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Insights into Pleistocene palaeoenvironments and biostratigraphy in southern Buenos Aires province (Argentina) from continental deposits

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ABSTRACT

The coastal cliffs of the Buenos Aires province (Argentina) have been the subject of intense paleontological studies since the XIX century. Therefore, many of the type localities in which is based the late Cenozoic Pampean biostratigraphic/chronostratigraphic scheme are located in this area. In this context, the sedimentites that crop out near the mouth of the Chocorí Creek contain a set of palaeontological sites that, because of their richness and well-preserved fossil content, hold high national and international importance. The aims of the present contribution are: 1) to make a stratigraphic and sedimentological characterization of the study area; 2) to list the fauna outcropped at these palaeontological sites and establish a biostratigraphic framework; 3) to elaborate a palaeoenvironmental model for the area.

The study interval was informally subdivided into a lower, middle and upper interval. Interpretation was based on the presence of a number of key features such as architectural elements; channel:overbank ratio and palaeosol occurrence. The first two intervals were interpreted as continental deposits of a fluvio-alluvial nature and are the focus of this paper. The upper interval was related to foreshore marine deposits and will be studied in a future contribution. The lower interval is characterized mainly by overbank architectural elements in which calcisols and argillic protosols were identified. Channel-fill deposits are isolated and surrounded by fine-grained overbank successions and sedimentary structures are suggestive of mixed-load transport. The contact between the lower and middle intervals is an irregular, highly erosive surface characterized by a significant vertical change in the facies. This surface defines the base of multistorey sandbodies which's internal arrangement alongside with the low participation of overbank deposits suggests deposition by a braided fluvial system.

Palaeosols and vertebrate fossils were used as palaeoclimatic, palaeoenvironmental and biostratigraphical proxies. Calcisol profiles, displaying Stages II to V morphologies (Machette, 1985), can be interpreted as evidence of periods of geomorphological stability that occurred under semi-arid to subhumid climatic conditions. The occurrence of argillic Protosols stacked amongst the Calcisols evidence periods of relatively less stability, higher sediment supply and aggradation rates in the system. The vertebrate fossil assemblage and the invertebrate trace fossils also indicate semi-open landscapes under a seasonal, semi-arid climate. The presence of *Platygonus*, *Glyptodon* and *Tolypeutes* fossil remains in the lower interval suggest an Ensenadan age (middle Pleistocene) while the presence of *Arctotherium bonariense* in the V1 layer indicates post-Ensenadan (late Pleistocene) times for the middle interval.

It is concluded that during accumulation of the Chocorí succession, glacio-eustasy and/or climate controlled the balance between generation of accommodation space and sediment supply. Analysis of the architectural elements indicates a general reduction in accommodation space. The lower interval represents the unconfined reaches of a large distributive system, more specifically, a low hierarchy, secondary drainage system inset in a high accommodation alluvial environment. The erosive surface identified at the base of the middle interval can be interpreted as representative of a period of negative accommodation in the system, when general erosion took place. The gradual restoration of accommodation in the fluvial system was accompanied by a low sediment accumulation rate and the development of a braided fluvial system in the middle interval.

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1. Introduction

The late Cenozoic deposits of the Bonaerian Pampa are part of the Argentinean Pampean Plain, one of the largest loess and loessoid sequence in the Southern Hemisphere (Fig. 1a). These Plio-Pleistocene deposits are the product of the reworking and resedimentation of primary tephra and other volcaniclastic levels that were originally deposited in the Andes piedmont (Teruggi, 1957), more than 900 km southwest from the Pampean Region. Reworking began by the activity of the main rivers in the piedmont region and it was followed by aeolian erosion and resedimentation in the southern Buenos Aires province basins (Fig. 1a) (Zárate and Blasi, 1991, 1993).

The coastal cliffs of the Buenos Aires province have been the subject of intense paleontological studies since the XIX century. Therefore, many of the type localities in which is based the late Cenozoic Pampean biostratigraphic/chronostratigraphic scheme are located in this area (Kraglievich, 1952; Marshall, 1985; Cione and Tonni, 2005; Soibelzon et al., 2009). In this context, the sedimentites that crop out west of Mar del Sur locality (Fig. 1b), near the mouth of the Chocorí Creek, contain a set of palaeontological sites that, because of their richness and well-preserved fossil content, hold high importance.

The present work arose from the relevance that the analysed palaeontological data have for understanding the palaeobiodiversity of the Pleistocene and Holocene in the south-eastern Buenos Aires province. It also responded to the pressing need for organizing the cloud of paleontological sites into a chronological and stratigraphic scheme. Work focused on the stratigraphic, sedimentological and palaeoenvironmental characterization of more than 10 km of sea cliffs where the main macromammals sites are found (Fig. 1b). This exceptional conditions provided for the reconstruction of the palaeoenvironment where these organisms lived led to different lines of research in order to cover all the aspects related to the palaeontological sites. In this context, the aims of the present contribution are: 1) to make a stratigraphic and sedimentological characterization of the study area; 2) to list the fauna outcropped at these palaeontological sites and establish a biostratigraphic framework; 3) to elaborate a palaeoenvironmental model for the study area.

2. Geological setting

The evolution and areal distribution of the Neogene and Quaternary Pampean basins (Fig. 1a) have been related to the Andean dynamics (Ramos and Folguera, 2005; Folguera and Zárate, 2011). These basins are part of the foreland region of central Argentina and are bounded to the east by the Atlantic passive margin and to the west by the Andean deformational front. The structuring of the Andean Cordillera between 35° and 38° S started around 15 Ma (Ramos and Folguera, 2005). The eastward migration of the arc and of the deformational front (*ca.*6–5 Ma) might have originated the uplift and tilting of tectonic blocks in central Argentina (Folguera and Zárate, 2009, 2011). This, in turn, led to the migration during the Pliocene of the depocenters to the eastern part of Buenos Aires province (Folguera and Zárate, 2011). Accumulation of post-Miocene deposits in the Pampean Region (Fig. 1a), near the passive margin, was favoured by high sediment availability, associated to the rise of the Andean Cordillera (Turic et al., 1996). In the southeastern Pampean Region, the late Cenozoic succession comprises a series of dispersed outcrops of Plio-Pleistocene continental deposits capped by an extensive plateau of loess and loess-like deposits of the late Pleistocene and Holocene.

