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RESEARCH PAPER

CLIMATIC, ENVIRONMENTAL AND OCEANOGRAPHIC CHANGES OVER THE PAST MILLENNIUM, RECONSTRUCTED FROM A PALYNOLOGICAL RECORD OF THE INNER URUGUAYAN CONTINENTAL SHELF

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Abstract

In order to strengthen and update knowledge on climatic, environmental and oceanographic changes on the inner Uruguayan continental shelf, we studied pollen, dinocyst and other non-pollen palynomorph assemblages on the sediment core GeoB13813-4. This core was taken from the Rio de la Plata (RdlP) mud depocenter and its remarkable high sedimentation rate for the last ca. 1000 cal yr BP reflects the high terrigenous supply from RdlP. Most pollen and spores are originated from the RdlP grasslands, the vegetation that covers the lower reaches of the La Plata Drainage Basin (LPDB). They mainly represent the regionally dominant grasslands, but also the riparian forests, *Butia yatay* palm populations, and the herbaceous-bushy marshes around the mouth of the estuary. Pollen from salt marshes, Atlantic rainforest, and *Araucaria* forests located in southern Brazil reached the study site, probably transported by coastal ocean currents, whereas pollen from Andean regions would represent a long-distance transport by wind. Changes in both proportion and concentration of freshwater and marine palynomorphs indicate variability in freshwater input to the inner Uruguayan shelf. From ca. 1000 to 230 cal yr BP, significant marine influence of Subtropical Shelf Waters (STSW) was inferred, which was diluted by the freshwater supply from the Uruguayan mainland. This time interval was interrupted between ca. 690 to 575 cal yr BP by an increased freshwater contribution to the study area under the influence of Subantarctic Shelf Waters (SASW). From ca. 230 to 25 cal yr BP, a strong influence of RdlP waters was detected, only followed by another phase of dominant STSW during the past century. Such changes were related to regional climatic variability, i.e., Medieval Climate Anomaly, Little Ice Age and Current Warm Period. After ca. 1960 AD, the anthropogenic impact within the LPDB was clearly evidenced both by eutrophication and the first occurrence of PINUS pollen.

Keywords: Palynology. Dinocysts. Diatoms. Southeastern South America. Southwestern Atlantic Ocean. Past climate.

1. Introduction

Palaeoceanographic records derived from marine sediment cores taken at a mud belt, located on the inner shelf of the southwestern Atlantic Ocean, provide an exceptional sedimentary record to reconstruct climatic and environmental changes during the Late Holocene (Anderson, 2007; Lantzsch et al., 2014; Perez et al., 2016). In particular, pollen analyses significantly contribute to the knowledge of past vegetational and climatic changes over the South American continent because they capture the variability derived from an interaction between a large river system (discharge as a result of precipitation) and an oceanic frontal zone on the continental shelf (location as a result of the regional wind regime; Mourelle et al, 2015a; Gu et al., 2017). Studies of marine depositional successions also allow for a direct correlation of marine and terrestrial signals as

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combined indicators of paleoenvironmental changes (Behling et al., 2002). Palynomorphs deposited in marine sediment may include both autochthonous (i.e., dinocysts) and allochthonous elements having originated from terrestrial vegetation (pollen grains, spores) and freshwater biota (algae, cyanobacteria). The allochthonous components also reflect long-distance transport by winds, fluvial discharge and ocean currents (Vernal, 2009). In addition, allochthonous elements can provide detailed information on the vegetation cover, but this requires a careful interpretation of marine pollen diagrams because of the complex transport pattern and sedimentation processes in the coastal ocean, which may lead to a strong potential bias of the results (Dupont, 1999). Palynological studies from marine successions collected from the inner continental shelf thus allow for paleoenvironmental reconstructions at local and regional scales.

Until today, palynological analyses in the *campos* region of the RdlP grasslands, the main complex of extended grassland ecosystems in South America (750,000 km², 28°-38°S; Soriano, 1991; Dixon et al., 2014) (Fig. 1A), have been used for paleolimnological reconstructions. Such studies suggested that grasslands were dominant in the whole region during the Late Holocene, while locally in the surroundings of the water bodies, the vegetation would have been diverse, consisting of freshwater marshes and riparian forests, under wet climatic conditions (Behling et al., 2005; Iriarte, 2006; García-Rodríguez et al., 2010; Mourelle et al., 2015a, b; 2017, 2018). This observation is consistent with the conditions inferred from the analysis of other paleo-environmental proxies, which inferred temperate to warm and humid conditions for the last 2000 cal yr BP (Iriarte, 2006; del Puerto, 2009). However, concomitant pulses of climatic amelioration and deterioration caused changes in the structure, composition and extension of plant communities (del Puerto, 2009). In particular, for southern Uruguay, the occurrence of both a warmer and more humid pulse during the Medieval Climatic Anomaly (MCA, 900-1250 AD), and a drier and colder pulse during the Little Ice Age (LIA, 1400-1850 AD) were suggested (del Puerto et al., 2013). Palynological analyses from the *campos* region do not reflect such climatic variability, possibly due to the low temporal resolution of the Late Holocene depositional successions.

Multi-proxy records performed on marine gravity cores have been studied to reconstruct vegetation, climate, and ocean dynamics in southern Brazil and the adjacent South Atlantic for the last 73.5 kyr (e.g., Razik et al., 2013; Gu et al., 2017, 2018b). These records were characterized by low temporal resolution for the Late Holocene. However, the inner continental shelf off the Uruguayan coast is characterized by an elongated seafloor depression, which represents the pre-Holocene surface of the ancient fluvial valley of the RdlP (RdlP paleo-valley; RPPV) (Cavallotto and Violante, 2005; Lantzsch et al., 2014). The RPPV extends from the Paraná River to Rio Grande do Sul (Brazil), carved under sub-aerial conditions during the last pre-Holocene regression, and then filled up during the last sea-level rise (Cavallotto, 2002; Cavallotto and Violante, 2005; Lantzsch et al., 2014). Sediment core GeoB13813-4 was taken from such sediments, containing a 10-m long record that encompasses the past millennium (Lantzsch et al., 2014) and therefore yields a high-resolution archive for a detailed and continuous paleoecologically reconstruction. In this sense, Perez et al. (2016, 2017, 2018) studied the diatom flora, conventional geochemical (C, N, and their isotopes), XRF element ratios (Ca, Ti, Al, Fe, and K) and biogenic silica (BSi) on core GeoB13813-4 to decipher the history of terrigenous sediment input from the RdlP system. In this study, we analyze the palynological content with in the same core in order to (1) determine how palynological assemblages changed in relation to the continental sediment supply, (2) evaluate the paleobotanical potential of this succession with regard to the different types of vegetation that proliferate in southeastern South America, and (3) integrate our results into a multi-proxy approach by comparing pollen to other paleoceanographic and paleolimnological records from the southeastern South America for the last 1000 cal yr BP in order to strengthen and update knowledge on climatic, environmental and oceanographic changes.

2. Study Area

2.1 Hydrology and hydrography

The continental margin off southeastern South America is characterized by both high sediment supply from the RdlP, as well as the confluence of two important oceanographic currents (Möller et al., 2008; Palma et al., 2008; Lantzsch et al., 2014) (Fig. 1). The RdlP constitutes the lower reach of LPDB, the second largest river system in South America, draining an area of approximately 3.1x10^6 km², which represents about 20% of the South American continent (Acha et al., 2008) (Fig. 1). The RdlP is formed by the confluence of the Paraná and Uruguay rivers, and discharges an average of 23,000 m^3 s^{-1} of freshwater and a large amount of sediment (some 79.8x10^6 t yr^{-1}) into the southwestern Atlantic Ocean (Depetris et al., 2003; Piola et al., 2008; Krastel et al., 2012; Razik et al., 2013; Lantzsch et al., 2014). The Paraná River supplies 79% of this discharge, and the Uruguay River contributes the remaining 21% (Pasquini and Depetris, 2007). Most of this discharge forms the low-salinity Plata Plume Water (PPW) that is spreads out over the inner Uruguayan and Brazilian continental shelf (Palma et al., 2008; Piola et al., 2008) (Fig. 1).

The inner continental shelf is overflown by the Subtropical Shelf Front (STSF) that forms a thermohaline boundary between the northward-flowing, cold and less saline SASW and the southward-directed warm and salty STSW (Möller et al., 2008; Piola et al., 2008) (Fig. 1).

