The Marine Isotopic Stage 3 (MIS 3) in Valleys of the Undulated Pampa, Buenos Aires Province, Argentina

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Abstract A depositional unit called DU2 identified for the period MIS 3 (ca— 30,000–60,000 year B.P.) formed by only one sedimentary facies (F3) was found in the Luján and Salto-Arrecifes rivers basins. F3 is a fluvio–lacustrine unit that overlies in erosive unconformity over eolian sediments with ages of 56,400 ± 6500 and 50,400 ± 10,200 years B.P. and is unconformably covered by another eolian vitroclastic sandy loess deposit, dated as 32,000 ± 4000 years (Infrared Stimulated Luminescence, IRSL) (Blasi et al. 2009a). It represents the recurrence of ephemeral fluvial streamlets and the development of temporary pools by subsequent damming of channels. It corresponds lithologically to sandy muddy gravel, gravelly muddy sand, gravelly mud olive to pale olive, feldspar and quartz sands, bearing extinct mollusks such as *Heleobia ameghini* and *Diplodon lujanensis*. Radiocarbon chronologies obtained on monospecific samples of *Cyprideis salebrosa hartmanni* and *Heleobia ameghini* yielded ages of 37,710 ± 840 years [14]C B.P. and >40,000 years [14]C B.P., respectively. Furthermore, the age obtained through the IRSL technique was of 44,000 ± 6500 years. Based upon the analyzed bioproxies (malacological, phytoliths and diatomological content) F3 accumulated under variable climatic conditions, ranging from temperate to colder and from subhumid to drier. According to the exhaustive stratigraphic identification, it is proposed that in N-E Buenos Aires Province, the so-called Undulated Pampa region, the

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sediments that were accumulated during MIS3 occur only in the central portion of the studied fluvial basins. This prompted two hypotheses related to the existence of a particular drainage pattern for the Late Pleistocene, different from the present one, and subsequent tectonic controls that allowed the identification of DU2 sediments only in some of the analyzed sections.

1   Introduction

The sedimentological, paleobiological, and chronological studies of the Late Pleistocene-Holocene cropping out in the middle fluvial valleys of the Undulated Pampa region of the Buenos Aires Province (locally known as the "Pampa Ondulada Bonaerense") allowed to identify different depositional units (DU), bounded by unconformities. Depositional units and their facies, as defined for the Luján river basin, were associated by Blasi et al. (2010) based on their stratigraphic position, chronological ages, and paleoclimatic and paleoenvironmental interpretations with different marine isotopic stages (MIS 4–2). As pointed out by Sowers (2000) the marine isotope record, which is the most complete record available of Quaternary climate cycles, is the standard to which we correlate other Quaternary paleoclimatic records.

The studied sequence lies in between the continental deposits and those of the corresponding marine isotopic stage. It offers a very valuable independence concerning the use of stratigraphic nomenclature (biostratigraphy, lithostratigraphy, chronostratigraphy, sequential stratigraphy, etc.) of different stratigraphic schemes established for the study area, generally based on relative chronologies (Blasi et al. 2009b). As pointed out by these authors, the large amount of formal and even informal stratigraphic terms for naming stratigraphic units locally and the use of synonyms for regional correlations eventually generated a nomenclature chaotic situation. These authors proposed to define stratigraphic schemes through the description of DU limited by unconformities, their lithofacies and facies variations.

The results obtained in the characterization of depositional unit 2 (DU2) are herein presented and explained. It is formed by one fluvial-lacustrine facies (F3) chronologically delimited and exposed in certain restricted areas of two large fluvial basins of the Undulated Pampa (the Luján and the Salto-Arrecifes rivers basins). Its association with the Marine Isotope Stage 3 (MIS 3) is discussed in this paper.

During the interstadial MIS 3, belonging to the last glacial stage, several climatic variations occurred with alternating warmer phases, the Dansgaard-Oeschger events (DO) and colder phases, known as the Heinrich events (H), defined according to different proxies analyzed in Antarctic and Arctic polar ice cores (Bond et al. 1993;

Clark et al. 2007; Van Meerbeeck et al. 2009; Rabassa and Ponce 2013; Sinddall et al. 2008). Climate variations taking place during that period somehow have affected the region under study and their consequences were recorded in the analyzed DU.

2 Geological Setting

The study area, in northeastern Buenos Aires Province, Argentina, is located within the "Pampa Levantada" ("raised Pampa") region (Pasotti 1971). It corresponds geomorphologically to the Pampa subregion called "Undulated Pampa" (Pasotti and Castellanos 1967) that covers part of the provinces of Buenos Aires, Córdoba and Santa Fe, with an area of approximately 44,000 km^2 (Fig. 1). It is characterized by the development of undulating landforms due to the presence of low hills aligned in a SW-NE direction and eroded by creeks, streamlets, and rivers. This undulating surface was produced by fluvial erosion and minor tectonic block movements, with differential displacement, associated with large faults related to the crystalline basement (Pasotti 1971, 1973, 2000).