The Chocorí succession broadly spans the Pleistocene (Heil et al., 2002; Soibelzon et al., 2009; Isla and Espinosa, 2009; Cenizo, 2011) and comprises continental deposits of fluvial and aeolian origin of the Punta San Andrés Alloformation as well as some foreshore marine deposits of the Centinela del Mar Alloformation. The thickness of the succession studied ranges between 6 and 8 m and comprises sandstones, silty sandstones and mudstones, with variable development of palaeosols.

3. Methods

The Pleistocene deposits that crop-out in Centinela del Mar and in the Chocorí Creek have been assigned to the Vorohué and Santa Isabel Formations (Kraglievich, 1952, 1959). Because of the nature of the present contribution (i.e. architectural analysis of the sedimentary bodies, interpretation of erosional surfaces and discontinuities), this lithostratigraphical approach will not be considered and an allostratigraphical scheme (Cenizo, 2011) will be used instead.

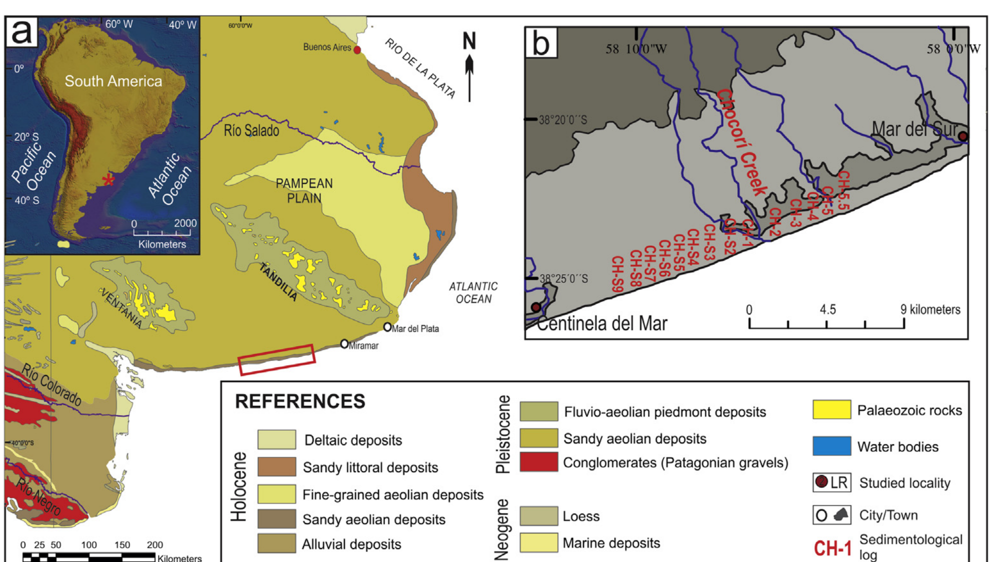

Fig. 1. Location maps. a) Geological units in the regional setting of the study area; b) detailed location of the analysed sedimentological logs.

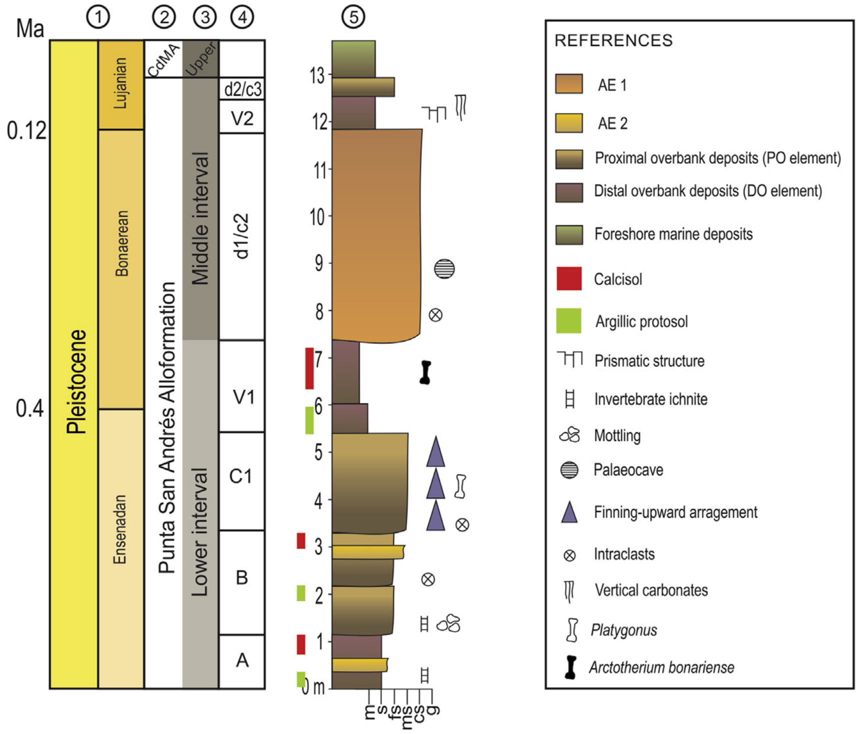

Fig. 2. Stratigraphic chart. 1) Geochronology and local ages (Gradstein et al., 2012; Cione and Tonni, 2005); 2) allostratigraphic units (Cenizo, 2011): Punta San Andrés and Centinela del Mar (CdMA) alloformations; 3 and 4) informal intervals and layers proposed in this work; 5) integrated sedimentological log of the Chocorí succession.

