well as the evaluated radiocarbon dates. The blue bands represent an immersion period of the study area and the green bands represent the development and establishment of the current mangrove.

Inversely, the species *E. macrescens, T. inflata* and *A. mexicana* are mostly linked with TOC and $CaCO_3$ enrichment. These variables reach the highest values in the core top, where calcareous species are absent giving place to agglutinated fauna as referred. These results suggest that benthic foraminifera assemblages dimension and structure were influenced by the hydrodynamics and the evolution of environmental conditions.

The Factor 1 of the PCA (Figure 8A) has significant positive correlation of with TOC and the negative with SR, foraminifera density, *A. parkinsoniana, A. tepida, B. striatula, C. excavatum, C. poeyanum, C. vadescens, E. discidale, E. gunteri, Elphidium* sp. and *H. germanica* indicate a strong negative impact of the excessive enrichment of organic matter on the microfauna. The extreme enrichment of organic matter causes the reduction of benthic foraminifera dimension and diversity and the loose of the calcareous species in the upper core layers deposited in last ≈300 yrs cal BP (upper 150 cm).

Else processes of organic matter degradation produce organic acids which can contribute to the pH declining in the sediments and to the dilution of calcareous tests (Martins et al., 2015 b, c) or to cause foraminifera inability to calcify the walls of their tests (Nooijer et al., 2009; Uthicke et al., 2013).

We should expect that the reduction of pH has been the main cause of the complete decline of the calcareous species in the last ≈300 yrs cal BP (upper 150 cm). However, this seems not to be completely true, since a gradual upward increase in carbonate content is observed. Else, the highest percentages of carbonates are found in the upper 160 cm of the core T1 in coincidence with the highest TOC content.

These results indicate that carbonates of these sediments are not only related to materials from the source rocks eroded by the rivers and supplied to the study area. Carbonates can also be deposited in evaporitic series under dry environments (e.g. Warren, 1989, 1999; Rouchy et al., 2001). This possibility agrees with the present day characteristics of Guaratiba Mangrove, a hypersaline transitional ecosystem (Pereira et al., 2007), which seems to be favorable to the precipitation of carbonates.

In the middle core section (340-150 cm), the sediments are fine grained, but the TOC values are relatively low. This section is characterized by a diversified and abundant fauna

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of foraminifers dominated by calcareous species. In such conditions, foraminifera fauna answers positively to the slight increase in organic matter. This is indicated by both SR and foraminifera density and by the abundance of *A. parkinsoniana, A. tepida, H. germanica, C. poeyanum* and *C. vadescens* (Fig. 8B; Group II). This is also suggested by the increase of species such as *B. striatula, B. elegantissima, A. mexicana, E. macrescens* and *T. inflata* (Figure 8B; Group III). These species are known to be linked to high organic matter content in this region (Laut et al. 2006, 2009, 2011, 2012; Laut and Rodrigues, 2011) or other in coastal systems (e.g. Coccioni et al., 2009; Frontalini et al., 2009, 2010, 2011; Martins et al., 2010, 2011, 2013, 2015 b, c, d, 2016; Clemente et al., 2015).

In some layers of the core T1, the benthic foraminifera assemblages are small and composed of both calcareous and agglutinated species, such as between 195-175 cm. In these layers, species such as *B. striatula, B. elegantissima* coexist with *A. mexicana*. The increase of these species is related to the rise of TOC content in the period between ≈380-350 yrs cal BP. Thus these layers may represent paleoevents of increased supply of organic matter to the benthic environment and depleted oxygen in sedimentary pore-waters.

These species are known for their opportunistic behavior when the supply of organic matter increase and by their tolerance to low oxic conditions (Brönnimann et al., 1981 a, b; Sen Gupta and Machain-Castillo, 1993; Moodley et al., 1997, 1998; Semensatto-Jr et al., 2004; Laut et al., 2009). This is also a transitional assemblage from the essentially calcareous foraminifera assemblies developed in the period ≈1300-380 yrs cal BP (340-195 cm) to the exclusively agglutinated microfauna that populated the area in the last ≈300 yrs cal BP (150-0 cm).

The foraminifera assemblage of the last ≈300 yrs cal BP (150-0 cm) includes species such as *A. mexicana, E. macrescens, H. manilaensis, H. wilberti, M. fusca* and *T. inflata*. The presence of these species and the absence of calcareous species in that layers are indicative of a typical mangrove fauna associated with a very high supply of organic matter, erratic and great oscillations of environmental parameters and high salinity values (Laut et al., 2006, 2011, 2012; Laut and Rodrigues, 2011; Murray and Alve, 2011; Camacho et al., 2015). According to the compilation of Murray (2006), these species are typical of saline swamps and mangroves. This feature was also observed by other authors (e.g. Zaninetti et al., 1979; Brönnimann et al., 1981b; Scott et al., 1990).

In the upper core section, the sediments are finer grained and display very high TOC content. These characteristics indicate an increase in the degree of confinement, which may also avoid the development of more sensitive species of benthic foraminifera to low oxic conditions and the excessive augment of salinity.

4.3. Environmental changes in the last 2400 yrs cal BP

The textural and compositional characteristics of the sediments, the abundance, specific richness and foraminifera assemblages composition in the core T1 indicate significant environmental changes along the last 2400 yrs in the area occupied by the current Guaratiba Mangrove.

The tests of benthic foraminifera are absent or rare in the sediments deposited for instance between ≈2400-1400 yrs cal BP (480-350 cm), around ≈250 yrs cal BP (130 cm), between ≈200-150 yrs cal BP (95-75 cm) and between ≈100-50 yrs cal BP (55-30 cm).

