SEDIMENTARY PALEOENVIRONMENT AND FOSSIL PLANTS OF THE EL FRENO FORMATION (EARLY JURASSIC) IN LAS LEÑAS VALLEY, NEUQUÉN BASIN

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ABSTRACT

Non-marine Early Jurassic successions in Las Leñas valley and their paleofloristic fossil content have been known since late nineteenth century, though they are scarce in the bibliography. It led us to study the sedimentology and paleobotanical content of El Freno Formation outcrops in the surroundings of the Portezuelo and Peuquenes creeks, report the first finding of fossil plants there and interpret their taphonomic features and enclosing sedimentary environment. The studied section is a lensoidal, fining- and thinning-upwards, conglomerate and sandy succession, with carbonaceous plant impressions and silicified trunks. It records the evolution of a gravel braided fluvial system (with longitudinal and transverse bars, abandoned channels and strong topographic irregularities) into a sand braided fluvial system (with transverse bars, overbank deposits and no evidence of lateral migration). Both flowed mainly towards the NNW and show a continuously increasing accommodation probably driven by a relative base level rise and regional sag or erosional lowering of the topography. Collected fossil plants include *Dictyophylum (Dictyophylum)* sp., *Goeppertella* sp. and undetermined Equisetopsida. *Goeppertella* sp. is recorded for the first time in this unit. Equisetopsida would have thrived in semi-permanent water bodies on abandoned channels and Dipteridaceae, in well-drained zones of the channel belt above the permanent channel level. Conversely, the trees would have lived in higher and well-drained areas with well-developed soils, probably outside the channel belt. Based largely on lithostratigraphical considerations, the age of the studied deposits was limited to the Hettangian?-Middle Sinemurian without identifying hiatus inside the fluvial succession or between it and the overlain marine beds.

Keywords: *Fluvial deposits, paleobotany, Early Jurassic, Precuyo mesosequence*

RESUMEN

Paleoambiente sedimentario y plantas fósiles de la Formación El Freno (Jurásico Temprano) en el valle de Las Leñas, Cuenca Neuquina.
Las sucesiones continentales del Jurásico Temprano del valle de Las Leñas y su flora fósil se conocen desde fines del siglo diecinueve, aunque están poco representadas en la bibliografía. Eso nos llevó a estudiar el ambiente sedimentario y contenido paleobotánico de los afloramientos de la Formación El Freno en los arroyos Portezuelo y Peuquenes, informar su taxonomía e interpretar sus rasgos tafonómicos. El perfil estudiado es una sucesión grano- y estratodecreciente de lentes de conglomerados y areniscas, con impresiones vegetales y troncos carbonizados que registra la evolución de un sistema fluvial entrelazado gravoso (con barras longitudinales y subordinadamente transversales, canales abandonados y fuertes desniveles topográficos) hacia otro entrelazado arenoso (con barras transversales, planicies de inundación y sin evidencias de migración lateral). Ambos ríos fluyeron principalmente al NNO y muestran una acomodación creciente constante, ya sea por ascenso relativo del nivel de base y subsidencia regional, o por erosión progresiva de la topografía. Las plantas halladas comprenden *Dictyophylum (Dictyophylum)* sp., *Goeppertella* sp. (registrada por primera vez en esta unidad) y Equisetópsida indeterminadas. Estas últimas habrían prosperado en cuerpos de agua semipermanentes de canales abandonados y las Dipteridaceae, en zonas bien drenadas de la faja de canales, por encima del cauce permanente. Los árboles habrían ocupado áreas altas y bien drenadas, con suelos bien desarrollados, posiblemente fuera de la faja de canales. Considerando rasgos litoestratigráficos, la edad de los depósitos estudiados queda acotada al Hettangiano?-Sinemuriano Medio, sin poder identificar hiatos dentro de la sucesión fluvial o entre ésta y las capas marinas suprayacentes.

Palabras clave: *Depósitos fluviales, paleobotánica, Jurásico Temprano, mesosecuencia Precuyo*

INTRODUCTION

The non-marine Early Jurassic outcrops in Las Leñas valley and their fossil content have caught the researchers' attention since late nineteenth century (Bodenbender 1892, Wehrli and Burckhardt 1898, 1900). However subsequent studies focused more on the Atuel valley, where most the well-known successions (including the type sections) and paleontological localities of the Early Jurassic are placed.

On the contrary in Las Leñas valley, about 50 km southwest of the Atuel region, the paleobotanical and sedimentological studies of the non-marine Early Jurassic are uncommon. Only Gerth (1925) studied the sedimentary sequences and their stratigraphy and mentioned the presence of fossil logs. This scarcity led us to investigate the sedimentology and paleobotanical content in the surroundings of the Peuquenes creek in Las Leñas valley (Figs. 1, 2) as a first approach.

The purpose of this paper is interpreting the sedimentary paleoenvironment of the Early Jurassic non-marine deposits at Arroyo Peuquenes section, reporting the taxonomy and taphonomic features of the contained fossil plants.

The study area covers the northern and northwestern margins of the Portezuelo and Peuquenes creeks respectively (35° 06´S and 70° 06´W), where the succession of the El Freno Formation unconformably overlie the Choiyoi Group volcanics and underlie the marine beds of the Puesto Araya Formation. The relevance of this locality is based on the fact that, up to now, this is the only known place where the base of the El Freno Formation crops out (Gulisano and Gutiérrez Pleimling 1994).

A detailed vertical section was recorded and a facies analysis and a paleocurrent study were carried out to determine the depositional system and its controls. Paleocurrents were measured from the orientation of fossil logs and stems, imbrications, channel axes, trough axes, trough cross-bedding and planar cross-bedding. Such directions were corrected for any bias introduced by superimposed geological structure and then paleocurrent diagrams were plotted with suitable software.

Plant fossils are housed in the paleobotanical collection of the Museo Argentino de Ciencias Naturales "Bernardino Rivadavia", Argentina (BAPB 5246 to 5249). Fossil plant impressions were studied through a Leica M50 binocular stereoscope. Photographs were taken with a digital camera Leica EC3 belonging to the same institution.