The study section was informally subdivided into the lower, middle and upper intervals (Fig. 2). The first two are interpreted as the continental deposits of the Punta San Andrés Alloformation and are the focus of this paper. The upper interval was related to the foreshore marine deposits of the Centinela del Mar Alloformation (Cenizo, 2011) and will be studied in a future contribution. Fourteen stratigraphic sections were measured in the Chocorí area (Fig. 1b); the more complete and representative of these (seven in total) were logged and sampled for facies and architectural analysis. Micromorphological studies were done in the palaeosols identified. Sedimentary facies (Table 1) were proposed following Miall's guidelines (Miall, 1978, 2006). Architectural elements were identified (Table 2) with the aid of facies associations, geometry, paleocurrents (from through cross-stratiphication), unit dimensions and determination of the hierarchy of the bounding surfaces (Miall, 1985, 2006). Palaeosols field observations included thickness, structure, texture, colour, root- and invertebrate-trace abundance and size, and carbonate abundance and types. Micromorphological analysis was carried out following the guidelines of Bullock et al. (1985) and Stoops (2003) and palaeosol classification followed the scheme of Mack et al. (1993).

The age model for the studied succession is based on stratigraphic correlation with previously dated units and on relative chronologies such as biostratigraphy (Fig. 2) (Cione and Tonni, 1999, 2005) and magnetostratigraphy. Palaeomagnetic polarity data constrain the studied succession to the Brunhes epoch (Heil et al., 2002; Soibelzon et al., 2009). This observation is confirmed with $^{40}Ar/^{39}Ar$ ages of 445 ± 21 ka and 230 ± 40 ka in the Punta San

Table 1
Sedimentary facies of the Chocorí succession following Miall's guidelines (1978; 2006).

Facies	Features	Interpretation	Architectural elements
Ss	Coarse to very coarse-grained, poorly-sorted sand. Seldom normal grading. Abundant intraclasts.	Scour-fill sand. Rapid deposition of bed load; lag deposits	AE 1
St	Fine to medium sandstone, sometimes pebbly. Trough cross-bedding.	Sinuous-crested and linguoids (3D) dunes	AE 1, AE 2
Sp	Fine to medium sandstone; silty sandstone. Planar cross-bedding. Tabular to concave-up based bodies with flat tops.	Transverse (2D) dunes	AE 1, AE 2
Sh	Fine to medium sandstone; silty sandstone. Horizontal bedding. Tabular bodies with erosive base.	Plane-bed flow (critical flow)	PO
Sl	Fine to medium sandstone; silty sandstone. Low-angle cross-bedding.	Humpback dunes; transition between subcritical and supercritical flow.	AE 2
Sm	Fine sitly to medium sandstone. Massive or with faint lamination. Tabular bodies.	Plane-bed flow (lower flow regime)	AE 1, AE 2, PO, DO
Fl	Interlamination of siltstone and very fine sandstone.	Deposition from suspension and from weak traction currents.	PO, DO
Fm	Mudstone and siltstone. Massive or with faint lamination. Sometimes with desiccation cracks. Tabular bodies.	Suspension fallout in still-stand water	DO

Table 2
Architectural elements of the Chocorí succession. They were identified with the aid of facies associations, geometry, paleocurrents, unit dimensions and determination of the hierarchy of the bounding surfaces (Miall, 1985, 2006).

Architectural element	Principal facies assamblage	Geometry and relationships	Interpretation
AE 1 (Multistorey fluvial channels)	St, Sp, Sm ± Ss, Sl	Sandbodies with concave-up to irregular erosional base (5th order surface) and sheet geometry (W/T: 15–35); internally 3 to 4 laterally shifted stories. Paleocurrents: S-SE with low dispersion. Internal concave-up and lateral-accretion 3rd order surfaces.	Low-sinuosity, fixed channel deposits
AE 2 (Single fluvial channels)	St, Sp, Sl, Sm or Sh, Sm	Single symmetric ribbon sandbodies (W/T < 3.5) with low relief basal erosion surface (4th order surface). Encased in fine-grained deposits. Characteristic absence of lateral accretion surfaces. Paleocurrents: N-NW with low dispersion	Minor floodplain channels; crevasse-channel deposits
Proximal overbank (PO)	Gmg, Sh, Sm or Sh, Fl, Sm	Erosionally based tabular bodies (0.1–0.2 m thick, 10's mts wide) stacked in 0.8–1.2 m successions. General arrangement of the beds is finning-upward. Internal arrangement is chaotic to narmaly graded. No bioturbation observed.	Mantiform flash flood events realted to episodical overbank flows and flooding of the proximal floodplain or deposits related to avulsion processes; immature paleosols
Distal overbank (DO)	Fl, Sm, Fm	Tabular beds (0.8–2 m thick, hundreds mts wide) with a 4th order basal surface. Abundant pedogenic features such as vertical root traces, mottling, slickensides and abundant calcium carbonate deposits. Trace fossils are common within beds in the form of vertical, cylindrical, unlined and lined, passively filled tubes. Pervasive bioturbation is common in some beds.	Deposition is related to suspension fallout in very shallow-water or isolated ephemeral ponds associated with flooding events in the distal floodplain. Abundance of pedogenic and biogenic processes.

Andrés Alloformation outcrops of Centinela del Mar (Schultz et al., 2004) and with an U/Th age of 93.5 ± 3.5 ka in equivalent levels in Claromecó (Isla et al., 2000). Biostratigraphic analysis followed the scheme proposed by Cione and Tonni (1999, 2005).

4. Results

4.1. Sedimentological analysis

4.1.1. Lower informal interval

All the measured sections documented this interval, although the more complete ones are CH-1 and CH-S6 (Fig. 3). Total thickness of the lower interval ranges approximately between 3 and 7 m and consists predominantly of fine silty sandstones, siltstones and mudstones. Sandstones occur as lenticular bodies with trough cross-bedding (St), planar cross-bedding (Sp), low-angle cross-bedding (Sl), faint lamination or massive (Sm). Sandstones also occur as tabular bodies with horizontal bedding (Sh), faint lamination (Sm) or massive (Sm) (Table 1). The finer sediments are represented by interlaminated siltstones and very fine sandstones (Fl) or by mudstones and siltstones with faint lamination or massive that can present desiccation cracks (Fm) and often display pedogenic features (see section 4.2). In some occasions, these tabular bodies present an erosive base and consist of matrix-supported gravel, crudely bedded with normal grading and medium to fine sandstone matrix (Gmg).