The sediments deposited in the period ≈2400-1400 yrs cal BP (480-350 cm) are characterized by coarser grained particles, relatively low carbonates content, intermediate values of TOC and absent or rare foraminifera tests and mollusk remains. These characteristics agree with the prevalence of highest hydrodynamic conditions in the study area, which avoid the settlement of benthic foraminifera and mollusk populations.

Considering the studies performed by Roncarati and Barrocas (1978) and Roncarati and Carelli (2012), Sepetiba Bay should have been protected by the Marambaia sand ridge hereafter 3440 yrs cal BP.

The textural and compositional characteristics of the sediments deposited in the period ≈2400-1900 yrs cal BP (480-415 cm) indicate that the study area should belong to a sandy bank. This sandy bank should be located in an interface between a wavy breaking zone and a shoreface zone with periods of sub-aerial exposition and extended dryness.

The sediments deposited in the period ≈1400-300 yrs cal BP (350-150 cm) are marked by the reduction of particles grain size, relatively low TOC and carbonates content and highest foraminifera density and diversity, as well as relatively abundant shells and bioclasts of mollusks. Foraminifera assemblages in this period are composed mostly of calcareous species, such as *A. parkinsoniana, A. tepida, Ammonia* sp., *C. excavatum, C. poeyanum, E. gunteri, Elphidium* sp. and *H. germanica*. These species are common in worldwide transitional coastal environments (Murray 1991, 2006) and are quite common in the shallower environments of Sepetiba Bay (Zaninetti et al., 1977; Brönnimann et al., 1981 a, b; Laut et al., 2009, 2012). This benthic foraminifera assemblage indicates that the studied area undergone immersion in the period between ≈1400 and 300 yrs cal BP. This illation is also supported by the values of C/S ratio (Fig. 9) in this period, which are similar to that commonly found in marine sediments (Morse and Emeis, 1990).

However, the results of $_{A.tepida}\delta^{18}O$ and $_{A.tepida}\delta^{13}C$ display some oscillations in the period ≈1400-300 yrs cal BP (350-150 cm). The increasing of $_{A.tepida}\delta^{18}O$ values should be related to the influence of colder marine waters. These events are also positively correlated with $_{A.tepida}\delta^{13}C$ values linked probably with a relatively high contribution of organic carbon from marine biological productivity. In fact, the range of $_{A.tepida}\delta^{13}C$ values obtained in the core T1 is similar to that found in living specimens of *A. parkinsoniana* in Bizerte Lagoon (Martins et al. 2016). In that lagoon, the organic matter supplied to the benthic communities seems to be mainly provided by the lagoonal biological productivity with a less expressive contribution from terrestrial sources (Martins et al., 2016).

However the results of $_{A.tepida}\delta^{18}O$ obtained in the core T1 are much lower than that obtained by Martins et al. (2016) in Bizerte Lagoon. This difference should be related to further continental imprint of the Guaratiba Mangrove than Bizerte Lagoon, which is highly influenced by Mediterranean waters. Guaratiba Mangrove is influenced by Piracão and Piraquê rivers, as well as by the low salinity plume from other rivers runoff that flow into Sepetiba Bay. In the Tunisian lagoon, the rivers are small and with much more seasonal discharges due to the semi-desert climatic characteristics of that region, which make the Mediterranean water a very important influence in this system.

Thus, the results of $_{A.tepida}\delta^{18}O$ and $_{A.tepida}\delta^{13}C$ indicate a marine influence in the period ≈1400-300 yrs cal BP (350-150 cm). These events should be related to phases with stronger marine water incursion into the study area.

The depth plot of the Factor Scores 1 and 2 along the core T1, foraminifera density, agglutinated species abundance and the values of the C/S ratio presented in Figure 9 as well as the description of the other biotic and abiotic results help us to summarize the possible conditions that prevailed in the study area in the last 2400 yrs cal BP. Results of Factor Score 1 suggest that the study area experienced wavy action and shoreface sub-aerial processes in the period between ≈2400-1400 yrs cal BP. Later, between 1.400-300 yrs cal BP, the study area undergone submergence. The assemblages of foraminifera of this period are abundant and similar to that found in present shallow and protected bottom environments of Sepetiba Bay. The immersion phase was more marked between ≈850-380 yrs cal BP and evolved during the last ≈350 yrs cal BP to the current characteristics of the Guaratiba Mangrove region. This mangrove environment seems to have been kept in the ≈last 100 yrs cal BP.

The reasons of this immersion phase in this region is not yet well understood. It should be related to a small oscillation of sea level induced by climatic oscillations (at the edge of the Medieval Warm Period and the Little Ice Age) and by the evolution of Marambaia sand ridge. The most significant regressive event since the maximum Holocene higher sea level (recorded at about 5100 yrs BP) occurred up to 2400 yrs cal BP, according to Pereira and Santos (2012) based on sedimentological and biogenic (mollusks) records in the study region. Thenceforward, the sea level has been a trend to rise with small oscillations (Pereira and Santos, 2012). A possible rupture of the Marambaia sand ridge may be suggested too for the submergence of the study area in the period ≈1400-300 yrs cal BP. This sandy spit broke several times in the past (Roncarati and Barrocas, 1978; Roncarati and Carelli, 2012). The ancient development of the Guaratiba Mangrove region needs to be further studied aiming to obtain a best temporal accuracy and definition of the events that marked its past evolution. This area outstands due to both their environmental particular characteristics (a nursery and protected area for fishes and other organisms) and its link with the Marambaia sand ridge, which protect the Sepetiba Bay.

5. CONCLUSIONS

Species richness and benthic foraminifera density and assemblages composition as well as the analyzed abiotic variables indicate that the depositional environment of the Sepetiba salt-march changed significantly in the last 2400 yrs cal BP.