Among other fluvial basins draining this region, those of the herein studied Luján and Salto-Arrecifes rivers are the most relevant for Quaternary studies. Both flow into the Paraná de las Palmas, which is one of the distributaries of the lower portion of the Paraná river, demarcating the western edge of the Río de La Plata delta (Fig. 1).
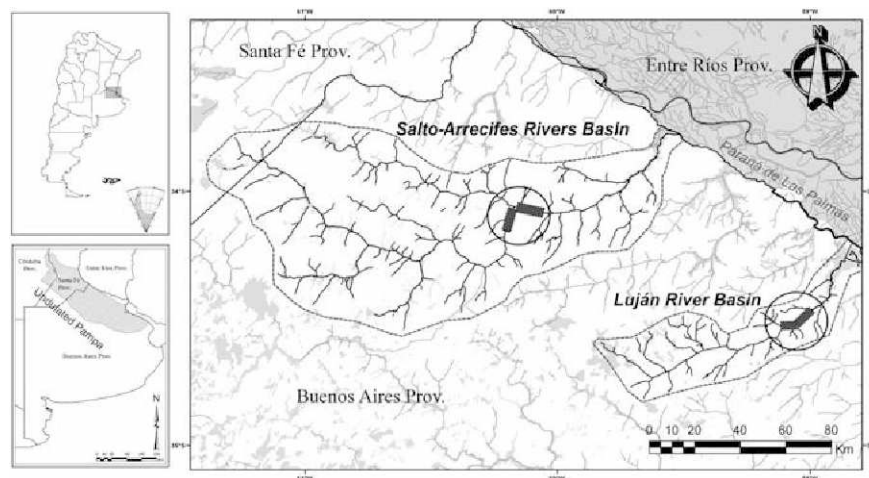
Fig. 1 Location map of the Luján and Salto-Arrecifes basins showing location of MIS 3 sections and geographic features

The Luján and Salto-Arrecifes stream basins initiate from small streamlets which in turn have their sources in shallow lacustrine water bodies. The main collectors appearing in the medium part of the basins are confined in most of the sections by very high cutbanks. Successive sediments exposed in the cutbanks show the paleoenvironmental and paleoclimatic evolution of the Late Pleistocene and Holocene of the Undulated Pampa valleys (Prieto et al. 2004; Blasi et al. 2010).

3 Materials and Methods

Information was gathered from seven localities at the Luján river basin and six other ones at the Salto-Arrecifes rivers basin (Fig. 1). The sedimentary facies exposed at the cutbanks of the studied localities were characterized by their colorimetric features (Munsell Color Chart), lithology, morphologic expression, and biological content. Samples were taken from each known facies, for sedimentological analysis as well as for their paleobiological and chronologic content (^{14}C standard, AMS radiocarbon dating and IRSL).

Sedimentological analysis was accomplished according to standard methods (Carver 1971). The analysis comprised the elimination of organic material with a solution of 30 % H_2O_2, and of cementing materials with a solution of 35 % HCl. For dispersion, 4 % $(NaPO_3)_6$ and mechanical shaking were used. Grain size analysis for sand fraction was performed by sieving at half Φ intervals and by pipetting for the silt clay fraction grain size classification (Craver 1971). The gravel, sand, silt, and clay content percentages were used for the grain size classification according to Folk (1954). Mineralogical analysis was performed in the very fine sand fraction (0.125–0.062 mm) by polarization microscopy. Clay mineralogy was performed in preparation of total and oriented samples, using a Phillips Difractometer X-rays PW3710 Cu tube.

Samples for biosiliceous particle counting and identification were treated with $(NaPO_3)_6$ for sediment disaggregation and clay removal. Then, 15 ml of 35 % HCl was added and the solution was allowed to stand for 24 h to eliminate carbonate precipitation. Samples were rinsed several times with distilled water. Next, 10 ml of 30 % H_2O_2 was added to eliminate organic matter and then the samples were boiled for 4 h and rinsed five times with distilled water. Permanent slides were mounted in Naphrax for counting and identification. A minimum of 400 biosiliceous particles was counted at ×1000 magnification in each sample with an Olympus BX 40 microscope.

Phytoliths were identified according to Bozarth (1992), del Puerto et al. (2006), del Puerto (2009), Fredlund and Tieszen (1994), Fernández et al. (2006), Gallego and Distel (2004), Twiss (1992), and Zucol (1998, 2000, 2001). Although phytoliths cannot be assigned to individual grass taxa, different ratios of phytoliths (pooid, chloridoid and panicoid) may serve as climatic indices for paleoclimatic interpretations of a given region. In this sense, where the C3-types occur, the ratio

C3 to C4 (Twiss 1992) can be used as an index of temperature following the equation: TI = (Pooid)/[(Pooid + Panicoid +Chloridoid) * 100].

Higher values suggest a cooler climate in high latitudes or altitudes (where C3 are prevalent), and lower values suggest warmer temperatures that would be found in lower latitudes or elevations. Similarly, by comparing chloridoid to the sum of chloridoid and panicoid phytoliths a humidity index: HI = (Chloridoid)/ [(Chloridoid + Panicoid) * 100] may be obtained. Values close to 100 indicate an arid climate, whereas lower values indicate a humid climate. Diatom species were identified and classified according to Frenguelli (1941, 1945), Metzeltín and García-Rodríguez (2003), Metzeltín et al. (2005) and Witkowski et al. (2000). Chrysophycean cysts were identified according to Duff et al. (1995) and sponge spicules were recognized according to Ezcurra de Drago (1993).