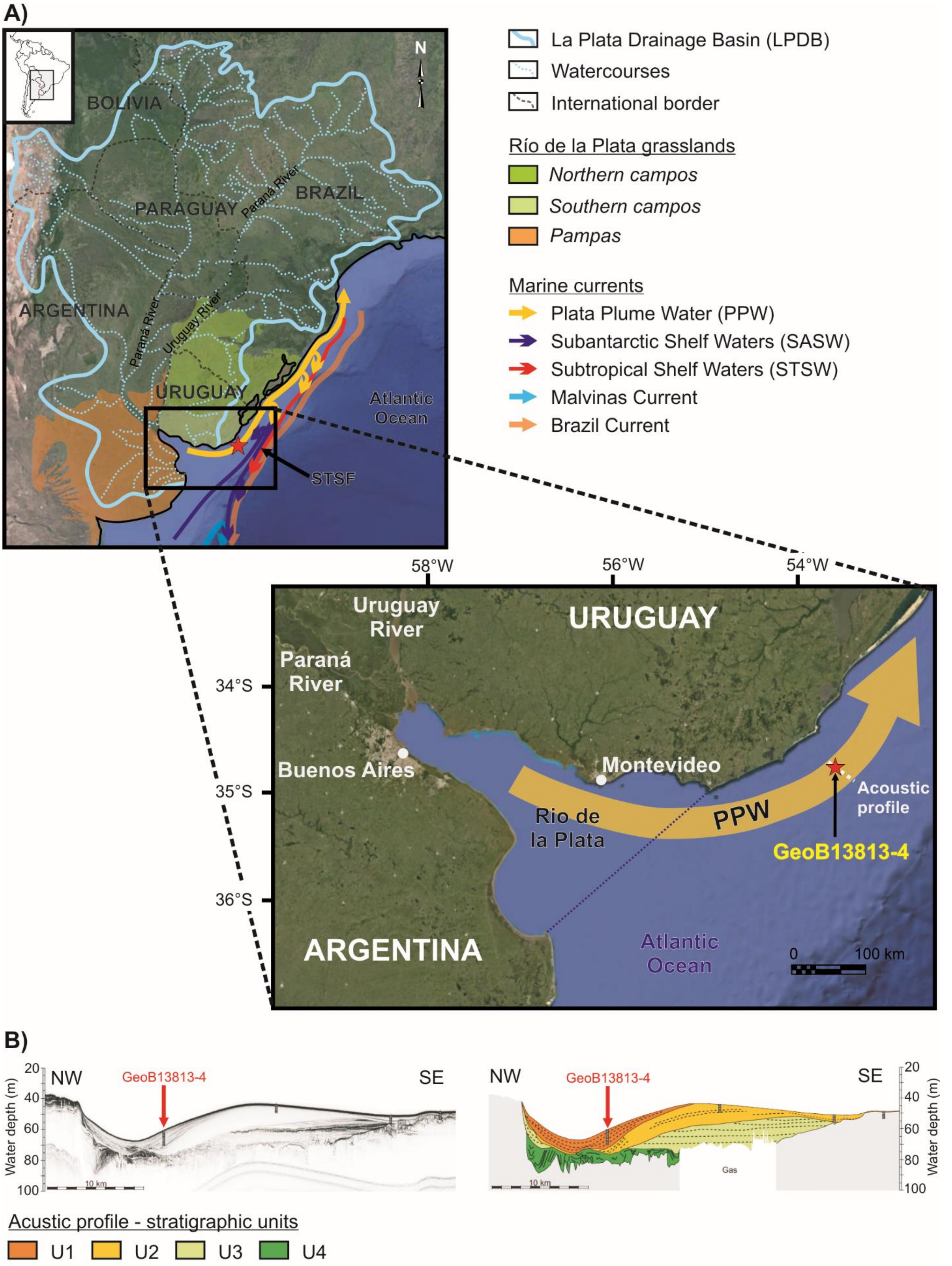


Fig. 1. A) Map of the study area: La Plata Drainage Basin, Rio de la Plata grasslands, and shelf water masses of the southwestern Atlantic Ocean. STSF: Subtropical Shelf Front. Inlet map: location of seismo-acoustic profile and core GeoB13813-4. Maps modified from Piola et al. (2005, 2008) and Lantzsch et al. (2014). B) Seismo-acoustic 4 kHz (PARASOUND) profile and interpreted inner-shelf architecture, with GeoB13813-4 core position, modified from Lantzsch et al. (2014).

The STSF is suggested to be the shelf-ward shallow-water continuation of the Brazil-Malvinas Confluence Zone, where the cold and less salty northward-flowing Malvinas Current collides with the warm, salty southward-flowing Brazil Current (Piola et al., 2000; Palma et al., 2008; Lantzsch et al., 2014) (Fig. 1).

2.2 Inner-shelf architecture and stratigraphic units

The inner continental shelf off the Uruguayan coast is characterized by an elongated seafloor depression that is located 40 km off the coast (Lantzsch et al., 2014). This depression represents the pre-Holocene surface of the ancient fluvial valley of the RdlP, that was about 35 km wide and up to 50 m deep before it became partly filled by Holocene sediments during the last sea-level rise (Cavallotto and Violante, 2005; Lantzsch et al., 2014). Above this depression, four stratigraphic units (U1-U4) have been defined according to their sedimentary characteristics, bounding unconformities and their acoustic facies (Lantzsch et al., 2014) (Fig. 1). U4 truncates into older strata (although of uncertain age). Channels were filled during sea-level rise and preceded the formation of U3, which sedimentary characteristics indicate a tidal origin under estuarine conditions. U2 represents a local inner-self sand depocenter that formed at ca. 4600 cal yr BP, when sea level was approximately +3 m higher than present level (Prieto et al., 2017), and therefore developed under full-marine conditions. U1 sediment accumulation started around 1000 cal yr BP, and represents a relatively modern shelf mud depocenter above the observed RPPV (Lantzsch et al., 2014).

2.3 Climate

Regional atmospheric circulation is under the influence of the South American Monsoon System (SAMS) and the South Atlantic semi-permanent high-pressure cell (Vera et al., 2006; Razik et al., 2013). Both systems are responsible for the transport of considerable moisture over the eastern LPDB, and hence, for the seasonal precipitation peak of the austral summer, when the Intertropical Convergence Zone (ITCZ) migrates southwards (Vera et al., 2006; Garreaud et al., 2009; Razik et al., 2013). During the austral winter, the Southern Westerly Wind Belt (SWWB) extends northwards to ~30° S promoted by the northerly position of ITCZ. As a consequence, the anticyclones gather moisture from local air masses and generate precipitation along the eastern LPDB by creating tropospheric instabilities associated with persistent polar fronts (Garreaud et al., 2009; Razik et al., 2013).

The regional climatic system exhibits an interannual and interdecadal variability, associated to environmental changes related to the El Niño-Southern Oscillation (ENSO) and the Pacific Decadal Oscillation (PDO), respectively (Depetris and Pasquini, 2007; Garreaud et al., 2009; Barreiro, 2010). It has been suggested that during both the warm El Niño and the positive PDO phases, there is an increasing trend in precipitations over the LPDB associated with an intensification of SAMS, which leads to a higher river discharge (Depetris and Pasquini, 2007; Garreaud et al., 2009; Barreiro, 2010; García-Rodríguez et al., 2014). At multidecadal timescales, the Atlantic Mutidecadal Oscillation (AMO) seems to reduce SAMS intensity in its positive phase (Chiessi et al., 2009). The opposite trend has been observed for negative ENSO, PDO and AMO phases.

The northward penetration of PPW along the Brazilian coast is primarily controlled by the intensity of southerly winds and secondarily by continental run-off. This northward expansion occurs predominantly during the austral winter (Piola et al., 2000, 2005). As a consequence, PPW drifts from 28°S during the austral winter to approximately 38°S during the summer, when northeasterly winds force a southeastward retreat of the PPW, spreading low-salinity waters over the entire continental shelf off the RdlP (Guerrero et al., 1997; Piola et al., 2000; Palma et al., 2008).

2.4 Vegetation

The lower reaches of LPDB flow through the RdlP grasslands, divided by León (1991) into the *pampas,* in the eastern Argentina, and the *campos*, in Uruguay and southern Rio Grande do Sul in Brazil (Fig. 1A). The *campos* region displays a noticeable biodiversity, with ca. 3000 species of vascular plants, including more than 550 different grass species from very diverse genera, such as *Paspalum, Nassella* and *Aristida* (Andrade et al., 2018). The presence of woody species gradually diminishes from north to south, many of them reaching their southern distribution boundary in *campos* region, hence being absent in the *pampas*.

Natural grasslands represent the predominant vegetation type in the *campos* region and are extended all over Uruguay (ca. 65% of the territory), in flat and gently-rolling relief, hills, gentle hills and low mountains (Lezama et al., 2011; MGAP-DIEA, 2011). Woody vegetation covers approximately 4.3% of the territory (Petraglia and Dell'Acqua, 2006), and consists of about 300 species of trees and shrubs (Brussa and Grela, 2007). They proliferate constrained to certain topographic features with relatively high-water availability or wind protection. Further information about the different vegetation types that develop in the *campos* region can be found elsewhere (Mourelle and Prieto, 2012, 2016).

Along the margin of rivers and water streams, riparian forests develop, dominated by tree species that are spatially arranged according to their water requirements. Hydrophilous trees develop in the floodplains, while mesophilous vegetation develops in areas of reduced water availability. Some exclusive hydrophilous taxa are *SALIX CHILENSIS, PHYLLANTHUS SELLOWIANUS, CEPHALANTHUS GLABRATUS* and *SEBASTIANIA COMMERSONIANA*, whereas some mesophilous ones are *SCUTIA BUXIFOLIA*, *CELTIS EHRENBERGIANA*, *LITHRAEA*

MOLLEOIDES, SCHINUS LONGIFOLIUS and many MYRTACEAE (e.g., *BLEPHAROCALYX SALICIFOLIUS, MYRCEUGENIA GLAUCESCENS, MYRCIANTHES CISPLATENSIS*) and Primulaceae (e.g., *MYRSINE CORIACEA, MYRSINE FERRUGINEA*) (Brussa and Grela, 2007). Humid riparian forests understory promotes the development of pteridophytes. *Butia yatay* palm grows interspersed among the dominant grasslands in Entre Ríos, Corrientes and Santa Fe provinces in Argentina, Uruguay and Rio Grande do Sul, Brazil (Geymonat and Rocha, 2009). They are considered as part of a relict community developed over sandy soils (Patterer et al., 2017).