Sandstone facies were interpreted as single fluvial channel-fill deposits (AE 2 architectural element) (Table 2). These symmetric ribbons have a width-to-thickness ratio (W/T) < 3.5, as well as a low relief basal erosion surface (over floodplain deposits of the lower Punta San Andrés Alloformation) and are encased in fine-grained deposits (Fl and Fm facies). The absence of lateral accretion surfaces is characteristic and paleocurrents show low dispersion (N-NW). Sheet-like, erosionally based bodies of matrix-supported gravel also occur in the lower interval and were interpreted as flash-flood deposits in the proximal overbank area (PO element). They are 0.1–0.2 m in thickness and tens of metres wide and they are stacked in 0.8–1.2 m successions. General arrangement of the beds is finning-upwards. Mudstones and siltstones are interpreted as proximal and distal overbank deposits (PO and DO elements, Table 2) which were weathered by palaeosols.

4.1.2. Middle informal interval

This interval is also present in all sections, although the more complete ones are CH–S3 and CH–S4 (Fig. 3). The sediment bodies are mainly ribbon-shaped in geometry and the dominant lithologies are pebbly medium sandstone and fine conglomerate with sandy matrix and trough cross-bedding (St), planar cross-bedding (Sp) or horizontal bedding (Sh). In order of decreasing abundance, other lithologies are coarse to very coarse-grained, poorly-sorted sand with intraclasts (Ss) and fine to medium sandstones with low-angle cross-bedding (Sl).

The sandbodies (AE 1 element) have a sheet geometry (W/T: 15–35) and present a concave-up to irregular erosional base. This fifth-order surface (*sensu* Miall, 2006) can be followed uninterruptedly along the marine cliffs. Internally they show 3 to 4 laterally shifted stories and concave-up and lateral-accretion surfaces. Paleocurrents present low dispersion (S–SE). They were interpreted as low-sinuosity, fixed channel deposits.

4.2. Palaeosols

Pedofeatures present in the studied intervals allowed identification of two pedotypes (representative palaeosols).

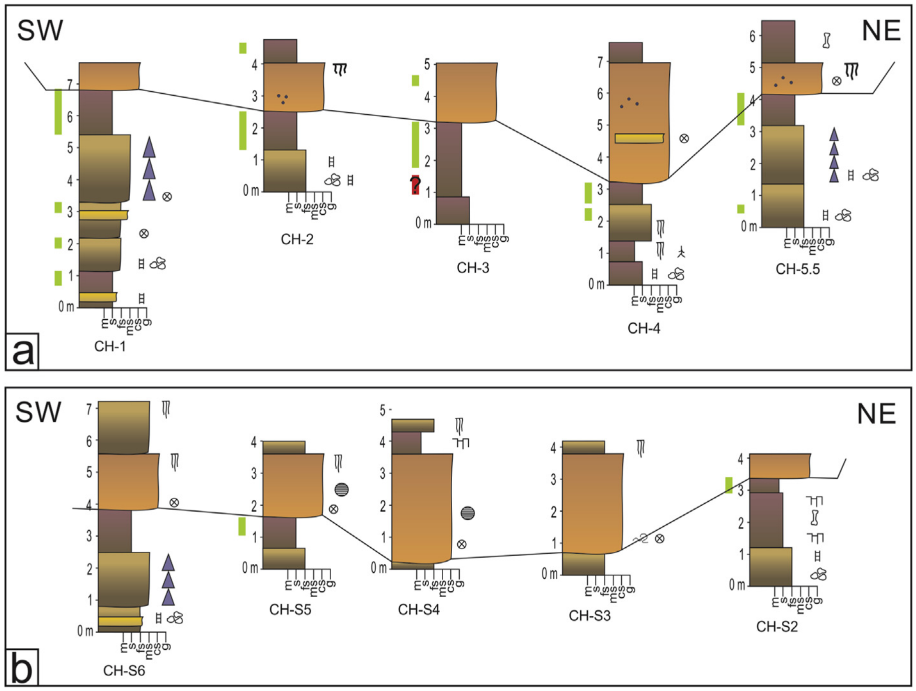

Fig. 3. Spatial distribution of the architectural elements in the Chocorí succession. Panel a is north of the Chocorí Creek and Panel b is south of the Creek. Correlation between the different sedimentological logs was made at the base of the middle interval. For references see Fig. 2.

4.2.1. *Calcisols*

This pedotype is weathered into the distal overbank deposits (DO element) and could be identified in three different strata of the lower interval (Fig. 2). Truncated at the top, these palaeosols constitute tabular bodies with a high $CaCO_3$ content and a lateral extent of hundreds of metres. The studied carbonates are pedogenic in nature and they could be classified, according to their macromorphology, as Stage II to V (Machette, 1985). The micromorphological study allowed the identification of alpha and beta microstructures (Wright, 1990) as well as crystalline pedofeatures. Alpha microstructure consists of a homogeneous calcite-rich groundmass with calcitic crystallitic b-fabric (Fig. 4a). Void and detrital grains with calcitic coatings and sparitic blocky patches were also identified (Fig. 4a,b). Laminar crusts are macromorphological feautres of the beta microstructure. Micromorphological analysis of these features show pisoids, coated grains, scattered organic matter in the groundmass and some structures indicative of microbial influence on calcite precipitation such as needle-fibre calcite (Fig. 4c).The pedological process that originated the previously described features is calcification (Schaetzl and Anderson, 2005). Even though is the main process acting in Calcisols, some other processes were identified. For instance, several voids displaying argillic coatings (Fig. 4d,e) were interpreted as the result of illuviation and the presence of ferric nodules and impregnations (Fig. 4f) were linked to redoximorphic events.

