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Holocene vegetation changes along the southeastern coast of the Argentinean Pampa grasslands in relation to sea-level fluctuations and climatic variability: Palynological analysis of alluvial sequences from Arroyo Claromec6

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ABSTRACT

Here we present palynological records from alluvial deposits in four outcrop sequences along the lower reaches of Arroyo Claromec6, Buenos Aires Province, Argentina (38° 50' S latitude, 60° 05' W longitude). These data indicate development of soils and grasslands with associated halophytic vegetation in the higher elevations of the floodplains between ca. 7200 and 6000 ¹⁴C yr BP (ca. 8000 and 7000 cal yr BP). At lower elevations halophytic saltmarsh vegetation was replaced by wetland communities (sedges) in response to a sea-level highstand at 6500 ¹⁴C yr BP (ca. 7400 cal yr BP). Soils were buried by expanding wetlands at ca. 6000 ¹⁴C yr BP, a trend that persisted until ca. 3400 ¹⁴C yr BP (ca. 3700 cal yr BP). Over this interval we observe repeated fluctuations between grassland and halophytic vegetation in response to variations in water level and physical-chemical conditions resulting from desiccation or flooding events. These variations are caused by hydrologic variability in a subhumid-dry climatic mean state. Channel incision occurred between ca. 3400 and 2500 ¹⁴C yr BP (ca. 3700–3200 cal yr BP), concurrent with sporadic and intermittent sediment deposition at higher elevations of the floodplain. The pollen record from the paleochannel infilling indicate grasses accompanied by halophytic taxa between ca. 2500 and 800 ¹⁴C yr BP (3200 and 700 cal yr BP) deposited in a shallow brackish-to-fresh water body. The palynological spectra from sediments deposited sporadically at higher elevations show halophytic vegetation and a trend toward wetland desiccation followed by development of psammophytic communities after ca. 1100 ¹⁴C yr BP. The tops of the alluvial sequences are covered by sand dunes whose modern spectra are characterized by psammophytic vegetation along with exotic tree taxa. Our results and inferences are consistent with previous studies and provide more detailed insights into the impacts of Holocene sea-level and climatic variations, aspects that are relevant for the coastal Pampa grasslands under various scenarios in a warming world.

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1. Introduction

Fossil pollen analysis carried out in the temperate Pampa grasslands of eastern Argentina has allowed reconstruction of Holocene vegetation from inland and coastal zones that show the response of vegetation to climatic variability and Holocene sea-level fluctuations (e.g. Prieto, 1996, 2000; Prieto et al., 2009; Stutz et al., 1999, 2006; Fontana, 2005; Vilanova et al., 2006a,b). However, for the coastal sector, more records are needed to estimate the marine influence on the vegetation in the lower reaches of coastal streams during Holocene sea-level highstands. Presently sediment sections from the

coastal zone have many spatial and temporal gaps and most existing pollen records have low temporal resolution or encompass short intervals. High resolution records from several sedimentary sequences within the same basin, representing different positions in the floodplain and distances from the shoreline would shed light on the relationship between regional climatic variability, sea-level changes, and vegetation dynamics in the southeastern Pampa grasslands.

Alluvial sedimentary sequences from inland and coastal Pampa grasslands, preserved in the floodplains of the major rivers, have provided abundant and well preserved pollen and non-pollen palynomorphs (here after NPP). Even though the palynological records could be biased as a result of variations in deposition rate and pedogenesis these alluvial sequences are remarkably constant and well preserved over large distances and present stratigraphic resolution that allows correlation over several kilometers along the region's entrenched streams. This makes possible to understand the stratigraphical complexity and to distinguish subtle variations in

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paleolandscape position and depositional environments along the basins. In particular, the thick sedimentary sequences outcropping along the Arroyo Claromecó on the southeastern Pampa grasslands coast have extensive lateral continuity and vertical development especially along the lower reaches of the basin (Figs. 1 and 2). These outcrops permit identification of spatial and temporal variations of environmental proxies, which is not possible with sediment cores or single outcrops that only yield a single vertical profile. Moreover, the location of these sequences in the lower reaches of Arroyo Claromecó allows us to differentiate between signatures of sea-level change and climatic variability, which contributes to the regional reconstruction of vegetation and environment history related to both forcing mechanisms. A regional reconstruction of Holocene environmental changes is relevant for postulating future vegetation dynamics in this highly sensitive area of the coastal Pampa grasslands, influenced by both climatic variability and sea-level.

The aims of this paper are: (1) to evaluate spatial and temporal patterns of palynological data obtained from alluvial deposits in four outcrop sequences in the lower reaches of Arroyo Claromecó; (2) to reconstruct from the palynological records past vegetation and paleoenvironmental conditions and interpret them in terms of sea-level fluctuations and climatic variability; (3) to compare our paleoecological interpretation from pollen and NPP with other proxy records e.g. diatoms, mollusks and stable isotopes; and (4) to integrate the interpretations with interpretations from previously studied localities along the southeastern coast of Pampa grasslands to establish the regional trends of vegetation and environmental dynamics.

1.1. Previous studies at the lower reach of Arroyo Claromecó

The alluvial sequences of the Arroyo Claromecó were first studied at the beginning of the 20th century, when stratigraphic and micro –

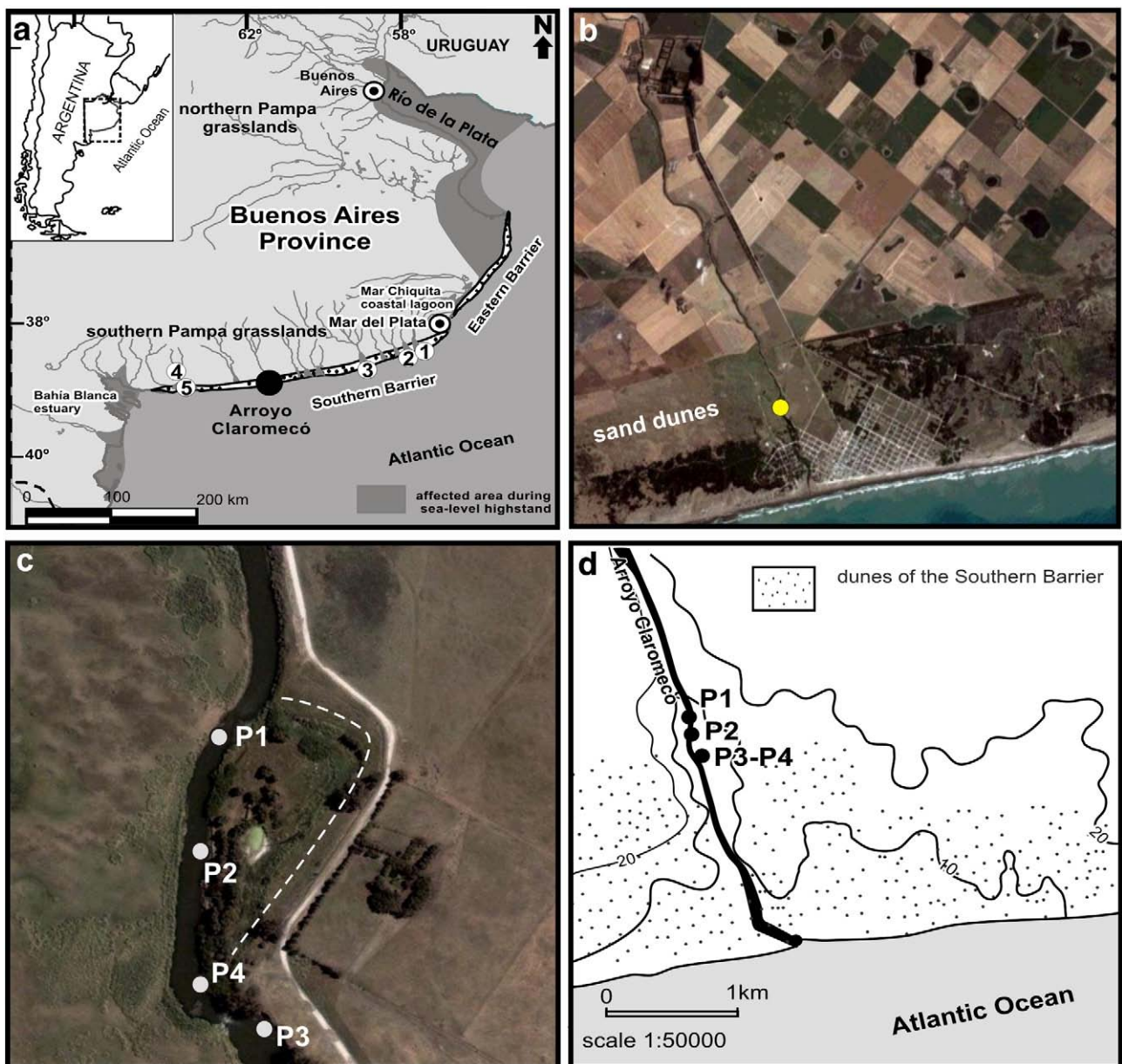


Fig. 1. (a) Location map of Arroyo Claromecó and sites mentioned in the text: Arroyo Las Brusquitas (site 1), Arroyo La Ballenera (site 2), Paso Vanoli (río Quequén Grande, site 3), Laguna del Sauce Grande (site 4), and La Olla 1 (site 5); (b) image of Arroyo Claromecó showing the studied area; (c) image of paleochannel adjacent to the present watercourse (dashed line) and location of selected profiles at the lower reach (d) location map of the selected profiles (P1–P4).

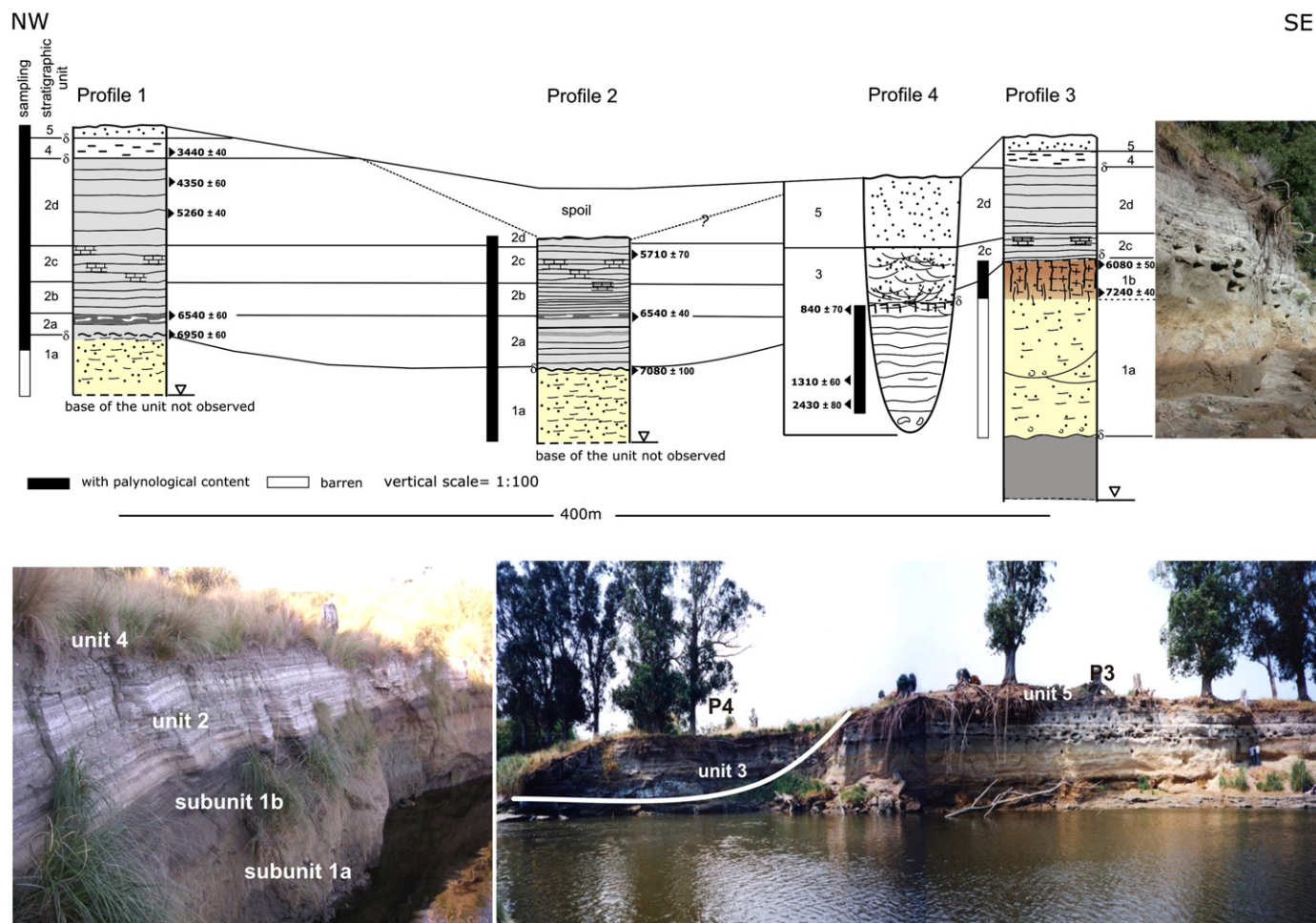


Fig. 2. General cross section of the late Pleistocene and Holocene stratigraphy from Arroyo Claromec6. Stratigraphic unit correlations among the studied profiles.

and macropaleontologic studies were carried out by Frenguelli (1928), mainly focused on diatom assemblages and extinct vertebrate remains. Frenguelli's stratigraphic terms have several meanings, and for that reason, Blasi et al. (2009) have proposed not to consider them in order to avoid mistakes and misinterpretations. In this study we have used informal numerical units refer for the stratigraphic units observed and correlated along the Arroyo Claromec6.

