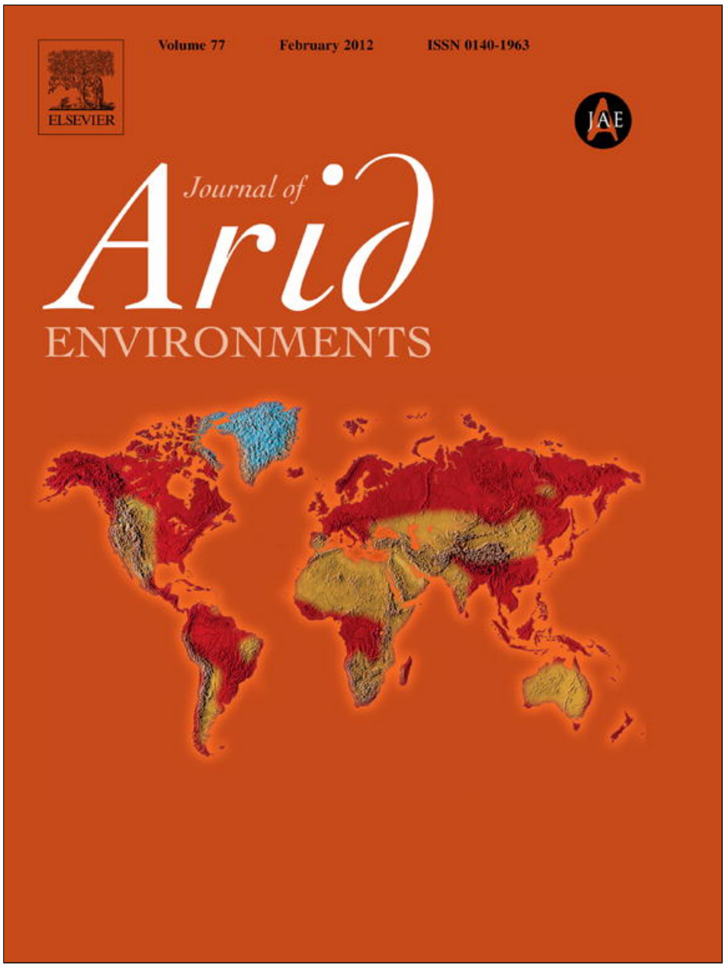
Volume 77
February 2012
ISSN 0140-1963
ELSEVIER
JAE
Journal of Arid
ENVIRONMENTS

Journal of Arid Environments 77 (2012) 110–122

Contents lists available at SciVerse ScienceDirect

Journal of Arid Environments

journal homepage: www.elsevier.com/locate/jaridenv

Mid- to Late Holocene pollen and alluvial record of the arid Andean piedmont between 33° and 34°S, Mendoza, Argentina: Inferences about floodplain evolution

L.D. Rojo[a,b,*], A.E. Mehl[a,c], M.M. Paez[b], M.A. Zárate[a,c]

[a] CONICET, Argentina
[b] Laboratorio de Paleoecología y Palinología, Universidad Nacional de Mar del Plata, Funes 3250 (7600), Mar del Plata, Buenos Aires, Argentina
[c] Instituto de Ciencias de la Tierra y Ambientales de La Pampa, CONICET-Universidad Nacional de La Pampa, Uruguay 151, Santa Rosa, La Pampa, Argentina

ARTICLE INFO

Article history:
Received 28 September 2010
Received in revised form
4 August 2011
Accepted 10 September 2011
Available online 10 October 2011

Keywords:
Andean piedmont
Arid vegetation
Fluvial environments
Holocene palynology

ABSTRACT

In arid and semiarid regions of Central West Argentina, paleoenvironmental conditions and history of the Holocene vegetation is still scanty. This paper presents the analysis of palynological records of two Mid- to Late Holocene alluvial sequences (La Escala -LES- and Brazo Abandonado -BA-) in the fluvial basin of the Arroyo La Estacada (33°27′S and 69°03′W), placed in the Cordillera Frontal central piedmont of Mendoza province. Variations in pollen assemblages of the two sequences related to the environments developed in the floodplains of the arroyo allowed us to infer the evolution of local plant communities. Between the *ca.* 4000 and 3000 ^{14}C years BP and between *ca.* 500 and 400 ^{14}C years BP, a larger representation of hydrophytic communities related to environments with local water availability was inferred; and between *ca.* 3000 and 500 ^{14}C years BP an increase in shrubby xerophytic communities related to environments with lower water availability was detected. These results led us to propose that the Holocene pollen spectra fluctuations observed in the alluvial sedimentary sequences prove mainly changes in plant communities of the floodplain environment in response to the fluvial dynamics of the arroyo.

1. Introduction

In arid and semiarid regions, low coverage of vegetation associated with a low pollen production, in combination with high-deposition rates of clastic sediments, hamper the production of continuous, well-dated, high-resolution paleoenvironmental archives to reconstruct past changes based on regional vegetation (Horowitz, 1992). In addition, the palynology of fluvial systems has been a discipline with little development as a paleoecological tool, mainly because the sedimentary environments show different sources of pollen grains and diverse taphonomic processes (depositional and post-depositional) that disguise the pollen record and obstruct the interpretation of past changes in regional vegetation (Fall, 1987; Hall, 1985, 1989; Solomon et al., 1982; Xu et al., 1996). In central- west regions of Argentina, paleoenvironmental reconstructions have been mainly based on the pioneering pollen studies of D'Antoni (1983) and Markgraf (1983) on the record of the Gruta del Indio archaeological site in the piedmont of Bloque de San Rafael (34°45′S and 68°22′W, 670 m asl) and the Salado (34°11′S and 69°32′W, 3200 m asl) and Salina 2 (32°15′S and 69°20′W, 2000 m asl) high meadows, both of them placed in the Andes cordillera. Later on, the study of human settlement and paleoenvironmental conditions of the Agua de la Cueva archaeological site located in the Precordillera of Mendoza (32°37′ and 69°09′W, 2900 m asl), permitted to document regional vegetation changes during the Pleistocene–Holocene transition (García et al., 1999).

As a result of this limited knowledge, the need arises for searching for new stratigraphic records mainly in the Andean piedmont to obtain updated paleoenvironmental information that enables a better understanding of the Late Pleistocene–Holocene and Holocene paleoenvironmental evolution of this arid to semi-arid region of Argentina.

Over the past 10 years, the central piedmont of Frontal cordillera, an Andes cordillera morphostructural unit, in Mendoza province, has been the subject of interdisciplinary studies, aimed to reconstruct the regional paleoenvironmental and paleoclimatic conditions of the Late Quaternary through the analysis of both geological and biological proxies (Zárate, 2002a).

The knowledge of the Late Pleistocene and Holocene vegetation history derived from alluvial records is commonly insufficient,

* Corresponding author. Permanent address: Instituto de Ciencias Básicas, Universidad Nacional de Cuyo - Departamento de Antropología, Museo de Historia Natural de San Rafael, Parque Mariano Moreno s/n, San Rafael (5600), Mendoza, Argentina. Tel.: +54 2627 423095.

E-mail addresses: ldrojo@conicet.gov.ar (L.D. Rojo), adrianamehl@gmail.com (A.E. Mehl), paez.marta@gmail.com (M.M. Paez), mzarate@exactas.unlpam.edu.ar (M.A. Zárate).

0140-1963/$ – see front matter © 2011 Elsevier Ltd. All rights reserved.
doi:10.1016/j.jaridenv.2011.09.006

discontinuous and with low temporal resolution; all of these features are principally attributed to poor pollen preservation in these arid sedimentary environments (Zárate, 2002a; Paez et al., 2010). However, Holocene alluvial palynological analysis carried out by doctoral studies at Mendoza piedmont (Guerci, 2011; Rojo, 2009) and the high Atuel river basin in the mountain area (Navarro, 2011) of Mendoza province, have permitted to consider new lines of interpretation and reevaluation of the pollen representativeness in sedimentary sequences of arid and semiarid regions (Paez et al., 2010).

In the Valle de Uco area, the sedimentary succession cropping out in the cut banks of Arroyo La Estacada, a tributary of the Tunuyán River, constitutes one of the main alluvial sedimentary deposits studied in the region spanning at least the last 50,000 years BP (Toms et al., 2004; Zárate and Mehl, 2008). Among the most relevant results, it can be highlighted 1) the geomorphological framework of the fluvial valley of Arroyo La Estacada, where Zárate and Mehl (2008) described a regional aggradational plain (RAP), a fill terrace unit (FT) (according to Bull, 1990, 1991) and a present floodplain (PF); and 2) a new lithostratigrafic framework for the area (Zárate and Mehl, 2008) that reinterpret the previous stratigraphic division by Polanski (1963). Besides, it could also be highlighted the results of malacological and palynological records of Arroyo La Estacada providing paleoenvironmental information for the Late Pleistocene and Pleistocene–Holocene transition (De Francesco et al., 2007; Zárate and Paez, 2001, 2002).

The aim of this paper, framed in the interdisciplinary studies mentioned, is to contribute to the knowledge of the vegetation history in the Andean piedmont of Mendoza. For this, it analyzes the palynological records of the Mid- to Late Holocene alluvial sequences on the hypothesis that, alluvial sedimentary deposits constitute appropriate palynological records to reconstruct the history of regional vegetation. The hypothesis is based on preliminary work made for this purpose in alluvial sequences of the Pampean region, in Buenos Aires province (Prieto, 1996; Prieto et al., 2004; Quattrocchio et al., 2008, and references therein). These studies suggest that the analysis of fluvial pollen can be used as a paleoecological tool, particularly in those regions where other sedimentary environments are not commonly available, as it happens in arid and semiarid regions.

In order to achieve the proposed objective the geological-geomorphological context of the study area is summarized and the results of palynological analysis are reported in a stratigraphic-sedimentological framework. Finally, paleoenvironmental inferences as well as the scope and limitations of the palynological study in alluvial sequences are discussed.

2. Physiographic frame

The Arroyo La Estacada fluvial basin (33°27′S and 69°03′W) is located in the central piedmont of the Frontal cordillera – Mendoza. Arroyo La Estacada is a tributary of the Tunuyán River (Fig. 1),