GEOLOGICAL SETTING

The Neuquén basin (Fig. 1) is a Mesozoic rifted back-arc basin placed on the western convergent margin of the South American plate (Uliana and Biddle 1988, Legarreta and Uliana 1991), attributed to the extension during the fragmentation of Gondwana and the opening of the South Atlantic Ocean. The basin evolution began with a series of unconnected depocenters (Manceda and Figueroa 1993, 1995) produced by the first rifting episode after the Middle Triassic, and finally connected in the Early Pliensbachian (Legarreta and Gulisano 1989) when most of the basin was transgressed. The unconnected depocenters were initially filled with non-marine siliciclastics and volcanics of the Precuyo Mesosequence (Legarreta and Gulisano 1989, Gulisano, 1981), also interpreted as synrift deposits. At the same time, the deepest areas were rapidly transgressed by nearshore sandstones and offshore shales of the Cuyo Mesosequence (Legarreta and Gulisano 1989), partly due to the post-Sinemurian regional sag (Vergani *et al.* 1995). Features, areal distribution and basal age of the transgressive deposits vary according to the rough fault-controlled basement topography which also controlled the partial synchronism between continental and marine units of the Upper Triassic–Lower Jurassic (Gulisano 1981, Gulisano and Gutiérrez Pleimling 1994).

One of these unconnected depocenters was the Atuel Depocenter (Manceda and Figueroa 1995, Álvarez *et al.* 2002, Giambiagi *et al.* 2003a, 2003b, 2005a) (Fig. 1) where synrift and sag phases occurred during Rhaetian-Late Early Sinemurian and Late Early Sinemurian-Toarcian respectively (Lanés 2002, 2005, Giambiagi *et al.* 2005b). Synrift phase gave way to different types of coarse deltaic and fluvial systems while sag phase also enabled the creation of estuaries and marine shelves. Synrift deposits recorded slope-type fan deltas, braided fluvial systems and low sinuosity fluvial systems while sag deposits include intermediate (Gilbert to shelf) type fan deltas, braided fluvial systems, low sinuosity fluvial systems with alternating side bars, estuaries and transgressive marine shelves (Lanés *et al.* 2008). Note that all the fluvial deposits belong to the El Freno Formation (Stipanicic and Bonetti 1970) irrespective of their sandy or conglomeratic composition and tectonic interpretation.

The Atuel Depocenter was limited to the southwest by the Dedos-Silla High (Gerth 1925, Legarreta and Kozlowsky 1984, see figures 4 and 8 in Manceda and Figueroa 1995), a basement high block which controlled the sedimentation and generated condensed sections (vertical sections much thinner than the contemporaneous ones in the centre of Atuel Depocenter), during the Jurassic and Early Cretaceous (Legarreta and Kozlowsky 1984, Lanés 2002).

The study area is located in the area of the Dedos-Silla High. There the fluvial conglomerates and sandstones of the El Freno Formation (Pre-Early Pliensbachian) unconformably overlie the Choiyoi Group volcanics, and underlie the marine storm sandstones of the Puesto Araya Formation of Late Sinemurian?-Early Toarcian age according to the enclosed ammonites, bivalves and brachiopods (Damborenea 1987, Lanés 2002).

PREVIOUS PALEOBOTANIC STUDIES

As it was mentioned above, the bulk of previous paleobotanical studies of the Early Jurassic floras were concentrated on El Freno Formation outcrops on both margins of the Atuel valley, where fossil