In particular, the presence of tropical vegetation along the Uruguay River leads to a much higher biodiversity in comparison to other minor rivers in the region. Similarly, the floristic contributions from the Paraná River generate a particularly high diversity on the southwestern Uruguayan coast (Brussa and Grela, 2007). Eastwards, salt marshes develop in intertidal coastal areas and topographic depressions that get seasonally inundated by marine water of the Atlantic Ocean. They are dominated by *Spartina* (Poaceae), *Sarcocornia* (Chenopodioideae), *Scirpus* (Cyperaceae) and *Juncus* (Juncaceae), all halophilous taxa (Isacch et al., 2006).

The vegetation of the Paraná River floodplain is a mosaic of vegetation assemblages, where in addition to riparian forests, herbaceous-bushy marshy vegetation with species tolerant to various degrees and frequencies of flooding develop. Marshy-herbaceous vegetation contains aquatic grasses (*Panicum elephantipes*), rooted floating species (*Ludwigia peploides*), and rooted species (*POLYGONUM PUNCTATUM*), while the bushy species consist of *Solanum glaucophyllum*, *Sesbania virgata*, *Mimosa pigra* and *Baccharis salicifolia* (Marchetti et al., 2013). In addition, different assemblages of aquatic vegetation are related to the characteristics of the floodplain water bodies, where rooted aquatic species such as *Myriophyllum aquaticum*, *Enydra anagallis* and *Hydrocotyle bonariensis* appear among the most frequent species. Other frequent species are free floating *Eichhornia* spp., *Azolla filiculoides*, *Limnobium laevigatum*, rooted floating *NYMPHOIDES INDICA*, *POLYGONUM FERRUGINEUM* and *PASPALUM REPENS* (Marchetti et al., 2013).

After the European colonization, the *campos* region has progressively become one of the most important areas of livestock and grain production in the world (Bilenca and Miñarro, 2004). Furthermore, the expansion of cropland areas, the introduction of exotic grass species and their associated weeds, and more recently the substitution of grasslands for exotic forest plantations, mainly by *Eucalyptus* spp. and PINUS spp., deeply modified the original landscape (Paruelo et al., 2004; Panario and Gutiérrez, 2007).

3. Materials and Methods

3.1 Sampling and sediment analyses

A 1028 cm long sediment core (GeoB13813-4; 34°44.22'S, 53°33.27'W) was taken from the mud depocenter (57 m water depth) using a gravity corer during research cruise M78/3a with the German research vessel METEOR on May 2009 (Fig. 1). During this expedition, 4 kHz sediment-acoustic data were collected with the Parasound P70 sub-bottom profiling and bathymetric survey system aboard RV Meteor (Krastel et al., 2012). Detailed information about the acoustic profiles from the Uruguayan shelf has been published by Lantzsch et al. (2014).

Sub-samples for pollen, spores, organic-walled dinoflagellate cysts (dinocysts) and other non-pollen palynomorphs (NPPs) were analyzed. In addition, further samples from the bottom of the core were analyzed for diatoms, in order to expand the diatomological study of Perez et al. (2017).

3.2 Stratigraphy and Chronology

The chronology of core GeoB13813-4 is based on six radiocarbon dates, determined on bivalve shell samples that were distributed evenly over the core and preserved in life position (Table 1) (Perez et al., 2016).

Radiocarbon dates were calibrated against the Marine13 calibration curve (Reimer et al., 2013). For reservoir correction, the conventional age of 324 ± 30 years determined by Alves et al. (2016) was applied. Age-depth model was constructed by the Bayesian age-depth modelling approach using the program "Bacon" (Blaauw and Christen, 2011).

3.3 Palynological analysis

Standard techniques were performed for palynological extraction using KOH, HCl, and HF (Fægri and Iversen, 1989). Acetolysis process was not applied to avoid the damage of dinocysts. Two *Lycopodium clavatum* spore tablets were added before treatment to calculate palynomorph concentration (Stockmarr, 1971).

Due to the low pollen concentration, at least 100 pollen grains were counted for all samples. Pollen grains and spores were considered as originated from the terrestrial vegetation and therefore represent the "continental" component to the palynomorph assemblage. Their proportions were calculated as the percentage of the total pollen sum plus spores sum. Algae and cyanobacteria represent the freshwater continental input, referred to as the "freshwater" component; whereas dinocysts, foraminifera and acritarchs represent the "marine" component to the palynomorph assemblage. Algae, cyanobacteria, dinocysts, foraminifera and acritarchs were calculated as the percentage of the total palynomorphs sum. The presence of *Azolla filiculoides* was inferred from the presence of their spores, glochids or massulae.

Pollen and spores were identified using atlases and published keys (e.g., Bauermann et al., 2013; Mourelle and Prieto, 2016), and the modern reference collection at the CURE-Rocha, Uruguay. Identification of dinocysts and

NPPs was based on van Geel (2001), Borel et al. (2003), Borel (2007) and Zonneveld et al. (2013). Vascular plant nomenclature follows the system of the Missouri Botanical Garden (http://www.tropicos.org/). Since there are significant differences between the concepts of "plant taxa" and "palynomorphological types" and in order to provide the necessary nomenclatural clarity as well, names of pollen and spores are presented in SMALL CAPITALS in figures and refrain from using *italics* (de Klerk and Joosten, 2007).

Results are presented as percentage and concentration palynomorph diagrams. All identified palynomorphs were considered to calculate the percentages and for numerical analysis. Palynomorph zones (PalZ) were determined by a CONISS stratigraphically constrained cluster analysis, and diagrams were drawn using the TGView 2.0.4 program (Grimm, 2004).

3.4 Diatom analysis

Diatom samples were treated with $Na_2P_2O_7$, 35%, HCl and 30% H_2O_2 (Metzeltin and García-Rodríguez, 2003). A minimum of 400 valves was counted in each sample. Diatom species were identified and separated into groups according to their ecological salinity preference, i.e., freshwater, marine and marine-brackish, following the standard diatom literature (e.g., Hasle and Syvertsen, 1996; Witkowski et al., 2000; Metzeltin and García-Rodríguez, 2003; Metzeltin et al., 2005; Hassan et al., 2009; Sar et al., 2010).

Tab. 1. Radiocarbon dates from GeoB13813-4 core (Perez et al., 2016). Poz = Poznań Radiocarbon Laboratory (Poland).

Code (Poz-)	Depth (cm)	^{14}C yr BP	Bacon weighted average age (cal yr BP)	Sedimentation rate (cm yr^{-1})
35198	255	640 ±30	136	1.3
47935	305	775 ±35	180	1.1
42428	447	1000 ±40	317	1.0
35199	560	1090 ±30	424	1.1
47937	705	1220 ±40	570	1.0
42429	964	1600 ±30	908	0.8

Results are presented in summarized diatoms percentage diagram, as the complete analysis has been published elsewhere (Perez et al., 2017). Taxa of indicative of warm waters were grouped (referred hereafter to as WW diatoms): *Thallassiosira oestrupii*, *Thallasionema pseudonitzschoides*, *Trigonium reticulum*, *Trigonium alternans* and *Cymatotheca weissflogii*. Diatom zones (DZ) were determined by using the CONISS stratigraphically constrained cluster analysis performed using all identified diatoms, and diagrams were drawn using the TGView 2.0.4 program (Grimm, 2004). Biogenic silica (BSi) analysis detailed in Perez et al. (2018) was used as indicative of diatom concentration changes relative to the 405 cm diatom concentration.

4. Results

4.1 Stratigraphy and chronology

The 4 kHz seismo-acoustic profiles reveal that the sedimentary succession of core GeoB13813-4 exclusively covers unit U1 (Fig. 1) (Lantzsch et al., 2014). It predominantly consists of gray mud with scattered shells throughout. Gray sandy mud is present between 520 and 260 cm depth, and in the upper most 130 cm (Fig. 2) (Krastel et al., 2012). The sediment core record spans the last 1000 cal yr BP. Radiocarbon dates and sediment stratigraphy indicate continuous sedimentation at an average rate of 1.1 cm yr^{-1} (Table 1; Fig. 3).