Our results indicate that: i) the period between ≈2400-1400 yrs cal BP, the study area should have been submitted to coastal waves followed by sub-aerial exposition and extended dryness; ii) between ≈1400-300 yrs cal BP, the study area was exposed to marine processes, this is, became a transitional shallow transitional environment similar to that found nowadays in Sepetiba Bay; iii) this environment evolved since the last ≈350 yrs cal BP to the present mangrove environment.

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Supplementary material 1. Sediment fractions, total organic carbon (TOC; %), total sulfur S; %); calcium carbonate (%); species richness (SR; number of species per samples) and foraminifera density (Foram D; nº/10 ml).

Depth (cm)	Coarse Sand (%)	Medium Sand (%)	Fine Sand (%)	Very Fine Sand (%)	Very Coarse Silt (%)	Coarse Silt (%)	Medium Silt (%)	Fine Silt (%)	Very Fine Silt (%)	Clay (%)	TOC (%)	S (%)	$CaCO_3$ (%)	SR	Foram D
0.0	7.7	24.5	11.1	13.0	17.6	10.2	6.6	4.7	2.5	2.2	7.03	0.26	19	4	136
10.0	18.2	23.3	23.1	15.6	8.6	4.8	2.9	2.0	1.1	0.4	2.66	0.12	22	11	144
20.0	0.0	0.0	13.8	21.2	24.0	16.9	10.3	6.3	3.3	4.1	4.00	0.58	20	4	25
30.0	6.3	20.9	19.1	21.2	16.7	8.2	3.8	1.9	1.0	0.8	3.56	0.42	18	0	0
40.0	20.2	19.5	17.1	20.1	12.5	5.8	2.5	1.3	0.7	0.2	2.79	0.79	21	0	0
55.0	22.8	14.6	19.0	21.2	12.0	6.3	2.5	1.0	0.4	0.1	2.97	0.94	22	0	0
65.0	5.2	8.9	14.2	32.1	26.0	9.6	2.6	0.8	0.4	0.2	2.59	0.56	20	3	107
75.0	20.4	27.0	20.9	15.6	9.2	4.6	1.5	0.6	0.2	0.0	2.50	0.96	23	0	0
85.0	64.3	16.9	7.1	5.8	3.8	1.6	0.5	0.0	0.0	0.0	2.50	0.43	20	2	4
95.0	10.8	2.8	13.1	33.2	26.6	1.0	5.6	3.1	1.6	2.0	2.28	0.69	18	1	2
110.0	7.3	6.8	14.5	30.2	24.2	10.7	3.7	1.5	0.7	0.5	2.94	0.98	17	9	38
120.0	30.6	24.8	16.8	14.8	1.1	6.7	2.9	1.3	0.7	0.2	2.52	0.59	21	1	2
130.0	41.8	27.3	6.5	6.7	8.4	5.6	2.5	0.8	0.3	0.1	1.48	0.42	20	0	0
140.0	24.6	27.6	15.9	12.2	9.3	5.6	2.5	1.3	0.6	0.1	1.33	0.70	20	3	3
150.0	24.3	23.0	16.1	13.1	11.9	7.5	2.5	1.0	0.5	0.1	1.45	0.41	21	2	2
165.0	15.8	23.7	19.9	17.3	10.8	6.5	3.2	1.7	0.9	0.2	1.45	0.41	21	8	96
175.0	11.0	27.2	17.7	17.5	11.8	7.1	3.5	2.1	1.2	0.9	2.41	0.65	17	8	88
185.0	12.1	17.9	18.5	26.7	15.2	5.7	2.3	1.0	0.5	0.1	1.20	0.57	10	9	204
195.0	7.2	10.8	13.7	27.1	25.2	11.1	3.3	0.8	0.4	0.4	1.33	0.50	16	11	261
205.0	18.6	18.7	10.4	19.3	18.2	8.9	3.4	1.6	0.7	0.3	1.25	0.64	15	5	118
220.0	11.1	17.0	18.2	23.2	16.4	8.1	3.4	1.5	0.8	0.3	1.14	0.60	15	8	242
230.0	0.0	0.4	6.2	21.7	29.1	23.8	9.7	4.3	2.0	3.0	1.29	0.55	16	8	218
240.0	23.9	19.1	16.8	16.7	12.1	6.6	2.7	1.3	0.6	0.1	1.64	0.72	16	9	307
250.0	47.5	15.4	6.8	8.5	9.8	6.8	2.9	1.2	0.4	0.6	0.97	0.53	14	9	317
260.0	9.4	17.4	14.4	20.6	19.0	10.4	4.4	2.2	1.1	1.1	1.03	0.64	16	7	241
275.0	14.9	7.8	10.2	18.2	20.7	15.0	6.9	3.0	1.3	1.9	1.00	0.43	18	8	315