Paleoenvironmental reconstructions related to sea-level variations during the Mid-Holocene have been carried out on a sediment sequence outcropping 1.5 km from the coast along the Arroyo Claromec6 (Profile 1 of this study) based on palynological analyses (Vilanova, 2005; Prieto et al., 2009), mollusks (Romero, 2008; Bruno, unpublished data), and diatoms, the latter for the period between 7000 and 6000 ¹⁴C yr BP only (G6mez, 2008). A sediment sequence outcropping 1.3 km (Profile 4 of this study) from the coast and dated between ca. 2500 and 800 ¹⁴C yr BP was interpreted by Isla and Espinosa (1998) as an estuarine facies related to the sea-level oscillations during the late Holocene. However, pollen (Stutz, 2000) and diatom (Hassan et al., 2004) analyses from this sequence indicate a shallow freshwater body without connection to the sea. In this paper we interpret this sequence as an abandoned channel whose formation and features are described in the stratigraphic context section.

2. Location and environmental setting

The Arroyo Claromec6 basin (~3017 km²) is situated in the southeastern Buenos Aires province (38° 50' S; 60° 05' W, Fig. 1). The basin has an elongated and lobular shape in a gently undulating

plain, with depressions of variable dimension of no more than 2 km width in its middle and upper reaches promoting the formation of small temporary and permanent ponds (Carbone and Piccolo, 2002). The Arroyo Claromec6 is 60 km long, formed by the confluence of three streams flowing in a north to south direction in a valley that fluctuates in width between 500 m and 2–3 km (Carbone and Piccolo, 2002). The channel has numerous abrupt slope breaks resulting in "cascadas" (rapids) suggesting that the longitudinal profile of Arroyo Claromec6 is still adjusting to baseline changes in its lower reach. The channel is deeply incised ca. 7 km upstream from the mouth until a terminal headwall delimits the extent of the downcutting.

Arroyo Claromec6 flows into the South Atlantic Ocean through 1 to 3 m high sand dunes of the Southern Barrier (Isla et al., 1996, 2001, Fig. 1). At its mouth, the stream is 88 m wide and 1.5 m deep, and is classified as a coastal plain estuary (B6rtola et al., 2005). The upstream limit of the modern estuary is 1.9 km inland, in the area of the second rapid, where water depth is less than 1 m at low tide, and the course never exceeds a 40 m in width. Water depth and width increase from this point to the mouth (Carbone et al., 2005). Tidal influence reaches 2 km upstream (B6rtola et al., 2005) with a significant influence of the sea upon the watercourse at rising tide, with high salinity values on the surface almost as far as 1 km upstream (Carbone et al., 2005). The coastal sector has a mesotidal regime, dominated by episodic storms; a tidal range of 2 m, and a high tide mark with over-elevation of 2.7 m (B6rtola et al., 2005).

The region is under the influence of two climatic zones: humid-subhumid and dry-subhumid (Carbone et al., 2004). The climate of this area corresponds to a transitional oceanic temperate zone with

marked thermal seasonality, with winds predominantly from the north and north-west (Bértola et al., 2005). Mean annual temperature is 13.99 °C and the mean annual precipitation is 693 mm. In particular, during the first years of the 20th century until the end of 1936, the dry periods were more frequent and intense than the humid periods, whereas after 1973 the humid periods became more frequent (Carbone et al., 2004), suggesting multi-decadal variations.

The vegetation of the Arroyo Claromecó area is part of the Pampa grasslands, which expand from 33° to 41° S latitude and 56° to 67° W longitude. At present, agricultural and cattle grazing activities have changed some areas, and have caused the extirpation of native species, allowing the establishment of exotic trees. Plantations of exotic trees (mainly *Tamarix*, *Acacia*, *Pinus*, *Cupressus*, *Eucalyptus*, and *Populus*) on seven hundred hectares were established to fix sand dunes and sandy soils along the creek banks. Natural or semi-natural grasslands are found in uncultivated or undisturbed areas. Native vegetation is still present on sand dunes of the Southern Barrier, especially several psammophytic communities represented by Poaceae and Asteraceae species such as *Panicum urvilleanum*, *Poa lanuginosa*, *Cortaderia dioica*, *Hyalis argentea*, *Baccharis divaricata*, *Solidago chilensis*, *Senecio quequensis*, *Gnaphalium* sp., *Aster* sp., *Ambrosia tenuifolia* and *Hypochoeris pampasica*. Other psammophytic species found on sandy soils and dunes are *Calycera crassiflora*, *Juncus acutus*, *Ephedra ochreatea* and *Margyricarpus pinnatus* along with *Melilotus album*, *Solanum sisymbriifolium* and *Oenothera mollissima*. In the interdune areas grow herbs and sedges (*Carex* sp. and *Schoenoplectus* sp.).

2.1. Stratigraphic context

The valley of the Arroyo Claromecó is carved into mid to upper Pliocene silty clay to sandy silt deposits (Fidalgo et al., 1986). These deposits crop out discontinuously along the Arroyo bank and are exposed in a 7–8 m high cliff on the east side of the Arroyo mouth, where they are unconformably overlain by shelly sandstones and conglomerates related to the last Interglacial coastal barrier (Isla et al., 2000). Chronological control is not available for dating either valley excavation or the beginning of valley infilling. In this passive margin setting, long-term trends of bedrock incision are likely driven by uplift during the Neogene. Late Pleistocene and Holocene alluvial deposits fill the present valley. The stratigraphic relations of the alluvial units at Arroyo Claromecó were determined by lithology field inspection and radiocarbon dating. From the Late Pleistocene to ca. 3500 ¹⁴C yr BP the water table would have been high and evidence for channel cutting is absent. In contrast, between ca. 3500 and 2500 ¹⁴C yr BP a channel incision occurred with a consequently water table drop; this paleochannel was observed during field inspection (Fig. 1). There is no evidence of increases in the magnitude or frequency of flooding that might have triggered channel entrenchment at this time. It seems most likely that a major factor in the formation of late Holocene channel entrenchment was a fall in sea level. A drop in mean sea-level has been proposed for the Bahía Blanca estuary (Fig. 1) dated at ca. 2700 ¹⁴C yr BP and correlated with a worldwide climatic change (Gómez et al., 2005).

In recent times, headward entrenchment in the lower reaches of the valley isolated deposits of the late Holocene channel area and preserved them in an abandoned channel (Fig. 1). The present entrenched channel no longer meanders and widens by bank failure (Figs. 1 and 2). During high flow events, the stream level reaches the top of the incised channel and sedimentation occurs intermittently on the floodplain and a temporary small pond develops (Fig. 1).

The relatively rapid incision of the modern channel allowed preservation outside the incision zone of an extensive suite of multi-aged pre-incision deposits related to the previous history of the alluviation episodes. For these deposits, five units have been distinguished whose stratigraphic positions are shown in Fig. 2.

Unit 1 is divided into two subunits: subunit 1a (before ca. 7000 ¹⁴C yr BP), composed by reworked sediments deposited by water flux in

the floodplain, characterized by greenish, brownish to yellowish sandy silts presenting ferruginous mottles, carbonate concretions and root traces with oxidation haloes. In some levels there are small calccrete roly stones. Fine laminations and planar stratification were observed, with diamicts, volcanic ash lenses and clasts in some sections from the lower levels, and with some remains of *Heleobia parchappii* and *Succinea meridionalis* shells (Romero, 2008) from which isotopic values were recorded. In the uppermost part of this subunit, a buried soil is recognized (subunit 1b), which is biodisturbed in the upper contact. The bulk organic matter from the upper 5 cm of this soil yielded 6080 ¹⁴C yr BP providing a close limit to perhaps a maximum age-estimate on burial of the soil.

Unit 2 (ca. 7000–3400 ¹⁴C yr BP) conformably overlay unit 1. It is characterized by dark brownish sandy silts finely laminated (subunit 2a) with shells of *Heleobia parchappii* and *Succinea meridionalis* (Romero, 2008), along with marine/brackish and brackish/freshwater diatom assemblages (Gómez, 2008). Overlying, there are clayey silts with finely stratification and intercalations of a clayey layer (subunit 2b) with shells of *H. parchappii* and *H. australis* (Romero, 2008). It is followed upward by dark to light clayey silt and black finely laminated clay and coarse stratification with presence of caliche (subunit 2c), and presenting high diversity and abundance of diatom assemblages with euryhaline species from brackish and freshwater environments (Gómez, 2008). Overlying subunit 2c, there is fine silty sand containing CO₃Ca, clayey silt and intercalated clays with presence of tufa and *H. parchappii* shells (subunit 2d). Isotopic values of $\delta^{13}\text{C}$ and of $\delta^{18}\text{O}$ were registered from *H. parchappii* and *H. australis* shells from the total unit.

Between ca. 3500 and 2500 ¹⁴C yr BP a channel incision occurred. At the same time as the paleochannel infilling was occurring (unit 3 ca. 3000–800 ¹⁴C yr BP), on the upper parts of the banks sediments of unit 4 (ca. 3400–1100 ¹⁴C yr BP) were depositing during extraordinary flood.

The unit 3 is composed by laminated silt clayey layers with *Heleobia parchappii* shell remains and plant macrorests, along with brackish to freshwater diatom assemblages (Hassan et al., 2004). It could be recognized due to a lateral channel migration in recent times that recrosses its previous zone of sedimentation. The occurrence of rolled lumps of clayed silt from the unit 2 in the channel fill suggests that the coarse load was not transported very far.

Unit 4 is a fining-upward unit mainly composed of fine sand with shell remains of *Heleobia parchappii* from which isotopes values were recorded.

Unit 5 is characterized by sand dunes of the Southern Barrier (SB). It covers the sequences, mainly in the left side of the Arroyo Claromecó from the coastline up to 2 km inland.

Freguelli (1928, 1945) described an outcrop near the Arroyo mouth which he interpreted as “marine/estuarine mollusk deposits” that indicated a period of sea-level highstand. This deposit, interbedded the units 1 and 2 of the present study, has been dated in other sequences between 6500 and 6000 ¹⁴C yr BP (Isla and Espinosa, 1998). The original outcrop no longer exists; it was either destroyed by human activities or eroded by sea storms. However, it was possible, through stratigraphical correlation to integrate this deposit with our studied outcrops and include the palaeoenvironmental aspects to the overall reconstruction of the development of the Arroyo Claromecó sequence and Holocene sea-level fluctuations.

3. Materials and methods

3.1. Sampling

Because of the completeness and lateral continuity of the late Pleistocene–Holocene sedimentary exposures, four profiles (P1 to P4) were sampled for palynological analysis in the lower reaches of Arroyo Claromecó (Figs. 1 and 2). P1, P2 and P3 were sampled where the watercourse is cutting the alluvial sequence and a steep cutbank is

developed, exposing a thick section of floodplain deposits. P4 was sampled from the paleochannel which is exposed in the Arroyo wall, within the late Pleistocene–Holocene sedimentary exposures (Figs. 1 and 2).