4.2.2. *Argillic protosols*

This pedotype is a non-calcareous sequence weathered into the top of proximal overbank deposits (PO element) (Fig. 2). Truncated at the top, these palaeosols are massive or present angular blocky ped structure and have a lateral extent of hundreds of metres. Bioturbation is moderate to intense, and related to invertebrate and root activity (Fig. 5a). These argillic protosols are vertically stacked amongst the calcisols, and no lateral relationship has been identified between the two pedotypes.

Micromorphological analysis determined a chitonic to porphyric coarse-to-fine (c/f) related distribution (Fig. 5a, b). The most common pedofeatures are voids and grains with argillic coating (Fig. 5a–d) that tend to be laminated and asymmetrical. Fabric pedofeatures, such as a reticulated striated b-fabric, were recognized as well as redoximorphic features (i.e. ferric impregnations) (Fig. 5e–h).

Protosols are paleosols that show weak development of horizons and little homogenization by pedoturbation (Mack et al., 1993). They display features characteristic of other palaeosols orders (i.e. argillic coatings), but this features are considered too poorly developed to be the most prominent pedofeature.

4.3. *Palaeontological record and biostratigraphy*

During fieldwork, collection of fossil vertebrates was made. A minimum of 100 specimens, all mammals, were collected. Most of the specimens (~40%) were recovered from the lower interval (C1 layer, Fig. 2); the rest were mainly recovered from facies Fl/Fm of the V1 layer (lower interval) and from the channel lag deposits of the middle interval (D1 layers, Fig. 2).The specimens collected are represented by isolated teeth and fragmentary cranial and postcranial remains.

A preliminary faunal list based on the collected specimens is summarized in Table 3. The assemblage is typical of the Pleistocene *s.l.* The highest palaeodiversity was found in the lower interval (C1 layer: *Neosclerocalyptus* sp., *Glyptodon* sp., *Eutatus* sp., *Propraopus* sp., *Tolypeutes* sp., *Platygonus* sp., Lamini indet., *Ctenomys* sp., *Lagostomus* sp.) (Table 3). *Platygonus* has a Chapadmalalan/Ensenadan age (middle Pliocene-middle Pleistocene) (Gasparini, 2013). The presence of *Glyptodon* and *Tolypeutes* (first record in the early Pleistocene for both) in the same layer as *Platygonus* allows to restrict the time interval to the Ensenadan (Soibelzon et al., 2010). The presence of *Arctotherium bonariense* (Bonaerian/Lujanian, i.e. middle – late Pleistocene) in the V1 layer indicates post-Ensenadan times (Soibelzon, 2004; Soibelzon et al., 2005).

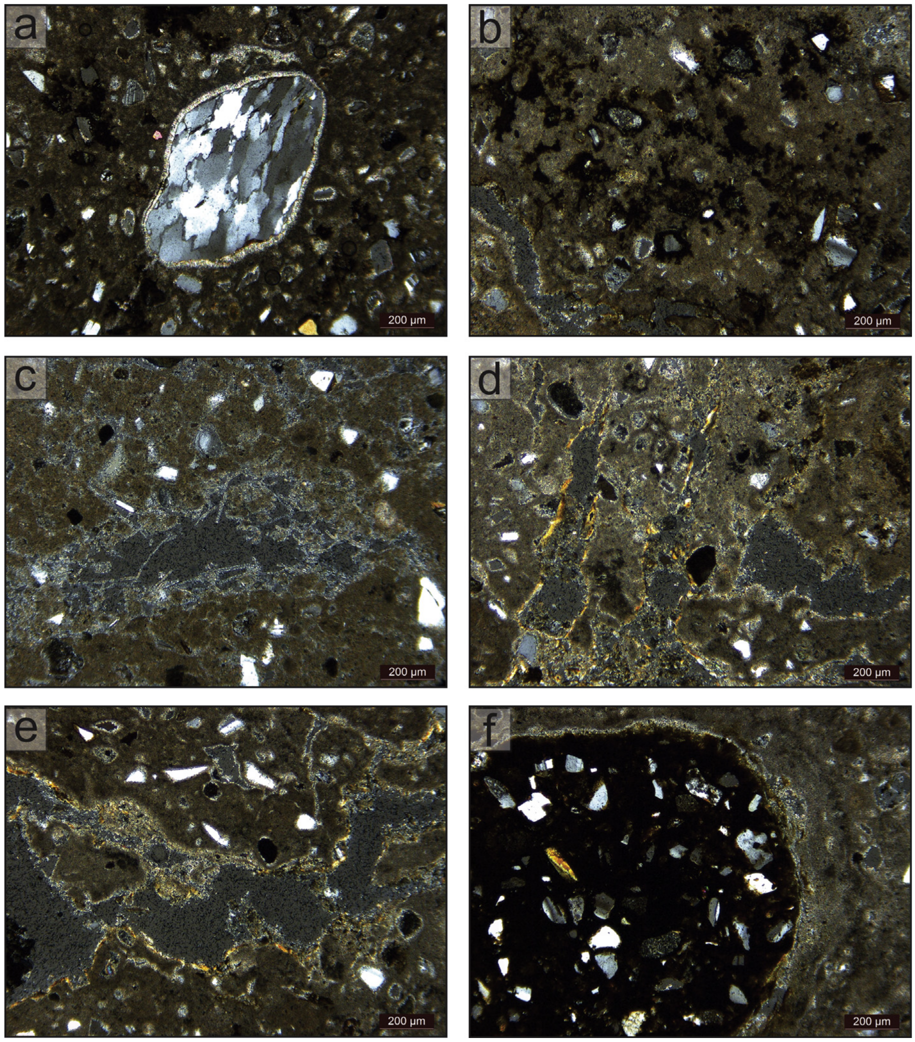

Fig. 4. Micromorphological features of the Chocorí calcisols. Most of the pedofeatures are related to calcification processes, i.e.: a and b) Alpha microstructure: homogeneous calcite-rich groundmass with calcitic crystallitic b-fabric. Void and detrital grains with calcitic coatings and sparitic blocky patches were also identified; c) Beta microstructure: structures indicative of microbial influence on calcite precipitation such as needle-fibre calcite. Other pedological processes were also identified: d and e) voids displaying argillic coatings interpreted as the result of illuviation; f) ferric nodules and impregnations were linked to redoximorphic events.