4.2 Palynological analysis

Pollen and spores contents of core GeoB13813-4 are characterized by herbs dominance (15-50%), mainly POACEAE, ASTERACEAE, CYPERACEAE and CHENOPODIOIDEAE (Figs. 4, 5). Despite woody pollen taxa were present throughout the sequence (<10%), each pollen type has a scattered distribution. They were represented by both mesophilous (MYRTACEAE, CELTIS, MYRSINE, LITHRAEA/SCHINUS, RHAMNACEAE and ALLOPHYLUS EDULIS) and hydrophilous (SALIX CHILENSIS, PHYLLANTHUS SELLOWIANUS, SEBASTIANIA/ACANTHOSYRIS and CEPHALANTHUS GLABRATHUS) taxa. Woody pollen from plants not described for the RdlP grasslands was also found, such as PODOCARPUS, ALNUS and NOTHOFAGUS, as well as PINUS from alien plants were registered in the uppermost part. Aquatic herbs reached up to 3% and were mainly represented by emergent taxa (e.g., POLYGONUM, APIACEAE, TYPHA and ECHINODORUS). Submerged MYRIOPHYLLUM and floating AZOLLA were also present. Spores were represented by Bryophytes (<3%) and Pteridophytes (<5%). Such palynomorphs represent the "continental" component to the palynomorph assemblage of the sediment core (20-55%).

NPPs include algae (*Botryococcus* and *Pediastrum*) and cyanobacteria (*Gloeotrichia*) and represent the "freshwater" component to the palynomorph assemblage, whose proportion did not significantly change over time (<5%). Dinocysts included *Operculodinium centrocarpum* and *Spinifertites* spp., and acritarchs encompassed *Michrystridium* and *Cymatiosphaera*. Dinocysts and acritarchs, together with foraminifera, represent the "marine" component (45-85 %). Such marine palynomorph proportions and concentrations were variable throughout the sequence (Figs. 4, 5).

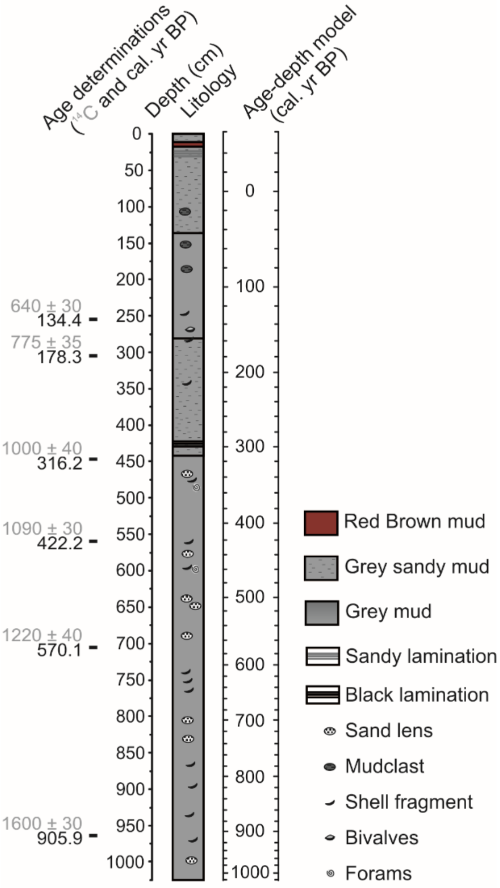


Fig. 2. Sediment description (modified from Krastel et al., 2012) and radiocarbon dates from GeoB13813-4 core, plotted against depth, and calibrated age scale (see Fig. 3).

CONISS cluster analysis applied to all identified palynomorphs allowed to define the following three palynological zones (PalZ; Figs. 4,5).

PalZ-I (1028 - 360 cm): marine palynomorph proportion fluctuated around 65% (45-85%), characterized by the dominance of dinocyst assemblage, mainly represented by *O. centrocarpum* (35-75%), accompanied by acritarchs (<15%) and foraminiferal linings (<5%). The marine palynomorphs showed highest concentration, with fluctuations and several peaks >60,000 palynomorphs/cm^3. Continental palynomorph concentration showed values around 20,000 palynomorphs/cm^3 (but reaching values higher than 30,000 palynomorphs/cm^3), while freshwater forms mainly fluctuated around 500 palynomorphs/cm^3, reaching values up to 1700 palynomorphs/cm^3).

PalZ-II (360 - 120 cm): palynological assemblage shifted toward a continental and marine co-dominance, both in terms of proportions and as in their concentration. Marine palynomorphs fluctuated around 60% (50-70%), still characterized by the dominance of dinocysts, but a decrease towards the upper section is observed, while the acritarch abundance increased up to 20%. Continental and freshwater palynomorph concentrations exhibited very similar values, whereas marine palynomorph concentrations sharply decreased, showing values lower than 20,000 palynomorphs/cm^3.

PalZ-III (120 - 0 cm): dominance of marine palynomorphs was recorded, where dinocysts increased and acritarchs diminished in relation to the previous zone. In addition, marine palynomorphs showed a slight increase in their concentration, ranging from 20,000 to 30,000 palynomorph/cm^3. A subzone was visually established to accommodate distinctive changes: PalZ-IIIb (65 cm) showed lower dinocysts and higher acritarchs proportions than PalZ-IIIa (<65 and >5%, respectively). In addition, a slightly higher freshwater palynomorph concentration was detected (with peaks higher than 400 palynomorphs/cm^3), simultaneously with the first Pinus appearance in the pollen spectra (Fig. 4).

4.3 Diatom analysis

Figure 6 shows the summarized diatom percentage diagram. Tycoplanktonic marine taxa are mainly represented by *Paralia sulcata*, whereas the freshwater group is almost exclusively made up of many species of *Aulacoseira* spp. all over the sequence.

Five diatom zones were defined based on the CONISS cluster analysis. DZ-I (1028 - 800 cm) was dominated by marine diatoms (up to 85%), mainly represented by tychoplanktonic and planktonic taxa. Freshwater diatoms displayed values up to 30%. DZ-II (800 - 710 cm) registered a sharp increase in freshwater diatoms to values up to 45% (together with the concomitant decrease in marine diatoms). In DZ-III (710 - 300 cm) marine diatoms dominated the assemblages again, reaching values up to 80%, with a slight decreasing tendency towards the upper section (DZ-III a to DZ-IIIb; 530 cm). In DZ-IV (300 - 100 cm), the freshwater diatoms dominated the assemblages with values up to 60%. Finally, freshwater diatom values decreased, with a concomitant increase in marine forms and, for the first time, of the marine-brackish group. These changes were further accentuated from 65 cm depth to the top of the core, where marine and marine-brackish diatoms reached values up to 70% and 30%, respectively.

Relatively high abundance of *Chaetoceros* spp. resting spores were observed throughout the sediment core (min = 0, max = 21.6 and mean = 7.7%), except for zones DZ-II, DZ-IIIb and DZ-IV (commonly of most up to 5%; Fig. 6). Resting spores were positively correlated with the group of the WW diatoms ($r^2 = 0.42$, $p < 0.05$), and they showed the same tendency described above, but at slightly higher values (up to 30%).