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Depth (cm)	Coarse Sand (%)	Medium Sand (%)	Fine Sand (%)	Very Fine Sand (%)	Very Coarse Silt (%)	Coarse Silt (%)	Medium Silt (%)	Fine Silt (%)	Very Fine Silt (%)	Clay (%)	TOC (%)	S (%)	$CaCO_3$ (%)	SR	Foram D
285.0	0.9	10.0	17.2	43.0	21.8	5.3	1.2	0.4	0.2	0.1	0.94	0.42	18	9	321
295.0	10.7	27.5	19.1	19.5	11.0	5.2	5.2	1.1	0.6	0.1	0.79	0.39	16	11	270
305.0	16.3	11.9	16.4	27.8	16.1	6.7	2.5	1.2	0.6	0.2	0.62	0.37	12	8	325
315.0	12.7	14.2	16.0	31.2	16.9	6.2	1.8	0.7	0.3	0.1	0.70	0.39	12	7	29
330.0	18.0	15.8	14.8	22.1	11.7	7.0	4.2	3.1	1.9	1.4	0.75	0.38	13	0	0
340.0	46.5	12.3	9.5	14.1	8.4	4.3	2.2	1.6	0.9	0.3	0.72	0.60	13	8	70
350.0	48.6	21.2	9.7	9.4	5.3	2.7	1.3	0.9	0.6	0.1	1.24	0.68	15	0	0
360.0	7.1	9.4	13.5	18.7	23.0	12.3	6.0	4.0	2.8	3.2	1.63	0.97	14	1	1
370.0	41.1	21.9	13.3	9.8	6.6	3.4	1.7	1.1	0.7	0.2	1.51	0.75	12	0	0
385.0	4.8	18.2	18.6	24.3	18.0	7.9	3.8	2.1	1.2	1.1	1.33	1.00	11	2	2
395.0	12.3	19.9	8.4	16.5	18.6	10.6	5.8	3.5	2.2	2.1	1.48	0.87	14	0	0
405.0	31.6	17.4	9.9	17.2	15.3	5.5	1.7	0.8	0.4	0.1	1.23	0.76	11	1	1
415.0	23.2	26.3	15.0	15.5	12.6	4.9	1.5	0.7	0.4	0.1	2.68	0.77	13	0	0
425.0	29.8	23.0	7.2	13.2	13.4	6.5	3.0	1.8	1.1	0.8	1.36	0.64	17	0	0
440.0	52.7	35.4	3.2	1.0	3.0	3.2	1.0	0.3	0.1	0.0	1.59	0.83	12	0	0
450.0	11.7	16.8	22.6	25.9	15.0	5.0	1.6	0.8	0.5	0.1	1.40	1.00	12	0	0
460.0	0.6	3.6	5.1	14.8	26.3	18.7	10.4	8.0	6.0	6.5	1.32	0.45	15	0	0
470.0	21.4	17.9	11.9	16.0	17.1	8.8	3.1	1.6	1.0	1.2	1.65	1.01	13	0	0
480.0	9.1	8.6	6.8	14.1	22.2	16.1	7.9	5.8	4.5	4.8	1.52	1.13	12	0	0
Max.	64.3	35.4	23.1	43.0	29.1	23.8	10.4	8.0	6.0	6.5	7.0	1.1	23.0	11.0	325.0
Min.	0.0	0.0	3.2	1.0	1.1	1.0	0.5	0.0	0.0	0.0	0.6	0.1	10.0	0.0	0.0

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Supplementary material 2. Sediment mean grain size (SMGS; µm) and other textural parameters along the core T1.

Depth (cm)	SMGS (µm)	Grain size classification	Mode 1 (µm)	Mode 2 (µm)	Mode 3 (µm)	Sorting (σ)	Skewness (ϕ)	Kurtosis (K)	Mode	Sorting (σ)	Skweness (ϕ)	Kurtosis (K)
0	84.37	Very Fine Sand	385.7	48.42	906.3	4.9	-0.109	0.881	Trimodal	Very Poorly Sorted	Fine Skewed	Platykurtic
10	196.8	Fine Sand	236.7	802.2	-	3.5	-0.251	1 094	Bimodal	Poorly Sorted	Fine Skewed	Mesokurtic
20	41.08	Very Coarse Silt	54.71	145.3	-	3.6	-0.258	1 057	Bimodal	Poorly Sorted	Fine Skewed	Mesokurtic
30	111.5	Very Fine Sand	341.3	113.8	906.3	3.3	-0.123	0.932	Trimodal	Poorly Sorted	Fine Skewed	Mesokurtic
40	162.7	Fine Sand	628.4	100.7	-	3.4	-0.109	0.847	Bimodal	Poorly Sorted	Fine Skewed	Platykurtic
55	153.5	Fine Sand	628.4	113.8	-	3.4	-0.037	0.816	Bimodal	Poorly Sorted	Symmetrical	Platykurtic
65	77.24	Very Fine Sand	78.9	236.7	802.2	2.7	0.129	1 221	Trimodal	Poorly Sorted	Coarse Skewed	Leptokurtic
75	232.6	Fine Sand	341.3	113.8	-	2.9	-0.243	0.93	Bimodal	Poorly Sorted	Fine Skewed	Mesokurtic
85	597.5	Medium Sand	710	-	-	2.1	-0.641	1 573	Unimodal	Poorly Sorted	Very Fine Skewed	Very Leptokurtic
95	62.44	Very Coarse Silt	69.83	-	-	2.8	-0.263	1 352	Unimodal	Poorly Sorted	Fine Skewed	Leptokurtic
110	76.46	Very Fine Sand	89.14	209.5	628.4	3.0	0.076	1 253	Trimodal	Poorly Sorted	Symmetrical	Leptokurtic
120	212.5	Fine Sand	628.4	113.8	-	3.5	-0.305	0.859	Bimodal	Poorly Sorted	Very Fine Skewed	Platykurtic
130	434.6	Medium Sand	710	42.86	-	3.4	-0.628	0.996	Bimodal	Poorly Sorted	Very Fine Skewed	Mesokurtic
140	270.1	Fine Sand	802.2	385.7	128.6	3.5	-0.346	0.896	Trimodal	Poorly Sorted	Very Fine Skewed	Platykurtic
150	228.1	Fine Sand	710	341.3	113.8	3.6	-0.296	0.798	Polymodal	Poorly Sorted	Fine Skewed	Platykurtic
165	175.7	Fine Sand	341.3	113.8	-	3.4	-0.231	0.959	Bimodal	Poorly Sorted	Fine Skewed	Mesokurtic
175	160.2	Fine Sand	385.7	209.5	100.7	3.6	-0.275	0.947	Polymodal	Poorly Sorted	Fine Skewed	Mesokurtic
185	119.7	Fine Sand	100.7	267.4	-	3.0	0.051	0.952	Bimodal	Poorly Sorted	Symmetrical	Mesokurtic
195	76.86	Very Fine Sand	61.81	341.3	-	3.0	0.155	1 092	Bimodal	Poorly Sorted	Coarse Skewed	Mesokurtic
205	113.3	Fine Sand	556.2	61.81	-	3.6	0.014	0.742	Bimodal	Poorly Sorted	Symmetrical	Platykurtic
220	111.6	Very Fine Sand	100.7	267.4	628.4	3.3	-0.017	0.954	Trimodal	Poorly Sorted	Symmetrical	Mesokurtic
230	36.73	Very Coarse Silt	33.57	-	-	2.7	-0.159	1 165	Unimodal	Poorly Sorted	Fine Skewed	Leptokurtic
240	193.2	Fine Sand	906.3	267.4	100.7	3.7	-0.17	0.833	Trimodal	Poorly Sorted	Fine Skewed	Platykurtic
250	467.8	Fine Sand	802.2	37.93	-	3.9	-0.665	0.766	Bimodal	Poorly Sorted	Very Fine Skewed	Platykurtic
260	92.62	Very Fine Sand	100.7	267.4	556.2	3.7	-0.028	0.905	Trimodal	Poorly Sorted	Symmetrical	Mesokurtic