3.2. Palynological analysis

Standard palynological techniques were applied for pollen extraction using KOH, HCl, ZnCl₂ for heavy liquid separation, HF and acetolysis (Faegri and Iversen, 1989). *Lycopodium clavatum* tablets were added to calculate pollen concentration (Stockmarr, 1971). Identification of NPP was based on van Geel (2001), Head et al. (2003) and Borel et al. (2003) and includes *Botryococcus*, *Pediastrum*, and *Spirogyra* (algae); *Cobricosphaeridium* (copepod or anastracod resting egg); Peridinoideae (dinoflagellate cysts); *Glomus* (fungi) and acritarchs; pollen was identified using reference collections at the Paleocology and Palynology Laboratory, Universidad Nacional de Mar del Plata.

Pollen percentages were calculated in relation to the total pollen sum. NPP percentages were calculated in relation to the total pollen sum plus NPP sum. Brassicaceae pollen was excluded from the total pollen sum in P4 due to this type's over-representation. Pollen zones were determined by CONISS stratigraphical constrained cluster analysis (Grimm, 2004). Pollen types selected for this analysis were those with mean percentages of $\geq 3\%$. The selected pollen types were Poaceae, Chenopodiaceae, *Limonium brasiliense*, Cyperaceae, Apiaceae, *Ruppia* sp., Asteraceae subf. Asteroideae, Asteraceae subf. Cichorioideae, and *Ambrosia* sp. Psammophytes include *Spergularia*, *Gilia*, *Cerastium*, *Margyricarpus*, *Polygala* and *Calycera*. Hydrophytic and aquatic herbs include: *Alternanthera*, *Gomphrena*, *Myriophyllum* and *Elodea*. TGVIEW program was used for plotting diagrams (Grimm, 2004). CONISS cluster dendrograms are displayed on the right side of each diagram and were used for determining pollen zones, except for two divisions in P1, which were made visually to accommodate the distinctive change in the representation of major NPP taxa which were not considered in the CONISS analyses.

4. Results

4.1. Chronology

Eight conventional and five AMS radiocarbon dates were obtained, expressed in uncalibrated years before present (¹⁴C yr BP) and calibrated ages (cal yr BP) (Table 1). Radiocarbon ages were calibrated using the program CALIB 5.0.1 (Stuiver et al., 2005). All ages were calibrated with the South Hemisphere curve (SHCal04) (McCormac et al., 2004). The stratigraphic units defined in the field, combined with the chronological control, provided the framework for the palynolog-

ical reconstruction. According to the radiocarbon dates, the palynological sequences represent the last ca. 7200 ¹⁴C yr BP. Linear interpolation using the Tilia 2.0 software (Grimm, 2004) was carried out for estimating age limits of the pollen zones as well as for the top and bottom age limits in each profile (Figs. 3–7). The correlations and reconstructed chronology for the sequences are supported by the fact that stratigraphic units in P1 and P2 are correlated on the basis of the stratigraphic analysis of the sections and that the pollen spectra at 6540 ¹⁴C yr BP have nearly identical radiocarbon ages.

4.2. Palynological records

Deposits corresponding to stratigraphic subunit 1a in sections P1, P2 and P3 were palynologically barren. In contrast, the remaining stratigraphic units and subunits contained abundant and well preserved pollen and NPP. The palynological content from P1, P2, P3 and P4 were divided in zones as following:

The P1 palynological record was divided into four zones and five subzones (Fig. 3):

P1-1 ca. 7200–6750 ¹⁴C yr BP (8000–7600 cal yr BP) 455–420 cm: is characterized by maximum percentages of Chenopodiaceae (up to 85%) accompanied by Poaceae and Asteraceae subf. Asteroideae. *Limonium brasiliense* reaches high values in this zone (<10%). Traces of NPP are registered. Total pollen concentration varies between 107 and 38,000 grains/g.

P1-2 ca. 6750–6500 ¹⁴C yr BP (7600–7400 cal yr BP) 420–395 cm: Cyperaceae pollen dominates the assemblage with maximum values up to 70%, accompanied by Poaceae (20–30%) and low values of Chenopodiaceae (5–20%). NPP are present in very low values. Total pollen concentration is the highest of all spectra, ranging between 100,000 and 425,000 grains/g.

P1-3 ca. 6500–3400 ¹⁴C yr BP (7400–3700 cal yr BP) 395–75 cm was divided into three subzones:

P1-3a ca. 6500–6000 ¹⁴C yr BP (7400–7050 cal yr BP) 395–345 cm: is characterized by the co-dominance of Poaceae (25–45%) and Chenopodiaceae (30–35%, and a peak of 60%) and by the increased values of *Ruppia* sp. (up to 15%). The NPP increase simultaneously: *Botryococcus* (up to 20%), *Spirogyra* (5%) and Peridinoideae (up to 35%) and acritarchs appear (up to 35%). Total pollen concentration values fluctuate between 14,500 and 81,900 grains/g.

P1-3b ca. 6000–5300 ¹⁴C yr BP (7050–6250 cal yr BP) 345–205 cm: is characterized by dominance of Poaceae (between 50

Table 1
Radiocarbon dates and calibrated ages from the studied sedimentary sequences at Arroyo Claromec6.

¹⁴ C yr BP	cal yr BP ($\pm 2\sigma$)	Median probability	Depth (cm)	Profile	Material	Technique	Lab. no.
840 \pm 70	635–820	723	265–275	4	Organic matter	Conventional	LP-833 ^a
1310 \pm 60	1056–1295	1185	375–385	4	Organic matter	Conventional	LP-866 ^a
2430 \pm 80	2032–2717	2447	440–450	4	Organic matter	Conventional	LP-822 ^a
3440 \pm 40	3479–3723	3628	69–74	1	<i>H. parchappii</i>	AMS	Beta-242311
4350 \pm 60	4789–5044	4868	121–127	1	Organic matter	Conventional	Beta-183023
5260 \pm 40	5893–6031	5964	176–182	1	<i>H. parchappii</i>	AMS	Beta-180656
6540 \pm 60	7320–7439	7387	394–396	1	Charcoal	AMS	Beta-180654
6950 \pm 60	7610–7859	7733	430–435	1	Organic matter	Conventional	Beta-175780
5710 \pm 70	6301–6570	6442	55–60	2	Organic matter	Conventional	Beta-180655
6540 \pm 40	7292–7479	7384	175–180	2	Organic matter	Conventional	LP-1423
7080 \pm 100	7660–8025	7849	255–258	2	Organic matter	Conventional	LP-1755
6080 \pm 50	6729–7009	6868	260–265	3	Organic matter	AMS	Beta-218307
7240 \pm 40	7933–8066	7997	315–320	3	Organic matter	AMS	Beta-233388

^a Isla and Espinosa (1998).

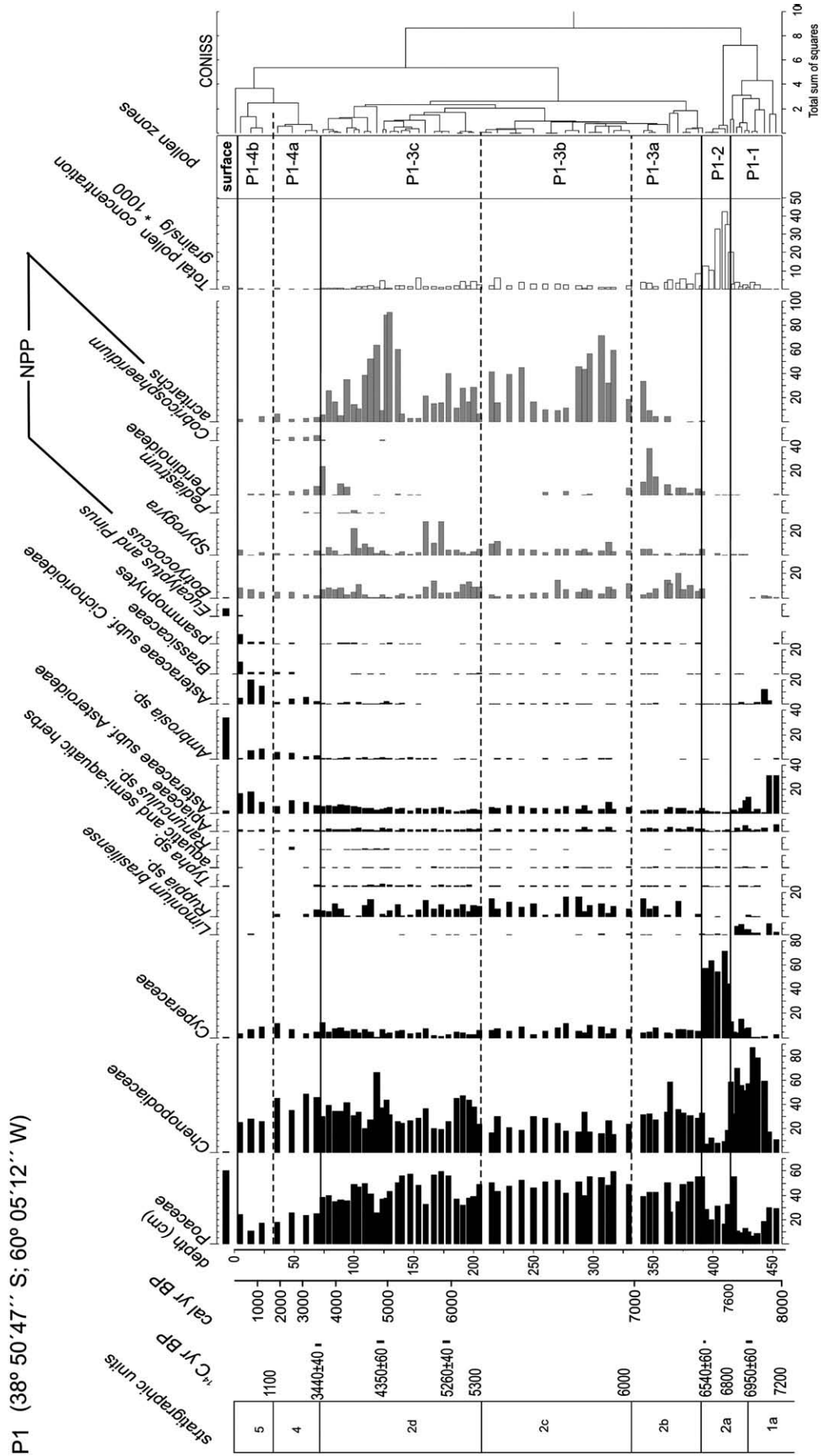


Fig. 3. Percentage palynological diagram and total pollen concentration from Profile 1 (P1). Psammophytes: *Spergularia*, *Gilia*, *Cerastium*, *Margyricarpus*, *Polygala* and *Calycera*. Aquatic semi-aquatic herbs: *Elodea*, *Myriophyllum*, *Alternanthera* and *Comphrena*.