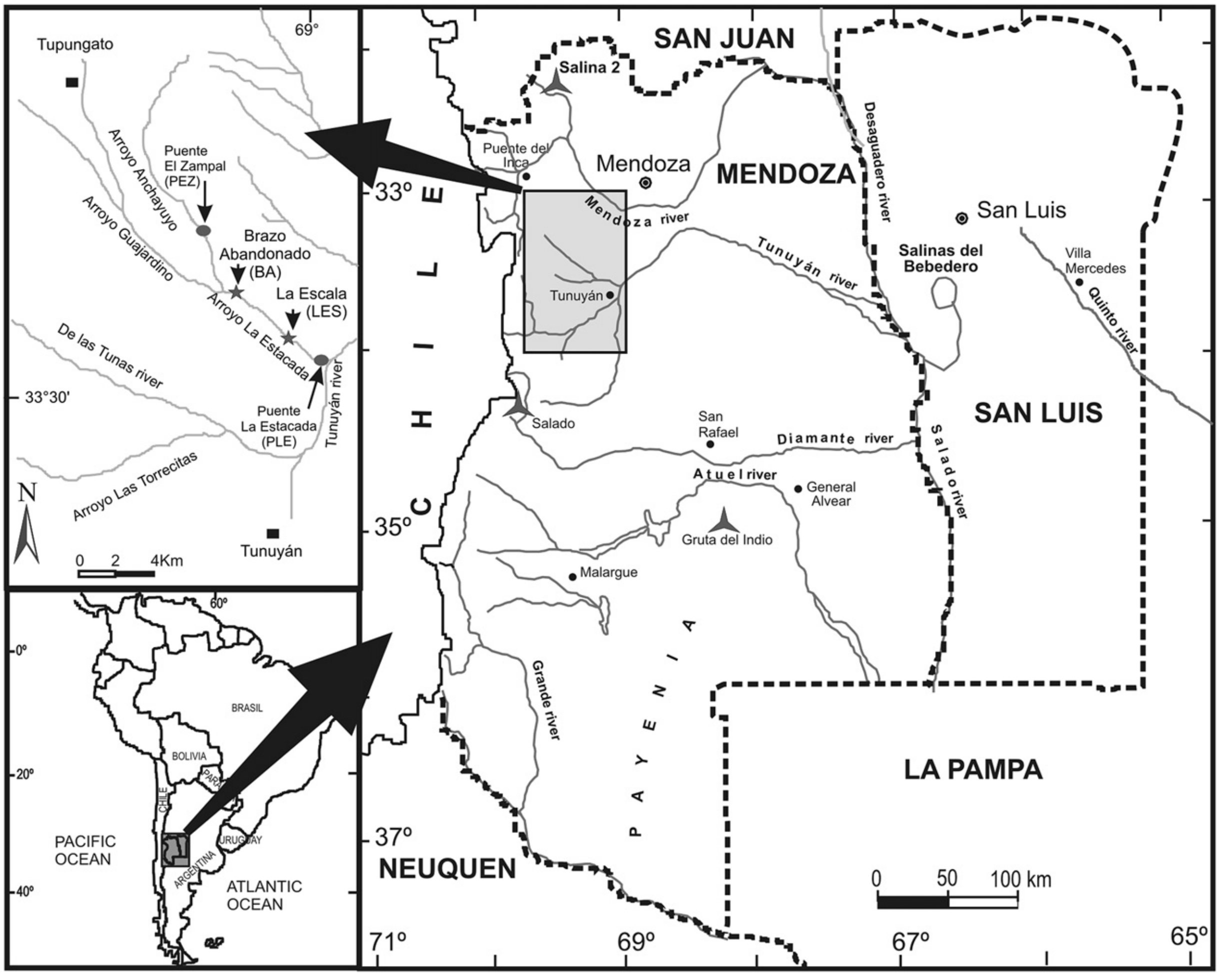

Fig. 1. Location of Arroyo La Estacada basin and stratigraphic sequences analized (★). Studied sequences by Markgraf (1983) and D'Antoni (1983) (▲)and Zárate and Paez (2002) (●) are also indicated.

the main collector of the river and arroyos systems draining this piedmont area known as Valle de Uco. The arroyo, of perennial discharge and meandering pattern – according to Brice and Blodgett (1978) -, gets water inputs from Arroyo Anchayuyo and Arroyo Guajardino, both of them fed by springs located along a fault line. This piedmont area, one of the most important regional production centers of greens and wine, composes a man-made oasis densely inhabited and deeply modified by agriculture.

The region is mainly dominated by an arid-semiarid climate (Burgos and Vidal, 1951), with mean annual temperature of 12.8 °C and average annual rainfall of 350 mm (San Carlos meteorological center, 33°46′S/69° W, 940 m asl, in Garleff, 1977). It is an area included in the South American Arid Diagonal (Bruniard, 1982) – a north-south climatic belt that registers the lowest humidity contribution from Atlantic and Pacific anticyclones at these latitudes-. The vegetation of the area consists of xerophytic shrublands ("*Jarillales del Monte*"), dominated by *Larrea divaricata*- associated to shrubs of *Prosopis* sp., *Atriplex* sp., *Schinus* sp. among others (Cabrera, 1976). Particularly, at Arroyo La Estacada basin, this association extends across the surface of the geomorphological units identified –RAP, FT and in the highest sectors of the PF (Fig. 2a and b.1)-. In the lower sectors of the PF, hydrophytic plant communities develop linked to environments where water is locally available, those areas are: 1) the vicinities of the stream where communities of *Cortaderia* sp. ("*cortaderales*") are observed (Fig. 2a and b.2), 2) the cutoff environments where paludal communities with *Typha*, rushes and sedges dominate (Fig. 2a and c.3), and 3) the back swamp areas where paludal communities mainly dominated by sedges are developed (Fig. 2a and d.4).

3. Geological and geomorphological setting

At the piedmont of Frontal cordillera of Mendoza the reference frame for Late Cenozoic studies was established by Polanski (1963). Specifically, at Arroyo La Estacada cut banks Polanski (1963) defined La Estacada Formation, mainly a fluvial unit representing, according to the author, the ending of the third cycle of fluvial aggradation recorded at the Andean piedmont and assigned to the Late Pleistocene. On top of these deposits, Polanski (1963) described the El Zampal Formation, a unit of aeolian genesis whose uppermost part holds present-day soil. Subsequent studies in the area (De Francesco et al., 2007; Zárate, 2002a, 2002b; Toms

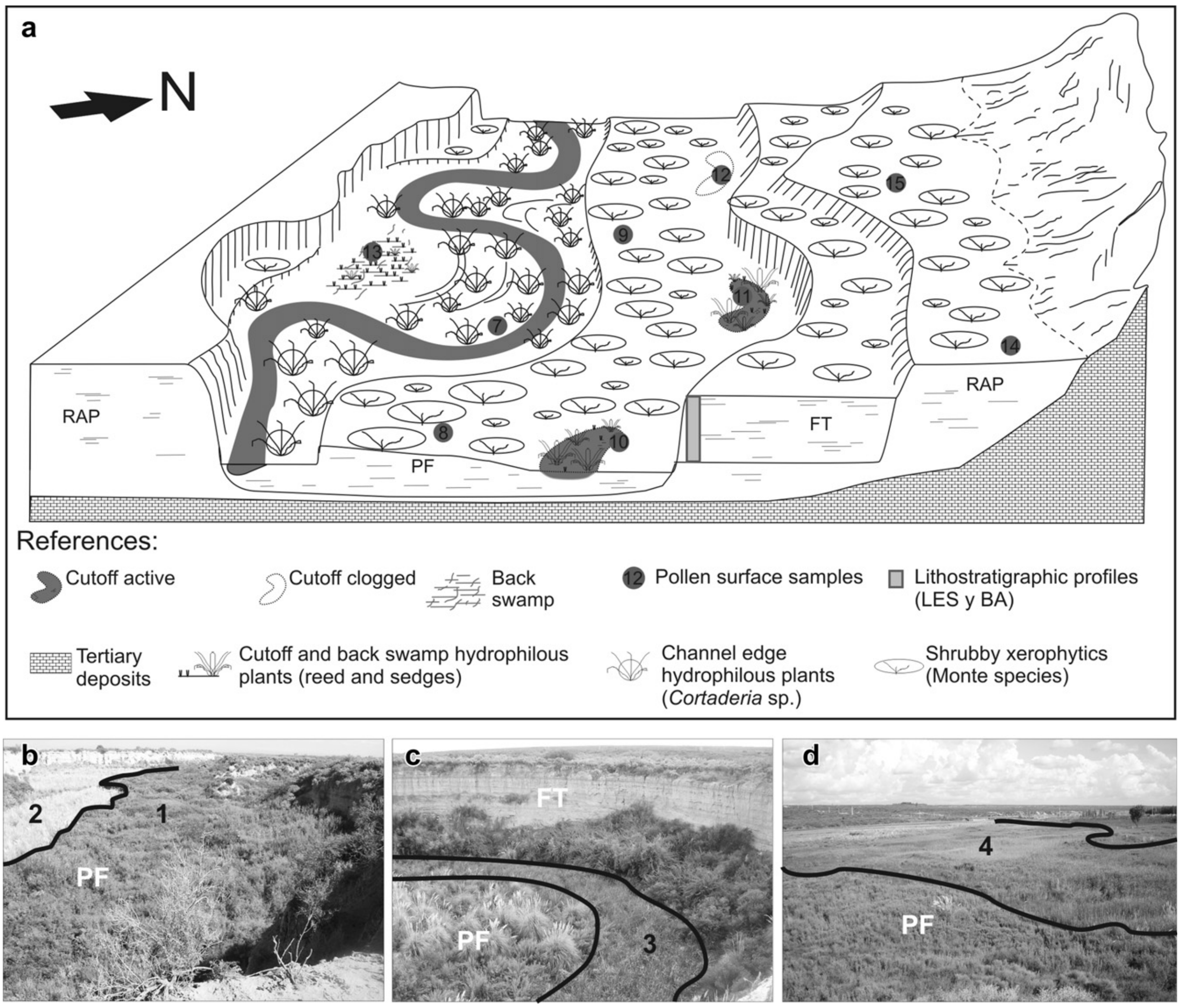

Fig. 2. a- Geomorphologic scheme of Arroyo La Estacada valley (adapted from Zárate and Mehl, 2008). RAP, regional aggradational plain; FT, alluvial fill terrace; PF, present-day floodplain. b- View of xerophytics shrublands (1) and *cortaderales* (2) in the PF. c- View of a cutoff (3) in the PF. d- View of a back swamp environment (4) in the PF.

et al., 2004; Zárate and Mehl, 2008) provided radiocarbon and Optically Stimulated Luminescence (OSL) dates that in accordance with the geomorphological and sedimentological – stratigraphic analysis permits to redefine the Late Pleistocene and Holocene stratigraphical scheme of the Arroyo La Estacada basin and consequently of the Andean piedmont (Zárate and Mehl, 2008). Based on the lithological homogeneity of the deposits, the authors defined a single unit called El Zampal Formation, that brings together the two formations initially proposed by Polanski (1963) and could be recognized in the three main geomorphological units -regional aggradational plain, alluvial fill terrace and the present floodplain (Fig. 2a)- identified in the Arroyo La Estacada fluvial valley. The regional aggradational plain consists of a sedimentary succession dominantly composed of silty sands. Its age was constrained by the chronology of tephra layers included in the alluvial sequence outcropping at the cut banks of Arroyo Las Torrecitas, reaching in the lower exposed section of the sequence a date of *circa* 50.000 yrs BP (Toms et al., 2004), and by several paleosols and organic matter levels interbedded in the sedimentary record, the youngest dated at *ca*. 3000 yrs BP (Zárate and Mehl, 2008) at Arroyo Anchayuyo –a tributary of Arroyo La Estacada- (Fig. 1). The fill terrace unit is formed by a fining upward sedimentary sequence encompassing an aggradational period spanning from some moment before the 5270 ± 65 ^{14}C years BP until *ca*. 435 ± 25 ^{14}C years BP. The present floodplain, characterized by stacking of horizontal silty sand and clayey silts beds, started its formation after the incision process that led to the formation of the fill terrace unit likely after *ca*. 400 ^{14}C years BP (Zárate and Mehl, 2008).

4. Materials and methods

The studies were carried out at La Escala (LES) and Brazo Abandonado (BA) alluvial sections, both located at Arroyo La Estacada banks and belonging to the fill terrace geomorphologic unit. The numerical ages of the analyzed alluvial deposits were based on radiocarbon dating of the organic matter fraction included in buried soils (Table 1); samples were taken from the uppermost 2 cm. The obtained radiocarbon ages represent minimum ages for the ending of pedological processes, *i.e*. close to the burial of them. Also the organic matter included at plant macrofossils and limnic levels interbedded with the alluvial deposits were radiocarbon dated (Table 1). Limnic levels are formed by both siliciclastic sediments and organic matter either transported in water suspension or derived from decomposition of underwater and floating aquatic plants (Soil Survey Staff, 2003; Miall, 2006).

Sedimentological analysis included textural composition, thickness, limits -according to Catt (1990)-, colour (Munsell soil color chart, 2000) and sedimentary structures of the deposits. Paleosols identification followed the main criteria pointed out by Catt (1990). Although pedogenetic features were the key criteria used to identify paleosols, their characteristics were not analyzed in detail in this work but they will be focused in future contributions.