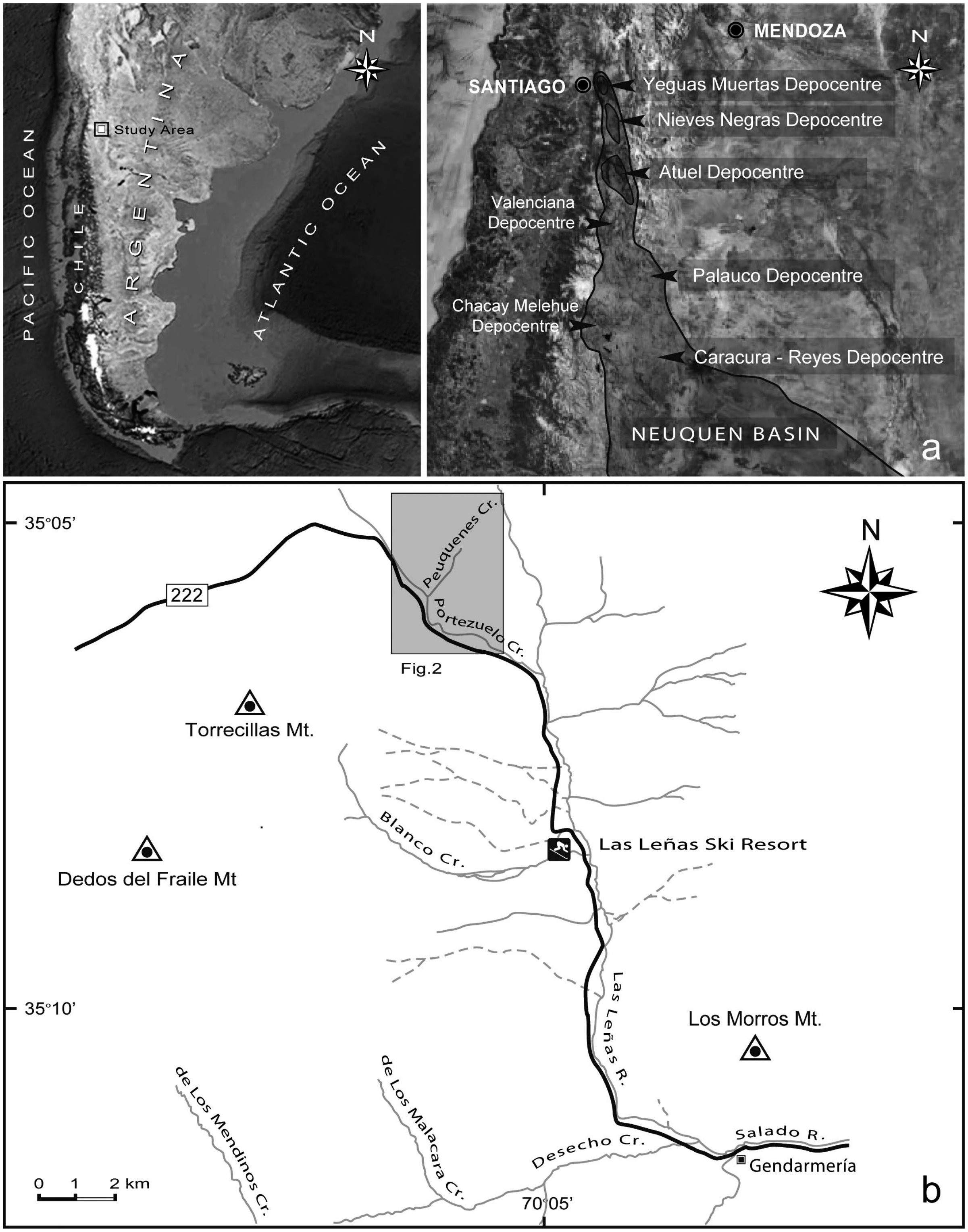

Figure 1: a) Location of the study area in Argentina and location of the depocentres of the northern extreme of the Neuquén Basin. b) Location of the study area in the Las Leñas valley.

plants have been known since the early twentieth century. They were studied by Kurtz (1921), Gerth (1925), Ugarte (1955), Herbst (1964, 1968), Herbst and Stipanicic (1996) and Artabe *et al.* (2005) among others, particularly in the classical localities Mina El Tránsito and Cerro La Brea. Afterwards Spalletti *et al.* (2007) described three detailed sedimentological sections at Cerro Las Chilcas and El Cholo Anticline, on the northern side of the Atuel valley, publishing the following list of paleofloral

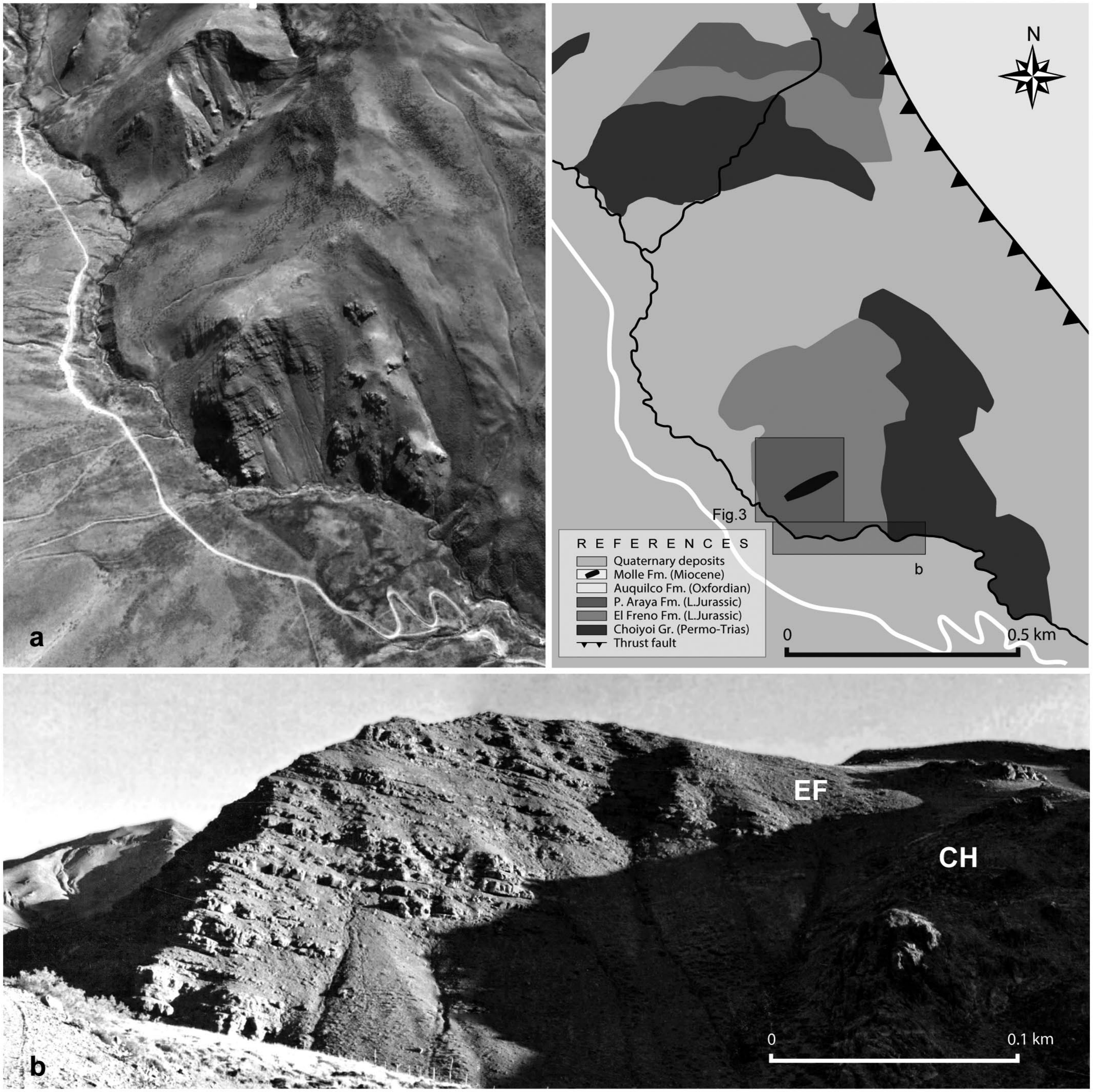

Figure 2: a) Aereal view of the El Freno Formation outcrops in the surroundings of the Portezuelo and Peuquenes creeks at Arroyo Peuquenes section and regional geologic map indicating the studied area. b) Detailed view of the southernmost and basal outcrops of the El Freno Formation (EF) at Arroyo Peuquenes section and the Choiyoi (CH) volcanites, view towards north.

