J Paleolimnol
DOI 10.1007/s10933-016-9916-0

ORIGINAL PAPER

Paleolimnology of the Santa Clara Arriba paleolake (Triassic Cuyana rift basin): integrating sedimentology and palynology

C. A. Benavente · A. M. Zavattieri · A. C. Mancuso · F. Abarzúa · E. H. Gierlowski-Kordesch

Received: 2 March 2016 / Accepted: 24 September 2016
© Springer Science+Business Media Dordrecht 2017

Abstract The Triassic Cuyana rift basin of west-central Argentina is composed of several asymmetric half-grabens with sedimentary fill representing diverse fluvial-lacustrine systems from the syn-rift to post-rift phases of the basin. The Santa Clara Arriba Formation (SCAF) consists of Triassic continental deposits cropping out at Santa Clara Creek which represents deposits of the Santa Clara subbasin located in the middle area of the rift basin. Integrated sedimentology and palynology studies of the SCAF have recognized a deltaic-lacustrine system where low delta plain and prodelta-lacustrine facies associations characterize the depositional setting during the final stage of rifting. Sedimentologic features of the sandstone bodies entering the lake suggest a low-gradient deltaic system. The organic matter (OM) rich lacustrine facies and its palynofacies support a stratified lake interpretation. The sedimentology and palynology suggest that the SCAF paleolake was a shallow overfilled lake. Palynostratigraphic analysis constrained a late Triassic (Carnian-early Norian) age for the SCAF, providing for the first time a framework for the last infill of the Santa Clara subbasin of the Cuyana rift basin.

Keywords Upper Triassic · Carnian-early Norian · Rift · Carbonates · Lacustrine

Electronic supplementary material The online version of this article (doi:10.1007/s10933-016-9916-0) contains supplementary material, which is available to authorized users.

E. H. Gierlowski-Kordesch: Deceased.

C. A. Benavente (✉) · A. M. Zavattieri · A. C. Mancuso
Centro Científico Tecnológico Mendoza (CCT-Mendoza), Instituto Argentino de Nivología, Glaciología y Ciencias Ambientales (IANIGLA), Consejo Nacional de Investigaciones Científicas y Técnicas (CONICET), Av. Adrián Ruiz Leal s/n, Parque General San Martín, CC330, CP5500 Mendoza, Argentina
e-mail: cebenavente@gmail.com

F. Abarzúa
Department of Geology, Universidad Nacional de San Juan (UNSJ), CONICET, Av. Ignacio de la Roza 590 (O), Complejo Universitario Islas Malvinas, CPJ5402DCS Rivadavia, San Juan, Argentina

E. H. Gierlowski-Kordesch
Athens, OH 45701-2979, USA

Introduction

The sedimentary successions of the Triassic Cuyana rift basin, located in west-central Argentina, have been thoroughly studied at the Potrerillos-Cacheuta subbasin (50 km NW of Mendoza city). The sedimentary infill constitutes the Uspallata Group (Rolleri and Criado Roqué 1968; Kokogian et al. 1999; Spalletti 1999; Chebli et al. 2001; Stipanicic 2001). An uppermost unit of the Uspallata Group, known as Cacheuta Formation, is the main source rock of the basin, thus motivating the initial studies in that area (Rolleri and Criado Roqué 1968; Kokogian and

Published online: 13 February 2017

Mancilla 1989; Kokogian et al. 1999). On the other hand, the absence of hydrocarbon in other subbasins, like the Cerro Puntudo area (70 km SW of San Juan city) (Benavente et al. 2015) has caused them to remain less explored. In this regard, a particularly interesting zone is the Santa Clara subbasin, located in the east-central area of the rift basin, whose study will be important to understand the paleohydrology patterns linked to sedimentation in the rift basin since its deposits consist mainly of fluvial-lacustrine sediments (Harrington 1971).

The combined analysis of the sedimentary organic matter, the palynomorph content, and the sedimentologic data of the sedimentary successions provides more complete information to interpret the depositional settings of sedimentary infill (Tyson 1993; Batten 1996; Batten et al. 2005; Sabato et al. 2005). The composition and distribution of dispersed microscopic organic matter particles and palynomorphs reflect the paleoenvironmental conditions that influenced their production in the original settings, transport to depositional sites, burial, and post-depositional changes. The integration of that information and sedimentology data in the context of lacustrine system controls (tectonics and climate) allow an integrated understanding of ancient continental depositional systems (Gierlowski-Kordesch and Kelts 1994).

In the Santa Clara subbasin, the Triassic units constitute the El Peñasco Group (Stipanicic et al. 2002; Spalletti and Zavattieri 2009), represented by 3000 m thick exposures of mainly fluvial-lacustrine deposits exposed in the Montaña and Santa Clara creeks (Harrington 1971) (see Fig. 1). The main focus of the present study is the paleoenvironmental reconstruction of the Santa Clara Arriba Formation (SCAF) (Harrington 1971) in order to understand the paleolake evolution in space and time in its tectonic and climatic context during the post-rift stage of the Cuyana basin. Moreover, we analyze the palynofacies as a complementary indicator of the depositional environment of the SCAF to characterize its organic content and what is more important, well-preserved spore-pollen assemblages are analyzed for dating purposes.