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Depth (cm)	SMGS (µm)	Grain size classification	Mode 1 (µm)	Mode 2 (µm)	Mode 3 (µm)	Sorting (σ)	Skewness (ϕ)	Kurtosis (K)	Mode	Sorting (σ)	Skweness (ϕ)	Kurtosis (K)
275	65.06	Very Fine Sand	37.93	802.2	209.5	4.6	0.128	0.983	Trimodal	Very Poorly Sorted	Coarse Skewed	Mesokurtic
285	88.5	Very Fine Sand	89.14	385.7	-	2.1	0.074	1 311	Bimodal	Poorly Sorted	Symmetrical	Leptokurtic
295	180.3	Fine Sand	385.7	113.8	710	3.0	-0.194	0.946	Trimodal	Poorly Sorted	Fine Skewed	Mesokurtic
305	109.8	Fine Sand	100.7	802.2	236.7	3.4	0.117	0.966	Trimodal	Poorly Sorted	Coarse Skewed	Mesokurtic
315	107.6	Very Fine Sand	100.7	302.1	710	2.9	0.119	0.962	Trimodal	Poorly Sorted	Coarse Skewed	Mesokurtic
330	119.8	Very Fine Sand	100.7	710	341.3	4.4	-0.112	1 017	Trimodal	Very Poorly Sorted	Fine Skewed	Mesokurtic
340	413.2	Medium Sand	906.3	113.8	-	3.7	-0.536	0.784	Bimodal	Poorly Sorted	Very Fine Skewed	Platykurtic
350	488.7	Medium Sand	710	113.8	-	2.8	-0.614	1 037	Bimodal	Poorly Sorted	Very Fine Skewed	Mesokurtic
360	60.32	Very Coarse Silt	54.71	556.2	236.7	4.4	-0.054	1 178	Polymodal	Very Poorly Sorted	Symmetrical	Leptokurtic
370	388.5	Medium Sand	802.2	128.6	-	3.2	-0.484	0.945	Bimodal	Poorly Sorted	Very Fine Skewed	Mesokurtic
385	98.29	Very Fine Sand	100.7	267.4	-	3.3	-0.094	1 017	Bimodal	Poorly Sorted	Symmetrical	Mesokurtic
395	81.98	Very Fine Sand	341.3	48.42	802.2	4.7	-0.031	0.913	Trimodal	Very Poorly Sorted	Symmetrical	Mesokurtic
405	236.6	Fine Sand	802.2	61.81	-	3.5	-0.241	0.679	Bimodal	Poorly Sorted	Fine Skewed	Platykurtic
415	245.3	Fine Sand	435.7	100.7	-	3.1	-0.297	0.792	Bimodal	Poorly Sorted	Fine Skewed	Platykurtic
425	289.5	Fine Sand	710	61.81	-	3.9	-0.48	0.781	Bimodal	Poorly Sorted	Very Fine Skewed	Platykurtic
440	517.2	Coarse Sand	710	-	-	2.0	-0.368	2 185	Unimodal	Poorly Sorted	Very Fine Skewed	Very Leptokurtic
450	128.3	Fine Sand	113.8	236.7	710	2.9	0.036	0.985	Trimodal	Poorly Sorted	Symmetrical	Mesokurtic
460	31.67	Coarse Silt	37.93	4 763	236.7	4.3	-0.243	1 203	Trimodal	Very Poorly Sorted	Fine Skewed	Leptokurtic
470	133.2	Fine Sand	710	48.42	-	4.0	-0.073	0.776	Bimodal	Poorly Sorted	Symmetrical	Platykurtic
480	42.65	Very Coarse Silt	37.93	492.3	710	5.9	0.029	1 227	Polymodal	Very Poorly Sorted	Symmetrical	Leptokurtic

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Supplementary material 3. List of species identified in the study area.