Table 1
AMS radiocarbon dates of studied sequences. OMS: organic matter on sediment (uppermost 2 cm of buried soils); M: plant macrofossil remains.

Profiles	^{14}C BP age	Lab code	d^{13}C (‰)	Depth (m)	Material dated
LES	435 ± 25[b]	NSRL12651	−24.4	1.05	Charcoal
	540 ± 25[b]	NSRL12652	−15.8	1.5	OMS
	3570 ± 20[b]	NSRL12653	−23.1	7.3	OMS
	3860 ± 40[b]	NSRL12654	−22.8	8.7	OMS
	5270 ± 65[a]	NSRL12655	−23.4	14	M
BA	2500 ± 40[b]	NSRL12650	−24.4	1.5	OMS
	3050 ± 25[b]	NSRL12649	−22.1	3.9	OMS
	3750 ± 45[b]	NSRL12648	−25.2	9.92	Charcoal
	3780 ± 45[b]	NSRL12647	−23.0	10.97	Charcoal

[a] Zárate (2002b).
[b] Zárate and Mehl (2008).

Palynological studies of the fill terrace geomorphologic unit were conducted by sampling both LES and BA alluvial sequences according to their main lithostratigraphic characteristics; the upper part of BA profile (0–1.5 m depth) was not accessible and as a consequence it was not sampled. This fossil pollen sampling was complemented with a surface sediments sampling of the different plant communities identified at the present floodplain environment of the Arroyo La Estacada (Fig. 2). The comparison between fossil and modern pollen results have permitted to interpret the fossil pollen data in terms of present vegetation analogous (see Discussion section).

The extraction of pollen grains from sediment samples taken in the Arroyo La Estacada alluvial deposits was conducted at the Laboratorio de Paleoecología y Palinología of the Universidad Nacional de Mar del Plata (UNMdP), applying pollen extraction techniques according to the standard protocol (Gray, 1965; Faegri and Iversen, 1989). Between 10 and 15 g of sediment were weighed and 2–3 tablets with *Lycopodium* spores (X = 10,679 spores, Stockmar, 1971) were added per sample to calculate pollen concentration (grains/g). The physical-chemical treatment of each sample consisted of filtering them with 125 and 200 microns meshes; in each fraction the clays were deflocculated and the humic acids present were eliminated using a solution of potassium hydroxide (KOH) to 10% and a thermal bath at 100 °C for 10 min. Then, calcium carbonates were removed with hydrochloric acid (HCl) to 10%. The inorganic fraction was separated by the addition of heavy liquids (Cl_2Zn, $\delta = 2$ g/cm^3), and silicates were removed by digestion with hydrofluoric acid (HF) in cold for 24 h. Finally, the cellulosic organic material was removed by acetolysis (reaction mix: 9 parts acetic anhydride and 1 part sulfuric acid). The final residue was poured into glass tubes of 5 cm^3 with the addition of few drops of glycerin. Aliquots residue homogenized with vortex were set and the preparation was sealed with paraffin.

For the identification of pollen types (1) the Pollen Reference Collection of the Laboratorio de Paleoecología y Palinología (UNMdP) and (2) specific atlas (Markgraf and D'Antoni, 1978; Heusser, 1971; Wingenroth and Heusser, 1984) were used. Pollen identification and counting of the samples were carried out with an optical microscope Olympus BH-2, with maximum increases of 1000×. Those samples with amounts of pollen grains between 3 and 37 grains were considered sterile after failing an amount representative. Over a total of 52 samples processed at LES section, 29 reached sums of between 262 and 924 grains; over a total of 29 samples processed at BA section, 10 were found to be sterile, while the remaining 19 sums varied between 360 and 560 grains.

Identified pollen types were grouped according to the main phytogeographic affinities of the region according to Roig (1960, 1972, 1982), Roig et al. (1992, 2000), Anderson et al. (1970), Peña Zubiate et al. (1998) and Böcher et al. (1972). These main groups are the Andean-Patagonian (AP), Monte (M), Monte-Espinal (ME) and Espinal (E). On the other hand, the group hydrophytes (H) includes hydrophilous taxa and the group "Other herbs and shrubs" (HA) brings together those pollen types widely distributed and/or whose taxonomic determination did not fit any of the other groups. The groups Andean-Patagonian and Monte-Espinal include those pollen types with genera present in both phytogeographic formations, respectively. A typical case is the genus *Prosopis*, with shrub and tree species distributed in both the Monte (mainly *Prosopis flexuosa*) and the Monte-Espinal (*Prosopis caldenia*). In the analysis of fossil pollen records of LES and BA sections percentage calculations and pollen concentration by weight (grains/g) were performed, also diagrams were drawn using the program TGView 2.0.2

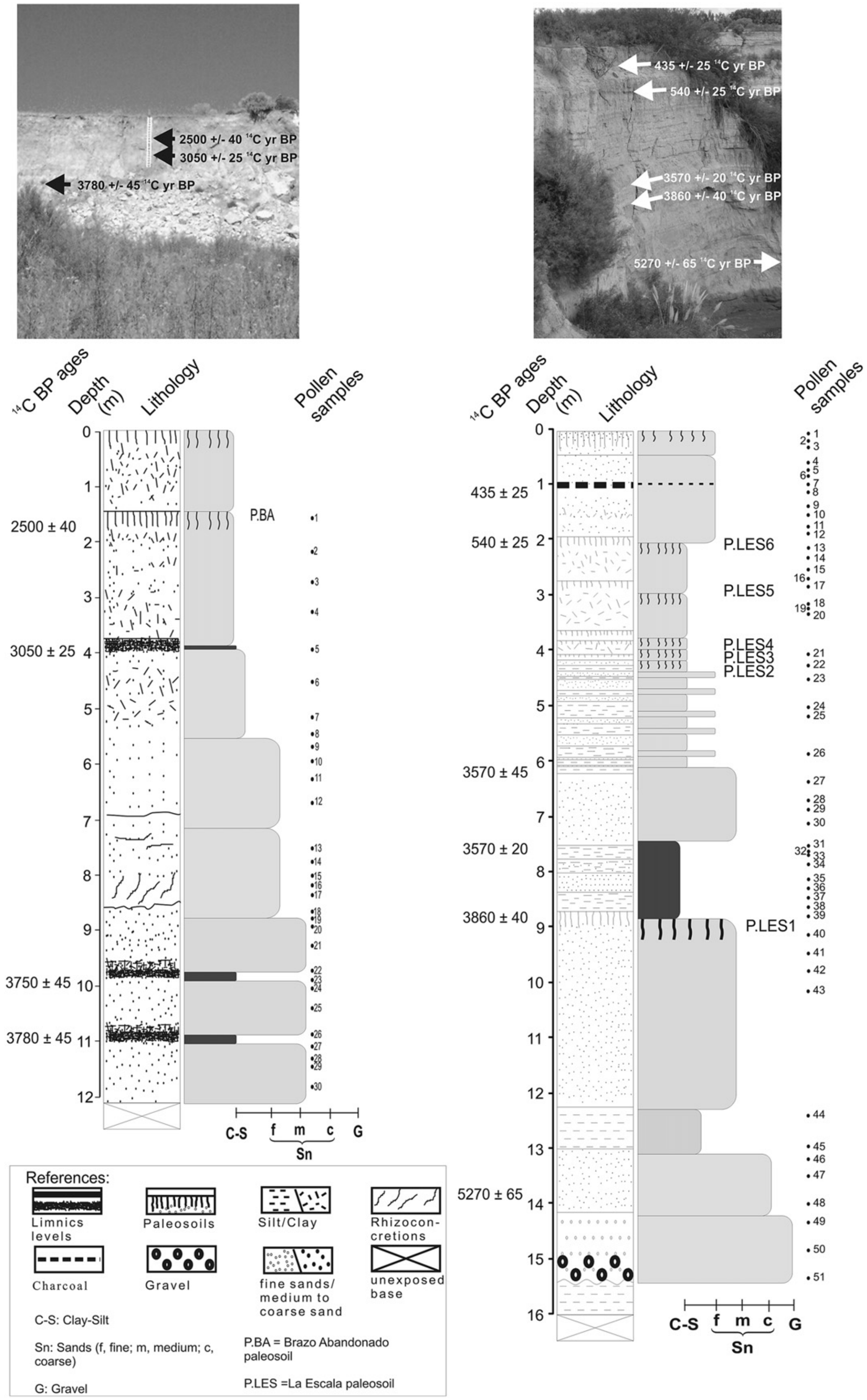

Fig. 3. Lithostratigraphic profiles from Brazo Abandonado (left) and La Escala (right) localities. At the top, representative photos from each of them; arrows indicate radiocarbon ages.

(Grimm, 2007). In this contribution each taxon is expressed as a percentage of the total pollen sum, percentages less than 1% are referred to as traces. Also, a stratigraphically constrained cluster analysis was made and the Edwards and Cavalli-Sforza's chord distance coefficient of dissimilarity (Overpeck et al., 1985) was applied to identify pollen zones along alluvial sequences.

5. Results

5.1. LES and BA alluvial sedimentary record

LES and BA alluvial sedimentary deposits are fining upward-like sequences liable to be related to deposition in a highly sinuous stream. Both sequences encompass the Mid- to Late Holocene. Thus, LES alluvial sequence, with a thickness of about 18 m, covers the period from *ca.* 5270 ± 65 to <435 ± 25 ^{14}C years BP; while at BA, the alluvial sequence with nearly 13 m thick and a not exposed base, involves the period spanning from *ca.* 3780 ± 45 to at least <2500 ± 40 ^{14}C years BP (Fig. 3).

The lower part of LES sequence is composed of massive silt deposits covered by a matrix-supported gravel deposit of *ca.* 1.5 m thick (river channel bar gravels) showing an erosional unconformity at its base. These deposits pass to massive medium sand, with gley and oxidization features at the lower and upper parts respectively; macrofossil plant remains, with a radiocarbon age of 5270 ± 65 ^{14}C years BP, were collected at a depth of 14 m from the top surface of the deposits. Sand grades upward into fine sand and fine silt levels that form the parent material of a paleosol (P -paleosols-. LES1: horizons A, AC, Cca) of *ca.* 3860 ± 40 ^{14}C years BP, buried by very fine silt and clayey silts layers, likely corresponding to swamp deposits.

Both the river channel bar gravels and the massive sandy beds likely indicate the occurrence of fluvial channel processes -*e.g.* channel fills or build-up of point bars-, or deposition in the most proximal channel belt floodplain area (Miall, 2006; Bridge and Demicco, 2008). The buried soil of *ca.* 3800 ^{14}C years BP could indicate the interruption of the aggradational process probably after the abandonment of a meander and the consequent stabilization of the alluvial surface in that location.

Upward there is a sand massive bed, 0.9–1.4 m thick, with humified plant remains. Then, the sequence grades upward into interbedded silt and sandy silt levels including numerous limnic levels and at least five buried soils (P.LES 2, P.LES 3, P.LES 4, P.LES 5 and P.LES 6) containing *Succinea* mollusk shells and non-defined shell fragments related. The uppermost buried soil (P.LES 6) was radiocarbon dated at 540 ± 25 ^{14}C years BP; it was buried by alluvial silty sand deposits containing a thin level of transported charcoal fragments, some of them dated at 435 ± 25 ^{14}C years BP (Fig. 3, Table 1). Renewed aggradation, after the development of the *ca.* 3800 ^{14}C years BP paleosols, continued in a floodplain environment affected by overbank depositional episodes and likely ox-bow-like lake formation (Miall, 2006; Bridge and Demicco, 2008) followed by soil forming intervals and alluvial sand and silty sand overbank deposition. Alluvial aggradation was interrupted in relatively recent times and the sequence was blanketed by sandy aeolian deposits with pedogenetic features in its uppermost part, corresponding to the present soil developed on the fill terrace surface.