content: *Equisetites* sp., cf. *Rienitsia colliveri, Marattia münsteri* (Goeppert) Zeiller, *Cladophlebis mendozaensis* (Geinitz) Frenguelli, *Cladophlebis ugartei* Herbst, *C. oblonga* Halle; *C. antarctica* Nathorts; *Dictyophyllum* (D) *atuelense* Herbst, *Archangelskya protoloxsoma* (Kurtz) Herbst, *Sagenopteris* sp.; cf. *S. rhoifolia* Presl, *Dejerseya lobata* (Jones and de Jersey) Herbst; *Kurtziana brandmayri* Frenguelli, *Scleropteris vincei* Herbst, *Ptilophyllum acutifolium* Morris, *Otozamites bechei* Brongniart, *O. hislopi* (Oldham) Feistmantel, *Williamsonia* sp., *Taeniopteris* sp. and *Elatocladus conferta* (Oldham y Morris) Halle. Most of the taxa reported by Spalletti *et al.* (2007) had already been recognized by Artabe *et al.* (2005) in material from Cerro La Brea, on the southern bank of the valley.

More recently, Gnaedinger (2006) and Zavattieri and Gnaedinger (2012) reported several coniferal taxa identified through anatomical analysis of silicified fossil woods from Cerro La Brea and Portezuelo Ancho. They recognized the genera *Aga-*

thoxylon, Kaokoxylon of the Araucareacea Family; *Podocarpoxylon* of the Podocarpaceae and the genus *Brachyoxylon* of the Cheirolepidiaceae Family.

EL FRENO FORMATION: GENERAL FEATURES, SEDIMENTOLOGY AND PALEOENVIRONMENTAL INTERPRETATION

The studied section is a green and brown coloured, fining- and thinning-upwards succession, 292 m thick (Fig. 3). It is made up of conglomerate lenses, sandstone lenses and lesser mudrock lenses, with carbonaceous plant debris (≤3 cm) and petrified trunks. Lenses are 0.2 to 2 m thick and show increasing–upwards widths, ranging between 1 and 7 m in the lower portion and between 10 and 20 m in the upper part. Bases are concave-up, erosive or load-deformed. In general conglomerates are clast-supported, medium to coarse grained, poorly to moderately size-sorted and mainly lithic with clasts of volcanics, granitoids (probably derived from Los Morros Mt., see Los Mendinos Monzogranite at Llambías and Palacios 1979), mudrocks and rippled sandstones. Sandstones include coarse gravelly ones and coarse to fine sandstones, usually with basal lags of mud clasts or rippled sandstone clasts. It is worth noting that the rippled sandstone clasts are indistinguishable from the rippled sandstone facies of the studied section. Finally, the muddy lenses consist of dark grey and light grey heterolithic sand-silt couplets and siltstones.

Four facies associations (Table 1) were recognized. The lower section shows abundant conglomerate lenses interbedded with and a few muddy lenses (facies associations A and B), while the upper part largely comprises sandy lenses alternating with wider muddy lenses (facies associations C and D respectively).

Conglomerate lenses begin with a massive portion, planar bedding and imbrication (through axe b), normal gradation, trough cross-bedding or planar cross-bedding (Gm, Gh, Gg, Gt or Gp) underlying massive, planar laminated or cross-bedded sandstones with gravel lags (Sm, Sh or St) (facies association A). They alternate with muddy lenses of massive silt (Fsm), or plane or ripple laminated heterolithic sand-silt couplets (Fl or Fr) with frequent water escape structures or load deformation (facies association B).

These facies are replaced upwards by wider lenses of trough cross-bedded or infrequent planar cross-bedded sandstones and gravelly sandstones (St, Sp, GSt, GSp), or minor trough cross-bedded conglomerates (Gt) underlying planar laminated, trough cross-bedded or planar cross-bedded and/or ripple laminated sandstones (Sh, St, Sp and/or Sr). Basal lags of mud clasts or rippled sandstone clasts, water escape structures and load deformation are common (facies association C). These lenses are covered by wider muddy ones (15 to 20 m wide, 0.1 to 3 m thick) with massive or plane laminated silt (Fsm or Fl) and rare heterolithic plane laminated sand-silt couplets (Fl) (facies association D).

The lower deposits were interpreted as longitudinal and minor transverse bars (facies association A) with abandoned channels on their tops (facies association B) in a gravel braided fluvial system. Conversely the up-section facies represent transverse bars (facies association C) and overbank deposits (facies association D) of a sand braided fluvial system (sensu Miall 1996). Evidences of lateral migration such as lateral accretion surfaces or definite crevasse splay were not identified. The fining-upwards trend, widening-upwards lenses and vertical facies changes evidence the evolution of a gravel braided fluvial system into a sand braided one ("low-sinuosity mixed-load river" sensu Miall 1996). The gravel braided fluvial system had strong topographic irregularities as the abandoned channel deposits confirm. On the other hand, the simple internal architecture of the sandstone bodies points to non-compound transverse bars and shallow perennial channels in the sand braided river (Miall 1996, Blodget and Stanley 1980, Crowley 1983). Lithological similarity of the rippled sandstone clasts in conglomerates and sandstones, with the rippled sandstone facies on the section, supports an origin related to slides from the top of relatively thick sandy bars.

Respect to the paleocurrents, in the basal part of the succession the currents flowed mainly to the NNW-NNE (Az 348º-Az 30º), and in a minor degree to the NW (Az 315º-Az 325º), NE (Az 32º-Az 55º), W (Az 266º), SW (Az 215º) and SSW- (Az 245º) (Fig. 3). Up section just the currents flowing to the NNW (Az 348º-Az 355º) prevailed. The consistency of the NNW paleocurrents along the whole section and the scarcity of NE paleocurrents suggest a possible control of fluvial channels by a Choiyoi high block located east of the studied section (Fig. 2).