Samples were washed under 0.5 mm mesh opening sieve to obtain and concentrate malacological species. Samples were observed under binocular glass (40×) where species were identifiedand measureded.

To the study of the ostracod fauna, samples were disaggregated with water and washed under a sieve of 63 microns (Tyler Screen System No. 230). All adults and juvenile specimens found in 1 g of dry sediment were picked up. The species were determined according to Moore and Pitrat (1961), Van Morkhoven (1963), Ramírez (1967), Bertels and Martínez (1990) and Ferrero (1996, 2009), among others.

Finally, in order to determine radiocarbon ages and ages through IRSL, samples were processed according to Blasi et al. (2010).

4 Analyzed Stratigraphic Sections

The sedimentary and paleobiological record of DU2 (Facies 3) exposed at the cutbanks of the Luján and Salto-Arrecifes rivers basins was sampled in a few places along the sections studied in both basins (Fig. 1). In these rivers, the deposits corresponding to this interval are circumscribed to the middle portion of the fluvial basins and were associated by Blasi et al. (2010) to the Marine Isotopic Stage 3. In the Luján river basin, it crops out in four clearly constrained sampling sites and in the Salto-Arrecifes rivers basin, in two sites (Table 1). Depending on the hydrologic state of the rivers, they are exposed in the middle to lower portion of the cutbanks (Fig. 2).

5 Results

The depositional unit 2 is formed by facies F3 (Blasi et al. 2010) and appears in massive lens shaped layers with variable thickness, from 1 to 1.30 m (Fig. 2). It rests in erosive to paraconcordant unconformity over the underlying depositional unit DU1/DU2 (Fig. 2). Below this unit, depositional unit 3 (DU3), (facies F4–F5)

Table 1 Studied sections in the Luján river and Salto-Arrecifes rivers, with the corresponding profiles

|		Studied localities
UD2 Facies 3	Luján river	Profile Arroyo Sin Nombre (PASN) (34° 34′ 54″ S/59° 10′ 20″ W)
		Profile Benedictinos (PBN) (34° 34′ 42″ S/59° 10′ 04″ W)
		Profile Puente Oeste (PW) (34° 34′ 27.27″ S/59° 07′ 40.34″ W)
		Profile Molino Viejo (PMV) (34° 34′ 8.59″ S/59° 07′ 29.04″ W)
	Salto-Arrecifes rivers	Profile Barranca Salto (PBS) (34° 8′ 14.3″ S/60° 11′ 16.9″ W)
		Profile Arrecifes (PAR) (34° 04′ 54.4″ S/60° 05′ 29.6″ W)

Fig. 2 Outcrops of depositional unit 2 (DU2) at the cut banks. a Arroyo sin Nombre at Luján river section (Blasi et al. 2010); b Arrecifes river section

and/or lacustrine Holocene deposits occur in stratigraphic uniformity (Blasi et al. 2010). It is lithologically composed of sandy muddy gravel, gravelly muddy sand, and olive green gravelly mud (5Y 5/6) (Figs. 3, 4).