In BA section, the lower part of the sequence is dominated by sand deposits with gley features. Upward the succession consists of fine sand, occasionally showing ripple cross-lamination and climbing ripple cross-lamination and including two limnic levels, located at 10 and 11 m of depth, and radiocarbon dated at 3750 ± 45 ^{14}C years BP and 3780 ± 45 ^{14}C years BP, respectively. These numerical ages allow us to correlate these levels with those burying the alluvial soil of *ca.* 3800 ^{14}C years BP at LES alluvial sequence. Sandy deposits could indicate the occurrence of overbank events sometimes with weak traction currents (Miall, 2006; Bridge and Demicco, 2008).

The upper section of BA, not analyzed because of difficulties getting access to the deposits, records a transitional change to finer deposits, with silty beds grading into silty clay beds at the top. At a depth of 3.9 and 1.5 m a limnic-like level and a buried soil (P.BA) register radiocarbon ages of 3050 ± 25 ^{14}C years BP and 2500 ± 40 ^{14}C years BP, respectively. Soil formation and limnic deposits

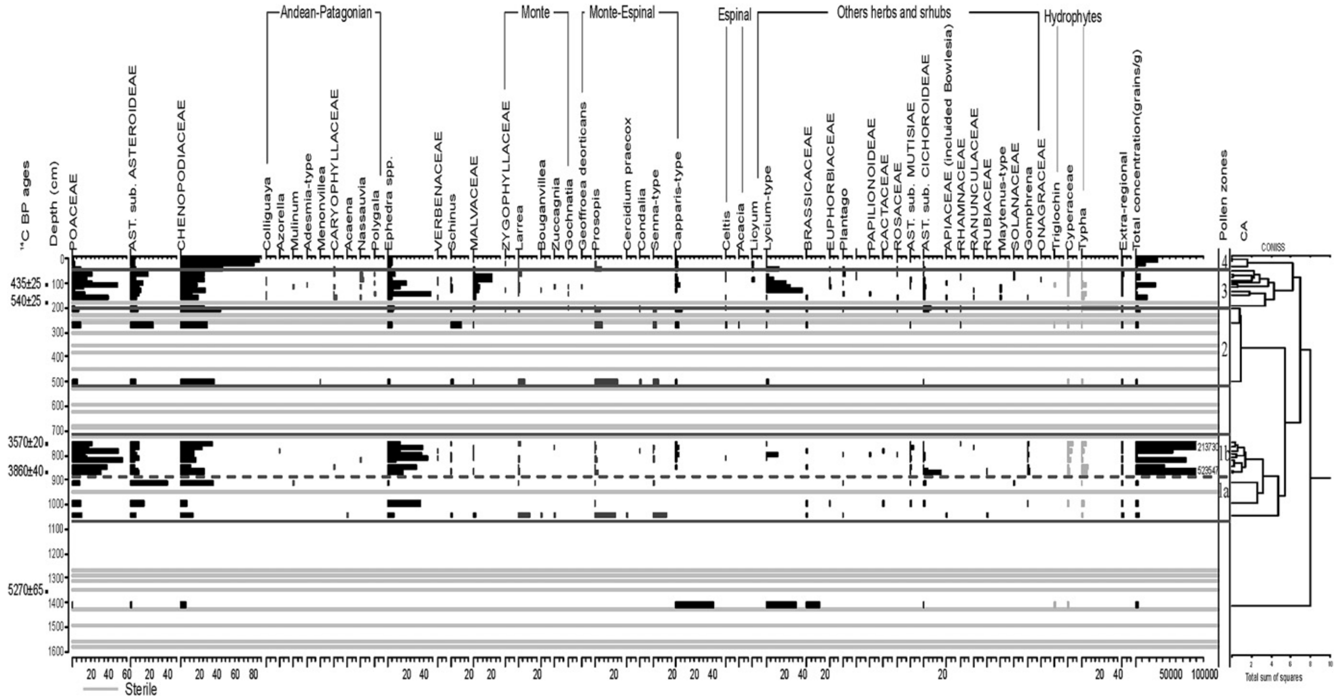

Fig. 4. Pollen diagram and zonation of La Escala lithostratigraphic sequence.

suggest the occurrence of a very low energy depositional environment, probably back swamp-like and/or distal floodplain environments, at least until *ca.* 2500 ± 40 ^{14}C years BP.

5.2. Pollen record from LES and BA alluvial sequences

In the lower section of LES profile (Fig. 4; 16–12.5 m), almost all of the samples are sterile but one at 14 m depth, coinciding with the plant macrofossil remain dated at 5270 ± 65 year ^{14}C BP, is characterized by *Capparis*-type (40%) and *Lycium*-type (>30%), Chenopodiaceae (<10%), Brassicaceae (15%), Asteraceae subf. Cichoroideae and *Triglochin* traces. In sterile samples taxa such as Chenopodiaceae, Poaceae, Asteraceae subf. Asteroideae, *Ephedra* spp., xerophytic species (*Gochnatia, Zuccagnia, Capparis*-type, *Acantholipia*) and hydrophytics (*e.g. Typha* sp. and Cyperaceae) were observed.

The following upward 12.5 m, cluster analysis shows the four pollen zones associated to the LES alluvial sequence:

Zone 1 (10.5–7.5 m): characterized by dominance of Poaceae, Asteraceae subf. Asteroideae, *Ephedra* spp. and Chenopodiaceae, with numerous shrubby and herbaceous taxa. The basal spectrum (10.4 m) is characterized by dominance of Poaceae (10%), Asteraceae subf. Asteroideae (<10%), Chenopodiaceae (<15%), *Ephedra* spp. (<10%), Monte elements of *Larrea* (<15%) and Monte-Espinal *Prosopis* (20%) and *Senna*-type (15%). Between hydrophytic taxa, *Typha* is present with 5%. Two subzones could be recognized according to clear different palynological trends between lower and upper parts of the zone:

Subzone 1a (10.5–9.1 m): the top of this subzone corresponds with the development of a paleosol (P.LES 1). In general, total pollen concentration shows low values (<1000 grains/g). Poaceae (10%), Asteraceae subf. Asteroideae (15–40%), Chenopodiaceae (<10–35%) and *Ephedra* spp. (<2–25%) dominate in percentages. Andean-Patagonian elements (*Mulinum, Acaena*), Monte (*Larrea*) and Monte-Espinal (*Prosopis* and *Senna*-type) reach up to 5%. Between hydrophytes, *Typha* and Cyperaceae are present with values lower than 5%.

Subzone 1b (9.1–7.5 m): the highest total pollen concentration (174000 grains/g) is registered in this subzone. It is characterized by increases in percentages of Poaceae (20–<60%) and *Ephedra* spp. (10–<40%), meanwhile Asteraceae subf. Aseroideae (<10%) and Chenopodiaceae (15–35%) diminish, particularly in the middle section (8–8.5 m). In this subzone, Monte elements (*Larrea* and *Zuccagnia*) and Monte-Espinal (*Prosopis, Senna*-type and *Condalia microphylla*) also increase, although with low values. Traces of Andean-Patagonian taxa (*Azorella*, Caryophyllaceae and *Nassauvia*) are observed. Hydrophytes rise with Cyperaceae and *Typha* reaching up to 5% and less than 10% respectively.

Between 7.5 and 5.5 m of depth, sediment samples are sterile; they correspond to massive sand deposits near 1 m thick, limited at bottom and top by limnic-like levels with radiocarbon dates of 3570 ± 20 ^{14}C years BP and 3570 ± 45 ^{14}C years BP (Table 1). Several samples from this section record Poaceae, Asteraceae subf. Asteroideae, Chenopodiaceae, *Prosopis*, *Capparis*-type, *Celtis*, Brassicaceae and Cyperaceae.

Zone 2 (5–2.1 m): this zone coincides with the development of several paleosols (P.LES 2 to P.LES 6) developed on silt to sandy silt alluvial deposits. This zone shows a total pollen concentration decrease to <1000 grains/g. Pollen percentages of Poaceae and *Ephedra* spp. diminish while Chenopodiaceae (30–50%) increases. Within Asteraceae subf. Asteroideae taxon, *Tessaria*-type shows a peak of 25% in one sample. Monte elements reach 5% (Zygophyllaceae and *Larrea*) and Monte-Espinal 10–30% (*Prosopis*, *Senna*-type, *C. microphylla* and *Geoffroea decorticans*). The shrubby taxon *Schinus* shows the highest values of the profile (<5–10%). Among Andean-Patagonian elements, *Menonvillea* (<5%) is only present. Hydrophytes (*Typha* and Cyperaceae) decrease to <5% values and *Triglochin* (<5%) appears in one sample. In sterile samples Apiaceae, Papilionoideae and *Plantago* are also registered.

Zone 3 (2.1–0.6 m): total pollen concentration rises up to 1000 grains/g in some samples. Poaceae (50%) and *Ephedra* spp. (5–45%) proportions increase in association to a minor increase of Asteraceae subf. Asteroideae (5–20%). Chenopodiaceae (15–30%) diminishes as well as Monte elements (*Larrea*), Monte-Espinal (*Prosopis*) and *Schinus*. Traces of Zygophyllaceae, *Bouganvillea, Zuccagnia, Gochnatia* and *G. decorticans* are observed in few samples. Andean-Patagonian elements (*Colliguaya, Mulinum, Adesmia*-type, Caryophyllaceae, *Nassauvia* and *Polygala*) increase in diversity, reaching up to 5%. Malvaceae (<5–20%) and *Lycium*-type (<5–40%) show sharp increments while *Maytenus*-type and Onagraceae appear for the first time in the alluvial record. Within hydrophytes, Cyperaceae shows similar values to zone 2 while *Typha* (up to 5%) increases showing a peak of 40% at the bottom of the zone.

Zone 4 (0.6–0.1 m): total pollen concentration shows similar values to that of zone 3. Percentages of Chenopodiaceae (50 to <90%) increase, associated with lower Poaceae (<5–20%), Asteraceae subf. Asteroideae (<5%) and *Ephedra* spp. (5%) values. Among Monte elements, Zygophyllaceae and *Larrea* traces are registered; Monte-Espinal is represented in one sample by *Prosopis* (<10%). Regarding Andean-Patagonian taxa, Caryophyllaceae is presented at the bottom. In the rest of the shrubby and herbaceous taxa, *Lycium*-type shows a peak (<20%) at the bottom. Hydrophytes, Cyperaceae and *Typha*, diminish to values lower than 5%.

Regarding extraregional pollen taxa, *Nothofagus dombeyi*-type and *Podocarpus* exhibit low values (<5%) in the whole profile. Among Espinal elements, *Celtis* is registered with low proportions (<5%) in zones 1–3, meanwhile *Acacia* traces are present in zone 2. The most common taxa among “others herbs and shrubs” are Brassicaceae, *Plantago*, Rosaceae, Asteraceae subf. Mutisiae, Asteraceae subf. Cichoroideae and Apiaceae, all of them expressed with low values. Few samples exhibit traces of Euphorbiaceae, Cactaceae, Rhamnaceae and Ranunculaceae.