Geologic setting

The Cuyana rift basin consists of several asymmetric half-grabens (Legarreta et al. 1992). It is located in the Precordillera geologic province (Spalletti and Zavattieri 2009), extending 600 km from the northern Cerro Puntudo subbasin in San Juan province to the southern Mendoza province (Strelkov and Alvarez 1984; Spalletti 2001; Barredo et al. 2011). Its sediments are entirely continental and represent the Triassic infilling (Stappenbeck 1910; Stipanicic 1947; Groeber and Stipanicic 1953; Spalletti 2001).

The Santa Clara subbasin, is part of the central area of the rift and is located north of Mendoza province near the border with San Juan province (Fig. 1). In this subbasin, the deposits of the Peñasco Group (Cortés et al. 2003; Spalletti and Zavattieri 2009) are formed by the Cielo, Mollar, Montaña, Santa Clara Abajo, and Santa Clara Arriba Formations (Fig. 1) (Spalletti and Zavattieri 2009). The Peñasco Group overlies Paleozoic deposits (Fig. 1). The SCAF (Harrington 1971) is composed of 1050 m of sandstones, siltstones, and mudrocks with tuffaceous sandy interbeds, outcropping at Yaguané hill (Harrington 1971) (Figs. 1, 2).

The paleontology of the Peñasco Group is mainly comprised of paleoflora and vertebrate remains (Nesossi 1945; Römer 1966; Rolleri and Criado Roqué 1968; Harrington 1971; Stipanicic 1983; Stipanicic et al. 2002; López-Arbarello and Zavattieri 2008). Vertebrate remains confirm a Triassic age due to the presence of fishes with affinities with Middle Triassic groups of the North Hemisphere (Bordas 1944). Moreover, trackways from basal archosaurs confirm a Middle and Late Triassic age (Anisian-Carnian) (Römer 1966; Baldoni 1972). Most recent studies include a sedimentologic characterization of the lowermost lacustrine unit (Mollar Formation) (Spalletti and Zavattieri 2009) and several contributions regarding the paleontologic content in the middle lacustrine unit (Santa Clara Abajo Formation) (López-Arbarello and Zavattieri 2008). However, a more precise dating of the SCAF is lacking.

Materials and methods

A detailed sedimentary log of the SCAF was measured at its type locality (Yaguané hill) (see Fig. 1) with color descriptions following the Rock Color Chart of the Geological Society of America (Goddard 1980). A total of 34 outcrop samples were taken. Fifteen samples were polished as slabs at the Laboratorio de