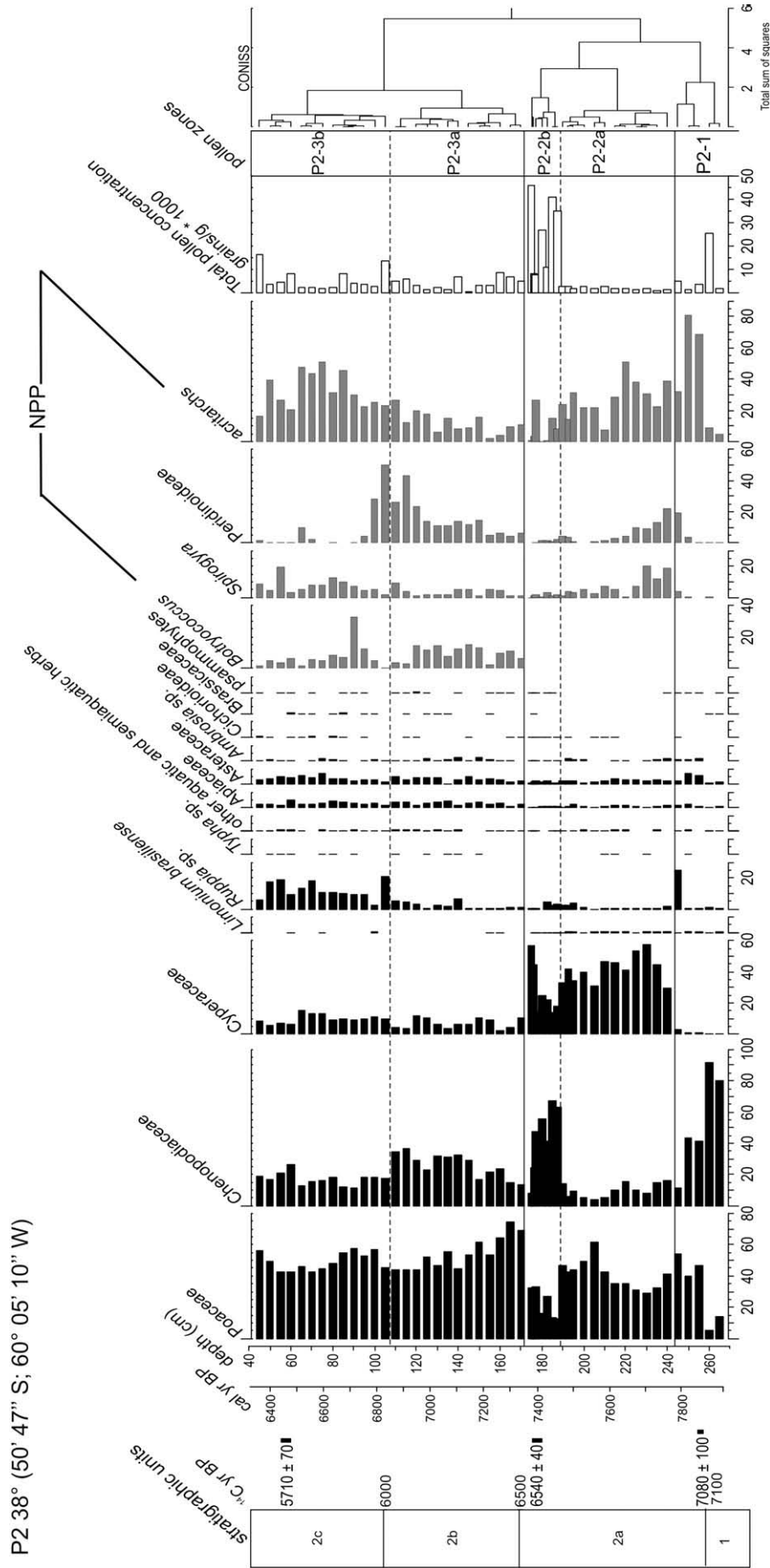


Fig. 4. Percentage palynological diagram and total pollen concentration from Profile 2 (P2) (psammophytes and aquatic, semi-aquatic herbs components are in Fig. 1 caption).

P3 (38° 50' 52" S; 60° 25' 12" W)

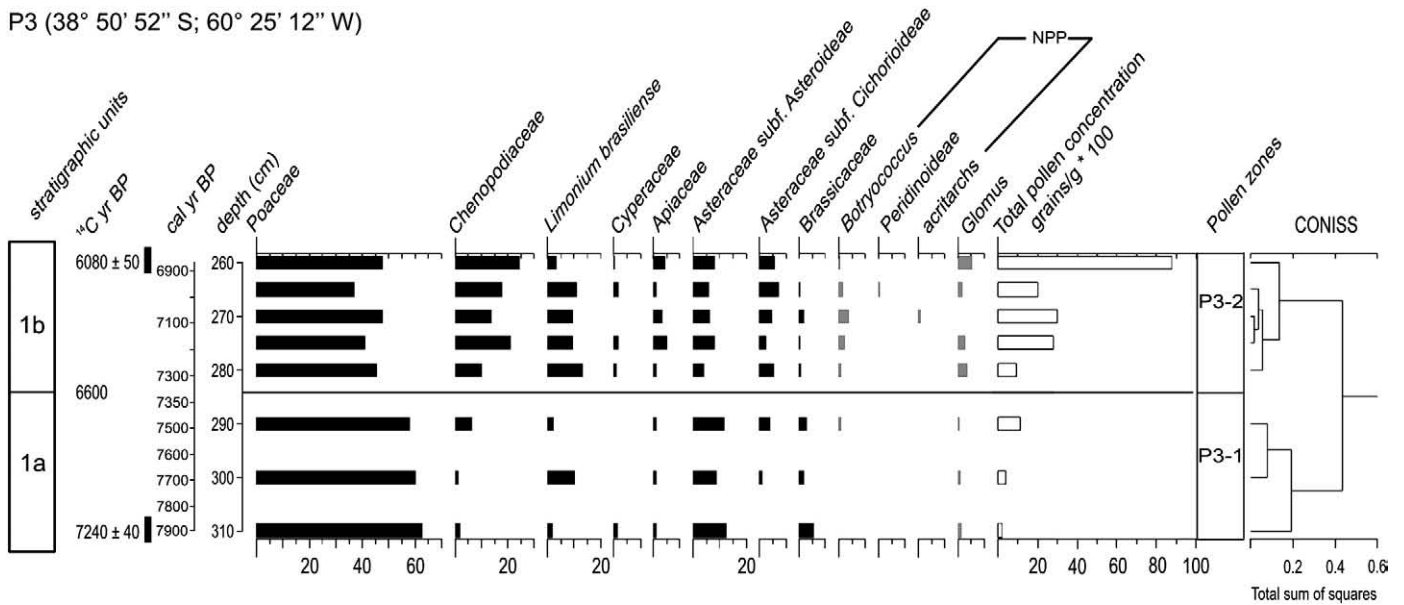


Fig. 5. Percentage palynological diagram and total pollen concentration from Profile 3 (P3).

and 60%) accompanied by Chenopodiaceae (15–35%) and by *Ruppia* sp. (up to 16%). The NPP registered are *Botryococcus* (2–20%), *Spirogyra* (1–12%), Peridinioideae (0–10%) and acritarchs (5–60%). Total pollen concentration fluctuates between 3500 and 60,800 grains/g.

P1-3c ca. 5300–3400 ¹⁴C yr BP (6250–3700 cal yr BP) 205–75 cm: is characterized by fluctuating values of Poaceae (30–60%) and Chenopodiaceae (20–65%) and by *Ruppia* sp. (up to 15%). The NPP exhibit fluctuating values: *Botryococcus* (0–14%), *Spirogyra* (1–30%), Peridinioideae (5–25%), acritarchs (5–90%). *Pediastrum* appears in low abundance during this zone (1–2%). Total pollen concentration decreases toward the top and fluctuates between 400 and 62,000 grains/g.

P1-4 (ca. 3400 ¹⁴C yr BP to present (3700 cal yr BP to present) 75–5 cm was divided into two subzones:

P1-4a ca. 3400–1100 ¹⁴C yr BP (3700–1550 cal yr BP) 75–30 cm: is characterized by Chenopodiaceae (35–50%) accompanied by Poaceae (20–25%). Asteraceae subf. Asteroideae, *Ambrosia* sp. and Asteraceae subf. Cichorioideae increase (5–10%). *Cobricopshaeridium* reaches 5%, Peridinioideae 10%, *Botryococcus*, *Spirogyra* and acritarchs 5% each. Total pollen concentration is between 160 and 1600 grains/g.

P1-4b ca. 1100 ¹⁴C yr BP to present (1550 cal yr BP to present) 30–5 cm: Poaceae pollen decreases (25–30%), accompanied by Chenopodiaceae (15–25%) Asteraceae subf. Asteroideae (5–20%) *Ambrosia* sp. (10%), Asteraceae subf. Cichorioideae (15–20%) and

P4 (38° 53' 52" S; 60° 25' 12" W)

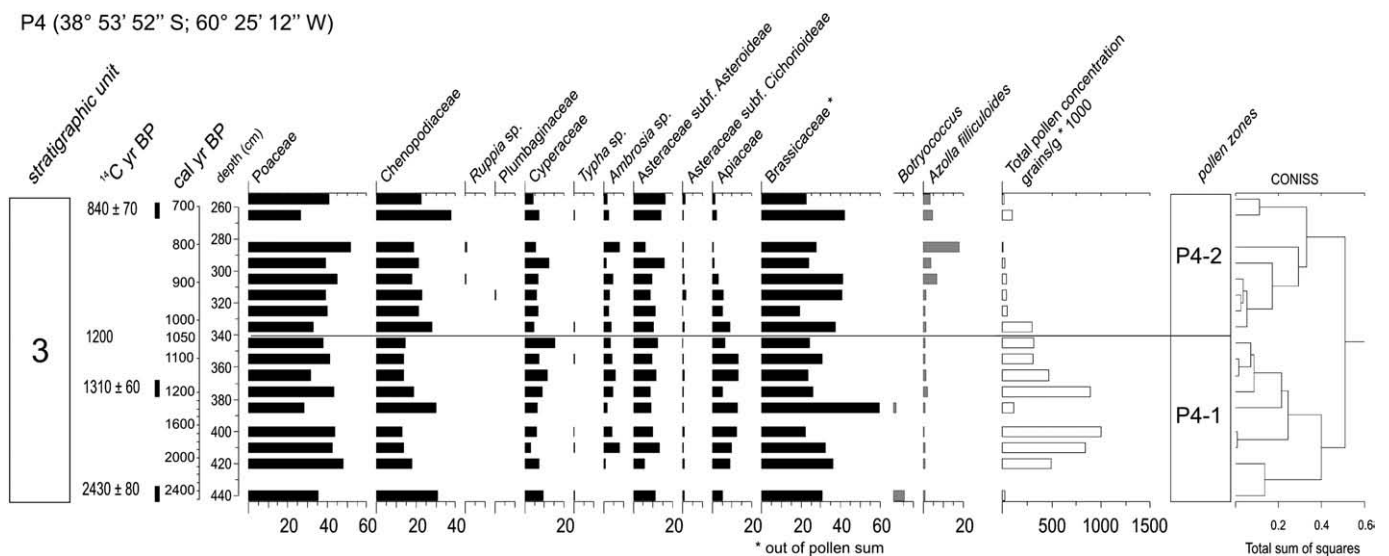


Fig. 6. Percentage palynological diagram and total pollen concentration from Profile 4 (P4).

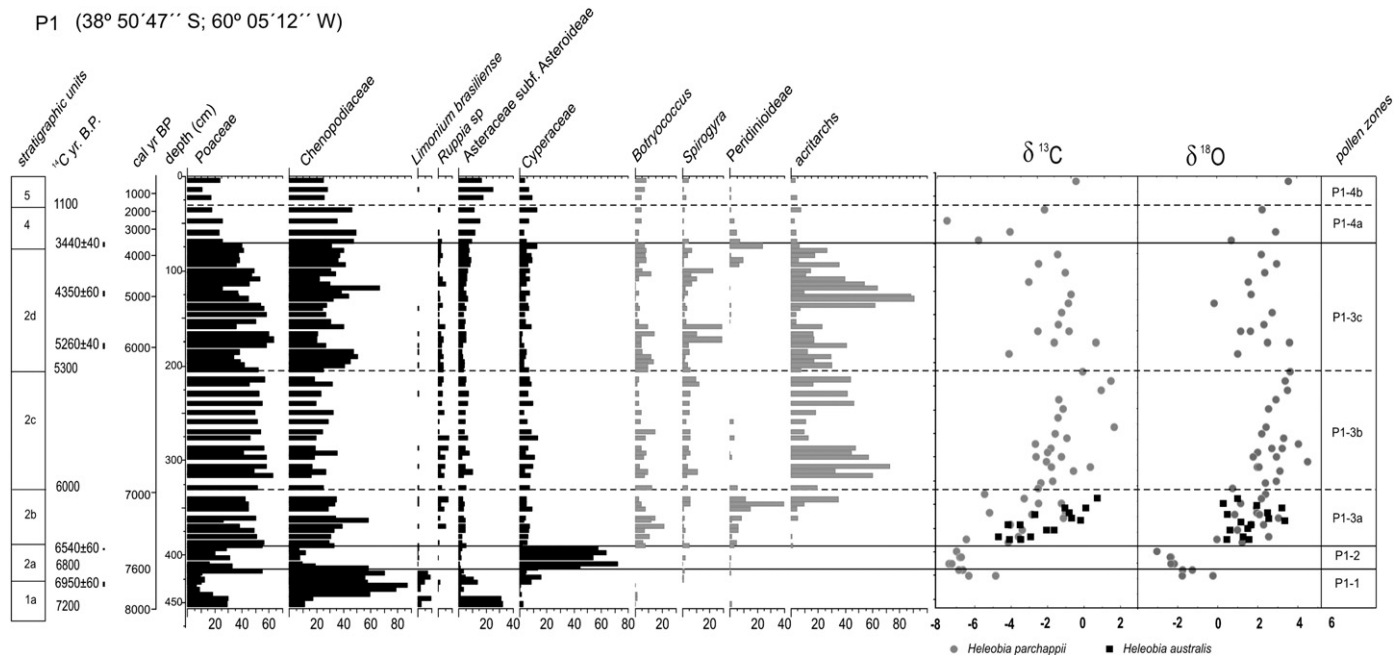


Fig. 7. Palynological diagram, $\delta^{13}\text{C}$ and $\delta^{18}\text{O}$ isotopic values on *Heleobia parchappii* and *H. australis* shells from profile P1 (P1).