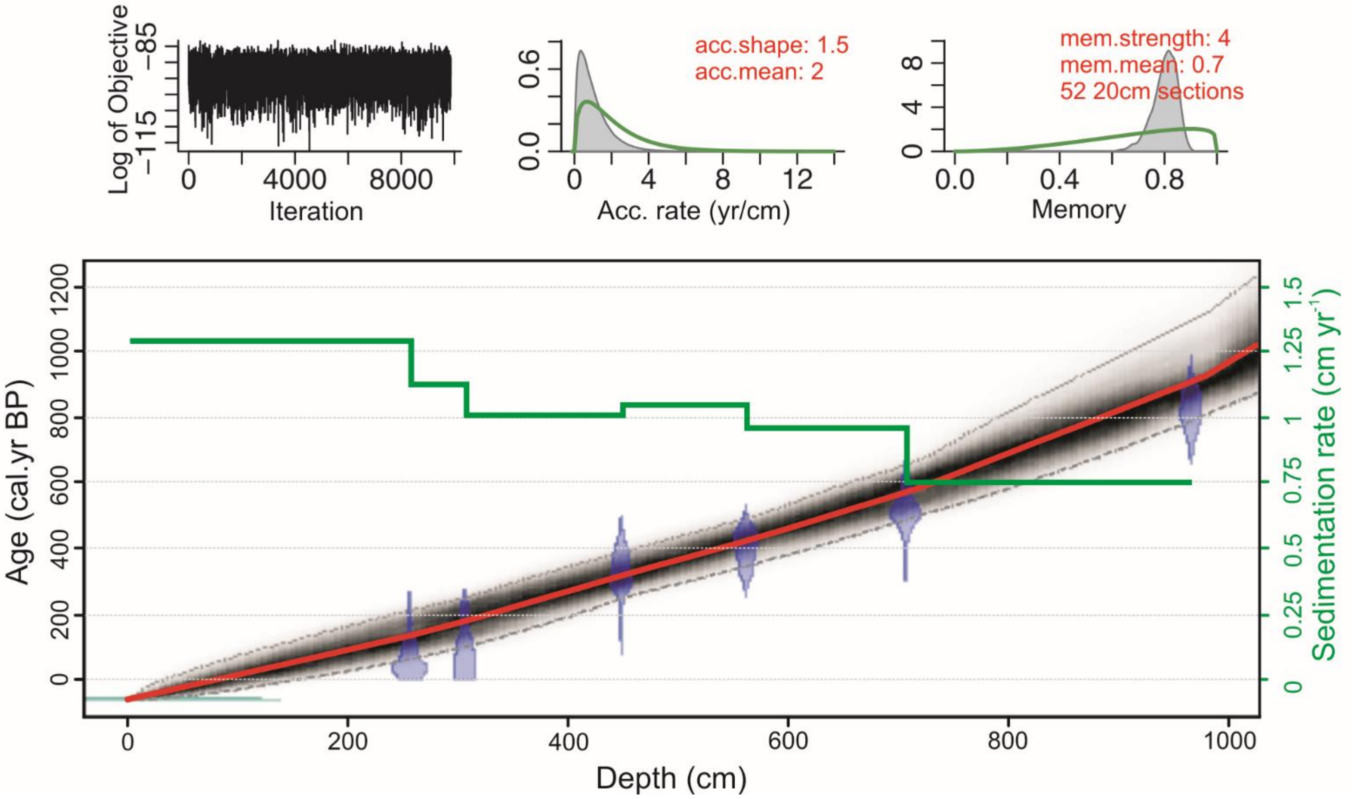


Fig. 3. Age-depth model for GeoB13813-4. Upper panels depict the Markov Chain Monte Carlo (MCMC) iterations (left); prior (green) and posterior (gray) distributions of accumulation rate (middle); and memory R (right). The bottom panel shows the age-depth model (gray), overlaying the calibrated distributions of the individual dates (blue); and sedimentation rates (green). Gray stripped lines indicate the age-depth model's 95% probability intervals, and the red curve the "best" fit based in the weighted mean age for each depth.

5. Discussion

5.1 Environmental background

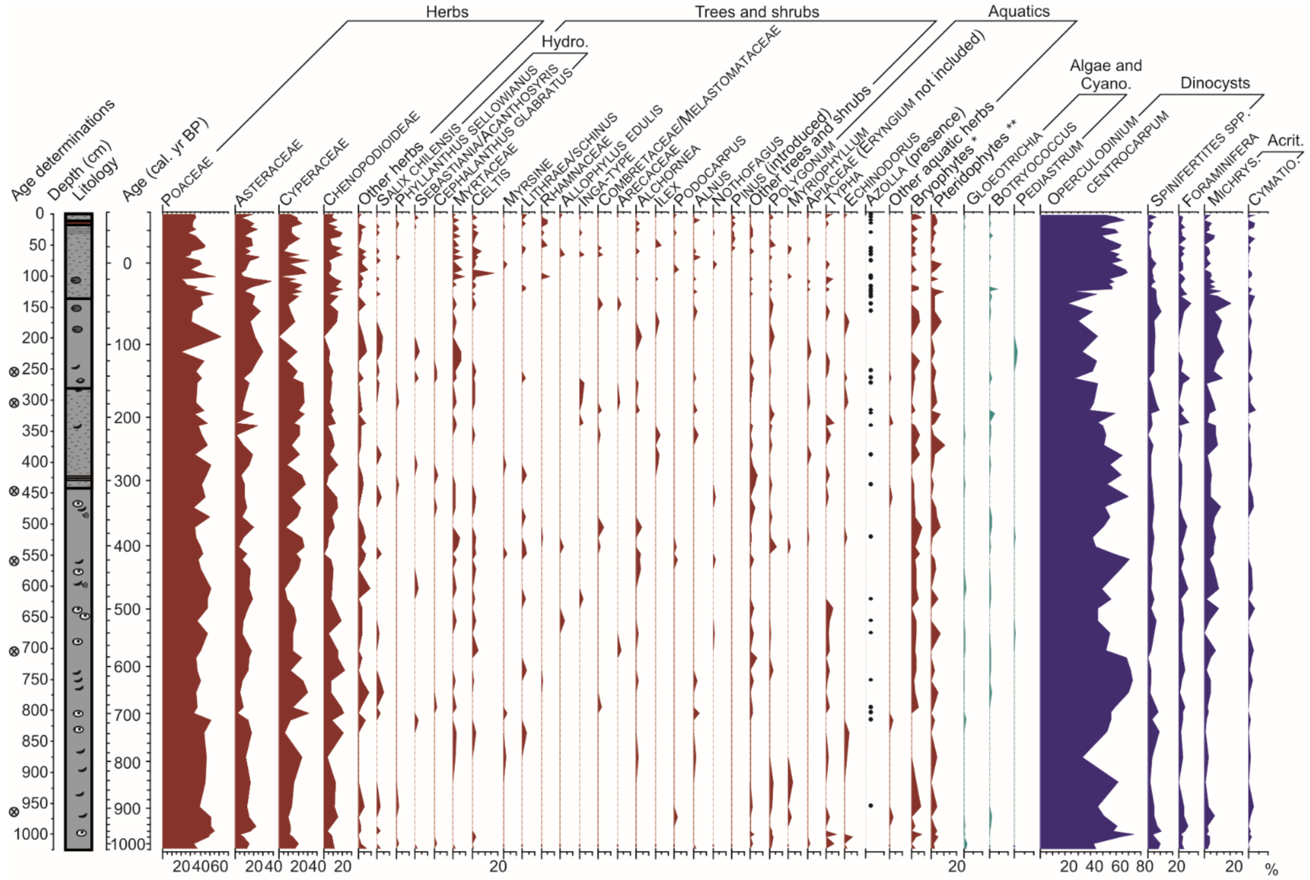
The mud depocenter on the inner Uruguayan continental shelf is characterized by homogeneous, predominantly muddy facies containing few shell fragments (Figs. 1B, 2). The transition from sand (U2) to mud (U1) deposition required a further weakening of the shelf current regime, most probably related to the southward shift of the STSF towards its modern position due to a stronger southward flow of the STSW, driven by more intense austral trade winds (Lantzsch et al., 2014; Razik et al., 2015). In addition, the beginning of unit U1 sediment accumulation should be connected to changes in LPDB, likely associated with the stabilization of the sea level (Prieto et al., 2017) and the onset of humid conditions in the Late Holocene (Behling, 2002; Behling et al., 2005; del Puerto et al., 2013; Mourelle et al., 2017), the latter having led to increasing RdlP discharge at about 2000 cal yr BP (Mahiques et al. 2009; del Puerto et al. 2013; Lantzsch et al. 2014). As a result of the increasing fluvial discharge and sediment transport, the Paraná delta formed at *ca.* 1700 cal yr BP (Cavallotto et al., 2004).

Sediment accumulation of unit U1 started around 1000 cal yr BP (Figs. 2, 3). Its remarkably high sedimentation rate reflects the strong and focused terrigenous supply by the RdlP. This agrees with Nd-isotope measurements on the sedimentary unit U1 that clearly identify the RdlP as the sole sediment source for the mud depocenter (Lantzsch et al., 2014).

5.2 Continental vegetation

Palynological assemblages deposited in the mud depocenter record consist of both allochthonous (pollen grains, spores, algae and cyanobacteria) and autochthonous (dinocysts, foraminifera and acritarchs) elements (Figs. 4, 5). No important changes were observed in pollen assemblages which could reflect stable plant communities at regional scale for the last 1000 cal yr BP, in agreement with other studies from the *campos* region and adjacent areas (Behling, 2002; Vilanova and Prieto, 2012; Mourelle et al., 2018, and references therein). However, fluctuations in the palynomorph concentration and in freshwater algae and cyanobacteria abundances (Figs. 5, 6) suggest variability in the freshwater input to the inner Uruguayan continental shelf. This freshwater influence is supported by conventional geochemical (C, N, and their isotopes), XRF element ratios (Ca, Ti, Al, Fe, and K) and diatom proxy data (Perez et al., 2016, 2017).

Pollen assemblages indicate the dominance of grasslands in the landscapes, mainly by the major POACEAE and ASTERACEAE values (Fig. 4). Nevertheless, POACEAE pollen probably comes also from the extensive floodplains of the Paraná River, where aquatic grasses such as *Panicum elephantipes* and *Paspalum repens* are very abundant, together with many CYPERACEAE and aquatic herbs, all of them also present in the pollen spectrum (e.g., CYPERACEAE, *AZOLLA*, *POLYGONUM*, *MYRIOPHYLLUM* and APIACEAE).



* include ANTHOCEROS, PHACEROS BULBICULOSUS, PHACEROS LAEVIS, PHACEROS TENUIS and RICCIACEAE.
** include POLYPODIACEAE, PTERIS-TYPE and BLECHNUM-TYPE.

Excluded from the pollen and spores sum

Fig. 4. Pollen, spores, dinocysts and NPPs percentage diagram for the main palynomorph types from GeoB13813-4 core. Hydro.: hydrophilous taxa; Cyano.: cyanobacteria; Michrys.: *Michrystridium*; Cymatio.: *Cymatiosphaera*; Acrit.: acritarchs.