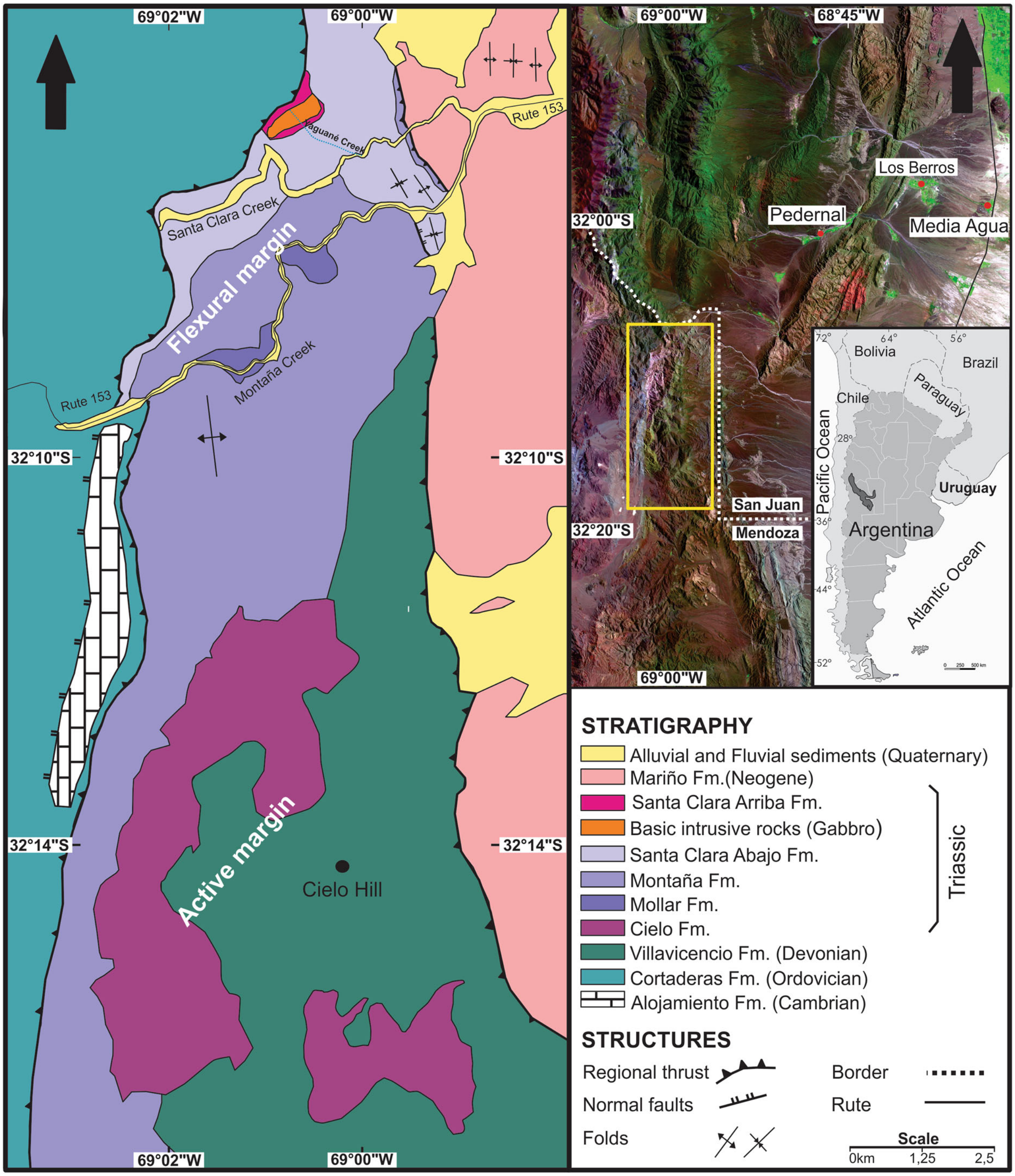
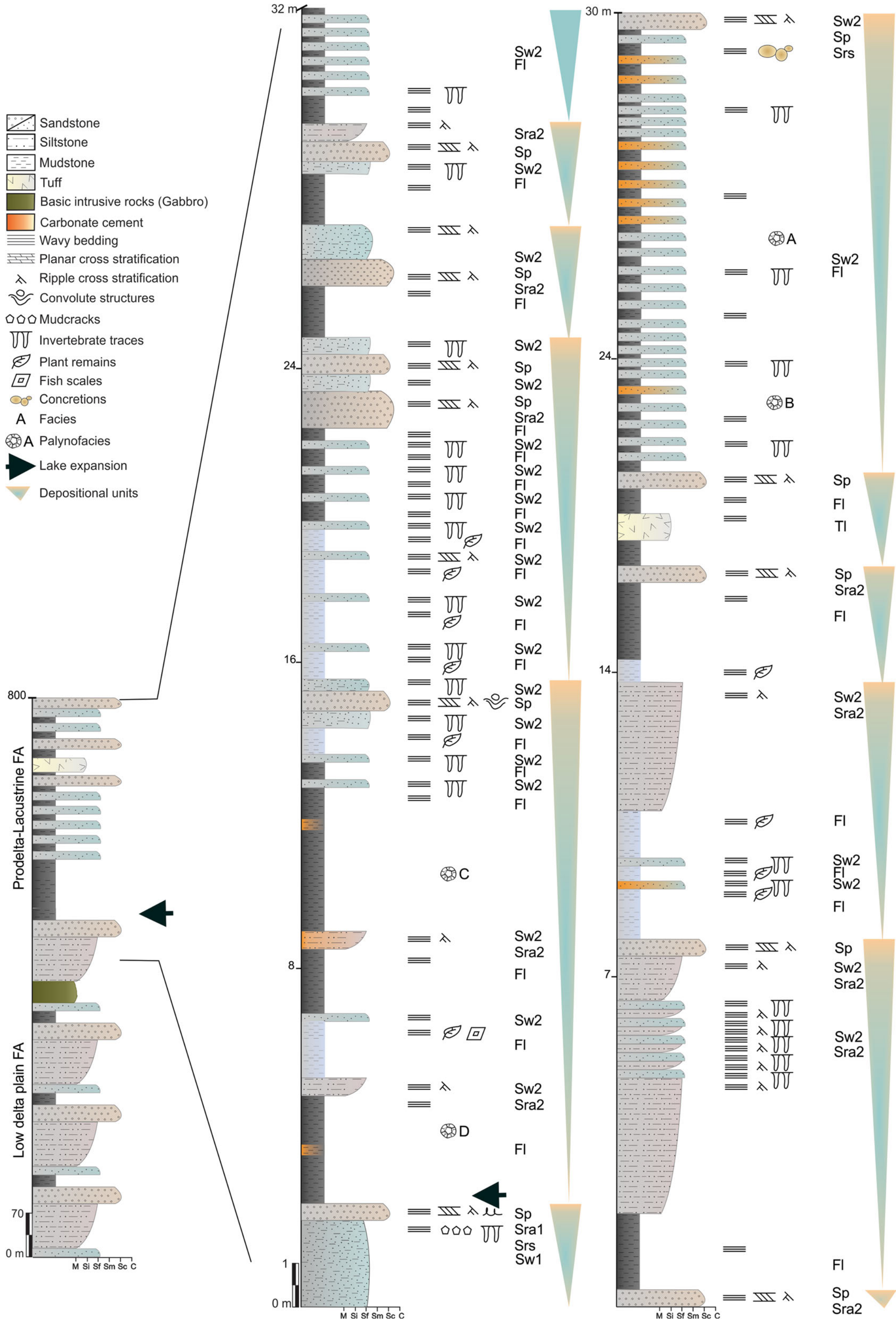