Brassicaceae (10%). Psammophytes increase to 9%, the NPP present are *Botryococcus* (5–10%), acritarchs and *Spirogyra* (both 5%). Total pollen concentration fluctuates between 200 and 1600 grains/g.

The pollen record from P2 was divided into three zones and four subzones (Fig. 4):

P2-1 ca. 7100–6980 ^{14}C yr BP (7900–7780 cal yr BP) 265–245 cm: is characterized by dominance of Chenopodiaceae (up to 90%), accompanied by Poaceae (5–55%) and maximum values of acritarchs (80%). Total pollen concentration fluctuates between 15,000 and 255,000 grains/g.

P2-2 (between 6980 and 6500 ^{14}C yr BP (7780–7390 cal yr BP) was divided into two subzones:

P2-2a ca. 6980–6600 ^{14}C yr BP (7780–7460 cal yr BP) 245–190 cm: Poaceae and Cyperaceae dominate the spectra, both with values fluctuating between 30 and 60%, accompanied by Chenopodiaceae (5–15%). *Limonium brasiliense* is continuous to be present as in P2-1. The NPP present have widely fluctuating values: *Spirogyra* (2–30%), Peridinioideae (1–20%) and acritarchs (15–50%). Total pollen concentration fluctuates between 11,000 and 30,000 grains/g.

P2-2b ca. 6600–6500 ^{14}C yr BP (7460–7390 cal yr BP) 190–170 cm: Poaceae decrease (12–30%) and Chenopodiaceae increase (up to 70%), codominating with Cyperaceae (15–60%). Acritarchs decrease (10–25%), *Spirogyra* and Peridinioideae have low values (1–5%). Total pollen concentration is the maximum of the whole sequence (up to 460,000 grains/g).

P2-3 between ca. 6500 and 5600 ^{14}C yr BP (7390–6350 cal yr BP) was divided into two subzones:

P2-3a ca. 6500–6000 ^{14}C yr BP (7390–6890 cal yr BP) 170–110 cm: Poaceae pollen is dominant reaching maximum values of up to 75%, accompanied by Chenopodiaceae (15–35%), which decrease. Cyperaceae decrease abruptly (3–12%). Acritarchs have variable values (2–27%), Peridinioideae show an increasing trend (up to 40%); *Botryococcus* appear (2–25%) and *Spirogyra* increases (1–20%). Total pollen concentration is between 8000 and 60,000 grains/g.

P2-3b ca. 6000–5600 ^{14}C yr BP (6890–6350 cal yr BP) 110–45 cm: Poaceae pollen is dominant (45–60%), Chenopodiaceae decrease (10–27%), and *Ruppia* sp. increases reaching maximum values up to 20%. Cyperaceae attain values between 5 and 10%. *Botryococcus* reach a peak of 46% and the remaining values range between 1 and 16%. Peridinioideae reach maximum values (up to 50%) and acritarchs increase from the bottom to the top (up to 48%). Total pollen concentration fluctuates between 20 000 and 160,000 grains/g.

The pollen record of P3 was divided into two zones (Fig. 5):

P3-1 ca. 7250–6600 ^{14}C yr BP (7900–7350 cal BP) 310–285 cm: is characterized by Poaceae (up to 60%) and Asteraceae (7–15%). *Glomus* occurs in low numbers (1–2%). Total pollen concentration is up to 400 grains/g.

P3-2 ca. 6600–6100 ^{14}C yr BP (7350–6900 cal BP) 285–260 cm: Poaceae are dominant (almost 50%) accompanied by Chenopodiaceae (25%) and *Limonium brasiliense* (up to 12%). Asteraceae subf. Asteroideae, and Asteraceae subf. Cichorioideae are present with less than 10%, *Glomus* with 3–5%, *Botryococcus* with 2–4% and Peridinioideae occur in trace values. Total pollen concentration varies between 940 and 8800 grains/g.

P4 pollen record was divided into two zones (Fig. 6):

P4-1 ca. 2500 and 1100 ^{14}C yr BP (2400–1050 cal yr BP), 440–340 cm: is characterized by Poaceae (30–48%) and Brassicaceae (15–60% out-of-sum) accompanied by Chenopodiaceae (15–30%) and Asteraceae subf. Asteroideae (5–10%) along with Apiaceae and Cyperaceae (5–15%). Total pollen concentration varies between 2650 and 100,000 grains/g.

P4-2 ca. 1100 and 800 ^{14}C yr BP (1050–700 cal yr BP), 340–255 cm: is characterized by Poaceae (35–55%), Brassicaceae (15–40%) and Chenopodiaceae (maximum of 40%). Asteraceae subf. Asteroideae show values similar to the previous zone. Total pollen concentration varies between 600 and 30,000 grains/g.

The modern pollen spectra at the top of P1 (Fig. 3) are dominated by Poaceae (61%) accompanied by *Ambrosia* sp. (34%). Cyperaceae and Asteraceae subf. Asteroideae are <2%. The exotic taxa *Pinus* and

Eucalyptus appear in the spectra with percentages of 5%. Total pollen concentration is 12,800 grains/g.

5. Discussion

Most of the samples analyzed from stratigraphic subunit 1a, deposited prior to ca. 7000 ¹⁴C yr BP contained very little or nil palynological content. The exposure to a sub-aerial environment initiated post-depositional oxidation processes by repeated and alternating wetting and drying cycles due to fluctuations in water table, which destroyed the pollen and NPP. An evidence of these taphonomic processes is the presence of ferruginous root traces. This was caused by a channel incision event which, according to our chronology, took place between ca. 3500 and 2500 ¹⁴C yr BP. Similar channel incision events and evidences of the incidence of oxidation conditions through the changes in the redox potential (Eh) were reported by Tonello et al. (2002) and correlated by Zárate et al. (2000) in other creeks and rivers in the Pampa grasslands.

In contrast, the stratigraphic subunit 1b and the units 2 to 5 providing abundant and well preserved palynological content that allowed an integrated reconstruction of the Holocene vegetation and environmental history for the lower reach of the Arroyo Claromecó. The following periods were selected according to changes in pollen and NPP assemblages:

Between ca. 7200 and 6000 ¹⁴C yr BP (ca. 8000–7000 cal yr BP), different plant communities developed in relation to their position on the floodplain and the different marine influence. Sea-level rose from –27 m to a level similar to its present position from ca. 8800 to 7000 ¹⁴C yr BP (Guilderson et al., 2000), reaching a highstand of +2.0–2.5 m between ca. 6500 and 6000 ¹⁴C yr BP (Isla and Espinosa, 1998). During this period a soil developed in the higher parts of the floodplain, such in section P3 (subunit 1b), while in lower-lying areas, such in sections P1 and P2 rapid succession of wetland plant communities are recorded and abundant organic matter and fine grained sediments accumulated (subunits 2a and 2b).

Pollen spectra from the soil in section P3 (Fig. 5), show that grasslands, characterized by Poaceae and Asteraceae subf. Asteroideae (P3-1) were substantially reduced after ca. 6600 ¹⁴C yr BP (ca. 7400 cal yr BP) when a high salt-marsh vegetation developed as shown by a decrease in Poaceae and increase in Chenopodiaceae and *Limonium brasiliense* (P3-2). The high salt-marsh vegetation developed as tides reached the area related to a rapid sea-level rise which affected the soil salinity. Soil genesis must occurred during and after sedimentation processes, and its buried surface is indicated by the high total pollen concentrations toward the top of the section, and the topward increase of *Glomus*, a component of soil mycorrhiza in most soils of the Pampa grasslands (Fernández, 1993). The buried soil formed during a period of stability of the floodplain, that together with the presence of Cyperaceae, *Botryococcus* and traces of Peridinoideae, suggest humid and swampy conditions (P3-2).

On low-lying parts of the floodplain, the highest values of Chenopodiaceae along with the salt-marsh taxon *Limonium brasiliense* (P1-1 and P2-1) suggest halophytic vegetation by ca. 7000 ¹⁴C yr BP (ca. 7900 cal yr BP) in middle to low salt-marsh. High values of acritarchs (P2-1) reflect the presence of brackish water in the slightly lower elevations. Although of unknown biological affinity, the acritarch's morphology is similar to that of the family of Prasinophyceae, which inhabit restricted intertidal environments adapted to coastal brackish conditions (Borel, 2007). High amounts of similar acritarchs, associated with Zygnemataceae cysts at Arroyo La Ballenera (site 2, Fig. 1), were interpreted as evidence for a brackish marsh with a restricted connection to the sea and shallow freshwater environments under seasonal desiccation (Borel, 2007). The presence of *Succinea meridionalis* shells (P1-1) provides further evidence for salt-marsh vegetation (Romero, 2008) because this species usually lives on *Spartina densiflora* (De Francesco, 2002), which is one of the main species of halophytic communities in Pampa grasslands estuaries and coastal zones (Isacch

et al., 2006). Low density (individual/cm³) of *Heleobia parchappii* shells (P1-1) indicates also shallow water development (Romero, 2008) in agreement with the presence of acritarchs.

Between ca. 6800 and 6500 ¹⁴C yr BP (ca. 7700–7400 cal yr BP), the salt-marsh vegetation was replaced by a hydrophytic community (P1-2 and P2-2a, b) indicated by the decrease in Chenopodiaceae and the increase in Cyperaceae. This hydrophytic vegetation occurred in association with Poaceae in P2-2a. Evidence of this association is preserved because the slightly lower position at the wetland centre (subunit 2a, Fig. 2) captured pollen from the surrounding vegetation of the marsh edges. The pollen spectra from both profiles in zones P1-2 and P2-2a are quite similar and suggest a change from salt-marsh to brackish-freshwater marsh in a wetland environment. The replacement of Chenopodiaceae by Cyperaceae can be explained by changes in the Arroyo base level as a result of eustatic adjustment of the basin to the rising sea-level. Sand bar formation at the watercourse mouth may have caused an overflow and the onset of wetlands. It is likely that the hydrophytic community acted as a trap for sediments and authigenic organic matter during a period of sea-level stability between pulses toward the highstand, building up and expanding the middle and high marsh environments. The maximum values of pollen concentration recorded in P1-2 could result from the increase in sediment trapping and deposition of organic and inorganic sediments. A decrease in salinity would have favored the increase in grasses reflected in P2-2.

The Cyperaceae pollen is most likely assigned to the genus *Carex* since their macrofossils were recorded in this level (Frenguelli, 1928). In general, most of Cyperaceae species and particularly *Carex* species are found in humid soils and wetlands of the Pampa grasslands (Cabrera and Zardini, 1978). The high amount of Cyperaceae may have been favored by higher freshwater input related to increased precipitation. In fact, quantitative pollen–climate relationship has shown that Cyperaceae pollen is positively correlated to precipitation (Tonello and Prieto, 2008). Humid conditions toward 6500 ¹⁴C yr BP are also reflected by light isotopic values ranging for $\delta^{13}\text{C}$ from –8 to –6‰ and for $\delta^{18}\text{O}$ from –4 to 0‰ (Fig. 7) analyzed on *Heleobia parchappii* shells. Environmental changes are also reflected by mollusk and diatom records. The greater density of *H. parchappii* (individual/cm³) and the gradual disappearance of *Succinea meridionalis*, ending with the total absence of gastropods towards 6500 ¹⁴C yr BP, indicate progressive flooding and expansion of swamps (Romero, 2008). The marine/brackish diatom taxa that developed ca. 7000 ¹⁴C yr BP and indicating coastal marsh environments decrease in abundance as brackish/freshwater taxa became dominant (Gómez, 2008); the inferred salinity decrease coincides with the development of Cyperaceae communities.