Species
Ammoastuta inepta (Cushman and McCulloch, 1939)
Ammotium cassis (Parker, 1870)
Ammonia parkinsoniana (d'Orbigny, 1839)
Ammonia tepida (Cushman, 1926)
Ammonia rolshauseni (Cushman and Bermúdez, 1946)
Ammonia sp.
Arenoparrella mexicana (Kornfeld, 1931)
Blysmasphaera brasiliensis Brönnimann, 1988
Bolivina striatula Cushman, 1922
Bolivinellina translucens (Phleger and Parker, 1951)
Buliminella elegantissima (d'Orbigny, 1839)
Cribroelphidium poeyanum (d'Orbigny, 1826)
Cribroelphidium vadescens Cushman and Brönniman, 1948
Elphidium discoidale (d'Orbigny, 1839)
Cribroelphidium excavatum (Terquem, 1875)
Elphidium gunteri Cole, 1931
Elphidium sp.
Haplophragmoides manilaensis Andersen, 1952
Haplophragmoides wilberti Andersen, 1953
Haynesina germanica (Ehrenberg, 1840)
Entzia polystoma (Bartenstein and Brand, 1938)
Miliammina fusca (Brady, 1870)
Paratrochammina clossi Brönnimann, 1979
Quinqueloculina lamarckiana d'Orbigny, 1839
Siphotrochammina lobata Saunders, 1957
Tiphotrocha comprimata (Cushman and Brönnimann, 1948)
Trochammina inflata (Montagu, 1808)
Entzia macrescens (Brady, 1870)
Trochammina sp.
Trochamminita salsa (Cushman and Brönnimann, 1948)
Warrenita palustris (Warren, 1957)

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Supplementary material 4a. Species abundance (nº/10ml) in the along the core T1 (at each 10 cm). Legend of this table: A. inepta - *Ammoastuta inepta*; A.cassis - *Ammotium cassis*; A.park. - *Ammonia parkinsoniana*; A.tep - *Ammonia tepida*; A.rolsh - *Ammonia rolshauseni*; Amm. sp.- *Ammonia* sp.; A.mex - *Arenoparrella mexicana*; B.brasil - *Blysmasphaera brasiliensis*; B.striat - *Bolivina striatula*; B.transl - *Bolivinellina translucens*; B.eleg - *Buliminella elegantíssima*; C.poey - *Cribroelphidium poeyanum*; C.vad - *Cribroelphidium vadescens*; E.disc - *Elphidium discoidale*; C.excav - *Cribroelphidium excavatum*; E.gunt - *Elphidium gunteri*; Elph. sp.; *Elphidium* sp.; H.manil. - *Haplophragmoides manilaensis*; H.wilb - *Haplophragmoides wilberti*; H.germ - *Haynesina germanica*; E.polyst - *Entzia polystoma*; M.fusca - *Miliammina fusca*.

Depth (cm)	0	10	20	30	40	55	65	75	85	95	110	120	130	140	150	165	175	185	195	205	220	230	240
Foram D	136	144	25	0	0	0	107	0	4	2	38	2	0	3	2	96	88	204	261	118	242	218	307
SR	31	31	31	31	31	31	31	31	31	31	31	31	31	31	31	31	31	31	31	31	31	31	31
A. inepta	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	1	0	0	0	0	0	0
A.cassis	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
A.park.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	2	3	62	39	21	36	53
A.tep	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	43	39	110	55	70	113	122	156
A.rolsh	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Amm. sp.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
A.mex	112	61	21	0	0	0	104	0	3	2	25	2	0	1	1	0	4	0	40	0	0	0	1
B.brasil	0	0	0	0	0	0	0	0	0	0	1	0	0	0	1	0	0	0	0	0	0	0	0
B.striat	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	5	7	3	1	6	4
B.transl	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0
B.eleg	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	12	14	0	0	1	0
C.poey	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	22	13	12	0	3	15	9	28
C.vad	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	24	0	33	0	0
E.disc	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0
C.excav	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	17	0	14	1	3	43	15	16
E.gunt	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	7	0	0	0	4	0	17
Elph. sp.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	9	10	0	0	0	21	4
H.manil.	2	14	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
H.wilb	0	23	0	0	0	0	0	0	0	0	3	0	0	0	0	0	0	0	0	0	0	0	0
H.germ	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	8	13	35	36	0	12	8	28
E.polyst	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0
M.fusca	0	5	0	0	0	0	0	0	0	0	1	0	0	1	0	0	0	0	0	0	0	0	0

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Supplementary material 4a (cont.). Species abundance (n.º/10ml) in the along the core T1 (at each 10 cm). Legend of this table: P.clossi - *Paratrochammina clossi*; Q.lamark - *Quinqueloculina lamarckiana*; S.lobat - *Siphotrochammina lobata*; T.comp - *Tiphotrocha comprimata*; T.infl - *Trochammina inflata*; E.macr - *Entzia macrescens*; Troch sp. - *Trochammina* sp.; T.salsa - *Trochamminita salsa*; W.palus - *Warrenita palustris*.

Depth (cm)	0	10	20	30	40	55	65	75	85	95	110	120	130	140	150	165	175	185	195	205	220	230	240
P.clossi	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0
Q.lamark	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0
S.lobat	0	1	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
T.comp	0	1	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0
T.infl	20	21	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	10	0	0	0	0
E.macr	2	15	1	0	0	0	0	0	1	0	4	0	0	0	0	0	0	3	10	0	0	0	0
Troch sp.	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
T.salsa	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0
W.palus.	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

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Supplementary material 4b. Species abundance (n.º/10ml) in the along the core T1 (at each 10 cm). Legend of this table: A. inepta - *Ammoastuta inepta*; A.cassis - *Ammotium cassis*; A.park. - *Ammonia parkinsoniana*; A.tep - *Ammonia tepida*; A.rolsh - *Ammonia rolshauseni*; Amm. sp.- *Ammonia* sp.; A.mex - *Arenoparrella mexicana*; B.brasil - *Blysmasphaera brasiliensis*; B.striat - *Bolivina striatula*; B.transl - *Bolivinellina translucens*; B.eleg - *Buliminella elegantíssima*; C.poey - *Cribroelphidium poeyanum*; C.vad - *Cribroelphidium vadescens*; E.disc - *Elphidium discoidale*; C.excav - *Cribroelphidium excavatum*; E.gunt - *Elphidium gunteri*; Elph. sp.; *Elphidium* sp.; H.manil. - *Haplophragmoides manilaensis*; H.wilb - *Haplophragmoides wilberti*; H.germ - *Haynesina germanica*; E.polyst - *Entzia polystoma*; M.fusca - *Miliammina fusca*.