The fining- and thinning-upwards trend, increasing abundance of muddy lenses towards the top, together with a low degree of amalgamation and a higher degree of isolation of the fluvial channels, reflect an increasing accommodation probably driven by a relative base level rise (Törnqvist 1993, Olsen *et al.* 1995, Miall 1996, Shanley and McCabe 1994, Wright and Marriott 1993, among others). Partly similar tendencies were identified by Spalletti *et al.* (2007) on the El Freno Formation deposits in the Atuel valley. Their figure 5 is an architectural panel of their Cerro Las Chilcas section, correlative of the one studied here. It displays several fluvial channel styles (from base to top): unconnected fluvial channels enclosed in fine overbank deposits, increasingly isolated channels surrounded by fines, more laterally connected channels, channel belts and finally laterally connected bed-load channels. In brief, that panel depicts an increasing-upwards and then decreasing-upwards accommodation. However such situation was not documented in arroyo Peuquenes where a uniformly finning-upwards trend (Fig. 3) and so a consistently increasing-upwards accommodation occurs. As the age of the succession partly coincides with the sag phase (Lanés 2005), the increase in accommodation could have resulted from the regional subsidence during the sag phase. But it could also reflect the con-

TABLE 1: Fluvial facies associations of the El Freno Formation at arroyo Peuquenes section. (Lithofacies codes after Miall 1978, 1996).

Name	Deposits	Depositional processes and paleoenvironment
A	Lenses (1-7 m wide, 0.2-2 m thick) filled with 2 different internal stacking patterns: a) Basal massive, planar bedded and imbricated or normally graded, clast-supported, medium to coarse conglomerates (Gm, Gh or Gg), underlying trough cross-bedded or planar cross-bedded clast-supported, medium to coarse conglomerates (Gt, Gp), massive sandstones (Sm), planar laminated sandstones (Sh) or trough cross-bedded sandstones (St) sometimes containing gravel lags. b) Basal trough cross-bedded or scarce planar cross-bedded, clast-supported, medium conglomerates (Gt or Gp), underlying planar laminated sandstones (Sh) or trough cross-bedded sandstones (St) sometimes containing gravel lags. Mud clasts and rippled-sandy clasts are usual in all the conglomerate types.	a) Nucleation and active downstream migration of gravel longitudinal bars. b) Nucleation and active downstream migration of subordinate gravel transverse bars. Braided fluvial system.
B	Lenses (up to 2 m wide and up to 0.5 m thick) filled with plane or rippled laminated sand-silt couplets (Fl or Fr) and/or massive silt (Fsm). Carbonaceous debris (< 3 cm long), water escape structures, load deformation and injection of underlying material are frequent.	Abandoned channel deposits on top of longitudinal and transverse bars. Braided fluvial system.
C	Lenses (10-15 m wide, 1-3 m thick) showing trough cross-bedded or rare planar cross-bedded sandstones and gravel sandstones (St, Sp, GSt, GSp) or minor trough cross-bedded conglomerates (Gt) overlain by planar laminated, trough cross-bedded, planar cross-bedded and/or ripple laminated sandstones (Sh, St, Sp and/or Sr). Basal lags of mud or rippled-sandy clasts are frequent, as well as water escape structures and load deformation features.	Nucleation and active downstream migration of transverse bars. Low sinuosity mixed-load fluvial system (sensu Miall 1996).
D	Lenses (15-20 m wide, 0.1-3 m thick) of massive or plane laminated silt (Fsm or Fl) and scarce heterolithic plane laminated sand-silt couplets (Fl).	Overbank deposits (floodplain of a mixed-load fluvial system).

tinuous erosional lowering of the paleotopography and subsequent supply of finer sediments.

SYSTEMATIC PALEOBOTANY

Studied fossil plant material was collected in green mudrock lenses at 32 m, 160 m and 165 m from the base by SL. These beds were also sampled for unsuccessful palynological studies.

Class Equisetopsida Meyen 1987
Equisetopsida indet.
Fig. 4a
Studied material: BAPB 5248, 5249.
Comments: Fragments of articulate ribbed axes preserved as impressions of internodal area, up to 2.9 cm long and 3.6 cm wide with longitudinal ridges 0.1-0.2 mm wide. Nodes and foliar whorls, which are the main diagnostic features for generic classification, are not preserved in this material. In the El Freno Formation, articulate forms belonging to the Equisetaceae have been recorded as *Neocalamites carrerei* (Zeiller) Halle and *Equisetites* sp. from Mina El Tránsito and Cerro La Brea in the Atuel valley (Herbst 1964, Artabe *et al.* 2005 and Spalletti *et al.* 2007). Equisetalean remains normally referred to *Equisetites* and *Neocalamites* are frequently recorded in the Triassic and Jurassic strata of Argentina, being the second genus more commonly recorded in the Triassic (Escapa *et al.* 2008).

Class Filicopsida
Order Filicales Engler and Prantl 1898-1902
Family Dipteridaceae Seward and Dale 1901
Comments: Impression-compression foliage assigned to the Dipteridaceae includes *Clathropteris, Dictyophyllum, Goeppertella,* and *Hausmannia* (cf. Taylor *et al.* 2009, p. 469). Herbst (1992) proposed to include *Clathropteris* as a subgenus of *Dictyophyllum,* whereas other authors keep the distinction between both genera (Van Konijnenburg-Van Cittert 2002, Wang 2002, Bomfleur and Kerp 2010, among others). These 4 genera are essentially distinguished by their whole morphology and venation pattern (Oishi and Yamasita 1936, Arrondo and Petriella 1982, Rees 1993, Rees and Cleal 2004). In this paper, two species belonging to the genera *Dictyophyllum (Dictyophyllum) sensu* Herbst 1992 and *Goeppertella* Oishi and Yamasita 1936 respectively, are described. Usually both form-genera have polygonal vein-meshes, and lamina segmentation is deeper. *Dictyophyllum* is characterized by monopinnate fronds (with pinnules directly arising from each frond-member) with toothed to lobulated margins deeply divided into lateral segments, free up to the base with veins branching at oblique angles in an irregular mesh. Diagnostic morphological features of *Goeppertella* are: bipinnate fronds (with each frond-member bearing pinnae and each pinna having pinnules) and polygonal venation with three orders of decreasing-size veins. Also typical for *Goeppertella* are the subsidiary pinnular elements (rachial pinnules and rachial laminae) on the rachis (Ress 1993). The terminology used in this contribution for specimen description follows Rees (1993) criteria. The identification and comparison of the genus *Goeppertella* was made according to the key by Arrondo and Petriella (1982).