A significant increase in Chenopodiaceae occurred in the slightly lower floodplain at ca. 6600 ¹⁴C yr BP (ca. 7400 cal yr BP, P2-2b), which along with a slight increase of *Ruppia* sp. suggests increased wetland salinity. This increase is not detected in the pollen spectra at P1 but is reflected at this stratigraphic level (subunit 2a) by an increase in marine/brackish diatom taxa, which tolerate salinities between 5 and 30‰ (Gómez, 2008). This increase in salinity is related to marine influence during the middle Holocene sea-level highstand. The difference between pollen spectra in P1-2 and P2-2b is related to different position on the floodplain and different sedimentation rate. The salinity increase revealed by diatoms indicates the rapid response of these algae.

Between 6500 and 6000 ¹⁴C yr BP (7400–7000 cal yr BP), the increasing salinity is reflected by the decrease of Cyperaceae (P1-3a and P2-3a) which are predominantly freshwater taxa tolerating slightly brackish conditions only. Also, an increase in water depth may have occurred since Cyperaceae do not growth below 1 m depth (Vervoorst, 1967). Among the NPP, *Botryococcus* and Peridinoideae started to increase simultaneously in both P1-3a and P2-3a, indicating relatively homogeneous physical–chemical water conditions within the wetlands. *Botryococcus* may be reflecting oligotrophic alkaline waters and variable saline/brackish conditions (Batten and Grenfell,

1996) whereas the increase in Peridinioideae cysts may be due to salinity and temperature variations as well as to the nutrients, especially a deficiency of N and P, and to high pH in an oligotrophic and oxidizing aquatic environments (Vardi et al., 1999; Godhe et al., 2001). Abundant *Chara* macrofossils (Frenguelli, 1945) may be related to alkaline/saline waters as well. This change in vegetation characterized by the re-establishment of halophytic vegetation and saline/alkaline water conditions coincides with a change in the physical stratigraphy from brownish sandy silts (subunit 2a) to clayey silts (subunit 2b) both containing different shell taxa; all of which mark a change in environmental conditions at ca. 6500 ¹⁴C yr BP that prevailed until ca. 6000 ¹⁴C yr BP.

Downstream from our sections, a deposit of intertidal and neritic mollusk shells, including among others *Brachydontes rodriguezii* and *Tagelus plebeius* (Frenguelli, 1928), indicates estuarine conditions at the Arroyo mouth at that time (6500–6000 ¹⁴C yr BP). The estuary developed for about 500 years and occupied a much wider extension than today and the marine influence also reached greater distance upstream than at present. This deposit correlates with those found upstream in P1 characterized by finely stratified clayey silts with intercalated clay layers containing shells of *Heleobia australis* and *H. parchappii*, (subunit 2b). *H. australis* shells represent further evidence for tidal influence reaching the area between 6500 and 6000 ¹⁴C yr BP (Romero, 2008) and its up-estuary expansion is coincident with the upper limit of tides (De Francesco and Isla, 2003). The fluctuating ecological composition of diatoms toward ca. 6000 ¹⁴C yr BP indicates environmental instability related to sea-level fluctuations (Gómez, 2008). The high variations of $\delta^{13}\text{C}$ and a positive trend of $\delta^{18}\text{O}$ values (from 0 to +2‰) (Fig. 7) suggest the influence of brackish water.

The shift in vegetation communities that occurred about every 500 yr (ca. 7000–6500–6000 yr BP) reflects the evolution of the environment related to salinity variations, tidal regime, sediment deposition and freshwater/brackish overflowing as sea-level attained the middle Holocene highstand, probably in rising pulses with intervening intervals of relatively stabilization. These plant communities, replacing each other over time, in response to shifting environmental conditions, resembles the modern ecological succession where plants resistant to stressful salinity conditions and daily tidal flooding colonize bare tidal flats, modifying the substrate and facilitating the establishment of other less salinity tolerant plants. In estuaries and saltmarshes at the coast of Pampa grasslands, e.g. the Mar Chiquita coastal lagoon (Fig. 1), the halophytic communities that develop in low and middle saltmarshes are mainly composed by *Sarcocornia perennis* (Chenopodiaceae) and the cordgrasses *Spartina densiflora* and *S. alterniflora* (Poaceae). These species tolerate high salinity variations and can colonize bare tidal flats under strong daily flooding periods. Cyperaceae (mainly sedges) grow on the landward edge of saltmarshes under freshwater input, and in the estuarine parts of rivers and coastal lagoons where there is a pronounced freshwater influence (Isacch et al., 2006). The close relationship between sea level rise and plant community dynamics, consistent with succession mechanisms has been recorded in fossil tropical saltmarsh sequences (González and Dupont, 2009).

At ca. 6000 ¹⁴C yr BP (ca. 7000 cal BP) the pedogenesis was interrupted when the floodplain was inundated as a consequence of marine transgression and the soil buried by wetland deposits as water bodies reached a greater extension across the floodplain (Fig. 2). This date was an unexpected because the paleosol was stratigraphically correlated with a buried paleosol identified in numerous fluvial valleys from the Pampa grasslands assigned to the late Pleistocene–Holocene boundary by Fidalgo et al. (1973). The period of the soil development is unknown since it is time transgressive and the age varies according to the geomorphological stabilization of the environment (Zárate, 2005). In several fluvial environments distant from the coast the soil was rapidly buried between ca. 11,000 and 9000 ¹⁴C yr BP by wetland deposits (Figini et al., 1998; Zárate et al.,

2000; Prieto, 2000; Prieto et al., 2004), formed under humid–subhumid conditions. In other fluvial environments next to the coast, such as in Arroyo Claromecó, the pedogenesis lasted longer until it became interrupted ca. 6000 ¹⁴C yr BP during the Holocene marine transgression as sea-level flooded the area or caused a flood due to a change in the base-level of the rivers. On the other hand, in the interfluvials, pedogenetic processes continued until recently and gave place to the present cultivated soil of Pampa grasslands (Zárate et al., 2000; Violante and Parker, 2004).

From ca. 6000 to 3400 ¹⁴C yr BP (7000–3200 cal yr BP) grasslands (Poaceae) with associated halophytic vegetation (Chenopodiaceae) were dominant in the floodplain (P1-3b and P2-3b). The highest percentages of *Ruppia* sp. reflect shallow brackish water, resembling the opportunistic *Ruppia maritima* that at present inhabits the shallow brackish waters in the Mar Chiquita coastal lagoon (Bortolus et al., 1998). The trends of NPP are similar in both profiles until ca. 5700 ¹⁴C yr BP, which indicates that physical–chemical water conditions were relatively similar within the water body. During this period a regressive sea-level phase began that was characterized by a step-wise lowering after ca. 6000 ¹⁴C yr BP to levels still above the present level (Isla and Espinosa, 1998). Decreasing total pollen concentration in P1 provides evidence of a changing depositional environment. In addition, stratigraphic changes occurred, firstly, the finely stratified clayey silts (subunit 2b) were replaced by clayey silts and black laminated clay with coarse stratification and caliche (subunit 2c); which, in turn, were replaced by silty sand containing CO₃Ca clayey silts and intercalated clays with the presence of tufa (subunit 2d). Based on palynological spectra and the sedimentological changes, two different paleoenvironmental conditions are distinguished: one between ca. 6000 and 5300 ¹⁴C yr BP (P1-3b and P2-3b) and the other between ca. 5300 and 3400 ¹⁴C yr BP (P1-3c).

In the first one ca. 6000–5300 ¹⁴C yr BP (7000–6250 cal yr BP), lower levels of salinity are suggested by the dominance of grasses. The different relative percentages of *Botryococcus*, *Spirogyra* and acritarchs indicate local changes with different signals probably related to seasonal variability of the water conditions: *Botryococcus* suggests the dominance of alkalinity while records of *Spirogyra* could be related to more freshwater input. The increase of acritarchs towards 5700 ¹⁴C yr BP indicates that salinity conditions varied in relation to marine influence and/or desiccation. The presence of caliche before 5700 ¹⁴C yr BP (subunit 2c, Fig. 2) may have resulted from an increase in higher salt concentration and CaCO₃ precipitation related to evaporative processes induced by an increase in water temperature. The trend to heavier shell $\delta^{13}\text{C}$ values and the shift of $\delta^{18}\text{O}$ to +2 indicate a highly evaporative environment (Fig. 7). The dominance of *H. parchappii* with good preservation suggests low energy conditions and *H. australis* disappearance support the decrease in salinity (Romero, 2008). The highest diversity and abundance of diatom assemblages were registered after ca. 6000 yr BP, composed by euryhaline species from brackish and freshwater environments and dominated by the benthic mesohalobous species *Hyalodiscus subtilis*, which reflect a deeper brackish water with aquatic vegetation (Frenguelli, 1945).

In the second interval, ca. 5300–3400 ¹⁴C yr BP (6250–3200 cal yr BP), variations in water level and salinity conditions occurred, which could be related to (1) episodic freshwater inundation reflected by maximum *Spirogyra* percentages and traces of *Pediastrum*, the latter at the end of this period; or (2) evaporation and desiccation processes occasioning brackish (saline/alkaline) conditions reflected by maximum acritarchs values and Peridinioideae re-appearance. Further evidence of variability in the environmental conditions is supported by the fluctuating isotopic values $\delta^{13}\text{C}$ from –4 to +2 and $\delta^{18}\text{O}$ from 0 to +4 (Fig. 7). The influence of salt water would have decreased due to sea-level lowering after ca. 5700 ¹⁴C yr BP; however, it cannot be dismissed since sporadically tidal influence and/or storm surge could also have affected the salinity levels during a period in which sea-level started to stabilize. Repeated fluctuations in the proportions of Poaceae

and Chenopodiaceae in a brackish-freshwater marsh can be a response to fluctuations in salinity, temperature, water level and physical-chemical water properties of the wetland. On the whole, the fluctuations recorded in the palynological spectra between 6000 and 3000 ^{14}C yr BP reflect flooding events, desiccation processes, and after ca. 5300 ^{14}C yr BP they reveal environmental instability. This instability suggests humid-dry cycles in the wetlands linked to climatic variability, and is in agreement with proposed dry conditions after ca. 5000/4000 ^{14}C yr BP (Zárate et al., 2000) and variable subhumid-dry climatic conditions (Prieto, 1996) for the southeastern Pampa grasslands.

The channel incision occurred between ca. 3500 and 2500 ^{14}C yr BP (ca. 3700 and 3200 cal yr BP) while in the higher zones of the floodplain, next to the channel, sediment deposition became sporadic and intermittent, producing discontinuity or a gap in the records. The pollen spectra from the paleochannel infilling sediments (unit 3, Fig. 2) indicate the development of grasses (Poaceae) accompanied by halophytic communities (Chenopodiaceae) along with Asteraceae subf. Asteroideae and *Ambrosia* sp. (Fig. 6). Apiaceae and Cyperaceae represent vegetation from the edges of the water body (P4-1) whereas Brassicaceae could be representing aquatic buoyant plants like watercress in shallow lentic brackish-to fresh water, which is evidenced by the presence of *Azolla filiculoides*. At present, *A. filiculoides* occurs in the paleochannel area when a small shallow pond is formed during a high precipitation event. Also, the diatom association indicates shallow to slightly brackish water with abundant aquatic vegetation in an alkaline environment, with eutrophic conditions and without a marine connection; and toward ca. 840 ^{14}C yr BP the association suggests an increase in desiccation and salinity (Hassan et al., 2004).