At the BA section, the pollen record (Fig. 5) is dominated by Poaceae, Asteraceae subf. Asteroideae, Chenopodiaceae and *Ephedra* spp.; numerous sterile samples are observed. Cluster analysis permitted to identify the three following pollen zones:

Zone 1 (12–8.7 m): total pollen concentration in this zone fluctuates between 1000 and 30000 grains/g. Two limnic levels (at 11 and 10 m of depth) are registered in the bottom. Pollen spectra are characterized by Poaceae (20%), Chenopodiaceae (20–60%) and *Ephedra* spp. (10–40%), and Asteraceae subf. Asteroideae with minor contributions (5–10%). According to Chenopodiaceae, *Ephedra* spp. and some other taxa, three subzones are distinguished:

Subzone 1a (12–11.3 m): this subzone is dominated by Chenopodiaceae (20–40%) at the bottom and *Ephedra* spp. (40%) at the top. Within Monte elements, *Larrea* (<5%) is registered with stable values while Zygophyllaceae and *Zuccagnia* are present in a few samples; Monte-Espinal elements are represented only by *Prosopis* and *Senna*-type (with its maximum percentage, 20%, in the profile). Andean-Patagonian taxa (*Colliguaya, Nassauvia*, Caryophyllaceae and *Acaena*) reach up to 5%. Hydrophytes (5%) are expressed by *Typha* and Cyperaceae (in some samples).

Subzone 1b (11.3–10 m): Chenopodiaceae values (40–60%) increase, meanwhile *Ephedra* spp. shows a decrease at the top. Monte (*Larrea* and Zygohyllaceae) and Monte-Espinal (*Prosopis, Prosopidastrum globosum*) elements do not overtake 5%. Andean-Patagonian pollen grains (*Nassauvia*, Caryophyllaceae, *Mulinum* and *Colliguaya*) show similar percentages to subzone 1a.

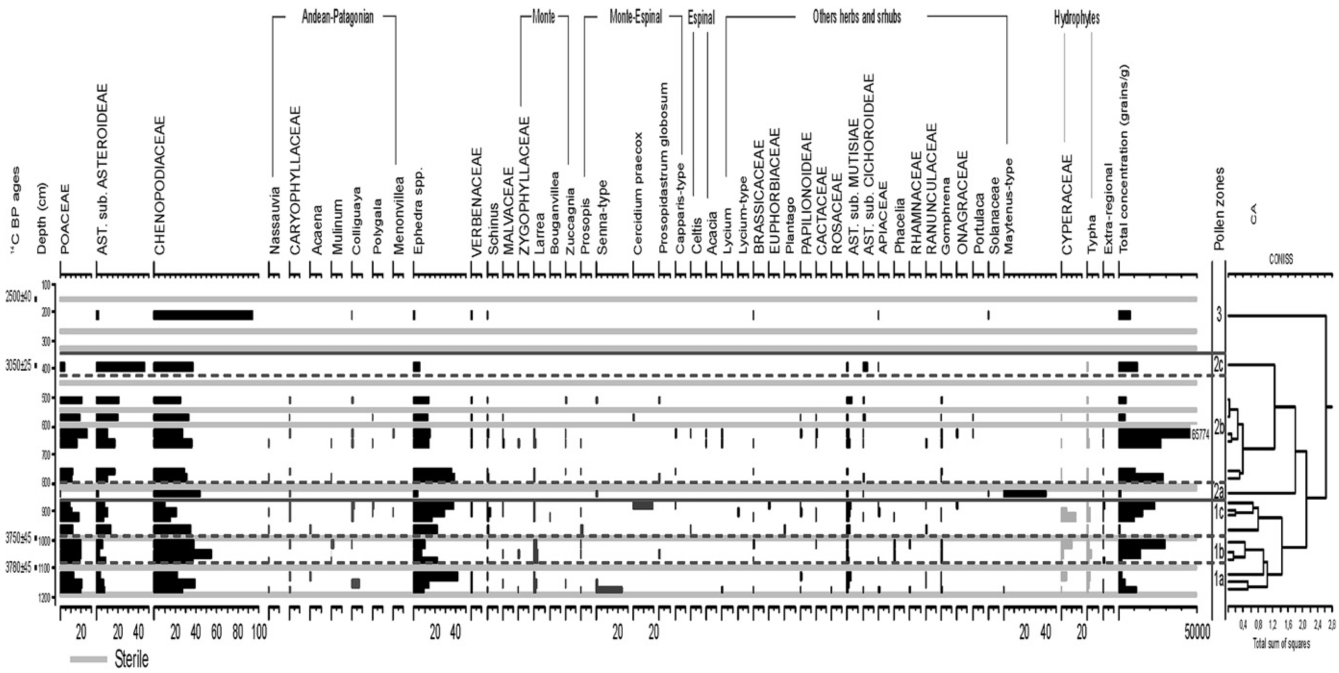

Fig. 5. Pollen diagram and zonation of Brazo Abandonado lithostratigraphic sequence.

Hydrophytes evidence an increase, particularly Cyperaceae with a peak of 10% at the top of the subzone.

Subzone 1c (10–8.7 m): in this subzone *Ephedra* spp. (20–40%) rises and Chenopodiaceae (10–<40%) diminishes at the top; other Monte (*Bouganvillea* traces) and Monte-Espinal (*Cercidium praecox*, with its maximum value in the profile, 20%) taxa appear for the first time in the alluvial record of BA. Andean-Patagonian diversity shows an increment (*Nassauvia*, Caryophyllaceae, *Acaena*,

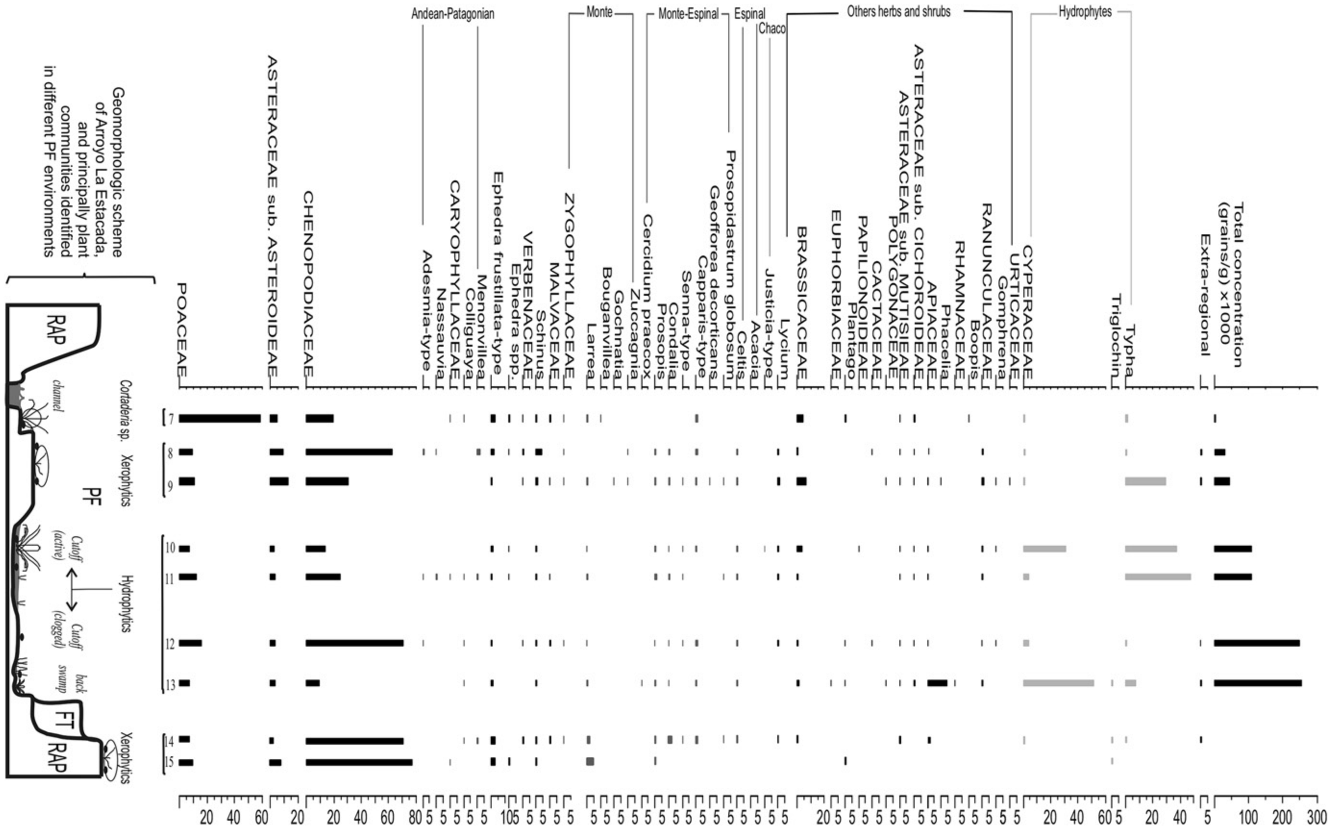

Fig. 6. Pollen diagram obtained from pollen surface samples of the main plant communities at Arroyo La Estacada basin (Rojo, 2009) and location of these samples (see Fig. 2 for more details) according to the geomorphologic scheme of Arroyo La Estacada valley (adapted from Zárate and Mehl, 2008).

Colliguaya, *Polygala* and *Menonvillea*). Hydrophytic taxa are expressed by *Typha* (5%) and Cyperaceae with up to a maximum proportion of 15% in this profile.

Zone 2 (8.4–3.9 m): total pollen concentration reaches the highest values of the BA alluvial sequence (65000 grains/g) in the middle section of this zone. Pollen spectra show that *Ephedra* spp. and Poaceae decline and Chenopodiaceae and Asteraceae subf. Asteroidea increase from the bottom to the top of the zone. Three subzones could be identified:

Subzone 2a (8.3 m): it corresponds to the basal sample of the zone which is distinguished by dominance of Chenopodiaceae (45%) and *Maytenus*-type (40%). Poaceae, Asteraceae subf. Asteroideae, *Ephedra* spp., *Senna*-type (Monte-Espinal) and Caryophyllaceae (Andean-Patagonian) register low values (5%).

Subzone 2b (7.9–5 m): it is represented by samples of the middle section of the zone, in which *Ephedra* spp. high proportions (40%) decrease to the top. In comparison with zone 1, Asteraceae subf. Asteroideae (15–25%) increases and Chenopodiaceae (25–35%) decreases, meantime Poaceae (15–25%) presents similar values. Monte (*Larrea,* Zygophyllaceae and *Zuccagnia*), Monte-Espinal (*Prosopis, Senna*-type, *C. praecox* and *P. globosum*) and Andean-Patagonian (*Nassauvia*, Caryophyllaceae, *Mulinum*, *Colliguaya*, *Polygala* and *Menonvillea*) are recorded with similar values to zone 1.

Subzone 2c (3.9 m depth): at the top of the zone, a limnic level is present with a pollen spectrum dominated by Asteraceae subf. Asteroideae (45%, its maximum percentage in the profile) and Chenopodiaceae (40%), linked to Poaceae, *Ephedra* spp. and *Typha* which are present with low proportions (5%). Asteraceae subf. Mutisiae, Asteraceae subf. Cichoroideae and Apiaceae are also recorded with minor contributions (<5%).

Zone 3 (3.9–1.5 m): this zone is represented by one sample, the rest of them are sterile samples, belonging to the uppermost part of a paleosol (P.BA) buried at *ca.* 2500 ± 40 ^{14}C years BP. The pollen spectrum is dominated by Chenopodiaceae (95%), meanwhile Asteraceae subf. Asteroideae, *Ephedra* spp., *Colliguaya*, *Schinus*, Verbenaceae, Brassicaceae, Apiaceae and Solanaceae are registered with low values (<5%).

Regarding other pollen taxa, traces of extraregional elements (*N. dombeyi*-type and *Podocarpus*) are present along the profile except in the upper section where they are absent. Traces of Espinal taxa (*Celtis* and *Acacia*) are present in a few samples.

As regards the present floodplain environment of the Arroyo La Estacada, the complementary sampling and pollen analysis of its surface sediments (Fig. 2a) permitted to identify different plant communities. The inferred pollen assemblages show a clear differentiation between "*cortaderales*", back swamps/cutoffs and xerophytic Monte communities (Fig. 6), all of them related to different topographic positions and water availability within the floodplain (Fig. 2).