Woody taxa from riparian forests in the *campos* region have mostly zoophilous pollination and they produce low quantities of poorly dispersed pollen grains (Mourelle and Prieto, 2016; Mourelle et al., 2017). As a consequence, the relatively low amount of woody pollen (<5%; Fig. 5) represents an important contribution into the mud depocenter, considering their very low concentration and its scattered presence throughout the sequence. Most of these pollen grains probably originated from riparian forest developed along the margins of the Paraná and Uruguay rivers, as suggested by the presence of hydrophilous *SALIX CHILENSIS*, *PHYLLANTHUS SELLOWIANUS*, *SEBASTIANIA*/*ACANTHOSYRIS* and *CEPHALANTHUS GLABRATUS* that exclusively develop in such forest types. Spores, mainly pteridophytes, are also frequent in modern riparian forest samples (Mourelle and Prieto, 2012), and are more easily transported by water over longer distances than pollen grains (Dai et al., 2014), which explains their important contribution to the analyzed assemblages. Woody pollen and spores transported via fluvial processes were already described for the northern RdlP coast (Mourelle et al., 2015a). More specifically, some woody pollen grains correspond to taxa that display their southern distribution boundary in the *campos* region of Rio Grande do Sul, such as ALCHORNEA TRIPLINERVIA, INGA VERA or TERMINALIA AUSTRALIS (Sobral et al., 2006). *INGA VERA* and *TERMINALIA AUSTRALIS* are also observed southwards along the Uruguay River (Brussa and Grela, 2007). As a consequence, *ALCHORNEA*, *INGA*-TYPE and COMBRETACEAE/MELASTOMATACEAE pollen reach the study area through hydrodynamic processes from the Uruguay River discharge into the RdlP. Probably, ARECACEAE pollen also reach the study area by the same riverine route, originating from the *Butia yatay* palm populations that nowadays grow interspersed among grasslands on both river sides. Although ARECACEAE pollen is usually under-represented, surface samples from *Butia yatay* palm populations showed relatively high values of this type of pollen (ca. 7-8%, Mourelle and Prieto, 2012; Muñoz, 2017).

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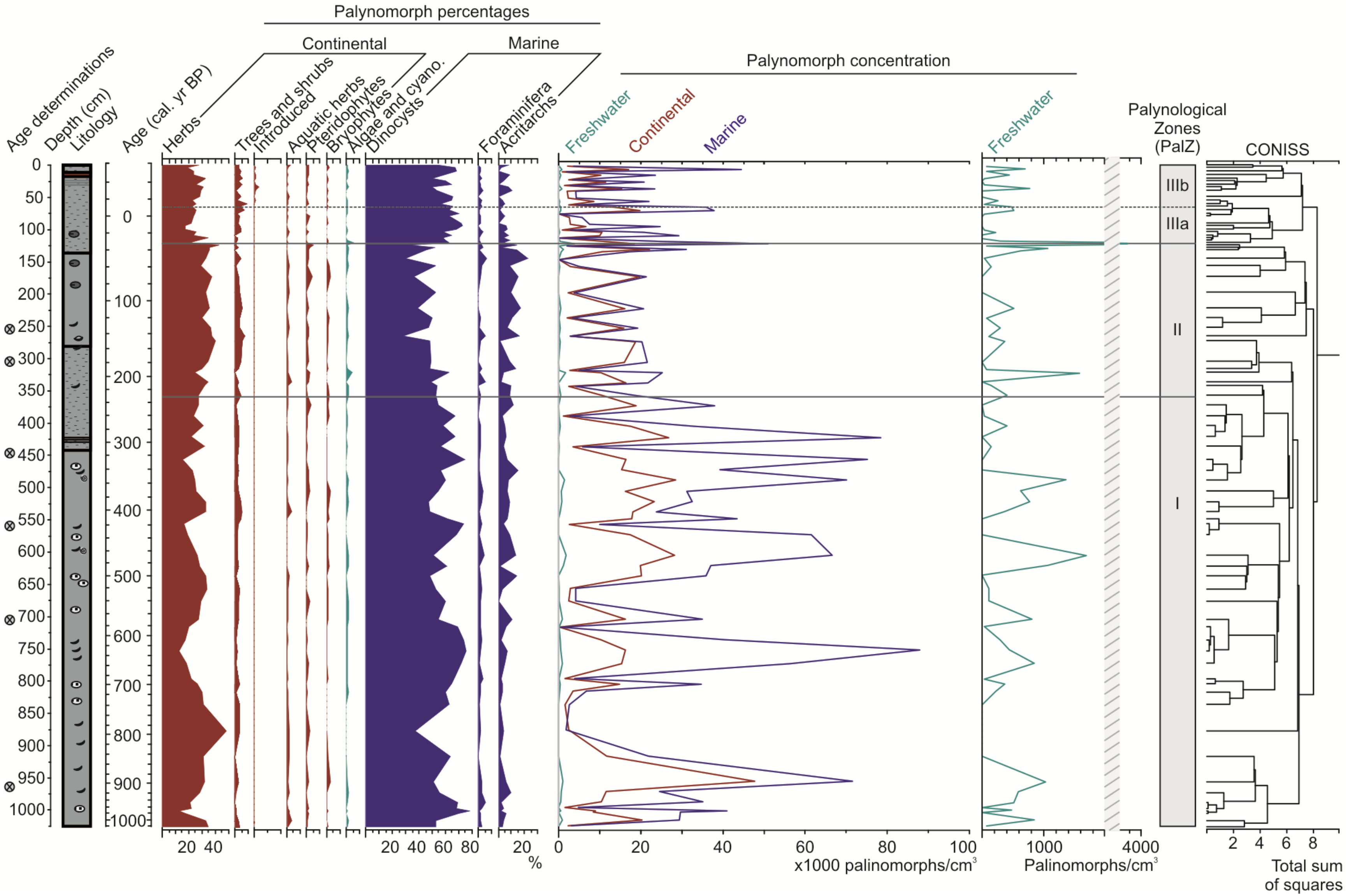

Fig. 5. Summary pollen and NPPs percentage and concentration diagrams, CONISS analysis and Palynological Zones (PalZ) from GeoB13813-4 core. Gray stripes represent axis brake.

The Patos Lagoon delivers freshwater to the southwestern Atlantic Ocean through a single man-made outlet, where intertidal salt marshes develop (Isaach et al., 2006). Further north, Atlantic rainforest dominates the coastal plains of southern Brazil, represented by species such as *Alchornea triplinervia* and *Euterpe edulis*, as well as of many Myrtaceae (Scudeller et al., 2001). In the highlands, the landscape is covered by a mosaic of grassland and *Araucaria* forests, the latter represented by *Araucaria angustifolia*, *Podocarpus lambertii* and *Ilex*, among others (IBGE, 2012). Therefore, pollen of Cyperaceae, Chenopodioideae and Typha (reliable indicators of Patos Lagoon coastal salt marshes; Medeanic, 2006; Medeanic et al., 2007), as well as Arecaceae, Alchornea, Ilex and Podocarpus, could have reached the study site being transported from southern Brazil southwards by the STSW. Morphological characteristics of Podocarpus pollen grains facilitate their dispersal through the air (Lu et al., 2011), so they probably reached the study area by wind transport from Brazil. Southwards, riparian forests and salt marshes developed scattered in the Uruguayan coast, particularly around numerous small water courses that flow into the RdlP and Atlantic Ocean. However, these areas do not seem to provide significant amounts of pollen to the inner continental shelf, given the huge amounts of sediments discharged by the RdlP.

Alnus and Nothofagus pollen indicate long distance transport, with Alnus stemming from the "Yungas" forests of northwestern Argentina, north of latitude 30°S, and Nothofagus from the foothills of the Andes, south of latitude 37 °S. Both pollen types probably reach the study area by wind, as they have been found in modern surface samples from the *campos* region overall Uruguay (Mourelle and Prieto, 2012). Nonetheless, Gu et al. (2018b) suggest that Nothofagus pollen could also reach southwestern Atlantic Ocean transported by rivers draining south and central Argentina. After reaching the ocean, Malvinas Current likely transports Nothofagus pollen northwards.

The human modification of the *campos* region, particularly due to the afforestation of economically important tree species, is indicated by Pinus pollen since ca. 1960 AD.

5.3 Inner Uruguayan continental shelf scenarios of material distribution and accumulation

5.3.1 From ca. 1000 to 230 cal yr BP (1028 - 360 cm depth; PalZ-I – DZ-I to DZ-III)

Marine conditions were inferred by the dominance of marine palynomorphs, both proportion and concentration, mainly represented by *Operculodinium centrocarpum* dinocyst (Figs. 4, 5). *Operculodinium centrocarpum* is a cosmopolitan and phototrophic dinocyst recorded in a wide range of temperature (from as low as 6.3°C to as high as 23.7°C) and salinity conditions, but highly abundant in sediments below the marine Brazil Current (Wall et al., 1977; Zonneveld et al., 2013; Gu et al., 2018a). Its relatively high abundance suggests an influence of the northern warm water masses on the upper section of the water column at the coring site, also supported by the presence of Alchornea and Podocarpus pollen, which would have reached the study area carried by STSW waters. *Spiniferites* spp. are also cosmopolitan and phototrophic dinocysts, very frequent in modern marine sediment (Zonneveld et al., 2013; Gu et al., 2018b). Their presence, together with foraminiferal linings and *Michrystridium* and *Cymatiosphaera* acritarchs, supports the inference of a significant marine influence (Borel, 2003) on the inner Uruguayan continental shelf.