Depth (cm)	250	260	275	285	295	305	315	330	340	350	360	370	385	395	405	415	425	440	450	460	470	480
Foram D	317	241	315	321	270	325	29	0	70	0	1	0	2	0	1	0	0	0	0	0	0	0
SR	9	7	8	9	11	8	7	0	8	0	1	0	2	0	1	0	0	0	0	0	0	0
A.inepta	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
A.cassis	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
A.park.	88	26	27	60	31	70	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
A.tep	153	162	154	77	52	183	11	0	20	0	0	0	0	0	0	0	0	0	0	0	0	0
A.rolsh	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Amm.sp.	15	0	0	0	25	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
A.mex	0	0	0	0	0	2	0	0	0	0	0	0	1	0	1	0	0	0	0	0	0	0
B.brasil	0	0	0	0	0	0	0	0	0	0	1	0	1	0	0	0	0	0	0	0	0	0
B.striat	1	0	0	0	2	4	2	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0
B.transl	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
B.eleg	0	0	1	0	0	0	2	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0
C.poey	22	15	36	37	35	20	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0
C.vad	0	0	3	13	11	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
E.disc	5	0	0	2	3	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0
C.excav	18	22	47	72	58	31	9	0	37	0	0	0	0	0	0	0	0	0	0	0	0	0
E.gunt	5	2	33	50	21	12	2	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0
Elph.sp.	0	3	14	0	26	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
H.manil.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
H.wilb	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
H.germ	10	11	0	9	6	3	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0
E.polyst	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
M.fusca	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

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Supplementary material 4b (cont.). Species abundance (nº/10ml) in the along the core T1 (at each 10 cm). Legend of this table: P.clossi - *Paratrochammina clossi*; Q.lamark - *Quinqueloculina lamarckiana*; S.lobat - *Siphotrochammina lobata*; T.comp - *Tiphotrocha comprimata*; T.infl - *Trochammina inflata*; E.macr - *Entzia macrescens*; Troch sp. - *Trochammina* sp.; T.salsa - *Trochamminita salsa*; W.palus - *Warrenita palustris*.

Depth (cm)	250	260	275	285	295	305	315	330	340	350	360	370	385	395	405	415	425	440	450	460			470	480
P.clossi	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0			0	0
Q.lamark	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0			0	0
S.lobat	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	45
T.comp	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	45
T.infl	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	53	45
E.macr	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	36	45
Troch sp.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	45
T.salsa	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	4	45
W.palus	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	45

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Supplementary material 5. Pearson correlations between selected variables (species abundance and abiotic parameters) in all the core T1 analyzed layers. Significant correlations are signed in red color (*p*> 0.50). Legend: SMGS - sediment mean grain size (µm); 63-125 - very fine sand fraction (%); TOC - total organic carbon (%); S-total sulfur (%); $CaCO_3$ - calcium carbonate (%); SR - species richness (nº species /sample); F.Dens - foraminifera density (nº/10 ml); A.park - *Ammonia parkinsoniana* (nº/10 ml); A.tep - *Ammonia tepida* (nº/10 ml); A.mex - *Arenoparrella mexicana* (nº/10 ml); B.striat - *Bolivina striatula* (nº/10 ml); B.elegant - *Buliminella elegantissima* (nº/10 ml); C.poey - *Cribroelphidium poeyanum* (nº/10 ml); C.vad - *Cribroelphidium vadescens* (nº/10 ml); E.disc - *Elphidium discoidale* (nº/10 ml); C.excav - *Cribroelphidium excavatum* (nº/10 ml); E.gunt - *Elphidium gunteri* (nº/10 ml); Elph. sp. - *Elphidium* sp. (nº/10 ml); H.germ - *Haynesina germanica* (nº/10 ml); T.infla - *Trochammina inflata* (nº/10 ml); E.macr - *Entzia macrescens* (nº/10 ml).