The gravel fraction is composed of fine-grained sedimentary lithic fragment (muddy intraclast), bioclasts (such as reworked bone fragments), and rounded to subrounded calcium carbonate clasts (calcretes fragments), larger than 2 mm. The sandy fraction shows muddy intraclasts, rounded calcrete fragments, as well as, siliciclastic and bioclastic grains. Among the latter, quartz is predominant over
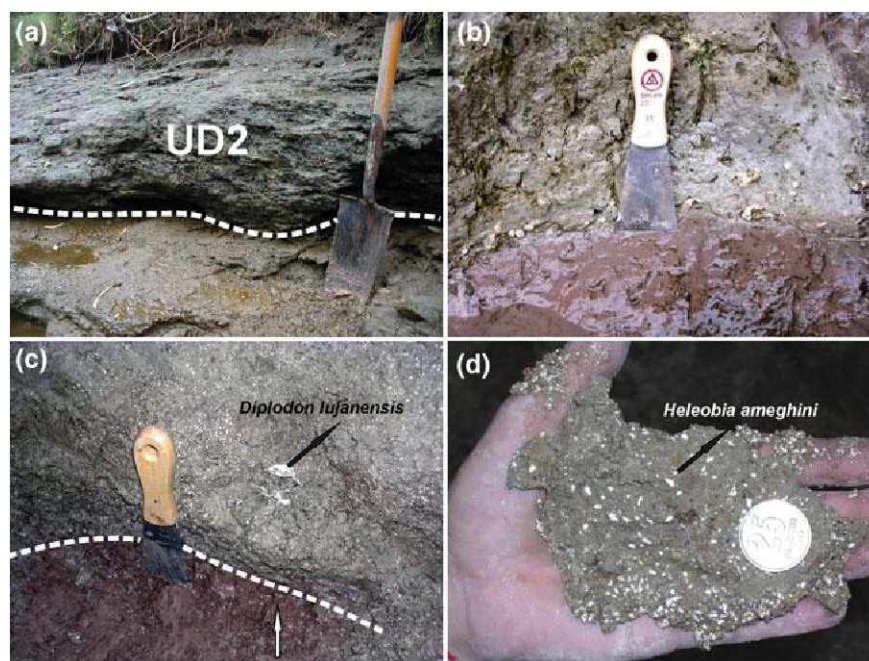
Fig. 3 Depositional unit 2 (DU2); **a** erosive contact between UD2 and UD1; **b** Net contact between *olive green* DU2 and *red* DU1, basal gravels of calcretes lithoclast; **c** UD2 *olive green*, gravelly muddy sand with *Diplodon lujanensis* shells; **d** Abundant shells of *Heleobia ameghini* in *olive green*, gravelly muddy sand
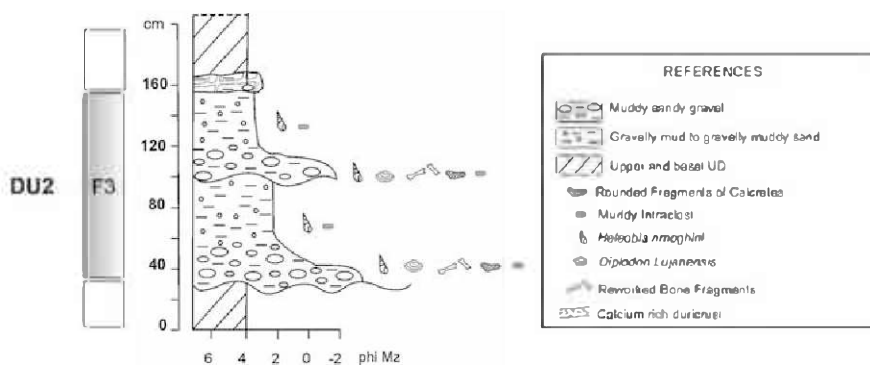
Fig. 4 Schematic model for the stratigraphic sequence of depositional unit 2—MIS 3 outcrops and lithostratigraphic column with depositional unit 2 (DU2) and Facies 3 characteristics

feldspar (mostly plagioclases) and some bioclasts such as small broken shell fragments and undetermined bone fragments. There are scarce volcanic glass shards. The clay fraction is represented by quartz, plagioclase, and clay minerals.
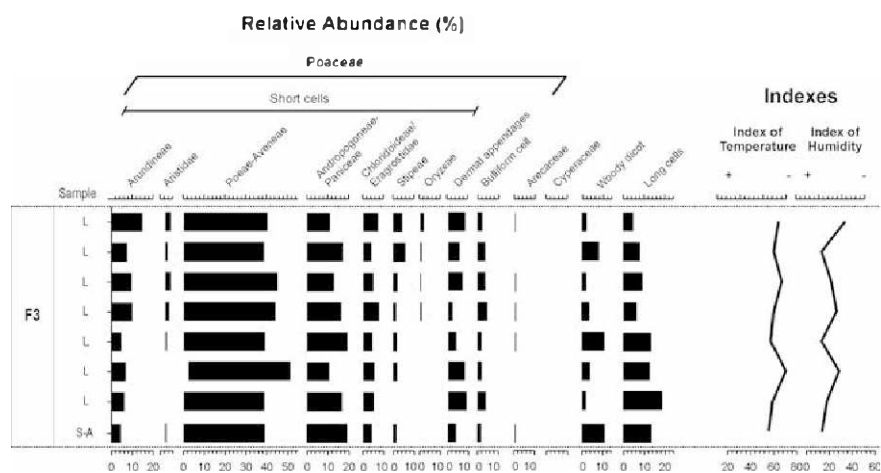
Fig. 5 Phytolytic diagram. Relative percentages of abundance of different gramineae morphotypes in samples from diverse Luján river sections and Barranca Salto section. Index of temperature and humidity, in the different samples showing fluctuating in climatic conditions (modified from Blasi et al. 2010)

The crystals which appear with a small amount are gypsum/anhydrite and calcite/dolomite. Illite is the dominant clay mineral, and kaolinite occurs in a smaller proportion.

In the biosilica content there is a broad predominance of gramineae phytoliths. According to the identified morphotypes, short winter gramineae cells, mainly Avenae and Poeae tribes prevail. They are followed by morphotypes assigned to species of the subfamily Arundinoideae, mainly from the tribe Arundinae. This family has C_4 species within the Aristidae (Aristide) tribe and C_3 in the Arundinae tribe (e.g. *Cortaderia* Stapf). Other gramineae C_3 morphotypes correspond to the Oryzeae tribe. C_4 species are mainly represented by morphotypes produced by the subfamilies Panicoideae and Chloridoideae (Fig. 5).