From 3400 ^{14}C yr BP (3200 cal yr BP) to recent time, the palynological spectra corresponding to sporadic sediment deposition (P1-4) show the dominance of Chenopodiaceae, reflecting predominance of halophytic vegetation. The increase of Asteraceae subf. Asteroideae, *Ambrosia* sp. and Asteraceae subf. Cichorioideae suggest the development of psammophytic communities, the latter taxa probably marking unstable or disturbance conditions (P1-4a). *Ruppia* sp. and *Typha* sp. present in traces, and low values of NPP suggest a trend towards wetland desiccation. Further evidence comes from the presence of *Cobricosphaeridium*, which appears in unstable environments associated with desiccation and accompanying changes in salinity and water level (Borel et al., 2003). High percentages of *Cobricosphaeridium* and Peridinioideae cysts at ca. 3000 ^{14}C yr BP in Arroyo Las Brusquitas (site 1, Fig. 1) also suggested processes of evaporation and desiccation related to dry periods (Vilanova et al., 2006a). The trend towards desiccation in Arroyo Claromecó may correspond to the regional dry periods. The unstable environment and desiccation trends are supported by the lighter and variable values for $\delta^{13}\text{C}$ (from -8 to 0‰) and $\delta^{18}\text{O}$ (from -4 to 4‰) (Fig. 7). The total pollen concentration is the lowest of the whole sequence (160–1600 grains/g) and can be related to the sporadic flooding events.

The relative values of Poaceae, Chenopodiaceae and Cyperaceae decrease after ca. 1100 ^{14}C yr BP (1550 cal yr BP) simultaneously with the increase of Asteraceae subf. Asteroideae, *Ambrosia* sp., Asteraceae subf. Cichorioideae and psammophytic taxa (P1-4b), which reflect vegetation and environmental changes that correlate with a transition from fine alluvial-aeolic sediments to sand dunes that constitute the Southern Barrier. The alluvial-aeolic sediments, transported and reworked and containing just a few shells and fragments of *Heleobia parchappii* (L.I. Bruno, pers. com, 2010) indicate that they were probably deposited during extraordinary flooding events, which is why the palynological content and sediments were deposited irregularly and associated only with flooding.

Sea-level decreased during the late Holocene, with a faster rate of lowering from ca. 1500 ^{14}C yr BP towards the present (Isla and Espinosa, 1998). Consequently, the marine influence would have had no effect on the vegetation and environment at the P1 area. Instead,

desiccation conditions related to climatic variability and dry events was the forcing mechanism during this period. The top of the alluvial sequence is covered by sand dunes of the Southern Barrier (unit 5). The modern spectra of these sand dunes (Fig. 3, top of the zone P1-4b) show Asteraceae subf. Asteroideae and *Ambrosia* sp., characterizing the psammophytic vegetation along with introduced tree taxa such as *Pinus* and *Eucalyptus*.

Regional Holocene vegetation history and environmental changes along the Southern Barrier related to sea-level highstand and climatic conditions.

The integration of Holocene vegetation and environmental reconstructions from Arroyo Claromecó with that from other studied sequences located along the Southern Barrier allows us to a reconstruct regional vegetation history and to differentiate between the marine influence, related to sea-level highstand, and the climatic changes.

At the southern tip of the Southern Barrier (La Olla 1, site 5 Fig. 1) a shallow marginal-marine environment similar to a coastal lagoon developed from ca. 7900 to 7580 ^{14}C yr BP (from 7890 to 7630 cal. BP) most likely prior to the sea-level transgression, during a time with levels somewhat lower than at present and small magnitude fluctuations (Fontana, 2005).

After ca. 7000 ^{14}C yr BP and until ca. 6000 ^{14}C yr BP similar environmental changes related to the sea-level highstand occurred in the three coastal paleoestuaries: Arroyo La Ballenera (site 2, Stutz et al., 1999), Paso Vanoli (site 3, Prieto et al., 2000) and Arroyo Claromecó (Fig. 1). The similar rapid response consisted in the development of hydrophytic communities when changes in the base level occurred in adjustment to sea-level rise and a barrier formed at the mouth of the streams. The hydrophytic communities ca. 6800 ^{14}C yr BP replaced halophytic vegetation in swampy and wetland environments (P1, Arroyo Claromecó), with associated grasslands (P2 and P3 Arroyo Claromecó) or replaced grasslands in association with halophytic vegetation (Arroyo La Ballenera and Paso Vanoli).

Most likely, the basin adjustment to sea-level rise and the consequent development of swampy wetland conditions triggered succession processes that resulted in up-stream changes in plant assemblages over time. After ca. 6500 ^{14}C yr BP progressive establishment and dominance of halophytic vegetation, occurred in salt marsh environments. Nearer to the present shoreline in Arroyo Las Brusquitas (site 1) the highstand fostered increasing development of saltmarsh halophytic communities in a supratidal marine-brackish environment.

Although the sea-level highstand was the main regional forcing mechanism, climatic change cannot be dismissed as another forcing mechanism since it may be masked by the strong marine influence. A drying trend is suggested in the northeastern Pampa after 9000 ^{14}C yr BP that ended with a shift to subhumid-dry climate after 7000 ^{14}C yr BP (Prieto et al., 2004). This shift has been proposed ca. 4000/5000 ^{14}C yr BP for the southeastern region of Pampa grasslands (Zárate et al., 2000). It seems most likely that variable climatic conditions, oscillating between humid-subhumid and subhumid-dry conditions, interplayed with the marine influence, especially when wetlands and hydrophytic vegetation developed in Arroyo Claromecó and Paso Vanoli.

At Arroyo Claromecó, from 6000 to 5300 ^{14}C yr BP wetland with deeper waters extended and occupied a wide area up-stream. Inundations and overflow stopped soil development in the higher elevations and buried the soils while grasslands associated with halophytic vegetation characterized the wetlands. At the same time, estuaries occupied greater areas than at present at the stream mouths of Arroyo Las Brusquitas, Arroyo La Ballenera and Arroyo Claromecó; the former two characterized by brackish shallow water bodies surrounded by brackish-freshwater marshes dominated by halophytic vegetation. Marine influence continued in relation to high sea-levels. Water evaporation and desiccation processes in Arroyo Las

Brusquitas and Arroyo Claromecó reflect that subhumid–dry conditions started to be manifested. Therefore, it is possible that both forcings acted simultaneously.

From 5300 to 3400 ¹⁴C yr BP unstable and variable conditions and high evaporation prevailed in the wetlands of Arroyo Claromecó with grassland associated with halophytic communities continuing as the dominant vegetation. In the nearer coastal sites (Arroyo Las Brusquitas and Arroyo La Ballenera) the maximum expansion of saltmarshes occurred over tidal flats related to a period when sea-level started a stabilization stage within the regressive phase. At the northeastern coastal plains of Pampa grasslands, fluctuations of Poaceae and Chenopodiaceae values similar to those occurring in Arroyo Claromecó suggested instability in environmental conditions in relation to geomorphological changes of littoral barriers between 4500 and 3300 ¹⁴C yr BP (Vilanova et al., 2006b). In Arroyo Las Brusquitas the sea-level lowering is reflected after 3900 ¹⁴C yr BP by the increase of brackish–freshwater herbs indicating a transition from saltmarsh to brackish marsh. Desiccation periods are reflected by the NPP *Cobricosphaeridium* and *Peridinioideae*. Drier events than before and variable subhumid–dry climatic conditions were the forcing mechanism for vegetation and environmental change during this interval.

From ca. 3400 to 1100 ¹⁴C yr BP wetlands experienced a desiccation trend and halophytic vegetation dominated at Arroyo Claromecó. Channel incision occurred sometimes during this period. In the paleochannel area, grasses with associated halophytic and psammophytic vegetation surrounded the edges of a shallow and lentic brackish-to freshwater body from ca. 2500 to 800 ¹⁴C yr BP. At the coastal site Arroyo Las Brusquitas psammophytic vegetation developed between ca.3000 and 2200 ¹⁴C yr BP near the water body where freshwater input prevailed and a freshwater marsh developed. However, towards ca. 2000 ¹⁴C yr BP a brackish–freshwater marsh with higher salinity developed due to either desiccation processes or a rare and unusually high tide range. In Laguna del Sauce Grande (site 4, Fig. 1), changes in water level for the last 2600 ¹⁴C yr BP (3000 cal yr BP) were inferred and related to fluctuations in precipitation (Fontana, 2005). From ca. 1100 ¹⁴C yr BP to recent times halophytic and psammophytic vegetation predominated in Arroyo Claromecó, the latter becoming dominant towards the present when dunes encroached on the area from the coast to 1–2 km up-stream, as well as in other sites along the Southern Barrier, accompanied by introduced exotic trees and herbs. Subhumid–dry to semiarid conditions have been proposed for the southwest Pampa grasslands during the late Holocene (Tonello and Prieto, in press). Our results and interpretations suggest, in general, that variable climatic conditions with dry events characterized the late Holocene along the Southern Barrier.

6. Concluding remarks

Palynological records demonstrate the importance of studying different sequences representing varying landscape positions along the floodplain for the lower reach in order to understand the vegetation dynamic and environmental evolution related to Holocene sea-levels and climatic conditions within the same basin.

The inferences from palynological records were in agreement with records from mollusk, stable isotope and diatom analyses, with slight differences related to their sensitive response to environmental changes.

The integration of Arroyo Claromecó palynological records with others from the Southern Barrier allowed us to recognize and differentiate regionally the effect of sea-level fluctuations and the effect of climatic variability: Between 7000 and 6000 ¹⁴C yr BP the effects of strong marine influence related to sea-level highstand was the regional forcing mechanism on vegetation and environmental changes, which masked the influence of climatic conditions. Between ca. 6000 and 3400 ¹⁴C yr BP fluctuations in salinity and water level

were related to higher temperatures or less precipitation than before due to variability of the subhumid–dry climatic mean state; nevertheless, marine influence should not be dismissed. After 3400 ¹⁴C yr BP unstable environmental conditions prevailed with a desiccation trend after 2500 ¹⁴C yr BP, which is related to climatic variability and dry events along the Southern Barrier area.

Regionally consistent and replicable information derived from palynological sequences from several other drainage basins in southeastern Pampa grasslands demonstrates that palynological analyses of alluvial deposits are useful for reconstructing paleoecological changes of the coastal Pampa grasslands that are highly sensitive to climate and sea-level changes.

The paleochannel sequence represented evidence of the very recent basin dynamics which is important for future management of the basin facing the sea-level rise and global warming. The past environmental conditions inferred from the palynological analysis of sediment sections from the Arroyo Claromecó will allow us to postulate environmental consequences of future climatic and sea-level changes that might help to mitigate the consequences for human activities.

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References

- Batten, D.J., Grenfell, H.R., 1996. Green and blue-green algae. 7D-*Botryococcus*. In: Jansonius, J., Mc Gregor, D.C. (Eds.), *Palynology: Principles and Applications*. AASP Foundation, pp. 205–214.
- Bértola, G., Cortizo, L., Juárez, V., Serra, S., Isla, F., 2005. Determinación de la problemática de las playas y médanos de los partidos de Tres Arroyos y San Cayetano, Buenos Aires. CIC y CGCC Universidad Nacional de Mar del Plata, pp. 69.
- Blasi, A., Prieto, A.R., Fucks, E., Figini, A., 2009. Análisis de las nomenclaturas y de los esquemas estratigráficos del Pleistoceno tardío-Holoceno en la cuenca del río Luján, Buenos Aires, Argentina. *Ameghiniana* 46 (2), 373–390.
- Borel, C.M., 2007. Algas no silíceas y acritarcos de depósitos costeros holocenos en el Arroyo La Ballenera, Buenos Aires, Argentina. *Ameghiniana* 44 (2), 359–366.
- Borel, C.M., Guersstein, G.R., Prieto, A.R., 2003. Palinomorfos acuáticos (algas y acritarcos) del Holoceno de la laguna Hinojales (Buenos Aires, Argentina): interpretación paleoecológica. *Ameghiniana* 40 (4), 514–531.
- Bortolus, A., Iribarne, O., Martínez, M.M., 1998. Relationship between waterfowl and the seagrass *Ruppia maritima* in a southwestern Atlantic coastal lagoon. *Estuaries* 21, 710–717.
- Cabrera, A.L., Zardini, E.M., 1978. *Manual de la flora de los alrededores de Buenos Aires*. Editorial ACME, pp. 755.
- Carbone, M.E., Piccolo, M.C., 2002. Humans and physical characteristics of the Claromecó River basin, Argentina. *Papeles de Geografía* 35, 27–35.
- Carbone, M.E., Piccolo, M.C., Scian, B.V., 2004. Análisis de los periodos secos y húmedos en la cuenca del Arroyo Claromecó, Argentina. *Papeles de Geografía* 40, 25–35.
- Carbone, M.E., Piccolo, M.C., Perillo, G.M.E., 2005. Morphology and physical parameters of the Claromecó creek estuary, Argentina. *Thalassas* 21 (2), 55–63.
- De Francesco, C.G., 2002. Significado paleobiológico y paleoambiental de las concentraciones holocenas de *Heleobia* (Gastropoda) presentes en el sudeste de la provincia de Buenos Aires. Tesis Doctoral. Universidad Nacional de Mar del Plata. Mar del Plata, Argentina, pp. 109 (unpublished).
- De Francesco, C.G., Isla, F.I., 2003. Distribution and abundance of Hydrobiid snails in a mixed estuary and a coastal lagoon, Argentina. *Estuaries* 26 (3), 790–797.
- Faegri, K., Iversen, J., 1989. In: Faegri, K., Kalana, P.E., Krzywinski, K. (Eds.), *Textbook of Pollen Analysis*, IV Edition. John Wiley and Son, p. 328.
- Fernández, C., 1993. Fungal palynomorphs and algae from Holocene bottom sediments of Chascomús Lake, Buenos Aires, Province, Argentina. *Palynology* 17, 170–187.
- Fidalgo, F., Colado, U.R., De Francesco, F.O., 1973. Sobre ingresiones marinas cuaternarias en los partidos de Castelli, Chascomús y Magdalena (Prov. de Buenos Aires). 5° Congreso Geológico Argentino. Argentina. *Actas* 3, 227–240.
- Fidalgo, F., Meo Guzmán, L.M., Politis, G.G., Salemme, M.C., Tonni, E.P., Carbonari, J., Gómez, G.J., Huarte, R.A., Figini, A.J., 1986. Investigaciones arqueológicas en el Sitio 2 de Arroyo Seco (Pdo. de Tres Arroyos)-Prov. de Buenos Aires-República Argentina. In: Bryan, A.I. (Ed.), *New Evidences of the Pleistocene Peopling of the Americas*. University of Maine: Centre for the study of Early Man: 238–253.