	SMGS	63-125	TOC	S	$CaCO_3$	SR	F.Dens	A.park	A.tep	A.mex	B.striat	B.elegant	C.poey	C.vad	E.disc	C.excav	E.gunt	Elph sp	H.germ	T.infla	E.macr
SMGS	1.00	-0.61	-0.09	-0.05	0.06	-0.18	-0.23	-0.19	-0.15	-0.21	-0.10	-0.14	-0.11	-0.16	0.17	-0.09	-0.03	-0.18	-0.09	-0.14	-0.10
63-125	-0.61	1.00	-0.06	-0.04	0.01	0.35	0.35	0.26	0.27	0.17	0.23	0.22	0.23	0.27	-0.01	0.27	0.22	0.13	0.24	0.02	0.11
TOC	-0.09	-0.06	1.00	0.04	0.52	-0.22	-0.19	-0.47	-0.51	0.57	-0.42	-0.25	-0.45	-0.27	-0.32	-0.57	-0.42	-0.22	-0.32	0.45	0.31
S	-0.05	-0.04	0.04	1.00	-0.31	-0.47	-0.50	-0.30	-0.31	-0.31	-0.21	-0.16	-0.31	-0.22	-0.23	-0.35	-0.28	-0.17	-0.20	-0.46	-0.33
$CaCO_3$	0.06	0.01	0.52	-0.31	1.00	0.06	0.06	-0.10	-0.16	0.35	-0.32	-0.27	-0.07	0.04	0.00	-0.15	-0.05	-0.04	-0.12	0.25	0.15
SR	-0.18	0.35	-0.22	-0.47	0.06	1.00	0.96	0.69	0.77	0.35	0.58	0.38	0.70	0.40	0.38	0.71	0.57	0.48	0.67	0.28	0.39
F.Dens	-0.23	0.35	-0.19	-0.50	0.06	0.96	1.00	0.78	0.84	0.34	0.60	0.36	0.77	0.44	0.39	0.76	0.62	0.51	0.71	0.29	0.33
A.park	-0.19	0.26	-0.47	-0.30	-0.10	0.69	0.78	1.00	0.92	-0.10	0.65	0.27	0.84	0.55	0.45	0.80	0.70	0.48	0.75	0.00	0.02
A.tep	-0.15	0.27	-0.51	-0.31	-0.16	0.77	0.84	0.92	1.00	-0.17	0.70	0.40	0.92	0.45	0.42	0.89	0.71	0.60	0.83	-0.07	0.00
A.mex	-0.21	0.17	0.57	-0.31	0.35	0.35	0.34	-0.10	-0.17	1.00	-0.02	0.10	-0.24	0.04	-0.18	-0.27	-0.16	-0.15	-0.02	0.74	0.69
B.striat	-0.10	0.23	-0.42	-0.21	-0.32	0.58	0.60	0.65	0.70	-0.02	1.00	0.67	0.45	0.29	0.17	0.58	0.30	0.39	0.63	0.08	0.21
B.elegant	-0.14	0.22	-0.25	-0.16	-0.27	0.38	0.36	0.27	0.40	0.10	0.67	1.00	0.12	0.31	-0.03	0.28	0.02	0.28	0.49	0.24	0.48
C.poey	-0.11	0.23	-0.45	-0.31	-0.07	0.70	0.77	0.84	0.92	-0.24	0.45	0.12	1.00	0.41	0.53	0.89	0.82	0.67	0.75	-0.19	-0.15
C.vad	-0.16	0.27	-0.27	-0.22	0.04	0.40	0.44	0.55	0.45	0.04	0.29	0.31	0.41	1.00	0.31	0.49	0.50	0.19	0.49	0.17	0.19
E.disc	0.17	-0.01	-0.32	-0.23	0.00	0.38	0.39	0.45	0.42	-0.18	0.17	-0.03	0.53	0.31	1.00	0.56	0.52	0.18	0.38	-0.10	-0.12
C.excav	-0.09	0.27	-0.57	-0.35	-0.15	0.71	0.76	0.80	0.89	-0.27	0.58	0.28	0.89	0.49	0.56	1.00	0.79	0.53	0.66	-0.16	-0.12
E.gunt	-0.03	0.22	-0.42	-0.28	-0.05	0.57	0.62	0.70	0.71	-0.16	0.30	0.02	0.82	0.50	0.52	0.79	1.00	0.47	0.50	-0.15	-0.20
Elph sp	-0.18	0.13	-0.22	-0.17	-0.04	0.48	0.51	0.48	0.60	-0.15	0.39	0.28	0.67	0.19	0.18	0.53	0.47	1.00	0.54	-0.13	-0.03
H.germ	-0.09	0.24	-0.32	-0.20	-0.12	0.67	0.71	0.75	0.83	-0.02	0.63	0.49	0.75	0.49	0.38	0.66	0.50	0.54	1.00	0.05	0.19
T.infla	-0.14	0.02	0.45	-0.46	0.25	0.28	0.29	0.00	-0.07	0.74	0.08	0.24	-0.19	0.17	-0.10	-0.16	-0.15	-0.13	0.05	1.00	0.79
E.macr	-0.10	0.11	0.31	-0.33	0.15	0.39	0.33	0.02	0.00	0.69	0.21	0.48	-0.15	0.19	-0.12	-0.12	-0.20	-0.03	0.19	0.79	1.00

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Supplementary material 6. Pearson correlations between selected variables (species abundance and abiotic parameters) in the section 185-340 cm of core T1 (with calcareous foraminifera and isotopic data). Significant correlations are signed in bold (*p*>0.50).

Correlations	*A.tepida* $\delta^{18}O$	*A.tepida* $\delta^{13}C$
A.tepida $\delta^{18}O$	1.00	**0.93**
A.tepida $\delta^{13}C$	**0.93**	1.00
Total sand fraction (%)	-0.42	-0.23
Total fine fraction (%)	-0.05	-0.16
Clay fraction (%)	0.13	-0.01
Coarse + medium sand fractions (%)	-0.40	-0.23
Total organic carbon (%)	**0.61**	0.44
Total sulfur (%)	0.10	0.02
Calcium carbonate (%)	-0.33	-0.16
Species Richness (nº species /sample)	**0.76**	**0.81**
Foraminifera density (nº/10 ml)	0.36	0.40
Ammonia parkinsoniana (nº/10 ml)	0.32	0.28
Ammonia tepida (nº/10 ml)	0.12	0.28
Arenoparrella mexicana (nº/10 ml)	**0.72**	**0.69**
Bolivina striatula (nº/10 ml)	**0.66**	**0.58**
Buliminella elegantissima (nº/10 ml)	**0.76**	**0.68**
Cribroelphidium excavatum (nº/10 ml)	0.00	0.05
Cribroelphidium poeyanum (nº/10 ml)	0.04	0.17
Cribroelphidium vadescens (nº/10 ml)	0.18	0.19
Elphidium discoidale (nº/10 ml)	-0.04	0.09
Elphidium gunteri (nº/10 ml)	0.38	0.41
Entzia macrescens (nº/10 ml)	-0.23	-0.22
Haynesina germanica (nº/10 ml)	0.24	0.16
Trochammina inflata (nº/10 ml)	-0.13	-0.06