The diatom record shows abundance of the planktonic species *Cyclotella meneghiniana* Kützing. Other frequent oligohalobus and mesohalobous bentonic taxa are *Amphora copulate* (Kützing) Schoeman and R.E.M. Archibald, and *Navicula peregrina*, (Ehrenberg) Kützing, respectively. This association is also formed by epiphyte species such as *Cocconeis placentula* Ehrenberg with oligohalobus tychoplanktonic features, the halobius *Fragilaria capucina* Desmazières, and oligohalobus indifferent aerophiles such as *Pinnularia borealis* Ehrenberg (Table 2) (Fig. 6).

Two extinct mollusk species were identified: the gastropod *Heleobia ameghini* (Doering) and the bivalve *Diplodon lujanensis* Ihering, (Blasi et al. 2010; De Francesco and Blasi 2012). In the Luján river basin only one and abundant ostracod, *Cyprideis salebrosa hartmanni* Ramírez, was found. In the DU2 of the Salto-Arrecifes basin, *C. salebrosa hartmanni* represents the dominant fraction of

Table 2 Relative frequency and ecological characteristics of the diatom taxa

		Diatom taxa	Abundance	Habitat	Salinity
UD2	Facies 3	*Amphora copulata* (Kütz.) Schoeman & Arch	F	B	OI
		Anomoeoneis sphaerophora (Ehr.) Pfitzer	S	B	OH
		Cocconeis placentula Ehr.	F	E	OI
		Cyclotella meneghiniana Kütz	A-VA	P	OH
		Cymbella cymbiformis Ehr.	S	E	OI
		Epithemia adnata (Kütz) Breb.	A	E	OI
		Navicula peregrina (Ehr.) Kütz	F-A	B	M
		Nitzschia amphibia Grun.	A	Aer	OI
		Pinnularia borealis Ehr.	F	Aer	OI
		Surirella minuta Bréb.	R	B	Po
		Tabularia tabulata Agardh	F	B	OH
		Gomphonema lujanensis Reichardt & Maidana	R	B	OI

References F frequent, *S* scarce, *A* abundant, *VA* very abundant, *R* rare, *B* benthic, *E* epiphytic, *P* planktonic, *Aer* aerphilous, *Ol* oligohalobus indifferent, *OH* oligohalobus halophyllus, *M* mesohalobus, *Po* polyhalobus
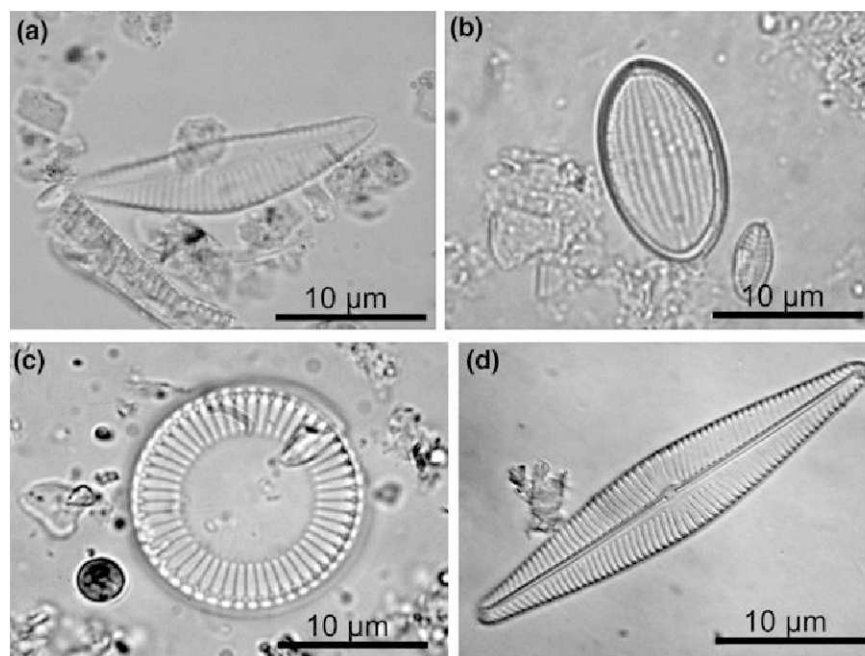
Fig. 6 The most abundant taxa of diatoms found in DU2. **a** *Amphora copulate*; **b** *Cocconeis placentula*; **c** *Cyclotella meneghiniana*; **d** *Epithemia adnata*

the ostracod association; accompanied in a lesser extent by species of *Limnocythere* Brady and *Ilyocypris* Brady and Norman. The ostracod association recovered from the DU2 is characterized by adult and juvenile specimens suggesting an autochthonous fauna (Boomer et al. 2003) (Fig. 7). Noteworthy, in the Arrecifes site (Table 1) and particularly in the DU2 deposits, bone remains that may be assigned to *Megatherium* Cuvier were found (S. Vizcaino, pers. comm.).