5. Depositional styles

The Chocorí deposits were previously interpreted as a continental succession (Heil et al., 2002; Cenizo, 2011). The new observations presented here show the detailed nature and evolution of fluvial/alluvial styles within this succession. Interpretation is based on the presence of a number of key features such as architectural elements; channel:overbank ratio and palaeosol occurrence (Miall, 2006; Trendell et al., 2013).

5.1. Lower informal interval

This interval is characterized mainly by overbank architectural elements (PO and DO) in which calcisols and argillic protosols were identified (Figs. 2 and 6) and a lesser participation of channel-fill deposits −mainly from the AE 2 architectural element. Channel-fill deposits are isolated and surrounded by fine-grained overbank successions. Depositional features are suggestive of mixed-load transport. A high overbank:channel deposition ratio can be related to high accommodation and sediment supply (Aslan and Blum, 1999) as well as to a poorly confined, low-sinuosity fluvial system (Fisher et al., 2007; Trendell et al., 2013).

The presence of calcisols in the Chocorí lower interval can be related to periods of relatively low sedimentation rates and good drainage conditions, as there is no evidence of ponding or soil saturation. Also, the presence of pedogenic carbonates points to a non-humid climate (Retallack and Alonso-Zarza, 1998).Vertically stacked with the calcisols, the argillic protosols point to periods of higher sedimentation rate. The argillic coatings can be related to clay eluviation/illuviation processes. Their dusty appearance and moderated to good sorting represent the youngest phase in clay illuviation in upper Bt-horizons (Stoops et al., 2010). The presence of earthworm trace fossils suggests seasonal precipitation (Verde et al., 2007).

5.2. Middle informal interval

The contact between the lower and middle intervals is an irregular, highly erosive surface characterized by a significant vertical change in the facies as it is underlain by floodplain sandy siltstones with palaeosol development and overlain by fine-to medium-grained channel-fill sandstones (Figs. 6 and 7). This erosive surface can be traced along the marine cliffs throughout nearly 15 km and characteristically defines the base of multistorey

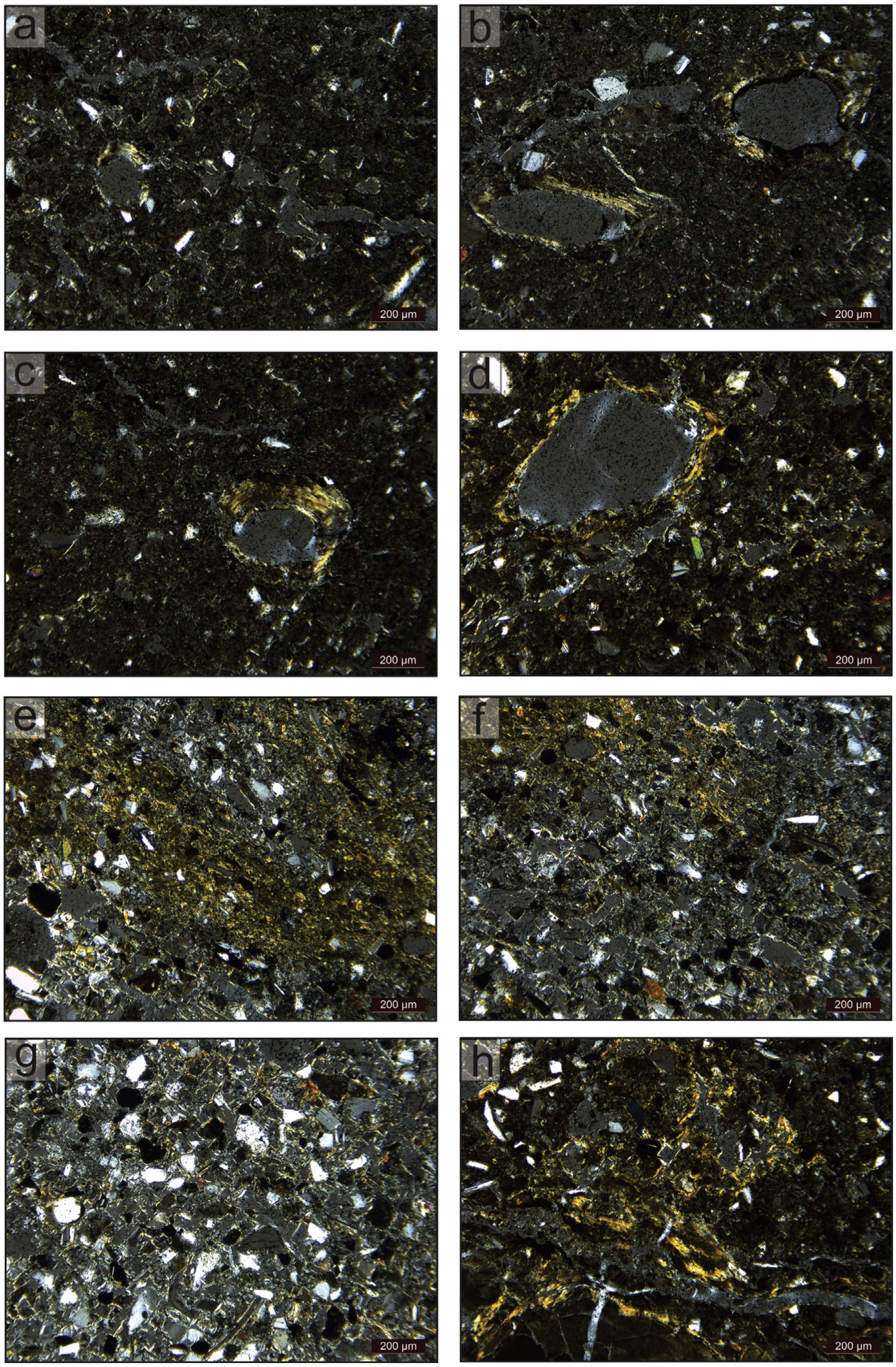

Fig. 5. Micromorphological features of the Chocorí argillic protosols. a) Channels related to bioturbation by invertebrates (earthworms) and root activity; b) chitonic to porphyric c/f-related distribution; a – d) voids and grains with laminated and asymmetrical argillic coatings; e – g) fabric pedofeatures: reticulated striated b-fabric; e and h) redoximorphic features (i.e. ferric impregnations).