Fig. 1 Location map, geologic map, and stratigraphy of the Santa Clara subbasin, which is in the center region of the Cuyana rift basin, Argentina

Rocas, IANIGLA, Mendoza city, and made into standard thin sections at the Laboratorio de Cortes, Universidad Nacional de San Luis. Polished slabs were viewed under a low magnification microscope (Nikon NI-150 SMZ 1000) and thin sections under a petrographic microscope (Olympus BX-51).



Sandstone
Siltstone
Mudstone
Tuff
Basic intrusive rocks (Gabbro)
Carbonate cement
Wavy bedding
Planar cross stratification
Ripple cross stratification
Convolute structures
Mudcracks
Invertebrate traces
Plant remains
Fish scales
Concretions
A Facies
A Palynofacies
Lake expansion
Depositional units
800
70
0 m
Prodelta-Lacustrine FA
Low delta plain FA
M Si Sf Sm Sc C
32 m
24
16
8
1
0 m
30 m
14
7
A
B
C
D
Sw2
Fl
Sra2
Sp
Sra1
Srs
Sw1
Tl

◀**Fig. 2** Stratigraphic log of the Santa Clara Arriba Formation in the Santa Clara subbasin, Cuyana rift basin, Argentina (Location of log is shown in Fig. 1)

The nineteen remaining samples were used for palynofacies and palynostratigraphic studies from which seventeen samples were digested using concentrated HCl and HF and part of the resulting organic matter residue (kerogen) was used to produce "palynofacies slides" (after Batten 1982; Tyson 1993). The term palynofacies (Combaz 1964) is used to describe the composition of acid-resistant sedimentary organic matter (SOM) per layer. The remainder organic residue was prepared according to standard techniques for systematic palynology studies (Volkheimer and Melendi 1976). The relative numbers (%) of the organic matter (OM) constituents were calculated (SOM after Tyson 1993) on 500 total particles counted under 20× magnification on "palynofacies slides" where material was sieved by a 10 µm mesh. The percentages of sporomorphs and organic walled-microphytoplankton were calculated on 300 count palynomorphs as a minimum (Electronic Supplementary Material [ESM] Figure 4a, b). The values given in ESM Figures 1–3 represent the relative proportions of each constituent used for the analysis trends. Their percentages (%) were calculated using the statistical program PAleontological STatistics (PAST) by Hammer et al. (2001). The palynofacies associations were discriminated using a combination of qualitative (optical data) and quantitative (relative abundances/percentage proportions of OM components) criteria to categorize phytoclasts and palynomorphs (Table 2) according to Batten (1996) and Batten et al. (2005). Their distribution was analyzed through the outcropping section stablishing the relationships between organic components per sample, and the SOM provenance (according to their terrestrial/lacustrine index).

The palynologic slides are housed in the Paleopalynological Slide Collection of the IANIGLA, CCT-CONICET-MENDOZA, Argentina under numbers: MPLP 3318–3336 (Mendoza-Paleopalinoteca-Laboratorio de Paleopalinología). The microscopic study was done with a transmitted light microscope (Olympus BX50) and the photomicrographs were taken with an Olympus digital camera. Coordinates of specimens are denoted by an England Finder (EF) reference.