Genus *Dictyophyllum* (Lindley and Hutton) Webb 1982
Subgenus *Dictyophyllum (Dictyophyllum)* Herbst 1992
Type species *Dictyophyllum rugosum* Lindley and Hutton 1834.
Dictyophyllum (Dictyophyllum) sp. sensu Herbst 1992
Fig.4b
Studied material: BAPB 5246.

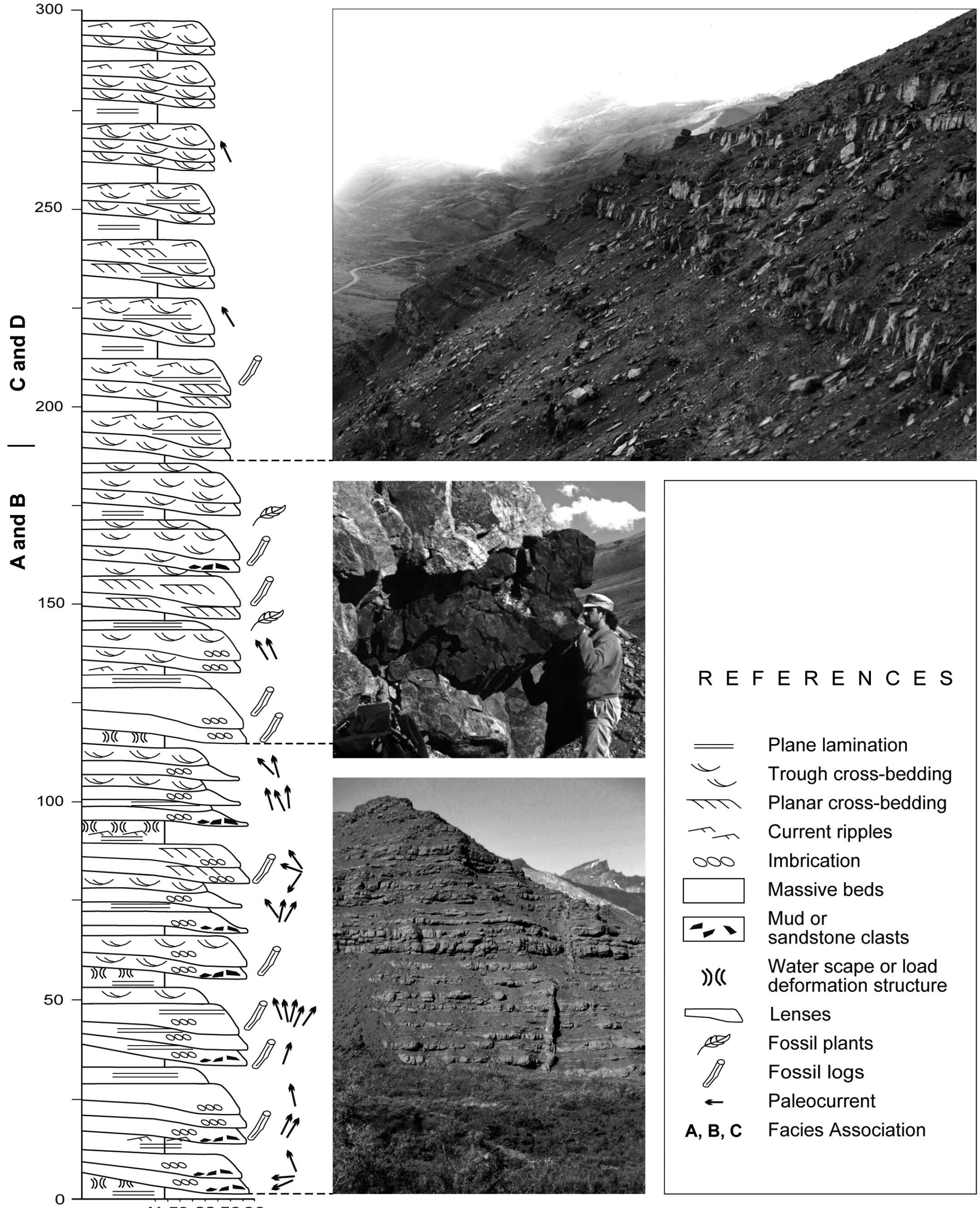

Figure 3: Profile of the El Freno Formation outcrops at the Arroyo Peuquenes section, showing fossiliferous levels and size of the petrified trunks.

Description: Preserved fragment of frond-member 4.70 cm long, 4.5 cm wide at the base, and 2.6 cm wide in its apical part. Rachis is 1.20 mm wide. Pinnules are subtriangular in shape, 1.9-2.35 cm long and 0.9 cm wide, alternating each other at low angle (75-90º). Pinnule apices are rounded with undulated to lobated margins. Midvein is prominent in each pinnule, 0. 7 mm near its base, with alternate pairs of lateral veins at 35-45º. The entire frond exhibits the characteristic reticulate mesh of veins with polygonal areoles of first order (*ca.* 4 mm wide) and of last order (0.6 mm wide).

Comments: The details of venation are unclear in the studied specimen, although the typical reticulate mesh of veins with polygonal areoles is observed. This reticulate pattern and the external morphology of pinnae and pinnules allow assigning the frond fragment to *Dictyophyllum (Dictyophyllum)* sp. sensu Herbst 1992.