6. Discussion

6.1. Mid- to Late Holocene fossil pollen and current pollen comparison

The palynological analysis carried out shows that both sequences are characterized by fluctuations in the dominant taxa Chenopodiaceae, Poaceae, Asteraceae subf. Asteroideae and *Ephedra* spp. These taxa, except *Ephedra* spp., currently dominate the regional and local records of Monte vegetation (Fig. 6) (Rojo, 2009).

In general, grasses have low values (<15%) in the modern local spectra, with an exception of a 60% in a sample that comes from the *Cortaderia* sp. community ("*cortaderal*") growing at the present floodplain by the edges of the present channel (Fig. 2b, 2). Therefore, the highest values of grasses on alluvial records are probably related to the pollen contribution from the "*cortaderal*".

The dominance of Chenopodiaceae and Asteraceae subf. Asteroideae taxa, associated with the Monte (*Bougainvillea*, *Gochnatia*, *Larrea*, *Zuccagnia* and Zygophyllaceae) and the Monte-Espinal (*C. praecox*, *C. microphylla*, *G. decorticans*, *Prosopis*, *Senna*-type and *P. globosum*) elements, which commonly reach up to 10% values, represent the development of the Monte shrub communities in the floodplain environment, but in a distal and much higher position in relation to the main channel (Fig. 2b, 1). The high values (up to 50%)

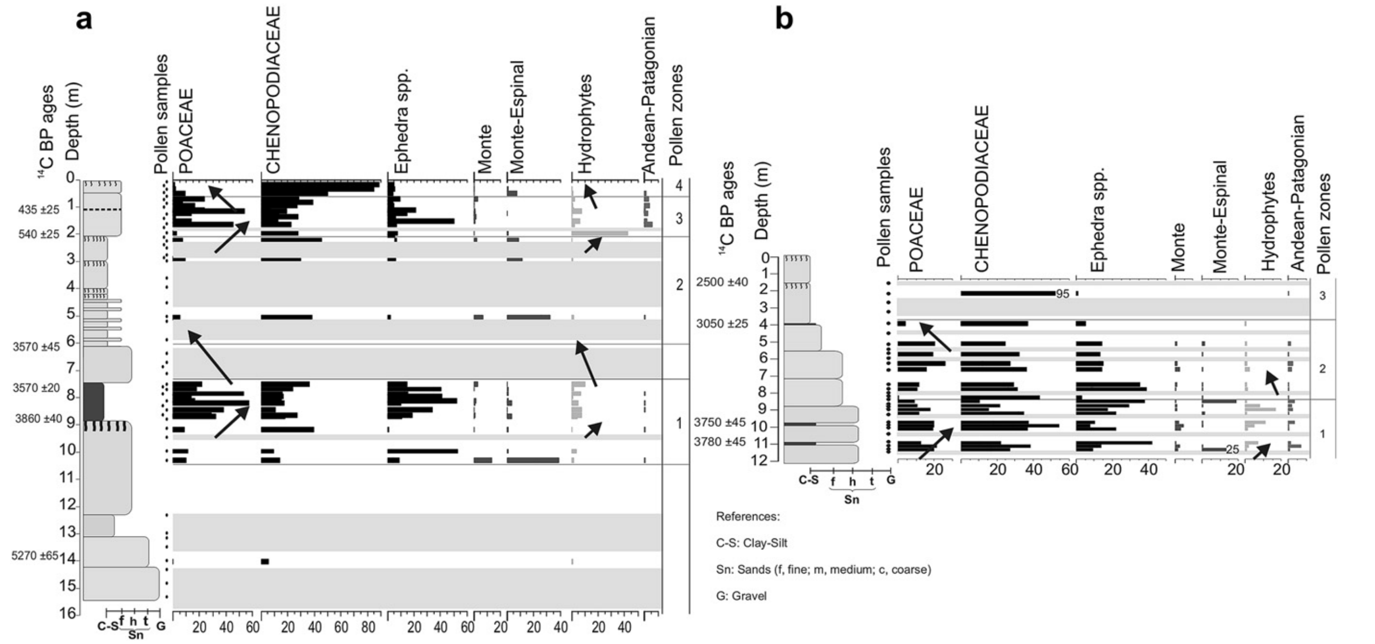

Fig. 7. Stratigraphic sequences, pollen diagrams and zonations of main taxa and grouped pollen grains. a) La Escala lithostratigraphic profile, b) Brazo Abandonado ithostratigraphic profile. Arrows indicate hydrophilous pollen trend.

of *Ephedra* spp. observed in the sedimentary record of the fill terrace contrast with the local and regional low current records (up to 5%) of the area. At present, maximum proportions of *Ephedra* (10%) are observed in Andean-Patagonian vegetation (Rojo, 2009), located about 40 km to west of the study area and 1900 m asl, where it is possible to find "*efedrales*", *i.e.* plant communities dominated by *Ephedra* genus (Roig, 1982) or with a higher abundance in comparison with Monte elements (González Loyarte, 2003). A similar behavior is evidenced by other fossil Andean-Patagonian pollen taxa (*Adesmia*, *Nassauvia*, Caryophyllaceae, *Acaena*, *Azorella*, *Mulinum*, *Colliguaya*, *Polygala* and *Menonvillea*) which reach up to 5%, percentages higher than traces values registered in current local and regional pollen spectra of the study area. Taking into account that pollen vegetation source is developed above 1900 m asl and that *Ephedra* genus is more abundant in that location, it is possible to hypothesize that the higher proportions of both Andean-Patagonian and *Ephedra* spp. pollen taxa in the alluvial sedimentary record would represent an altitudinal descent of Andean-Patagonian vegetation toward the piedmont perhaps associated with a decrease in temperature, and/or a fluvial input coming from higher topographic reaches.

In the alluvial successions analyzed, pollen percentages of hydrophytes Cyperaceae and *Typha* (<5–10%) are lower than the values observed today (60%) in cutoffs (Fig. 2c, 3) and back swamps (Fig. 2d, 4) areas of the floodplain. Fluctuations of these hydrophytic taxa in the fossil record would be linked with fluctuating development of paludal communities linked to water availability in the floodplain environment.

Other features observed at the alluvial sedimentary record is that extraregional Subantartic forest (*N. dombeyi*-type and *Podocarpus*) and Espinal (*Celtis* and *Acacia*) taxa are presented in traces, with similar values to local and regional current records in the study area.

Comparing fossil pollen records and modern pollen spectra of the floodplain environment a lower overall similarity in pollen taxa assemblages is observed. In fossil records, Poaceae-hydrophytes taxa show an opposite trend to shrubby Monte, Monte-Espinal and Chenopodiaceae taxa. While the increase in Poaceae-hydrophytes would be linked to preponderance in communities developed along the channel edges and paludal environments of the present floodplain, the increase in shrubby xerophytic taxa would be related to the predominant development of "*jarillales*" in distal and/or topographical elevated settings of the floodplain (Fig. 2b. 1) respect to more proximal positions to the channel of the arroyo.

6.2. Mid –to Late Holocene vegetation and floodplain evolution of the Arroyo La Estacada

The palynological and sedimentological analysis performed at LES and BA alluvial sequences permitted to reconstruct the paleoenvironmental fluctuations of this fluvial basin during the Mid- to Late Holocene. Accordingly, some intervals of the vegetation history in the Arroyo La Estacada basin (Fig. 7) were inferred in connection with pollen composition, percentages of pollen dominant taxa-phytogeographic groups and the sedimentological features of alluvial deposits. Radiocarbon ages from LES profile led to infer that aggradation of the alluvial sequences observed at the fill terrace unit began before *circa* 5270 ± 65 ^{14}C years BP (Fig. 7a). In the period *ca.* 5200–3800 ^{14}C years BP, sandy deposits accumulated in the fluvial valley represent river channel and proximal main channel floodplain environments where almost all pollen samples are sterile. In the upper part of this interval, characterized by fine sands and ending with the development of a soil at *ca.* 3800 ^{14}C years BP (Zone 1, Fig. 7a), a dominance of Asteraceae subf. Asteroideae, Chenopodiaceae and *Ephedra* spp. associated with Monte (*Larrea*) and Monte-Espinal (*Prosopis* and *Senna*-type) taxa was observed, although they are present along the whole profile. Between *ca.* 3800 and 3500 ^{14}C years BP (mid- to upper section of Zone 1, Fig. 7a), high total pollen concentration – with low representation of Monte (*Larrea* and *Zuccagnia*) and Monte-Espinal (*Prosopis*, *Senna*-type and *C. microphylla*)- associates to channel edges and paludal communities, in concordance to paludal-like deposits possibly related to a cutoff or a back swamp environment. High proportions of *Ephedra* spp. in these deposits could be

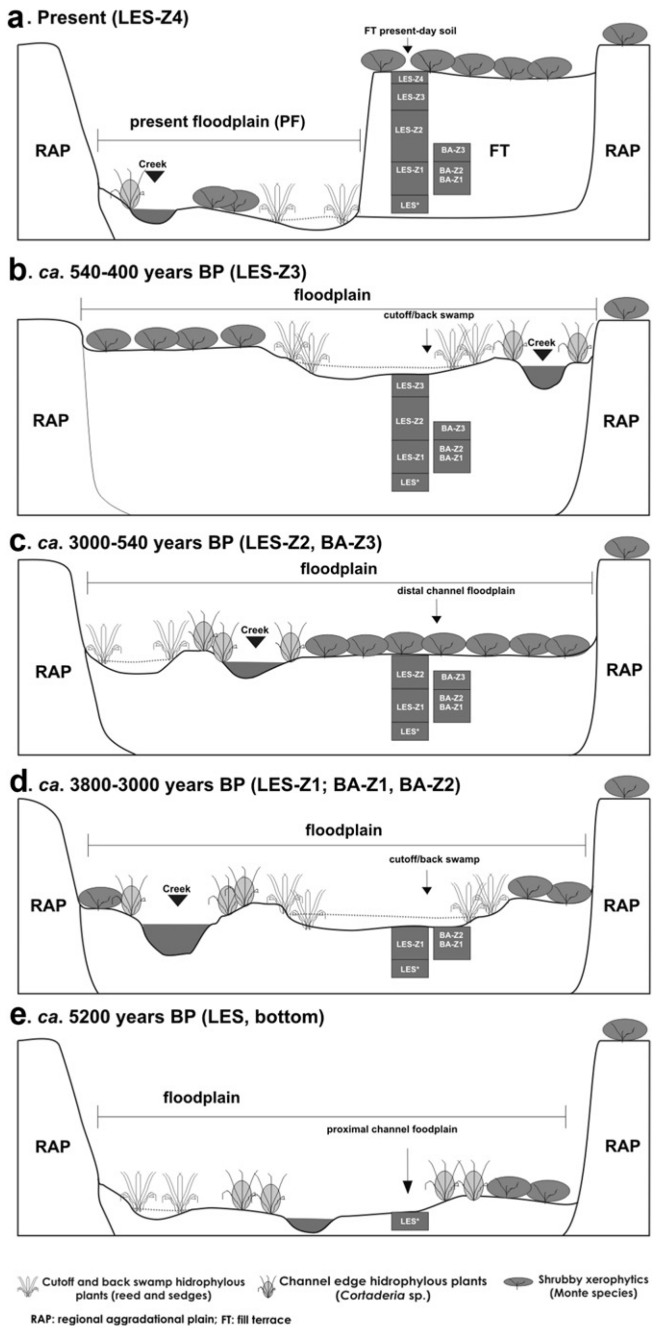

Fig. 8. Schematic representation of vegetation history and floodplain evolution from Arroyo La Estacada, inferred from the pollen and stratigraphic records of La Escala and Brazo Abandonado lithostratigraphic profiles. From (e) to (a), evolution of floodplain and vegetation development according to the lateral migration of stream. LES-Z1 to LEZ-Z4 and BA-Z1 to BA-Z3 indicate pollen zones. *No pollen zones associated with this LES interval (see section 5.2.).