Results

Sedimentology

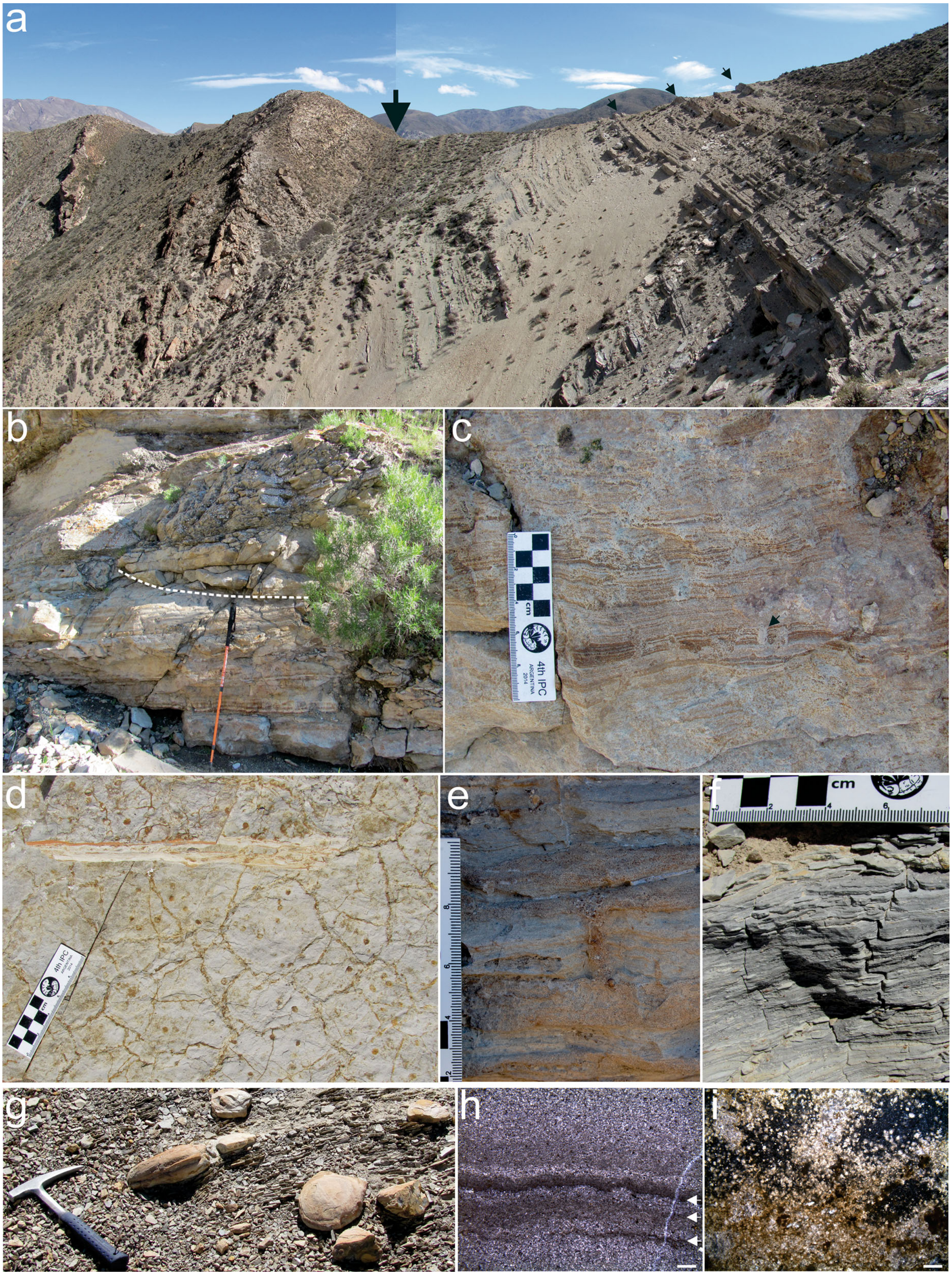
The lower section of the SCAF contains fine sandstone to siltstone layers with wavy bedding, trough cross-stratification, and ripple cross-lamination in 0.5–2.0 m thick units. They constitute 50–100 m thick packages alternating with siltstones and rarely mudstones for a total 800 m thickness. The upper section of the unit consists of stratified, very fine sandstones that alternate with organic-rich finely-laminated mudrocks (Fig. 2). This latter is the focus of this contribution (Fig. 3a). Details about the facies defined for the entire formation (lower and upper sections) are presented in Table 1 and a brief overview of the facies associations follows.

Facies associations

Facies association a

This facies association is represented by facies St–Sw1–Sra1–Srs–Fh–Fc–Tl (Table 1; Fig. 3b–e) and characterized by very fine to medium, poorly to well sorted sandstones, grayish orange (10YR7/4) in color. They form tabular to lenticular strata and 0.5–5 m thick units, and are laterally continuous for several tens of meters with inclined bedding and sharp to erosive bases (Fig. 3b). Tabular to lenticular layers are composed of wavy bedding defined by muddy siltstone alternating with fine sandstone (Sw1) (Fig. 3c) and sandstones with ripple cross-lamination (Sra). Symmetric ripples (Srs) are commonly associated with Sw1. Facies Sw1 presents vertical tubes (Fig. 3d), 5 cm long and 1 cm wide with passive infill (Fig. 3e). Facies Sw1, Srs, and Sra form units up to 25 m thick and are capped by thin (2 cm) pale green (5G7/2) siltstones with plant remains, vertebrate footprints, and tubes (Fh). Also associated with these facies are thin (0.2 m) coaly mudstone (N1) interbeds (Fc). Sandy, lenticular, laterally amalgamated layers of 1 m thick, show trough cross-stratification (St). Tuffaceous sandstones (Th) are interbedded with facies Fh (Fig. 2, 17 m).