Radiocarbon ages were obtained from specimens of *Cyprideis salebrosa hartmanni, Heleobia ameghini*, and *Diplodon lujanensis*. In two cases, the ages were beyond the limits of the radiocarbon dating method. One age was also obtained by means of the IRSL technique (Table 3).
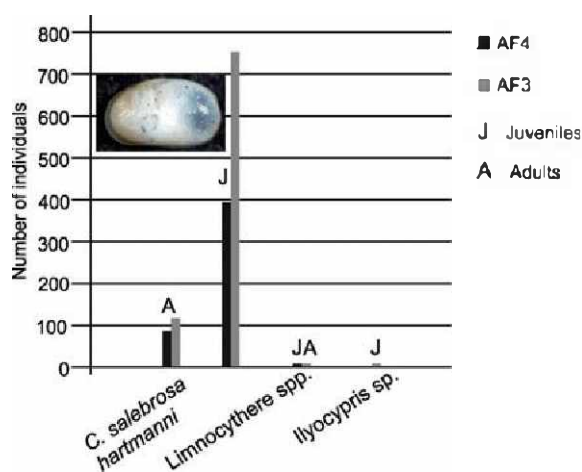

Fig. 7 Ostracod species and their abundance in DU2 for the Arrecifes river section; illustrated ostracod: *Cyprideis salebrosa hartmanni*, female left valve

Table 3 Radiocarbon and IRSL dating

Age (a:^{14}C yr BP) (b: IRSL)	Laboratory number	Sample	Geographic coordinates	Stratigraphic assignment
37.710 ± 840 a	Beta— 217826	*Cyprideis salebrosa hartmanni*	34° 34′ 08″ S 59° 07′ 29″ W	UD2 Luján river (Blasi et al. 2010)
>40.000 a	LP—1733	*Helobia ameghini*	34° 34′ 55″ S 59° 10′ 20″ W	
44.000 ± 6500 b	UNL—1928	feldespar	34° 34′ 08″ S 59° 07′ 29″ W	
>40.000 a	LP—2985	*Diplodon* sp.	34° 04′ 4.4″ S 60° 05′ 29″ W	UD2 Salto-Arrecifes rivers

Beta Beta Analytic; *LP* LATYR, La Plata; *UNL* University of Nebraska, Lincoln

It should be noted that the green color of DU2 was used to correlate outcroppings of the same color appearing in different basins of other geographic areas, independently from their stratigraphic or temporal location. It was also used as an informal stratigraphic nomenclature. Di Lello et al. (2009) determined by Mössbauer spectroscopy that the dark green color of a hermetically kept sample dried in argon atmosphere showed a couplet corresponding to about 10 % spectra of ferrous iron (Fe^{2+}). Some authors suggested that this could come from minerals of the original sediment (such as ferrous illite), neoformed minerals, and incorporation and/or adsorption of ferrous ion in crystalline structures under negative Eh conditions.

6 Paleoenvironmental Reconstruction

The DU2 facies 3 was interpreted as a mixed or hybrid deposit (Pettijohn et al. 1987) with two origins: the deposit of detritus transported by channelized floods and sheet floods of sporadic flash floods generated by strong rains under arid climatic conditions or strongly seasonal, and decantation of very fine sand and muddy sediments in lentic bodies formed afterwards.

Channelized or sheet flows could have been drained to lower areas of the land carving numerous gullies or streamlets in older deposits (the DU1/facies F2). This mechanism is considered as the greatest provider and transporter of a large amount of sediments (sediment delivery, sensu Hooke and Mant 2002) in environments characterized by water deficit. At a later stage, gullies or streamlets could have experienced damming by deposition of the bedload (tractionload), originating the development of temporary pools or small lentic bodies. With another climatic fluctuation, a new cycle with channelized flows developed and subsequent small lentic bodies may have restarted. Intraformational clast-size gravel may have formed during the first stage of intense erosion due to sheet flows and streamlets runoff. These are formed by erosion and reworked older sediments, which act as source of fine-grained sedimentary lithoclast (muddy intraclast), fragments of calcretes (locally known as "tosca") and bone fragments. This coarse bedload is transported under high hydrodynamic flow conditions. At a later stage, sandy and/or sandy/muddy sediments may have accumulated among the high energy open gravels once a reduction of energy for load transport is produced. There may have also been some input of fine eolian vitroclastic material defined as sandy loess by Zárate and Blasi (1991) that may have been masked by large amounts of local alluvium deposits.

Temporary pools were formed by damming of streamlets, no major depositional processes occurred, and the diversities of diatoms, ostracods and mollusks are low. During wetter periods, there were probably flooding events and generation of lentic bodies with larger water surface. During the most arid periods, these meso- to eutrophic water lentic bodies may have undergone environmental stress due to the sharp fluctuation of water level, salinity, and temperature. That was probably the

reason for the development of monospecific microfauna of ostracod, mollusk and diatom, such as *Cyprideis salebrosa hartmanni, Heleobia amheghini,* and *Diplodom lujanensis*, as well as frequent mesohalobuis algae (*Navicula peregrina*) which are tolerant of greater salinity. As mentioned before the ostracod association was dominated by *C. salebrosa hartmanni* together with species of *Limnocythere* and *Ilyocypris. Cyprideis* is aeuryhaline genus which lives also in fresh to brackish waters, and is very adaptable to this type of environmental conditions. Ornellas and Wurdig (1983) found this species in hyposaline environments (0–29 psu) with a temperature range from 15 to 25° C in sandy silt sediments rich in organic matter and littoral vegetation. On the other hand, Ferrero (1996, 2009) suggested that this species is typical to brackish environments, and Ramírez (1967) mentioned it in limnic environments of Buenos Aires Province. The faunal association, recovered in this study suggests similar conditions, from fresh to oligohaline environments. Also, the abundance of aerophilous diatoms suggests that the water bodies or pools may have been intermittent or temporary; whereas the strong seasonal rain under temperate to colder climatic conditions would be evidenced by the larger presence of gramineae phytoliths C3 and a high representation of chloridoid morphotypes within C4.