- Figini, A.J., Huarde, R.A., Carbonari, J., Tonni, E.P., 1998. Edades C-14 en un perfil del Arroyo Tapalqué, provincia de Buenos Aires, Argentina. Contribución a la cronología de acontecimientos faunísticos – ambientales: In: Congreso Latinoamericano de Geología y VI Congreso Nacional de Geología Económica, 1, Actas, Buenos Aires, 27–34.
- Fontana, S., 2005. Holocene vegetation history and palaeoenvironmental conditions on the temperate Atlantic coast of Argentina, as inferred from multi-proxy lacustrine records. *Journal of Paleolimnology* 34, 445–469.
- Frenguelli, J., 1928. Observaciones geológicas de la región costanera sur de la provincia de Buenos Aires. Universidad Nacional del Litoral. Facultad de Ciencias de la Educación, Anales II (Sta. Fé). Sección de Historia y Geografía, pp. 145.
- Frenguelli, J., 1945. Las diatomeas del Platense. *Revista del Museo de La Plata. Tomo III. Paleontología*, Nº 16, 77–115.
- Godhe, A., Norén, F., Kuylenstierna, M., Ekberg, C., Karlson, B., 2001. Relationship between planktonic dinoflagellate abundance, cysts recovered in sediment traps and environmental factors in the Gullmar Fjord, Sweden. *Journal of Plankton Research* 23 (9), 923–938.
- Gómez, L.C., 2008. Análisis paleoambiental durante el máximo transgresivo del Holoceno en una secuencia aflorante en el Arroyo Claromecó (Buenos Aires) basado en diatomeas. Tesis de Grado. Universidad Nacional de Mar del Plata. Mar del Plata, Argentina, pp. 31 (unpublished).
- Gómez, E.A., Martínez, D.E., Borel, C.M., Guerstein, G.R., Cusminky, G.C., 2005. Submarine evidence of Holocene sea-level fluctuations in the Bahía Blanca estuary, Argentina. *Journal of South American Earth Sciences* 20, 139–155.
- González, C., Dupont, L.M., 2009. Tropical salt marsh succession as sea level indicator during Heinrich events. *Quaternary Science Reviews* 28, 939–946.
- Grimm, E., 2004. Tilia software 2.0.2, Illinois State Museum Research and Collection Center Springfield.
- Guilderson, T.P., Burckle, L., Hemming, S., Peltier, W.R., 2000. Late Pleistocene sea-level variations derived from argentine shelf. *Geochemistry Geophysics Geosystems* 1, 1–15.
- Hassan, G., Espinosa, M.A., Isla, F.I., 2004. Análisis paleoambiental de una secuencia del Holoceno tardío del Arroyo Claromecó (provincia de Buenos Aires, Argentina) basado en diatomeas. *Ameghiniana* 41 (2), 161–170.
- Head, M.J., Borel, C.M., Guerstein, G.R., Harland, R., 2003. The problematic aquatic palynomorph genus *Cobricosphaeridium* Harland and Sarjeant emend. with new records from the Holocene of Argentina. *Journal of Paleontology* 77, 1159–1181.
- Isacch, J.P., Costa, C.S.B., Rodríguez-Gallego, L., Conde, D., Escapa, M., Gagliardini, D.A., Iribarne, O., 2006. Distribution of saltmarsh plants communities associated with environmental factors along a latitudinal gradient on the south-west Atlantic coast. *Journal of Biogeography* 33, 888–900.
- Isla, F.I., Espinosa, M.A., 1998. Modelo sedimentario de colmatación de pequeños estuarios dominados por limo, provincia de Buenos Aires. 7ª Reunión Argentina de Sedimentología. Salta, Argentina, Actas, pp. 24–36.
- Isla, F.I., Cortizo, L.C., Schnack, E.J., 1996. Pleistocene and Holocene beaches and estuaries along the Southern barrier of Buenos Aires, Argentina. *Quaternary Science Reviews* 15, 833–841.
- Isla, F.I., Rutter, N.W., Schnack, E.J., Zárate, M.A., 2000. La transgresión belgranense en Buenos Aires: una revisión a cien años de su definición. *Revista Cuaternario y Ciencias ambientales. Publicación especial Nº 4. Vol. 1*, 3–14.
- Isla, F.I., Cortizo, L.C., Turno Orellano, H.A., 2001. Dinámica y evolución de las barreras medianas, provincia de Buenos Aires, Argentina. *Revista Brasileira de Geomorfología* 2, 73–83.
- McCormac, F.G., Hogg, A.G., Blackwell, P.G., Buck, C.E., Higham, T.F.G., Reimer, P.J., 2004. SHCal04 Southern Hemisphere calibration 0–1000 cal BP. *Radiocarbon* 46, 1087–1092.
- Prieto, A.R., 1996. Late Quaternary vegetational and climatic changes in the Pampa Grassland of Argentina. *Quaternary Research* 45, 73–88.
- Prieto, A.R., 2000. Vegetational history of the Late Glacial–Holocene transition in the grassland of Argentina. *Palaeogeography Palaeoclimatology Palaeoecology* 157, 167–188.
- Prieto, A.R., Stutz, S., Vilanova, I., 2000. Cambios de la vegetación entre los 7000 y 6000 ¹⁴C a. A. P. en la actual barrera arenosa austral; Provincia de Buenos Aires. XI Simposio Argentino de Paleobotánica y Palinología: Ameghiniana, 37 (4). Suplemento 61R.
- Prieto, A.R., Blasi, A.M., De Francesco, C.G., Fernández, C., 2004. Environmental history since 11000 ¹⁴C yr B.P. of the northeastern Pampas, Argentina, from alluvial sequences of the Luján River. *Quaternary Research* 62, 146–161.
- Prieto, A.R., Vilanova, I., Tonello, M.S., Stutz, S., 2009. Reconstrucción de la vegetación y del clima de los pastizales pampeanos durante el Pleistoceno tardío-Holoceno a través del análisis palinológico. *Quaternário do Rio Grande do Sul: integrando conhecimentos. Monografias da Sociedade Brasileira de Paleontologia: 107–12*
- Romero, V., 2008. Análisis tafonómico de *Heleobia australis* (D'Orbigny) y *H. parchappii* (D'Orbigny) durante el máximo transgresivo del Holoceno en el sudeste de la provincia de Buenos Aires. Tesis de Grado. Universidad Nacional de Mar del Plata. Mar del Plata, Argentina, pp. 46 (unpublished).
- Stockmarr, J., 1971. Tablets with spores used in absolute pollen analysis. *Pollen et Spores* 13, 615–621.
- Stuiver, M., Reimer, P.J., Reimer, R.W., 2005. Calib 5.0.1. <http://calib.qub.ac.uk/calib/>.
- Stutz, S., 2000. Historia de la vegetación del litoral bonaerense durante el último ciclo transgresivo–regresivo del Holoceno. Tesis Doctoral. Universidad Nacional de Mar del Plata. Mar del Plata, Argentina, pp. 128 (unpublished).
- Stutz, S., Prieto, A.R., Isla, F.I., 1999. Cambios de vegetación durante el Holoceno en el SE de la provincia de Buenos Aires análisis polínico del Arroyo La Ballenera. *Asociación Paleontológica Argentina. Publicación Especial* 6, 65–69.
- Stutz, S., Prieto, A.R., Isla, F.I., 2006. Holocene evolution of the Mar Chiquita coastal lagoon area (Argentina) indicated by pollen analysis. *Journal of Quaternary Science* 21, 17–28.
- Tonello, M.S., Prieto, A.R., 2008. Modern vegetation–pollen–climate relationship for the Pampa grasslands of Argentina. *Journal of Biogeography* 35 (5), 926–938.
- Tonello, M.S., Prieto, A.R., in press. Tendencias climáticas para los pastizales pampeanos durante el Pleistoceno tardío-Holoceno: estimaciones cuantitativas basadas en secuencias polínicas fósiles. *Ameghiniana*.
- Tonello, M.S., Zárate, M.A., Mancini, M.V., 2002. Trazas radicales ferrosas en una secuencia aluvial del río Quequén Grande (Buenos Aires): implicancias estratigráficas y ambientales. *Ameghiniana* 39, 163–174.
- Van Geel, B., 2001. Non-pollen palynomorphs. In: Smol, J.P., et al. (Ed.), *Tracking Environmental Change Using Lake Sediments, Terrestrial Algal and Siliceous Indicators*. Kluwer, pp. 99–119. Dordrecht, The Netherlands, Vol. 3.
- Vardi, A., Berman-Frank, I., Rozenberg, T., Hadas, O., Kaplan, A., Levine, A., 1999. Programmed cell death of the dinoflagellate *Peridinium gatunense* is mediated by CO(2) limitation and oxidative stress. *Current Biology* 9 (18), 1061–1064.
- Vervoorst, F.B., 1967. Las comunidades vegetales de la Depresión del Salado. La vegetación de la República Argentina. INTA: Serie Fitogeográfica Nº 7, Buenos Aires, p. 262.
- Vilanova, I., 2005. Dinámica de cambio de la vegetación y variabilidad climática desde el Pleistoceno tardío en el actual sector costero bonaerense (35°–45° S). Tesis Doctoral. Universidad Nacional de Mar del Plata. Mar del Plata, Argentina (unpublished).
- Vilanova, I., Prieto, A.R., Espinosa, M., 2006a. Palaeoenvironmental evolution and sea-level fluctuations along the southeastern Pampa grasslands coast of Argentina during the Holocene. *Journal of Quaternary Science* 21, 227–242.
- Vilanova, I., Prieto, A.R., Stutz, S., 2006b. Historia de la vegetación en relación con la evolución geomorfológica de las llanuras costeras del Este de la provincia de Buenos Aires durante el Holoceno. *Ameghiniana* 43, 147–159.
- Violante, R.A., Parker, G., 2004. The post-last glacial maximum transgression in the de la Plata River and adjacent inner continental shelf, Argentina. *Quaternary International* 114, 167–181.
- Zárate, M.A., 2005. El Cenozoico tardío continental de la Provincia de Buenos Aires. In: RE. De Barrio PO, Etcheverry, MF, Caballé and Llambías (Eds). *Geología y Recursos Naturales de la Provincia de Buenos Aires. Relatorio del XIV Congreso Geológico Argentino*, La Plata, Argentina, 139–15
- Zárate, M.A., Kemp, R.A., Espinosa, M.A., Ferrero, L., 2000. Pedosedimentary and palaeoenvironmental significance of a Holocene alluvial sequence in the southern Pampas, Argentina. *The Holocene* 10 (4), 481–488.