Interpretation Trough cross-stratifed sandstones (St) forming sandy lenticular and laterally amalgamated bodies represent channelized tractive flows


a
b
c
d
e
f
g
h
i
cm
4th IPC
ARGENTINA
2014

◀**Fig. 3** Outcrop photographs and thin section microphotographs of the facies associations defined for the Santa Clara Arriba Formation (late Triassic), at the Santa Clara subbasin, Cuyana rift basin. **a** General overview of the upper section of the SCAF showing the change in the stacking pattern from progradational to aggradational (*arrow*) and again to progradational (*arrows*). **b–e** Photographs of facies association a. **b** Tabular to lenticular sandstones (*line*) with sharp bases and associated with Sw1 and Sr with abundant vertical tubes disrupting lamination. **c** Detail of **b** showing Sw1 disrupted by vertical tubes (*arrow*). **d** Plane view of silt drapes with abundant polygonal desiccation cracks and cross-sections of tubes. **e** Detail of the vertical tubes disrupting lamination in Sw1 facies showing passive infill. **f–i** Photographs of facies association b. **f** Detail of very fine lamination in the OM-rich mudstones of Fl facies. **g** Variable size pyrite-rich concretions aligned in the Fl facies. **h** Microphotograph showing the micrite lamination (*arrows*) in a very fine silty sandstone of the Sw2 facies. Scale is 2 mm. **i** Microphotograph showing spar intergrowth in the OM-rich mudstones of the Fl facies. Scale is 2 mm

likely associated with a tributary fluvial system. Coaly mudstones interbedded with St are interpreted as suspension settle-out deposits formed in ponds or lakes within floodbasins laterally adjacent to distributary channels on the delta plain (Nadon 1994; Makaske 2001) with high OM accumulation. Sw1 and Sra forming sheet-like sandstones indicate non-channelized tractive flows entering a body of water, probably a lake on a lower delta plain (Benvenuti 2003; Rajchl et al. 2008; Barrier et al. 2010; Bos 2010). Fh facies points to suspension settle-out processes from waning tractive flows entering a body of water (Larsen and Smith 1999) or simply overbank flow into lake flood basins from channel tributaries (Makaske 2001; Stoner and Holbrook 2010). Srs show wave reworking processes on sand within the delta front (Nadon 1994). Mudcracks, interpreted as desiccation cracks, within the muddy siltstone layers in the wavy bedding (Sw1) indicate short periods of exposure between sedimentation events. On the other hand, vertebrate footprints indicate that the delta plain lake was not very deep. The vertical tubes in Sw facies are interpreted as invertebrate burrows within the lake of the lower delta plain. Since outcrop is not well exposed being interrupted by faults, this interpretation is preliminary.

Facies association b

This facies association includes facies Sw2–Sra–Fl (Table 1; Fig. 3f–h) and is characterized by finely laminated mudrocks (Fl) of black color (N1) and 0.05–2.50 m thick with laminae 0.5 mm thick (Fig. 3f). The mudrocks have plant remains and fish scales and also pyrite-rich concretions from 5 to 20 cm in diameter that grew along layers horizontally (Fig. 3g). Thin sections of Fl facies show abundant OM aggregates preserved with pyrite (Table 1, ESM Figure 5, 32). These aggregates are characterized by rounded dark and opaque centers and they are approximately 10 µm in diameter. The mudrocks are interbedded with thin (2 mm), laterally lensoid and discontinuous layers of very fine sandstone from the lithofacies Sw2 and Sra. In thin section, this very fine sandstone/muddy siltstone (Sw2 facies) also has thin (40 µm) laminae of micrite (Fig. 3h). Thin sections of the Fl show spar infilling vugs and voids (Fig. 3i).

Interpretation Fl was deposited as suspension settle-out plumes in the offshore of the paleolake. Thin layers of Sw2 and Sra interbedded within Fl indicate minor contribution of tractive flows into the nearshore area dispersing sediment to the profundal zone characterizing the transition from the prodelta sedimentation towards the offshore (Fig. 2, 450 m, arrow; Fig. 3a, arrow) (Horton and Schmitt 1996). In this area, tractive flows from the delta front serve an underflows onto the lake bottom (Sturm and Matter 1978; Cohen 1990; Johnson and McCave 2008). The OM aggregates found in Fl are formed by coccoid algae remains that were preserved from oxidation. The spar in Fl is interpreted as secondary cement infilling vugs and voids. Micritic wavy laminae in Sw2 facies are interpreted as algae biofilms that favored substrate biostabilization (Noffke et al. 2001).

Depositional setting

The overall depositional setting proposed for the SCAF is a lower delta plain (facies association a) associated with prodelta deposits in a lacustrine system (facies association b). This might point to a gentle-sloped delta entering a shallow paleolake (Hamblin 1992; Rajchl et al. 2008), and could explain the lack of a facies association representative of the delta front subenvironment (Kroonenberg et al. 2005) in the low delta plain-prodelta-lacustrine facies transition found for the SCAF. That type of delta-lacustrine system is common in the hinge margins of rift basins during the sag stage (Hamblin 1992; Liu and Yang 2000), though a post-rift stage it is presumed for

Table 1 Facies associations and their characteristics defined for the Santa Clara Arriba Formation (Late Triassic) at the Santa Clara subbasin, central area of the Cuyana basin