The current material is closely similar to *Dictyophyllum (Dictyophyllum)* atuelense described by Herbst (1964), due to its subtriangular pinnules alternately arranged at low angles (75-90º). Apices of pinnules are rounded, occasionally acute, with undulated to lobated margins. Midvein is

Figure 4: a) cf. *Neocalamites* sp. (BAPB 5248, 5249). b) *Dictyophyllum (Dictyophyllum)* sp. *sensu* Herbst (BAPB 5246). c-d) *Goeppertella* sp.; bipinnate frond bearing pinnae and rachial pinnules; c1 – c2: detailed portions of the fragment showing the classical reticulate (pentagonal to hexagonal) venation pattern; c, c1, c2: BAPB 5247b; d: BAPB 5247a. d) bipinnate frond bearing pinnae and pinnule (arrow). Bar scale a-b, c, d = 1 cm; c1-c2 = 0.5 cm.

prominent in each pinnule, with alternate pairs of lateral veins at 35-45º. The frond has a reticulate mesh of veins with polygonal areoles (pentagonal to heptagonal). *Dictyophyllum (Dictyophyllum) atuelense* Herbst has been previously reported in El Freno Formation at cerro La Brea by Herbst (1964, 1968), Herbst and Stipanicic (1996) and Artabe *et al.* (2005), and on the northern margin of the Atuel valley by Spalletti *et al.* (2007). More material in a better preservation condition would be necessary for specific determination.

Genus *Goeppertella* Oishi and Yamasita 1936

Type species *Goeppertella microloba* (Schenk) Oishi and Yamasita 1936

Goeppertella sp.

Fig.4c-d

Studied material: BAPB 5247a, 5247b.

Description: Two fragments of bipinnate fronds are described. Specimen 5247a has preserved a portion 3.9 cm long and 7 cm wide; specimen 5247b has preserved a frond area 3.6 cm long and 4.8 cm wide. Rachis is 1.5- 2 mm wide, alternating pinnae and interspersed rachial pinnules are seen (Fig. 5a-b). Pinnae show well-defined rachis 0.5-0.9 mm wide. Pinnules alternate at low angles (35-40º) (Fig. 5a). In specimen 5247a, developed pinnules coalescent at the base with sub-acuminate to slightly rounded apex, 1.5 cm long x 0.5 mm wide near the apex, are observed. The primary vein is distinct in each pinnule, is 0.4 mm wide at its base and tapers towards the apex with alternate pairs of lateral veins. In specimen 5247b, the pinnules are less developed coalescent almost up to the apex (Fig. 5b). The midvein is distinguishable in each pinnule, being 0.2 mm at the base and tapering towards the apex, alternate pairs of lateral veins form the reticulate venation of three orders of decreasing-size polygonal areoles (1° order: 4.2-3.5 mm; 2° order: 0.7- 0.6 mm and 3° order: 0.3-0.2 mm) (Fig. 5c). In this specimen, the pinnae regularly alternating with subtriangular rachial pinnules 1.2 cm long, with a midvein arising from the rachis segment, are clearly seen.

Comments: These fragments are incomplete and in moderate preservation state to be confidently assigned to any species of the genus. According to Arrondo and Petriella (1982) one of the diagnostic characters used to differentiate species of this genus is the number of rachial pinnules (subsidiary elements).

The specimens examined here could be closely related to the species *G. taverai* described by Herbst (2000) from the Upper Triassic of Chile due to the occurrence of one subtriangular rachial pinnule between the pinnae, and of the pinnae with crenate-lobated to pinnatifid margins, deep up to half-width, suggesting the development of pinnules. It can also be compared with *G. diazzi* Arrondo and Petriella 1982 reported in the Nestares Formation at Alicurá, Neuquén (Hettangian), which has two rachial pinnules between the pinnae (in Fig. 5b, two probable rachial pinnules can be observed). *G. neuqueniana* Herbst 1966 recorded in the Piedra Pintada Formation, Neuquén province, is also similar to the El Freno specimen, although this

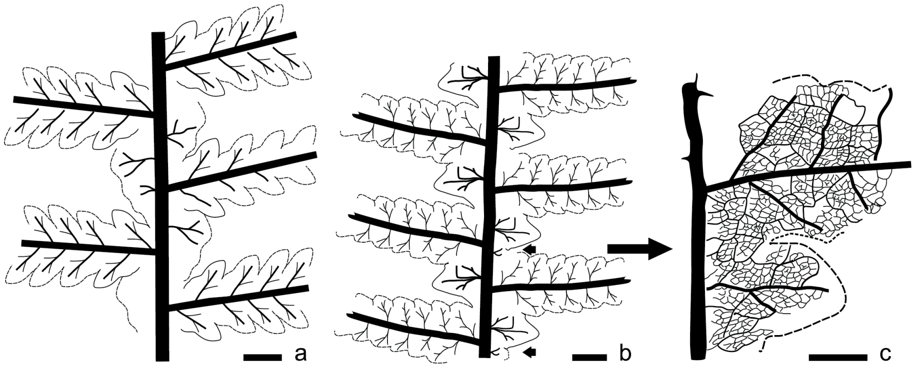

Figure 5: *Goeppertella* sp. a-b) reconstruction line-drawing of bipinnate frond bearing pinnae and rachial pinnules, c) detail of frond fragment showing the classical reticulate venation pattern. (a: BAPB 5247a; b-c: BAPB 5247b). Bar scale, a-b = 1 cm, c = 0.5 cm.

last species has well-developed pinnules and may have up to three rachial pinnules between the pinnae.

Specimen 5247a is closely similar to that figured by Escapa *et al.* (2008, its figure 2.1) as *Goeppertella* sp. but apparently the Chubut specimen has a higher number of rachial pinnules.

The genus *Goeppertella* has been previously recorded in Late Triassic and Early Jurassic strata of the Northern Hemisphere (Oishi and Yamasita 1936, Harris 1946). On the contrary a few species of *Goeppertella* have been previously found in Gondwana, in Late Triassic beds of Argentina and Chile: *G. stipanicicii* Herbst 1993 from the Paso Flores Formation, Argentina and *G. taverai* Herbst 2000 in the Las Breas Formation, Chile (Rees and Cleal 2004, Escapa *et al.* 2008). In the Lower Jurassic of Argentina (not younger than Pliensbachian) *Goeppertella* has been reported for the Nestares and Piedra Pintada Formations (Neuquén province) and in the cañadón del Zaino Formation, sierra de Taquetrén, Chubut (Herbst 1964, 1966, 1992; Arrondo and Petriella 1982). In Antarctica, Rees (1993) and Rees and Cleal (2004) have recorded this genus in Hope Bay.