linked mainly with fluvial inputs, *i.e.* pollen transported by Arroyo La Estacada tributaries from higher areas of the basin. These levels are buried by a 1 m thick sand massive stratum in which pollen samples were sterile (section between Zone 1 and 2), that, according to ages in the base (3570 ± 20 ^{14}C years BP) and the top (3570 ± 45 ^{14}C years BP), would represent an overbank flooding event. Later, aggradational process continued linked to overbank events in the floodplain environment interrupted by periods of stability in the floodplain surface (development of P.LES 2-6 buried soils); in these overbank deposits, almost all pollen samples are sterile. Few records (Zone 2, Fig. 7a) show pollen assemblages related to the development of shrubby xerophytic Monte communities; this association extends to sometime before *ca.* 540 ^{14}C years BP. Between 540 ^{14}C years BP and <400 ^{14}C years BP, fine sands deposits evidence a slight increase in pollen concentration. A change in the pollen record evidences the development of channel edge and paludal communities associated with lower Chenopodiaceae and shrubby Monte (*Larrea* and *G. decorticans*) and Monte-Espinal (*Prosopis*) taxa (Zone 3, Fig. 7a). In this period, Andean-Patagonian (Caryophyllaceae, *Colliguaya*, *Mulinum*, *Nassauvia, Adesmia* and *Polygala*) and *Ephedra* spp. show higher proportions than the previous period which could be related mainly to fluvial input coming from headwater high positions. A limnic level in the upper section (*ca.* 435 ^{14}C years BP, about a meter depth) registers a sharp increase in *Lycium*-type (20%) and Malvaceae (40%) which would be synchronous with the introduction of cattle by the Spanish communities into the Valle de Uco region (Cortegoso et al., 2010). Taking into account the existence of introduced species of the Malvaceae family in Argentina (Zuloaga and Morrone, 1999) and the presence of *Lycium* species identified in disturbed lands around Arroyo La Estacada basin (Leandro Rojo, personal observation), it is possible to consider the sharp increase of Malvaceae and *Lycium* pollen types in relation to anthropogenic disturbances in the area. In the top section of the fill terrace (Zone 4, Fig. 7a), corresponding approximately to 30 cm from present-day soil surface, pollen spectra show the predominance of Monte shrub communities, similar to current regional xerophytic vegetation developed in the area ("*jarillales*").

At BA succession, limnic levels dated about 3700 ^{14}C years BP and probably related to floodplain back swamp environments, show high pollen concentration. Pollen assemblages are associated to channel edge and paludal communities (Zone 1, Fig. 7b). Monte (*Larrea, Bouganvillea, Zuccagnia*, Zygophyllaceae) and Monte-Espinal (*Prosopis, Prosopidastrum globosum, Senna*-type, *C. praecox*) taxa are expressed with similar percentages but the diversity is greater when comparing with those registered in LES alluvial sequence between *ca.* 3800 and 3500 ^{14}C years BP. In turn, Andean-Patagonian taxa (*Nassauvia*, Caryophyllaceae, *Acaena, Mulinum, Colliguaya, Polygala* and *Menonvillea*) show an increase in this interval, which could be related to fluvial inputs. Upwards the succession continues with low energy floodplain environments. Previous to *ca.* 3000 ^{14}C years BP (Zone 2, Fig. 7b), Asteraceae subf. Asteroideae increase and Cyperaceae decrease could be explained by a minor development of paludal communities. Between *ca.* 3000 and 2500 ^{14}C years BP, lower energy depositional conditions dominated and the two pollen spectra mainly represented by Chenopodiaceae and Asteraceae subf. Asteroideae (Zone 3, Fig. 7b) would indicate the development of Monte shrub vegetation in distal and elevated areas of the floodplain.

In summary, the mid- to late Holocene fill terrace sedimentary and palynological records evidence the dynamics of plant communities developed in different environments of the arroyo floodplain (Fig. 8). The beginning of the deposition *ca.* 5200 ^{14}C years BP would be characterized by river channel and proximal channel floodplain environments in which scarce pollen spectra were registered (Fig. 8e, Table 2). Between *ca.* 3800–3000 ^{14}C years BP, hydrophytic communities developed, probably linked to cutoffs and back swamp environments, associated to a low representation of Monte shrub vegetation (Fig. 8d, Table 2). The interval between *ca.* 3000 and 540 ^{14}C years BP registers a predominance of Monte vegetation and a concomitant decrease of hydrophytes in relation to distal channel floodplain environments and soil formation

Table 2
Floodplain environments evidenced by pollen and sedimentological data.

Lithostratigraphic sequence	^{14}C AP ages	Sedimentary deposits	Main pollen taxa	Represented environment
LES	*Ca.* 5200->3800	Gravels and coarse to medium sands	No record (pollen grains absence)	Channel bars
	Ca. 3800–3500	Massive silts, horizontally bedded or laminated. Diatomaceous content	*Dominant*: Poaceae, hydrophytes and *Ephedra* spp. *Associated*: Chenopodiaceae, Asteraceae subf. Asteroideae, Monte and Monte-Espinal	Cutoff and/or swamp
	Ca. 3500–540	Massive Clayey silts, silty clays, fine to very fine sands, horizontally bedded and/or laminated. Pedological features presence.	*Dominant*: Asteraceae subf. Asteroideae, Chenopodiaceae, Monte (*Larrea*) y Monte-Espinal (*Prosopis* y *Senna*-type) *Associated*: Poaceae, hydrohytes, *Ephedra* spp. - No records in several levels	Distal floodplain area and paleosoils
	Ca. 540–435	Massive medium to fine sands, horizontally bedded and interbedded carbonaceous levels	*Dominant*: Poaceae, hydrophytes, *Ephedra* spp., Andean-Patagonian *Associated*: Chenopodiaceae, Asteraceae subf. Asteroideae, Monte and Monte-Espinal	Proximal floodplain area
	<435–0	Massive and loose fine sands, horizontally bedded. Pedological features presence.	*Dominant*: Chenopodiaceae *Associated*: Poaceae, *Ephedra* spp., hydrophytes	Aeolian deposition and soil formation in the fill terrace surface
BA	*Ca.* 3800–3000	Upward gradding medium to fine sands and sandy silts. Interbedded limnics levels	*Dominant*: Poaceae, hydrophytes, *Ephedra* spp, Chenopodiaceae, Andean-Patagonian *Associated*: Asteraceae subf. Asteroideae, Monte and Monte-Espinal	Swamp and/or cut off
	Ca. 3000–2500	Clayey silts and silty clays beds, horizontally bedded. Development of pedological features	*Dominant*: Asteraceae subf. Asteroideae, Chenopodiaceae *Associated*: Poaceae, hydrophytes, *Ephedra* spp. Andean-Patagonian -No record in several levels	Distal floodplain area and paleosoil

intervals (Fig. 8c, Table 2). *Circa* 540–400 ^{14}C years BP, it is recorded a dominance of hydrophytic communities and a minor development of Monte vegetation likely related to reactivation of aggradational mechanisms that built up the upper deposits of the fill terrace (Fig. 8b, Table 2). The aggradational process would have culminated sometime after *ca.* 400 ^{14}C years BP when the Mid- to Late Holocene deposits were incised and later followed by the renewal of aggradation in the present floodplain. The pollen record of the fill terrace uppermost section mainly reflects the currently Monte vegetation development on its surface (Fig. 8a, Table 2).

6.3. Pollen concentration and sterile samples from LES and BA alluvial sequences

Pollen concentrations in both alluvial sections are variable, ranging from 1000 grains/g to *ca.* 170000 grains/g (Figs. 4 and 5). In present-day samples from Arroyo La Estacada, high pollen concentrations are associated to alluvial sedimentary environments characterized by high water availability (Fig. 6), for example back swamps and partially active meanders (or cutoffs). In turn, in the sedimentary record sterile samples are frequent in sandy deposits from LES basal sections and paleosols in both LES and BA alluvial sequences (Figs. 4 and 5). In the modern record, sterile samples were not registered.

This concentration variability, from high pollen concentration samples to numerous sterile samples in both alluvial profiles, suggests the existence of hydrodynamics and taphonomic processes that would have influenced the pollen input to the alluvial system and its preservation in the sedimentary record, as it has been inferred to occur in alluvial sedimentary deposits from other regions (Hall, 1985; Fall, 1987; Xu et al., 1996). According to these studies, pollen input and preservation in alluvial sedimentary archives could be controlled by pollen source, fluvial transport, depositional processes, sedimentary facies involved and post-depositional changes associated to weathering processes (*e.g.* pedogenesis, percolation, groundwater level fluctuations). As an example, the coarse sediment fraction -sand- from the LES basal section could explain that pollen input transported by water was not retained in this deposit because of the smaller size of pollen grains that probably moved downstream. Besides, if some pollen grains were retained in these coarse grain deposits they would be eliminated by percolation after deposition. Other cases are related to sterile samples coming from paleosols, where the absence of pollen grains could be the result of soil forming processes and associated weathering. Nonetheless, the existence of sterile samples does not alter the general pollen trend that indicates the continuous development of vegetation in relation to the different environments of the floodplain during the Mid- to Late Holocene.

7. Concluding remarks

The results obtained from this study have permitted to infer that the pollen spectra fluctuations observed in the alluvial sedimentary succession of Arroyo La Estacada during Mid- to Late Holocene would be mainly linked with variations in plant communities developed in relation to the floodplain environment of the arroyo, mainly in response to its fluvial dynamics and probably to pollen inputs and preservation conditions in the record.

Previous pollen and sedimentological studies of alluvial sequences record a major vegetation change during the Late Pleistocene–Holocene climatic transition (shift from halophytic plant communities toward Monte communities) in accordance with the establishment of Holocene climatic conditions, in general similar to the present ones (Zárate, 2002a, 2002b; Zárate and Paez, 2001, 2002). In contrast, the fluctuations observed in the pollen record of the Mid- to Late Holocene fill terrace alluvial sequence would not reflect changes in regional vegetation, but the prevailing local paleoenvironmental fluctuations at the arroyo basin.

The different representativeness (local vs. regional) observed in alluvial pollen record could probably be a consequence of the much lower magnitude of environmental changes during the Mid- to Late Holocene in comparison with those of the Pleistocene–Holocene climatic transition (Prieto, 1996; Prieto et al., 2004; Quattrocchio et al., 2008; Zárate, 2002a, 2002b; Zárate and Paez, 2001, 2002). In addition, changes in regional vegetation are expected to be more probably detected in sedimentary archives close to phytogeographic transitional vegetation (*e.g.* cordilleran peats located close to Monte/Patagonian and/or Patagonian/Andean ecotones). Likely, alluvial sedimentary records could only preserve regional vegetation modifications resulting from major climatic changes, for example the change from glacial to interglacial conditions as registered by Zárate and Paez (2001, 2002).

It is hoped that future contributions allow testing the hypothesis that changes observed in the alluvial pollen record reflect local variations in the vegetation communities mainly as a result of sedimentary environment fluctuations in the floodplain of Andean piedmont fluvial valleys. Also, it is necessary to carry out specific taphonomic studies to assess the different causes that determine the variability in pollen concentration and the low overall similarity in percentages between fossil and modern pollen records.

Acknowledgment

This paper is part of the thesis research projects carried out by two of the authors (L.D.R and A.E.M.) with scholarships of the National Research Council of Argentina (CONICET). The authors thank CONICET and Universidad Nacional de Mar del Plata for providing financial support for this study (CONICET-PIP 2904, CONICET- PIP 5819, UNMdP-EXA 354/06). They would also like to thank to Dr. David Thomas, reviewer who provided helpful and constructive comments on the manuscript. The first author (L.D.R.) wants to thank Dra. Isabel Vilanova and Dr. Diego Navarro for helpful contributions to interpret alluvial pollen.