Facies Association (FA)	Facies	Sedimentary structures	Bed geometry	Vertical and lateral relations	Fossil content	Processes	FA interpretation
a	Fossiliferous wavy bedding **(Sw1)**	Fine- to very fine-grained, well-sorted sandstones alternating with muddy silty layers. Sandy and silty layers are 1 cm thick with horizontal lamination and ripple cross-lamination. Mudcracks with 10 cm wide polygons in muddy silt layers	Tabular to lenticular, 0.5–2.0 m thick	Underlies facies Fh, Sra and Srs; overlies facies Sra	Abundant vertical tubes (trace fossils or plant stems), plant remains, vertebrate footprints	Tractive flows alternating with subaerial exposure	Distributary channels and ponds in the lower delta plain associated with mouth bars at the delta front
	Current ripple sandstones **(Sra1)**	Medium-grained, moderately sorted sandstones. Sra: asymmetric ripple cross-lamination, 5–7 cm thick ripple forms, amplitude is 10–15 cm. Rip-up clasts and convolute structures	Tabular, 0.5–1.5 m thick, inclined tops, convex to erosive bases	Underlies and overlies facies Sw1	Rare trace fossils	Tractive flows	
	Wave ripple sandstones **(Srs)**	Alternating very fine-coarse-grained well sorted-sandstone. Srs: symmetric, 2–4 cm thick ripple forms, amplitude is 20 cm	Tabular, 0.25–3.00 m thick	Underlies facies Sra and overlies facies Sw1	Rare trace fossils	Waves	
	Siltstones **(Fh)**	Horizontally-laminated muddy siltstones, laminae are 1 cm thick	Tabular, 0.1–0.5 m thick	Underlies and overlies facies Sw1	Plant remains	Suspension settle-out	
	Trough cross-stratifed sandstones **(St)**	Medium- to coarse-grained, poorly sorted sandstones with pebbles. St: 2 cm laminae in sets of 10 cm and cosets 50 cm thick; clast lags	Lenticular, 0.5–1.0 m thick	Underlies facies Sw1 and Fc, overlies facies Sra	–	Channelized tractive flows	
	Coaly mudstones **(Fc)**	Massive mudstones rich in OM	Tabular, 0.2 m thick	Underlies facies Sw1 and overlies facies St	–	Suspension settle out	
B	Finely laminated mudrocks **(Fl)**	Mudrocks with Fl: laminae are 1 mm thick, Fe concretions 5–20 cm in diameter, variable OM content associated with pyrite	Tabular 0.05–2.5 m thick	Underlies facies Sw2, Sra and Th; overlies facies Sw2, Sra, and Th	Plant remains, fish scales	Suspension settle-out	Prodelta to offshore lacustrine
	Tuffaceous sandstones **(Th)**	Very fine-grained-sandstone—single layer, containing angular quartz (70 %) and K-feldspar (5 %) crystals up to 1 mm long and 0.5 mm crystals of opaque minerals in a massive texture in the upper 85 cm with faint relict horizontal laminae (5 mm thick) of silty sandstone in the lowermost 15 cm	Tabular 1 m thick	Underlies and overlies facies Fl	–	Ash fall	
	Bioturbated wavy bedding **(Sw2)**	Fine to very fine-grained, well-sorted sandstones alternating with muddy silt layers. Horizontal lamination and ripple cross-lamination. Sandy and silty layers are 1 cm thick	Tabular, 0.5-2.0 m thick	Underlies facies Sra and Fl; overlies facies Sra and Fl	Abundant trace fossils only	Tractive flows	
	Current ripple sandstones **(Sra2)**	Medium-grained, moderately sorted sandstones. Sra: asymmetric ripple cross-lamination, 5–7 cm thick ripple forms, amplitude is 10–15 cm	Tabular, 1.5 m thick, inclined upper contacts, convex bases	Underlies facies Sw2 and Fl, overlies facies Sw2 and Fl	–	Tractive flows	

the SCAF deposits in agreement with the tectonic framework of the Cuyana rift, which did not reach a sag stage (Kokogian and Mancilla 1989; Barredo et al. 2011). Furthermore, sedimentation in delta systems of the hanging wall has been characterized as fine-grained deposits forming fewer, thicker, and sandier sequences than in the foot wall of rifts (Hamblin 1992; Soreghan and Cohen 1996). This is consistent with the proposal of the SCAF as being the infill of the Cuyana rift during late Triassic coincident with a post-rift stage of the basin. This lacustrine system may be of the overfilled type since a large river system is connected to a freshwater lake (Bohacs et al. 2000, 2003; Bohacs 2012). These type of lakes are formed within a tectonic basin as subsidence slows and the accommodation rate decreases, like during an early post-rift stage. A shallower basin would allow drainage to remain open and thus enabling overfilled lake conditions.

Palynology

Palynofacies analysis

Different components (palynomorphs, phytoclasts and amorphous organic matter [AOM]) and their features (size, shape, state of preservation) were identified in the palynofacies (Table 2; Fig. 4a–l). For the prodelta-lacustrine lithofacies associations, four groups of samples (Palynofacies assemblages A–D) (Figs. 4m–x; ESM Figure 3) were recognized. However, there are transitional characteristics of the organic components among established palynofacies assemblages.