7 Correlation

Blasi et al. (2010) correlated DU2 with the different stratigraphic units defined by different authors in the Luján area. In this way, DU2 is related to the "Pampeano Lacustre" terrain of "Villa de Luján" (layer 3), as it has been defined by Ameghino (1880–1881: 568) and Layers 5, 6, and 7 defined in Paso de Azpeitía (Ameghino 1880–1881: 567). Furthermore, DU2 correlates with the deposits assigned to the true "Piso Pampeano Lacustre" (layers 9, 8 and 7) by Ameghino (1884: 165) and with the "Piso Lujanense" (following Ameghino 1889).

This unit is also correlated with the yellowish green, sandy and nodular, lacustrine sediment bearing mammal remains of the "Bonaerense lacustre" or "Lujanense" beds as defined by Rovereto (1914). It also correlates with the "Prebonaerense" stage of Frenguelli (1921: 66) and/or the "Lujanense" beds of Frenguelli (1928). There are also similarities with the Units1 A and B as defined by Dangavs and Blasi (1995) in the Luján river, (Blasi et al. 2010).

Recently, Toledo (2011) included an unconformity named as "Interlujanense" in the stratigraphic scheme of Ameghino (1880–1881), overlying a greenish, fining upward sequence with radiocarbon ages from 46,500 ± 4000 years [14]C B.P. to 32,000 ± 1400 years [14]C B.P., (the "Lujanense Verde Inferior" sequence). Above the unconformity is another fining upward deposit, (the "Lujanense Rojo" sequence), that starts with a basal conglomerate.

In this sense, most of the UD2 discussed in this paper may be correlated with the depositional sequence "Lujanense Verde Inferior" ("Lower Green Lujanense") or the Jáuregui Member of the Luján Formation (Toledo 2011), whereas an upper

portion of the DU2 (the upper conglomerate level shown in Fig. 3) may be correlated with the level defined by Toledo (2011) as basis for the "Lujanense Rojo" ("Red Lujanense depositional sequence") or basal section of the La Eloísa Member of the Luján Formation.

It should be noted that the Luján Formation was defined by Fidalgo et al. (1973) for the Río Salado basin (Blasi et al. 2009b) and that this lithostratigraphic unit was subdivided in two members: the Guerrero and Río Salado members.

However, Toledo (2011) created another Luján Formation, to define the Late Pleistocene interval of the previously Luján Formation as defined by Fidalgo et al. (1973). Similarly, the Luján Formation is renamed by Toledo (2011) (in its Holocene or Río Salado member portion, Fidalgo et al. 1973) as a new lithostratigraphic unit called the La Plata Formation. However, this author was not in compliance with the provisions of the Argentine Stratigraphic Nomenclature Code (Comité Argentino de Estratigrafía 1992), Sect. 31.13 (page 29) on Lithostratigraphic Units, which specifies that no identical name given to a previous lithostratigraphic unit can be used for a new one.

8 Why Is UD2 (MIS3) Present Only in Short and Middle Areas of the River Basins?

The depositional unit DU2 has only been recognized in restricted and discontinued areas of sections located in the middle portion of the fluvial basins (Fig. 1). This information is quite significant for the understanding of the evolution of the area from the Late Pleistocene to the Holocene, and contributes to the paleontological research, limiting the expectations of finding fossil remains plausible of being assigned to the interval 60,000–30,000 years B.P. The DU2 could be observed only in streches about 7 km long in the main course of the Luján river basin and up to the present, this is the same for the Salto-Arrecifes rivers basin (Fig. 1).

In order to explain the reasons for the absence of outcrops of DU2 upstream and downstream of the mentioned stretches, some hypotheses may be proposed to be tested in future works. Although they are not the object of this work, so far, it is believed that these hypotheses are relevant in the context of this chapter.

Hypothesis 1: This phenomenon could be related to the existence, within the interval of accumulation of DU2 of the "parallel ravine model" posed by Pasotti (1971, 1973).