sandbodies of the AE 1 architectural element. These tabular bodies (W/D: 15–35) are characterized by planar and trough cross-stratified sandstones within basal scours and reflect the infilling of channels by migration of dune forms. The upward termination of the channel-fill shows low-stage reworking of larger bedforms. Sandstones of the middle interval are thicker and coarser-grained than sandstones of the lower interval. The complex internal arrangement of these sandstones and pebbly sandstones resulted from avulsion of smaller channels within the major trunk channel belt and by lateral or downstream migration of bars (Bentham et al., 1993). The lower part of the middle interval lacks of overbank deposits (Fig. 7a–b), which suggests reworking as the channels drifted across the alluvial plain (Trendell et al., 2013). The upper portion of the middle interval (Fig. 7c) is also dominated by AE 1 deposits, but with a higher degree of overbank (PO) deposits preservation. The internal arrangement of the AE 1 deposits alongside with the low participation of overbank deposits (either proximal or distal) suggest a braided fluvial system.

Paleocurrents of this interval (S–SE) are opposed to the ones in the lower interval (N-NW). This phenomena is interpreted to reflect the angular relationship that exists between the crevasse- and minor channels that drained the floodplain during the lower

Table 3
Faunal list of the Chocorí palaeontological sites including systematics and informal stratigraphic layers in which each taxa was found. The assemblage is typical of the Pleistocene s.l.

Order	Family	Taxa	Ensenadan			Bonaerean			Lujanian	
			A	B	C1	V1	D1	C2	V2	D2
Rodentia	Ctenomyidae	*Ctenomys*	X		X	X		X		
	Caviidae	*Cavia*			X		X			
	Cricetidae	Cricetidae indet.	X	X			X			
	Chinchillidae	*Lagostomus*			X	X	X			
Cingulata	Glyptodontidae	*Glyptodon*		X	X					
		Neosclerocalyptus		X	X		X		X	X
		Hoplophorinae indet.					X			
	Dasypodidae	*Propraopus*			X					
		Eutatus			X			X		
		Tolypeutes		X	X					
Tardigrada	Megatheriidae	*Megatherium*							X	
	Mylodontidae	*Glossotherium*				X				
Artiodactyla	Tayassuidae	*Platygonus*			X					
	Camelidae	Lamini indet.			X					
Notoungulata	Toxodontidae	*Toxodon*				X			X	
Carnivora	Ursidae	*Arctotherium bonariense*				X				

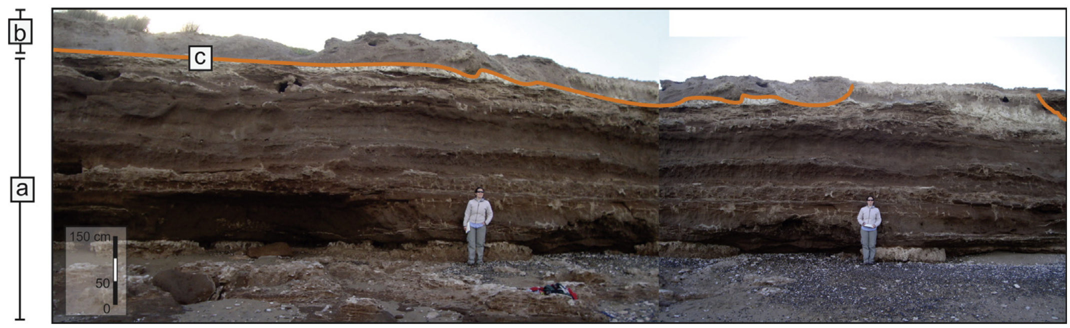

Fig. 6. Lower informal interval. This interval is characterized mainly by overbank architectural elements in which calcisols and argillic protosols were identified. The contact between the lower (a) and middle (b) intervals is an irregular, highly erosive surface (c).

interval and the larger, braided channels that constituted the main drainage during the middle interval.

6. Discussion – depositional and palaeoenvironmental model

The architectural and facial characteristics of the lower interval allowed to interpret this succession as an unconfined, low-sinuosity fluvial system with no or small and discontinuous levees. This kind of facies distribution can be related to the unconfined reaches of large distributive systems (*sensu* Tooth, 1999). If that is the case, PO and DO elements can be interpreted as intermediate floodouts, originated by floodings that expanded through the floodplain in a non-channelized way first, and in a channelized manner later to constitute a low hierarchy, secondary drainage system (AE 2 element). Weathering of palaeosols on top of each flood strata indicates that geomorphologic pauses occurred between successive flooding events. These periods of stability took place in semi-open environments (i.e. grasslands; intermediate vegetated areas *sensu* Cione et al., 2003) under a seasonal, semi-arid climate as indicated by the presence of *Arctotherium, Glyptodon, Eutatus, Megatherium, Platygonus, Toxodon*, *Ctenomys*, and *Lagostomus* and the invertebrate traces fossils (Cione and Tonni, 2005; Soibelzon et al., 2009). The presence of mature calcisol profiles, displaying Stages IV and V morphologies (Machette, 1985), can be interpreted as another evidence of semi-arid to sub-humid climatic conditions. The occurrence of argillic protosols stacked amongst the calcisols evidence periods of relatively less stability, higher sediment supply and aggradation rates in the system.