This influence of STSW waters is also suggested by the dominance of marine diatoms, mainly *Paralia sulcata*, and by the high WW diatoms proportions (Fig. 6). *Paralia sulcata* displays salinity ranges between 15 and 22 (optimum 20), considered as a meso-polihaline diatom (Hassan et al., 2009). WW diatoms are indicative of tropical-subtropical systems (de Wolf, 1982; Hasle and Syvertsen, 1996; Kandari et al., 2009), abundant in sediments underneath the Brazil Current and diminishing in sediments located further south (Romero and Hensen, 2002). Furthermore, and despite the fact that it is not always possible to identify the *Chaetoceros* species only through the analyses of their resting spores (Ishii et al., 2011), we were able to identify four species that also indicate warm water conditions: *Chaetoceros costatus*, *Chaetoceros seiracanthus*, *Chaetoceros lorenzianus* and *Chaetoceros didymus* (Hasle and Syversten 1996; Romero and Hensen, 2002; Kandari et al., 2009; Sar et al., 2010). *Chaetoceros* resting spores could also be suggesting such warm environmental conditions.

In contrast, freshwater input from the mainland to the inner Uruguayan continental shelf is also detected, carrying allochthonous palynomorphs such as algae (*Botryococcus* and *Pediastrum*) and cyanobacteria (*Gloeotrichia*), freshwater diatoms, and terrigenous lithic material rich in Ti and Fe from the RdlP watershed (Perez et al., 2018). Freshwater diatoms are almost only represented by *Aulacoseira* spp. (Perez et al., 2017), a widespread genus inhabiting lacustrine/riverine freshwaters, where it is commonly an important component of the phytoplankton developing under several trophic conditions (Denys et al., 2003; Hassan, 2010). Its co-occurrence together with *Paralia sulcata* in the sediment of the mud depocenter could be explained by this freshwater input to the inner continental shelf.

However, fluctuations in the palynomorph concentration suggest variable intensity in freshwater input, supported by fluctuating Ti/Ca, Fe/Ca and C/N ratios (Perez et al., 2017, 2018). The progressive decrease in diatom concentration at a time when marine diatoms are replaced by freshwater ones (DZ-IIIa to DZ-IIIb) suggests an increasing intensity of the fluvial input over time.

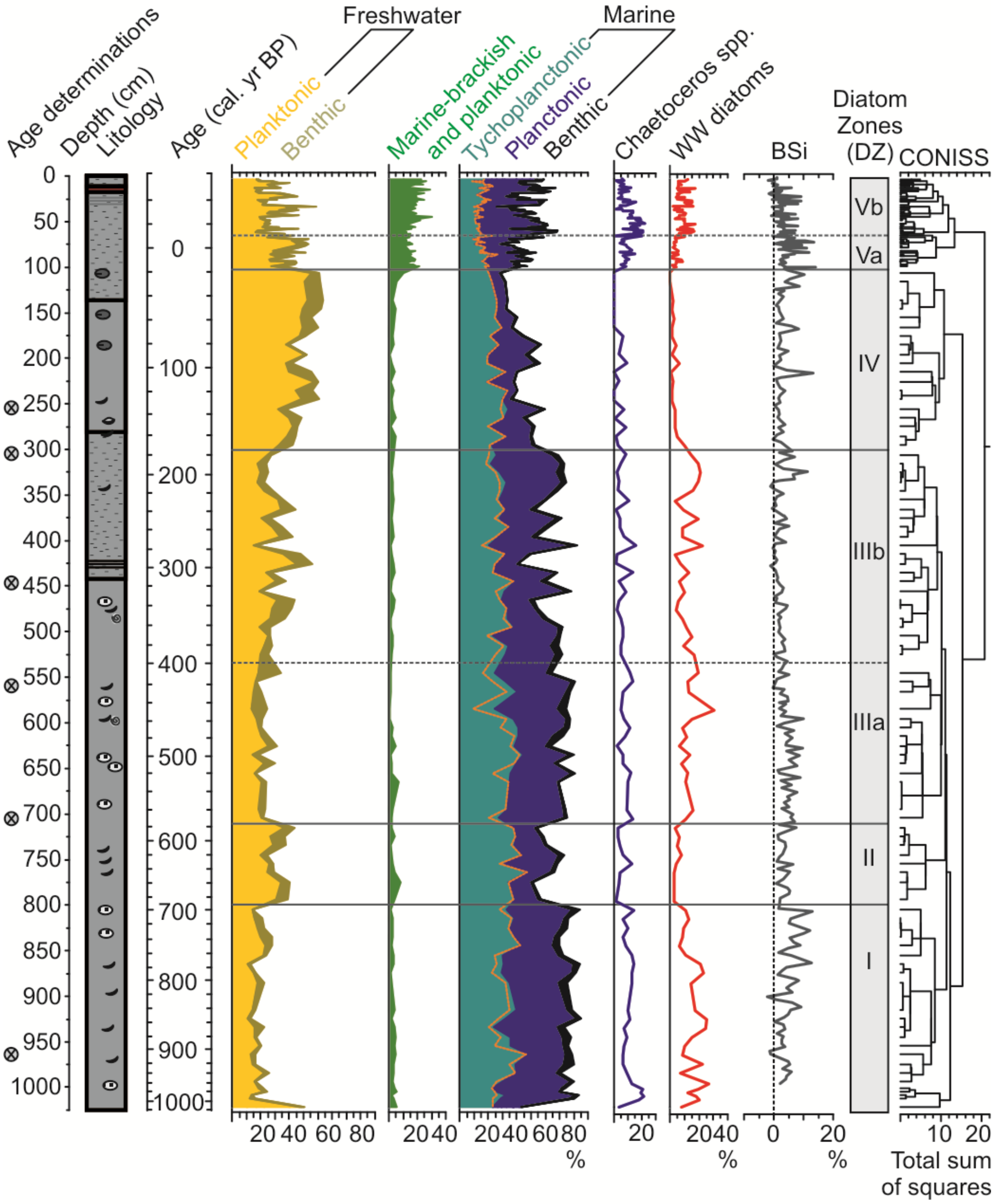

Fig. 6. A) Summary diatom percentage diagram, *Chaetoceros* spp., warm-water taxa proportion (WW diatoms), Biogenic silica proportion (BSi; Perez et al., 2018), CONISS analysis and Diatom Zones (DZ) from GeoB13813-4 core. Dotted orange line represents *Paralia sulcata* proportion. Modified from Perez et al. (2017).

Superimposing this general trend, different environmental characteristics are suggested for the time interval at 690 to 575 cal yr BP (800 – 710 cm depth; PalZ-I – DZ-II). Increasing freshwater contribution to the inner continental Uruguayan shelf is indicated by the sharp increase in freshwater diatoms relative to the marine species, as well as by a decreasing BSi proportion, which is interpreted as a depletion of the diatom signal. Nevertheless, marine conditions persisted allowing *Paralia sulcata* and dinoflagellates to be present.

However, the WW diatoms decrease (mainly *Thallassiosira oestrupii* and *Thalassionema pseudonitzschoides*) suggests that the study area was influenced by the cold and less salty SASW marine waters during this time interval. In addition, and since we were not able to identify all the *Chaetoceros* resting spores, the peak found in this period could correspond to a cold-water influence indicated by species belonging to the Malvinas Current, as it was previously found by Romero and Hensen (2002) for the southwestern Atlantic Ocean. Furthermore, *Operculodinium centrocarpum,* while indisputably abundant in sediments beneath warm water currents, is certainly not limited to warm waters but also abundant underneath cool waters (Wall et al., 1977). *Operculodinium centrocarpum* cysts are produced by *Protoceratium reticulum*, a dinoflagellate with a wide geographical distribution, in a range of hydrographic conditions, which comprise different water masses including the Malvinas Current (Akselman, 2015).

5.3.2 From ca. 230 to 25 cal yr BP (1590 to 1925 AD; 360 – 115 cm depth; PalZ-II – DZ-IV)

During this period, a strong influence of RdlP waters, transported via PPW into the inner continental shelf, is indicated by a sharp decrease in marine palynomorphs concentration, within which the dinocyst proportion decreases relative to an increase in acritarchs (Fig. 5). A dinocyst decline could be consequence of an ecological inhibition of dinoflagellates by high turbidity and low salinity (Tyson, 2012), whereas *Michrystridium* and *Cymatiosphaera* acritarchs seem to be able to tolerate turbid environments, as suggested by the fossil record from the RdlP northern coast (Mourelle et al., 2015a). High C/N and terrigenous element ratios suggest an increasing supply in suspended continent-derived material (Lamb et al., 2006; Perez et al., 2017, 2018), and historical documents report that since 1975 AD a Paraná Delta high rate of progradation of about 100 m yr^{-1} (Barros et al., 2005).

A weak STSW influence is also indicated by very sparse WW diatom taxa, the marine diatoms being replaced by freshwater forms (Fig. 6), mainly *Aulacoseira granulata* and *Aulacoseira ambigua* (Perez et al., 2017). These species indicate eutrophic conditions in the RdlP during this time interval, and they are also adapted to live in systems with high amounts of suspended particulate matter, such as the case of RdlP (Licursi et al., 2006).