Pasotti (1972, 1973) posed for the first time the question that the "Undulated Pampa" could show the overlapping of two hydrological models formed at two different times. During the Pleistocene, the "Collinear" paleomodel of "parallel ravine model" and/or "last paleomodel" would have been active; in turn, during the Holocene, the hydrographic network developed the present ("grilled") configuration. The collinear model is represented by a series of straight paleo-ravines parallel to each other, regularly separated, which formed no hierarchical networks, SW-NE

bound, with high gradient draining a eastern more bound, "broad and uniform" Pampa (Pasotti 1971, 1973, 1974, 2000). Pasotti (1972) stated that these models appear from the Saladillo river up to Arroyo del Medio (at the Santa Fe-Buenos Aires provincial border) and in the "Pampa Bonaerense", "farther south than the Arrecifes river". According to this author, the present networks cut the paleo-ravines at differing angles (straight and obtuse) which, in some cases, match those of the older network, but only in short stretches. In 1971–1973 Pasotti stated: "I think this network is the last of Pleistocene age and I named it as the last paleo-model" (Pasotti 2000: 4; free translation by the present authors). "The present hydrographic networks superpose the previous one, cutting the ravines or streamlets with differing angles that due to tectonics match only as an exception and in short stretches" (Pasotti 1971, 1973).

These ideas allowed the present authors to formulate the second hypothesis:

Hypothesis 2: The small area where DU2 can be found is due not only to the present network overlapping with the Pleistocene draining network (ravines) but also to a differential tectonic control that caused that this unit could only be observed at the base of cut banks in stretches coincident with raised tectonic blocks.

Neotectonic records of the Argentine Pampa plains were studied by Brunetto and Iriondo (2007). These authors developed several analyses including studies of the structural alignments, identification of geomorphological units and topographic features, from the interpretation of satellite images and field observations, thus being able to demarcate structural blocks. They also referred that the changes exerted by such structural elements on the direction of the superficial drainage allowed for the existence of some degree of deformation during the Late Pleistocene.

More recently, Racca (2010) in his regional scale studies on Arroyo del Medio fluvial basin (provincial boundary between the Provinces of Santa Fe and Buenos Aires), related the origin of greater-sized landforms (alignment) within the basin to neotectonic factors. Therefore, according to the this author, the study area would be affected by large movements due to very recent tectonic events (Holocene) that may have modified the existing of extremely flat topography (Late Pleistocene) and Pasotti's collinear model (1972). This highlights that the macromorphology of the area under study would have tectonic origin, minimizing the possible influence of paleoclimatic variability.

For the area of the Río de La Plata, Cavallotto (2002) concluded that through the pre-Holocene general topographic characteristics, the existence of a tectonic control shown by transversally oriented river alignments had been identified. On the other hand, the differences in radiometric values of the elevation of the Holocene maximum sea transgression registered along the Argentine coast would also reflect perhaps a neotectonic influence (Codignotto et al. 1992).

9 Conclusions

The depositional unit 2 (DU2) overlies an erosive unconformity on eolian sediment with IRSL ages of ~56,400 ± 6500 and 50,400 ± 10,200 years. These sediments are also overlain by sandy loess deposits of the same eolian genesis (UD3, in Blasi et al. 2010) dated ca. 32,500 ± 4100 years (IRSL) (Blasi et al. 2010).

Ages obtained for the lower and the upper DU2 deposits suggest an association with the Marine Isotopic Stage 3.

For this unit (DU2) a fluvial-lacustrine facies (F3) has been identified, representing ephemeral fluvial streams with gullies or streamlets formed during instantaneous rainstorm episodes and development of temporary pools of eutotrophic to distrophic characteristics formed by subsequent damming of the channels. The dominant lithology is sandy gravelly mud. These sediments are hybrid or mixed deposit according to Pettijohn et al. (1987), with predominance in the gravel size fraction of muddy intraclast, rounded fragments of calcretes ("tosca") and pebbled of bones. The sandy fraction is mainly quartz in composition. The scarce presence of volcanic glass in its petrographic characteristics should also be noted, whereas clay minerals are mainly illite.

Olive green coloring is highlighted by the presence of reduced iron ions in the illitic clay matrix (Di Lello et al. 2009). Some authors suggested that it could have originated in the alteration of detrital illite clay and/or adsorption of ferrous ion in crystalline structures under Eh negative conditions. Therefore, this attribute could repeat itself in any sector of the stratigraphic columns that may have been modified by the same processes.

Another relevant feature is the presence of mollusk species such as *Diplodon lujanensis* and *Heleobia ameghini*, that lack representation in modern fauna and which constitute an exceptional case for the Late Quaternary of Argentina (De Francesco and Blasi 2012).

Ages ascribed to the MIS3 were obtained from specimens of *Cyprideis salebrosa hartmanni*, *Heleobia ameghini*, and *Diplodon lujanensis*. In two cases, the obtained ages were beyond the accepted, reliable limits of the radiocarbon dating method. Age was also obtained through the IRSL technique. Climatic conditions inferred for the DU2 deposits were from rather temperate to colder, with subhumid–humid and subhumid—drier phases or strongly seasonal.

Likewise, the following questions were raised: Did the Luján and the Salto-Arrecifes rivers basins flow in the Late Pleistocene (during MIS3) as gullies or ephemeral stream lets subparallel to each other with high gradient and drainage courses with SW-NE direction? Have the geofractures associated with the crystalline basement and minor fractures in the sedimentary filling been active during the Holocene? And therefore, is there tectonic control over the present configuration of drainage networks and exposition of sequences associated with the MIS3? Can the superposition of both models be located in some uplifted blocks, and thus explain that they only appear in the referred stretches?

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