The erosive surface identified at the base of the middle interval can be interpreted as representative of a period of negative accommodation in the system, when general erosion took place. The event that triggered erosion was probably a decrease in local base level, with consequent rejuvenation of the fluvial system and incision of floodplain deposits. Causes of this lowering might have been climatic and/or glaci-eustatic (Rabassa et al., 2005; Beilinson et al., 2013). The architectural elements preserved in the middle interval represent the gradual restoration of accommodation in the fluvial system after the development of a subaerial unconformity (Posamentier and Allen, 1999). The lower portion of the interval can be characterized as a period in which the ratio between the limited newly-generated accommodation and the sediment supply determines a low accumulation rate (Posamentier and Allen, 1999) while the shift to the upper portion of the interval indicates an increase in accommodation in the fluvio-alluvial system.

7. Conclusions

1. The study interval was informally subdivided into a lower, middle and upper interval. The first two are interpreted as continental deposits of a fluvio-alluvial nature and are the focus of this paper. The upper interval was related to foreshore marine deposits and will be studied in a future contribution.
2. The lower interval is characterized mainly by overbank architectural elements in which calcisols and argillic protosols were identified. Channel-fill deposits are isolated and surrounded by fine-grained overbank successions and depositional features are suggestive of mixed-load transport. The contact between the

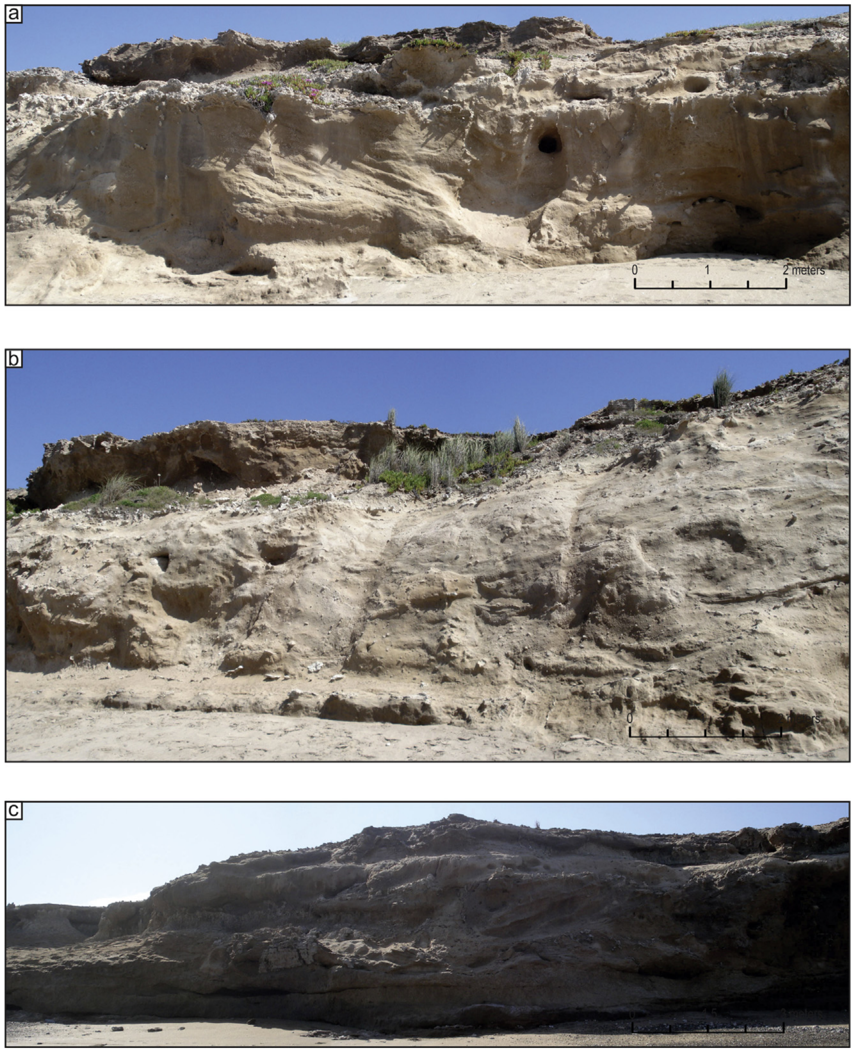

Fig. 7. Middle informal interval. Fine-to medium-grained channel-fill sandstones characterized by planar and trough cross-stratified sandstones within basal scours. The lower part of the middle interval (a–b) lacks of overbank deposits, which suggests reworking as the channels drifted across the alluvial plain. The upper portion of the middle interval (c) is also dominated by channel-fill deposits, but with a higher degree of overbank deposits preservation.

lower and middle intervals is an irregular, highly erosive surface characterized by a significant vertical change in the facies. This surface defines the base of multistorey sandbodies. Their internal arrangement alongside with the low participation of overbank deposits suggests a braided fluvial system.

3. Pedofeatures present in the studied intervals allowed identification of two pedotypes. Calcisol profiles, displaying Stages II to V morphologies, were interpreted as evidence of periods of geomorphological stability that occurred under semi-arid to sub-humid climatic conditions. The occurrence of argillic protosols stacked amongst the calcisols evidence periods of relatively less stability, higher sediment supply and aggradation rates in the system. The vertebrate fossil assemblages and the invertebrate trace fossils also indicate semi-open environments under a seasonal, semi-arid climate.
4. The presence of *Platygonus, Glyptodon* and *Tolypeutes* fossil remains in the C1 layer suggest an Ensenadan age (middle Pleistocene) for the lower interval while the presence of *A. bonariense* in the middle interval indicates a post-Ensenadan (late Pleistocene) age (Soibelzon, 2004; Soibelzon et al., 2005).
5. During accumulation of the Chocorí succession, glacio-eustasy and/or climate controlled the balance between generation of accommodation space and sediment supply. Analysis of the architectural elements indicates a general reduction in accommodation space. The lower interval represents the unconfined reaches of a large distributive system, more specifically, a low hierarchy, secondary drainage system inset in a high accommodation alluvial environment. The erosive surface identified at the base of the middle interval can be interpreted as representative of a period of negative accommodation in the system, when general erosion took place. The gradual restoration of accommodation in the fluvial system was accompanied by a low sediment accumulation rate and the development of a braided fluvial system in the middle interval.

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