PALEOECOLOGICAL AND TAPHONOMIC CONSIDERATIONS

As it was mentioned above, carbonaceous plant debris (≤3 cm) and petrified trunks occur along the whole studied section (Fig. 3). The frond impressions and ribbed axes are moderately preserved as moulds or compressions. The fronds lay obliquely overlapping each other.

The logs appear mainly in the upper section as massive and fragmented silicified trunks, 1.20 to 1.60 m long and 0.20 to 0.40 m wide, without roots, branches or internal voids. They occur in the centre of conglomerate lenses or sandstone troughs of longitudinal or transverse bars, parallel to the flow direction. The only exception to the sizes above was a log 1.40 m wide and 1.70 m long, parallel to the flow direction of imbrication (trunk on figure 3).

Hygrophilous condition of Equisetopsida indicates semi-permanent water bodies in abandoned channels, which lasted long enough to allow mud deposition. Notice that in a high energy fluvial system like the one in the lower section, the bar tops or terraces are the only areas where mud deposition and occasional plant colonization can happen (Miall 1996, Williams and Rust 1969).

Conversely, Dipteridaceae would thrive in a well-drained terrain above the permanent channel, in terraces or areas of the channel belt (e.g. bars) active only during major floods. Frond obliquity and low mechanical strength of leaves (Spicer 1991) confirm a short transport from the channel margins and its local provenance. According to the ecological constrains of each element, this assemblage would be autochthonous-parautochthonous (Kidwell *et al.* 1986).

The size and number of carbonaceous plant debris and silicified trunks demonstrate well-established neighbouring tree vegetation, probably in higher areas with well-developed soils. The parallelism between logs and flow directions was favoured by the trunk shape, the higher current velocity (Macdonald and Jefferson 1985) and the fluvial channel narrowness. The lack of branches, roots or core voids evidence a moderate damage before or during the short transport. As channel depth and rough bed obstacles control log dispersion (Spicer 1990), transport distances were short considering that braided or low-sinuosity fluvial systems have wide shallow and roughly-bedded channels. However trunk provenance from upstream areas probably located outside the channel belt confirms their allochthonous attribute (Kidwell *et al.* 1986).

DISCUSSION ON AGE OF THE EL FRENO FORMATION

Determination of the age of the El Freno Formation can be problematic because of the wide stratigraphic range of some of the plant genera involved and the diachronous nature of the unit top (Riccardi and Damborenea 1993).

One of the first data about the age of the El Freno Formation was published by Gerth (1925; 1931) who correlated the floristic levels at Cerro La Brea with similar conglomerates on the northern margin of the Atuel river, where they underlay marine beds with molluscs of Sinemurian-Pliensbachian age. Such correlation allowed Gerth to assign the mentioned levels to the Hettangian. They were later considered Hettangian-Early Sinemurian by Ugarte (1955) or solely Hettangian by Levy (1964) based on the same lithostratigraphic correlation.

Soon afterwards, Herbst successively allocated the plant-bearing beds at Cerro La Brea to the Hettangian-Early Toarcian (Herbst 1964) and to the Early Jurassic in general terms (Herbst 1968) indicating the impossibility of assigning them to any particular stage. In a similar line, Stipanicic and Bonetti (1970) attributed the floristic deposits at cerro La Brea and others on the north margin of the Atuel valley to the Hettangian-Early Toarcian.

At arroyo Peuquenes section, the outcrops of the El Freno Formation are overlain by marine sandstones with ammonites, bivalves and brachiopods of Late Sinemurian?-Early Toarcian age (Damborenea 1987, Lanés 2002). The granitic pebbles of the fluvial conglomerates, probably derived from Los Mendinos Monzogranite (Middle Triassic-Late Triassic, López Fontenla 1984), would constrain the maximum age to the Hettangian. However *Dictyophyllum (cf. Dictyophyllum atuelense)* and *Goeppertella* have been previously recorded in Late Triassic and Early Jurassic strata, limited to the Sinemurian-Pliensbachian range. As a final conclusion mainly based on the shortage of collected fossil plants, this succession of the El Freno Formation can be considered Hettangian?-Middle Sinemurian. Unfortunately at this point, the gathered paleofloristic material inhibits the assessment of hiatus inside the fluvial succession or between it and the overlain marine beds.

CONCLUSIONS

The first finding of fossil plants in the El Freno Formation outcrops at arroyo Peuquenes section, Las Leñas valley, is reported. The taphonomic features of the fossil plants as well as the surrounding sedimentary environment were also interpreted.

The studied succession records the evolution of a gravel braided fluvial system into a sand braided one, which flowed both mainly towards the NNW. The initial gravel braided fluvial system showed abundant longitudinal bars, infrequent transverse bars, abandoned channels and strong topographic irregularities. Conversely, the sand braided fluvial system included transverse bars, several overbank deposits and no evidence of lateral migration.

Fining- and thinning-upwards trend, increasing upwards abundance of fines and increasing upwards isolation of fluvial channels evidence a uniformly increasing accommodation. It could have been driven by a relative base level rise and regional subsidence during the sag phase or by the erosional lowering of the topography.

Collected plant material includes *Dictyophylum (Dictyophylum)* sp., *Goeppertella* sp. and undetermined Equisetopsida. *Goeppertella* sp. is recorded for the first time, increasing the plant diversity of the unit.

Equisetopsida confirm the occurrence of semi-permanent water bodies on abandoned channels, while Dipteridaceae imply well-drained zones inside the channel belt but above the permanent channel. Frond obliquity and its low mechanical strength confirm a short transport and local provenance. Carbonaceous plant debris and trunks indicate well-established vegetation in higher areas with well-developed soils, outside the channel belt. The lack of branches, roots or core voids in the logs mark a moderate damage before or during the short transport. To sum up, these different types of plant prove certain features of the fluvial systems such as abandoned channels and different topographic levels.

Based largely on lithostratigraphical considerations, the studied column can be assigned to the Hettangian?-Middle Sinemurian without being able to assess the existence of hiatus inside the fluvial succession or between it and the overlain marine beds.

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