References

Anderson, D.L., Del Aguila, J.A., Bernardon, A.E., 1970. Las formaciones vegetales en la provincia de San Luis. Revista de investigaciones Agropecuarias 7 (3), 153–183. INTA.

Böcher, T.W., Hjerting, J.P., Rahn, K., 1972. Botanical studies in the Atuel valley area, Mendoza province, Argentina. Part. III. Dansk Botanisk Arkiv 22 (3), 195–358.

Brice, J.C., Blodgett, J.C., 1978. Countermeasures for Hydraulic Problems at Bridges. In: Analysis and assessment, vol. I. Federal Highway Administration, Washington, D.C (Final report. Jun 75-Sep 78). Report no. FHWA/RD-78/162.

Bridge, J., Demicco, R., 2008. Earth Surface Processes, Landforms and Sediment Deposits. Cambridge University Press, Cambridge, UK, 815 p.

Bruniard, E., 1982. La diagonal árida Argentina: un límite climático real. Revista Geográfica 95, 5–20.

Bull, W.B., 1990. Stream-terrace genesis: implications for soil development. Geomorphology 3, 351–367.

Bull, W.B., 1991. Geomorphic Responses to Climate Change. Oxford University Press, New York.

Burgos, J.J., Vidal, A.L., 1951. Los climas de la República Argentina según la nueva clasificación de Thornwaite. Meteoros 1, 1–32.

Cabrera, A.L., 1976. Regiones Fitogeográficas Argentinas, Fascículo 1. Buenos Aires. In: Kugler, W.F. (Ed.), Enciclopedia Argentina de Agricultura y Jardinería, vol. 2, pp. 1–85.

Catt, J.A., 1990. Paleopedology Manual, Quaternary International 6. Pergamon press, Oxford.

Cortegoso, V., Durán, V., Pelagatti, O., Lucero, G., 2010. La cría y tráfico de ganado mayor como factores de cambio ambiental en la cordillera central y piedemonte oriental de Mendoza (siglos XVII a XX). Una aproximación arqueológica e histórica. In: Gil, A., Neme, G., Zárate, M.A. (Eds.), Paleoambientes y ocupaciones del centro-oeste de Argentina durante la transición Pleistoceno-Holoceno y Holoceno. Sociedad Argentina de Antropología, Capital Federal, Buenos Aires, pp. 277–308.

D'Antoni, H.L., 1983. Pollen analysis of Gruta del Indio. Quaternary of South America and Antarctic Peninsula 1, 83–104.

De Francesco, C.G., Zárate, M.A., Miquel, S.E., 2007. Late Pleistocene mollusc assemblages and inferred paleoenvironments from the Andean piedmont of Mendoza, Argentina. Palaeogeography, Palaeoclimatology, Palaeoecology 251, 461–469.

Faegri, K., Iversen, J., 1989. Textbook of Pollen Analysis. John Wiley & Sons, Chichester.

Fall, P.L., 1987. Pollen taphonomy in a canyon stream. Quaternary Research 28, 393–406.

García, A., Zárate, M.A., Paez, M.M., 1999. The Pleistocece/Holocene transition and human occupation in the Central Andes of Argentina: Agua de la Cueva locality. Quaternary International 53/54, 43–52.

Garleff, K., 1977. Höhenstufen der argentinischen Andes in Cuyo, Patagonien und Feverland. Göttinger Geographic Abhand 68, 1–150.

González Loyarte, M.M., 2003. Relationship among grain-size, plant communities, and fluvial and eolian processes in a piedmont of the central Andes in Argentina. Ecología Austral 13, 27–48.

Gray, J., 1965. Extraction technique. San Francisco. In: Kummel, B.G., Raup, D.M. (Eds.), Handbook of Palaeontological Techniques. Part III. Freeman, pp. 530–587.

Grimm, E., 2007. TGView-Tilia Software Version 1.0.1. Illinois State Museum, Research and Collection Center Springfield, Illinois USA.

Guerci, A., 2011. Reconstrucción del clima y la vegetación durante el Holoceno al sur del río Atuel, Mendoza. Doctoral Thesis. Universidad Nacional de Cuyo, (In preparation).

Hall, S.A., 1985. Quaternary pollen analysis and vegetational history of the southwest. In: Bryant Jr., V.M., Holloway, R.G. (Eds.), Pollen Records of Late Quaternary North American Sediments. American Association of Stratigraphic Palynologists Foundation, Dallas, pp. 95–123.

Hall, S.A., 1989. Pollen analysis and paleoecology of alluvium. Quaternary Research 31, 435–438.

Heusser, C.J., 1971. Pollen and Spores of Chile. University of Arizona Press, Tucson.

Horowitz, A., 1992. Palynology of Arid Lands. Elsevier Science Publishers, Amsterdam.

Markgraf, V., 1983. Late and Postglacial Vegetacional and paleoclimatic changes in Subantarctic, Temperate and arid environments in Argentina. Palynology 7, 43–70.

Markgraf, V., D'Antoni, L.H., 1978. Pollen Flora of Argentina. University of Arizona Press, Tucson.

Miall, A.D., 2006. The Geology of Fluvial Deposits: Sedimentary Facies, Basin Analysis and Petroleum Geology. Springer-Verlag Berling Hridelberg, Italy, 582 p.

Navarro, D. 2011. Ambientes holocenos pedemontanos y de Montaña del sur de Mendoza. Doctoral thesis. Universidad Nacional de Mar del Plata. (unpublished).

Overpeck, J.T., Webb III, T., Prentice, I.C., 1985. Quantitative interpretation of fossil pollen spectra: dissimilarity coefficients and the method of modern analogs. Quaternary Research 23, 87–108.

Paez, M.M., Navarro, D., Rojo, L.D., Guerci, A., 2010. Vegetación y paleoambientes durante el Holoceno. In: Zárate, M., Gil, A., Neme, G. (Eds.), Paleoambientes y ocupaciones humanas del centro-oeste de Argentina durante la transición Pleistoceno-Holoceno y Holoceno. Sociedad Argentina de Antropología, Capital Federal, Buenos Aires, pp. 175–212.

Peña Zubiate, C.A., Anderson, D.L., Demmi, M.A., Saenz, J.L., D'Hiriart, A., 1998. Carta de suelos y vegetación de la provincia de San Luis. INTA E.E.A, San Luis.

Polanski, J., 1963. Estratigrafía, neotectónica y geomorfología del Pleistoceno pedemontano entre los ríos Diamante y Mendoza. Revista de la Asociación Geológica Argentina 17, 127–349.

Prieto, A.R., 1996. Late Quaternary vegetational and climatic changes in the Pampa grassland of Argentina. Quaternary Research 45, 73–88.

Prieto, A.R., Blasi, A.M., De Francesco, C.G., Fernández, C., 2004. Environmental history since 11,000 ^{14}C yr B.P. of the northeastern Pampas, Argentina, from alluvial sequences of the Luján River. Quaternary Research 62, 146–161.

Quattrocchio, M.E., Borromei, A.M., Deschamps, C.M., Grill, S.C., Zavala, C.A., 2008. Landscape evolution and climate changes in the Late Pleistocene-Holocene, southern Pampa (Argentina): evidence from palynology, mammals and sedimentology. Quaternary International 181, 123–138.

Roig, F.A., 1960. Bosquejos fitogeográficos de las provincias de Cuyo, Comité Nacional Estudios Problemas Regiones Áridas y Semiáridas. Subcomité Zona Cuyo, Publicación n° 3, Mendoza.

Roig, F.A., 1972. Bosque Fisonómico de la Vegetación de la provincia de Mendoza. Boletín de la Sociedad Argentina de Botánica 13, 49–80 (Suplemento).

Roig, F.A., 1982. Conservación de la vegetación natural de la República Argentina. In: Fundación Miguel Lillo-Sociedad Argentina de Botánica (Ed.), Serie Conservación de la Naturaleza. Fundación Miguel Lillo, Tucumán, pp. 1–127.

Roig, F.A., González Loyarte, M.M., Martínez Carretero, E., Berra, A., Wuilloud, C., 1992. La Travesía de Guanacache. Tierra Forestal. Multequina 1, 83–91.

Roig, F.A., Martinez Carretero, E., Mendez, E., 2000. Vegetación de la Provincia de Mendoza. In: Abraham, E.M., Rodriguez Martínez, F. (Eds.), Recursos y Problemas Ambientales de la Zona Árida. Primera parte: provincias de Mendoza, San Juan y La Rioja. Tomo I: Caracterización ambiental. IADIZA, Mendoza, pp. 63–66.

Rojo, L.D., 2009. Condiciones paleoambientales durante el Holoceno entre los 33°-34°S (Mendoza y San Luis). Doctoral thesis. Universidad Nacional de Mar del Plata (unpublished).

Soil Survey Staff, 2003. Keys to Soil Taxonomy. United States Department of Agriculture, ninth ed. Natural Resources Conservation Service. p.334.

Solomon, A.M., Blasing, T.J., Solomon, J.A., 1982. Interpretation of floodplain pollen in alluvial sediments from an arid region. Quaternary Research 18, 52–71.

Stockmar, J., 1971. Tablets with spores used in absolute pollen analysis. Pollen and Spores 13, 615–621.

Toms, P.S., King, M., Zárate, M.A., Kemp, R.A., Foit Jr., F.F., 2004. Geochemical characterization, correlation, and optical dating of tephra in alluvial sequences of central western Argentina. Quaternary Research 62, 60–75.

Wingenroth, M., Heusser, C.J., 1984. Polen en la alta cordillera. IANIGLA, Mendoza.

Xu, Q., Xiaolan, Y., Chen, W., Lingyao, M., Zihui, W., 1996. Alluvial pollen on the north China plain. Quaternary Research 46, 270–280.

Zárate, M.A., 2002a. Los ambientes del Tardiglacial y Holoceno en Mendoza. In: Gil, A.F., Neme, G.A. (Eds.), Entre montañas y desiertos: arqueología del sur de Mendoza. Sociedad Argentina de Antropología, Buenos Aires, pp. 9–42.

Zárate, M.A., 2002b. Geología y Estratigrafía del Pleistoceno tardío-Holoceno en el piedemonte de Tunuyán-Tupungato, Mendoza, Argentina. In: Cabaleri, N., Cingolani, C., Linares, E., López de Luchi, M.G., Ostera, H.A., Panarello, H.O. (Eds.), Actas del XV Congreso Geológico Argentino. El Calafate, Santa Cruz, Argentina, pp. 615–620.

Zárate, M.A., Mehl, A., 2008. Estratigrafía y geocronología de los depósitos del Pleistoceno tardío/Holoceno de la cuenca del arroyo La Estacada, departamentos de Tunuyán y Tupungato (Valle de Uco), Mendoza. Revista de la Asociación Geológica Argentina 63 (3), 407–416.

Zárate, M.A., Paez, M.M. 2001. Paleoambientes y Paleoclimas de la transición Pleistoceno-Holoceno entre los 32–38°S de Argentina. VIII Congresso da ABEQUA. Boletim de resumos, Mariluz, Imbé-RS, pp. 350–351.

Zárate, M.A., Paez, M.M., 2002. Los Paleoambientes del Pleistoceno-Holoceno en la Cuenca del Arroyo La Estacada, Mendoza. In: Trombotto, D., Villalba, R. (Eds.), Ianigla, 30 años de Investigación Básica y Aplicada en Ciencias Ambientales, pp. 117–121. Mendoza.

Zuloaga, F., Morrone, O., 1999. Catálogo de Plantas Vasculares de la República Argentina, vol. II.