5.3.3 From ca. 25 cal yr BP to the present (1925 AD to the present; 115 cm depth to the top core; PalZ-III – DZ-V)

Over the past century, a major oceanic influence, mainly by the STSW is suggested by a high marine palynomorph concentration, where dinocyst abundance increased and acritarchs decreased (Fig. 5), thus suggesting the return towards saltier and less turbid waters on the inner Uruguayan continental shelf. This observation is supported by the presence of marine-brackish and marine diatoms (including warm-water indicators), whose abundance significantly increased during this interval. Freshwater input is evidenced by the presence of freshwater algae and cyanobacteria, and of freshwater diatoms (Figs. 5, 6). High C/N ratios indicate a significant continental contribution to the sedimentary organic matter composition (Perez et al., 2017).

After ca. 1960 AD (65 cm depth; PalZ-IIb – DZ-Vb) the scenario substantially changes, in parts due to a major influence by the STSW, but mainly due to the anthropogenic impact in the LPDB (Bonachea et al., 2010). Increased erosion by overgrazing, agricultural activities, and deforestation has caused a rise in nutrient levels in the southwestern Atlantic Ocean, as documented by Gu et al. (2018a) for the past 120 years. Eutrophication favors periodic proliferation and dominance of harmful blooms of cyanobacteria, which increases water turbidity and hence restricts light penetration in the affected ecosystems (Paerl and Paul, 2012). Higher *Gloeotrichia* frequencies reaching the inner continental shelf during this period could be a consequence of such a scenario, as well as a decrease in diatom production (inferred by decreased BSi; Figs. 4, 6). In addition, a high input of nutrients to the coastal ocean is commonly associated with turbidity (Margalef, 1978; Möller et al., 2008), which could have promoted the acritarchs development observed for that period. Such a kind of nutrient enrichment is also suggested by the presence of *Actinocyclus normanii* diatom and by the highest values in δ^{15}N recorded over the past millennium (Perez et al., 2017). The appearance of PINUS sp. pollen (Fig. 4) is related to forestation activities, strongly promoted during this period (Panario and Gutiérrez, 2007).

5.4 Southwestern Atlantic Ocean scenarios and paleoclimatic implications

A southward shift of the ITCZ during Late Holocene would have increased instability and amplified the potential for SWWB wind anomalies which are required to initiate ENSO events (Haug et al., 2001; Lengaigne et al., 2004; Koutavas et al., 2006). Therefore, wetter conditions and higher rainfall over southwestern Atlantic Ocean (Behling, 2002; Behling et al., 2005; Mourelle et al., 2017), in particular during the more frequent El Niño events, could have been originated by increased precipitation over LPDB related with a high ENSO amplitude around 2000 cal yr BP (Woodroffe et al., 2003; Gyllencreutz et al., 2010), displacing the PPW northward and enhancing sediment export to the southwestern Atlantic Ocean (Perez et al., 2017), providing the sediment to the mud depocenter. However, this long-term trend of changing the amount of rainfall over southwestern Atlantic Ocean was overlain by inter-annual to decadal, multi-decadal and centennial variations (Moy et al., 2002), which modulate the RdlP river discharge. Short-term cyclicities (<100 yr) were assigned to the AMO, PDO and ENSO climatic modes, while long-term changes were most probably related to solar forcing (Perez et al., 2018). Terrigenous sediment supply from the RdlP to the Uruguayan continental shelf was strongly controlled by both long-term regional climatic cyclicities as well as inter-annual frequencies (Perez et al., 2018), and the palynological and diatomological assemblages in the record sensitively document these changes (Figs. 5, 6).

From ca. 1000 to 230 cal yr BP, the inner Uruguayan continental shelf was characterized by strong marine influence, more precise the STSW. Such condition has also

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been inferred over the inner continental shelf off southern Brazil (Gu et al., 2017). STSW most likely exerted a major influence on these areas because of the prevalence of northeasterly winds (Perez et al., 2017). Climatically, this period is partially related to the MCA (1050 to 700 cal yr BP; 900 to 1250 AD) and to the LIA (550 to 100 cal yr BP; 1400 to 1850 AD), interpreted as times when the SAMS mean state was first significantly weakening (MCA) and afterwards strengthening again (LIA), respectively (Lamy et al., 2001; Vuille et al., 2012; Apaéstegui et al., 2014; Lüning et al., 2018). Climatic conditions derived from these states seem to correlate well with our observations, in which the lowest freshwater input from mainland to the inner Uruguayan continental shelf took place during the MCA, whereas the trend of increase intensity in freshwater input is partially concomitant to the LIA, which would have caused a northward shift of the PPW.

Between MCA and LIA, our results suggest an influence of SASW on the inner Uruguayan continental shelf. This observation could be explained by a northward shift in SWWB, which entails a northward extension of the Malvinas Current along with a northward shift of the Brazil-Malvinas Confluence Zone (Sijp and England, 2008), supplying cold marine waters into the study area through the STSW. In addition, El Niño events are triggered by atmospheric noise, especially by the SWWB anomalies (Lengaigne et al., 2004; Koffman et al., 2014), and so this SWWB northward extension could be related also to increase rainfall over LPDB. Both the prevalence of the southwesterly winds and the higher terrigenous supply would consequently have provoked a northward displacement of the PPW.

From ca. 230 to 25 cal yr BP, the inner Uruguayan continental shelf was characterized by the strongest influence of RdlP waters overall the period, transported via PPW into the inner continental shelf under low marine influence. Increased influx of water from the main land can be attributed to an increase in precipitation over LPDB and/or a prevalence of the SWWB winds, and consequently a northward displacement of the PPW (Perez et al., 2017). This could suggest strong El Niño activity.

Finally, the period from 1925 AD to the present integrates the Current Warm Period (1900 AD to present), developed on a scenario of anthropogenic climatic change and is characterized by a reduced SASM activity, which happened more abrupt and sustained than the onset of the MCA (Bird et al., 2011). A southward migration of the SWWB took place during Current Warm Period (Bender et al., 2013; Koffman et al., 2014), which might have determined a stronger STSW influence in the study area. However, our major finding clearly highlights a positive trend in yearly averaged precipitation mainly from the late 1960s to the early 1980s (Boulanger et al., 2005). The lower/higher RdlP river discharge before/after 1970 is related to a dominance of La Niña/El Niño events accompanied with a cold/warm PDO phases, and positive/negative AMO phases (Marrero et al., 2014).

6. Conclusion

Geographical location, grain size distribution, sedimentation rate, as well as geochemical and biological (palynological and diatomological) analyses indicate a strongly fluctuating fluvio-marine depositional environment over the mud depocenter on the inner Uruguayan continental shelf during Late Holocene. More specifically, the sedimentary record is defined as a marine deposit with a significant admixture of a continuous, powerful fluvial input but with variable intensity of this riverine influence through time.

Freshwater supply carried terrigenous material, such as pollen and spores that were captured by the Paraná and Uruguay rivers flowing through the southeastern South America basin. This palynological material reflects the terrestrial vegetation on the lower reach of the LPDB. Its spectrum mainly represents the regionally dominant grasslands, but also the riparian forests, *Butia yatay* palm populations, and the herbaceous-bushy marshes around the mouth of the estuary. Such results reflect stable plant communities at regional scale for the last 1000 cal yr BP, which are in agreement with other studies from the *campos* region and adjacent areas.

Palynological data also evidence that pollen from remote phytogeographical areas reaches the study site, mainly transported (1) by coastal ocean currents from salt marshes, Atlantic rainforest, and *Araucaria* forests in southern Brazil; and (2) by wind from Andean forests. This long-distance transported pollen highlights the high paleobotanical potential of this sequence, because of capturing pollen from a large regional scale.

Ecological information provided by changes in dinocysts, acritarchs, algae and cyanobacteria proportion and concentrations in GeoB13813-4 sediments represent a new line of evidence of changes in terrestrial run-off to the inner Uruguayan continental shelf, mainly related to a variable precipitation regime over LPDB, in addition to ocean hydrography and wind activity. The main scenarios characterizing the environmental dynamics include:

(1) From ca. 1000 to 230 cal yr BP: significant marine STSW influence was inferred, diluted by the freshwater supply from the Uruguayan mainland of increased intensity over time. Climatically, this period is partially related to the MCA and the LIA, when the SAMS mean state was first significantly weakening (MCA) and thereafter strengthening again (LIA), with the consequent lower/higher freshwater contributions into the inner Uruguayan continental shelf, respectively.

(2) This period was interrupted between ca. 690 to 575 cal yr BP by increased freshwater contribution under SASW influence. This observation could be explained by a northward shift in SWWB, which entails a northward extension of the Malvinas Current along with a northward shift of the Brazil-Malvinas Confluence Zone.

(3) From ca. 230 to 25 cal yr BP, a strong influence of RdlP waters was detected that could be attributed to an

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increase in precipitation over LPDB and/or a prevalence of the SWWB winds, thus suggesting a strong El Niño activity and a northward displacement of the PPW.

(4) Return to dominant STSW over the past century, climatically related to the Current Warm Period developed on a scenario of anthropogenic climatic change characterized by a reduced SASM activity. In particular, after ca. 1960 AD the anthropogenic impact within the LPDB was evidenced by both eutrophication and the appearance of PINUS sp. pollen.

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