Palynofacies A (samples 3319, 3320, 3334, 3335, 3336) (Fig. 4m–o; ESM Figures 1–3) It is characterized by highly terrestrial components. Common brown biostructured plant debris (woody particles, tracheids, cuticles and other tissues) occur together with translucent plant tissues and a high proportion of diverse terrestrial palynomorphs in good preservational state (Fig. 4m–n). Gymnosperm pollen (saccate and sulcate) dominates over diverse pteridophytic and bryophytic spores (commonly in tetrads); the ephedrale polyplicate grains are also common (ESM Figure 4). Samples 3319 and 3320 have the highest amount of vascular palynomorphs (Fig. 4m–o; ESM Figure 3). Sample 3336 presents organic vascular plant debris (mainly palynomorphs and woody fragments) highly corroded and obliterated by pyrite crystals (Fig. 4o). The AOM is mainly fibrous to membranous and in less proportion than in the other palynofacies assemblages. Unstructured debris (black and brown-dark phytoclasts) are minor components; however, the ratio of opaque and translucent phytoclasts fluctuates between these samples (ESM Figures 1–3).

Interpretation The relative abundance of sporomorphs with respect to other palynomorphs (especially microphytoplankton) indicates proximity to terrestrial sources. Sporomorph concentrations capable of diluting all other components are also generally restricted to the vicinity of active fluvio-deltaic sources (Tyson 1993). The iron supply along with bacterially-favored syngenetic formation of pyrite occurs from OM decomposition (Martin 1999). The palynofacies represents the highest percentage of total terrestrial material interpreted as fluvial input to the lacustrine depositional environment associated with the prodelta subenvironment of the SCAF paleolake (Fig. 5).

Palynofacies B (samples 3321, 3322, 3329, 3330) (Fig. 4p–r; ESM Figures 1–3) The fibrous and spongy AOM is the dominant component in this assemblage (69 up to 86 %), mostly in dispersed fragments rather than in masses or clottes. Biostructured brown to dark-brown phytoclasts are also common (Fig. 4p; ESM Figures 1–3). Unstructured phytoclasts (brown–black fragments) are comparatively fewer in proportion than in palynofacies A, and black debris are scarce. Well preserved gymnosperm pollen grains are abundant components (Fig. 4 p–q; ESM Figures 1–3); pteridophytic tetrad spores are also observed. The aquatic component is mainly represented by *Botryococcus* colonies (Fig. 4l, r; ESM Figure 4).

Interpretation This palynofacies exhibits high terrestrial input (Fig. 4p–q) suggesting that the degradation of terrigenous organic components contributed to the production of AOM and the palynofacies assemblages contain phytoclasts that suggest transportation due to their highly oxidized state (Fig. 4p). However, the presence of algal components (Fig. 4r), which are absent in Palynofacies A, points to a more lakeward subenvironment (Fig. 5). *Botryococcus* is a chlorococcalean green algae that characterizes lacustrine, fluvial, and deltaic facies in continental sequences.

Table 2 Principal components (palynomorphs and organic debris) identified within Palynofacies A–D characterized for the Santa Clara Arriba Formation (Late Upper Triassic), Santa Clara subbasin, Cuyana rift basin, Argentina

Palynomorphs and organic debris	Description and main features	Interpretation
Palynomorphs **(PAL)**	Spores and pollen grains; fungal remains; freshwater algae (Fig. 4m–o, l)	Vascular plants spores and pollen
Structured Phytoclasts **(SOM)**	Structured OM remains, mainly woody fragments, cuticles (epidermal cells, leaves and stems of vascular plants) with cellular structures, tubes and filaments, etc. (Fig. 4a, b, e–k)	Plant tissues derived from vascular plants (herbaceous and parenchyma)
Non-Structured Phytoclasts **(NSOM)**	Mainly woody and cuticular, highly degraded fragments, yellow–brown or orange–brown in color, angular in shape and small, without cellular structures. Black–brown to nearly black, highly degraded (without organic structures) particles, angular in shape and variable in size. Resin particles, yellow–orange in color or transparent with globular aspect and concoidal fractures (Fig. 4c–d)	Probably derived from woody remains
Opaque Black Debris **(OBD)**	Opaque dark–brown small particles, polygonal in shape (rectangular to triangular) (Fig. 4c, n–o)	Derived from highly oxidized woody remains (inertinite and vitrinite)
Amorphous Organic Matter **(AOM)**	Masses or aggregates with variable texture, fluffy, clotted, granular, fibrous, spongy etc., varying from colorless, through yellow to pale brown or brown–orange or brown (Fig. 4a, c, d, i–j, p–x)	Derived from highly degraded terrestrial matter and/or algal remains

Palynofacies C (samples 3318, 3324–3328, 3331) (Fig. 4s–u; ESM Figures 1–3) It is dominated by spongy and fibrous highly degraded AOM forming large masses or aggregates that include angular and small black–brown fragments and opaque particles (Fig. 4s–t). Rounded or angular opaque equidimensional phytoclasts (highly oxidized) occur together with degraded unstructured particles indicating transport (samples 3324–3328, 3331). Scarce woody fragments and other structured terrestrially-derived organic debris are minor constituents (Fig. 4s–u; ESM Figures 1–3). Palynomorphs (gymnospermous pollen grains) are also very scarce and poorly preserved (ESM Figures 4a–b).

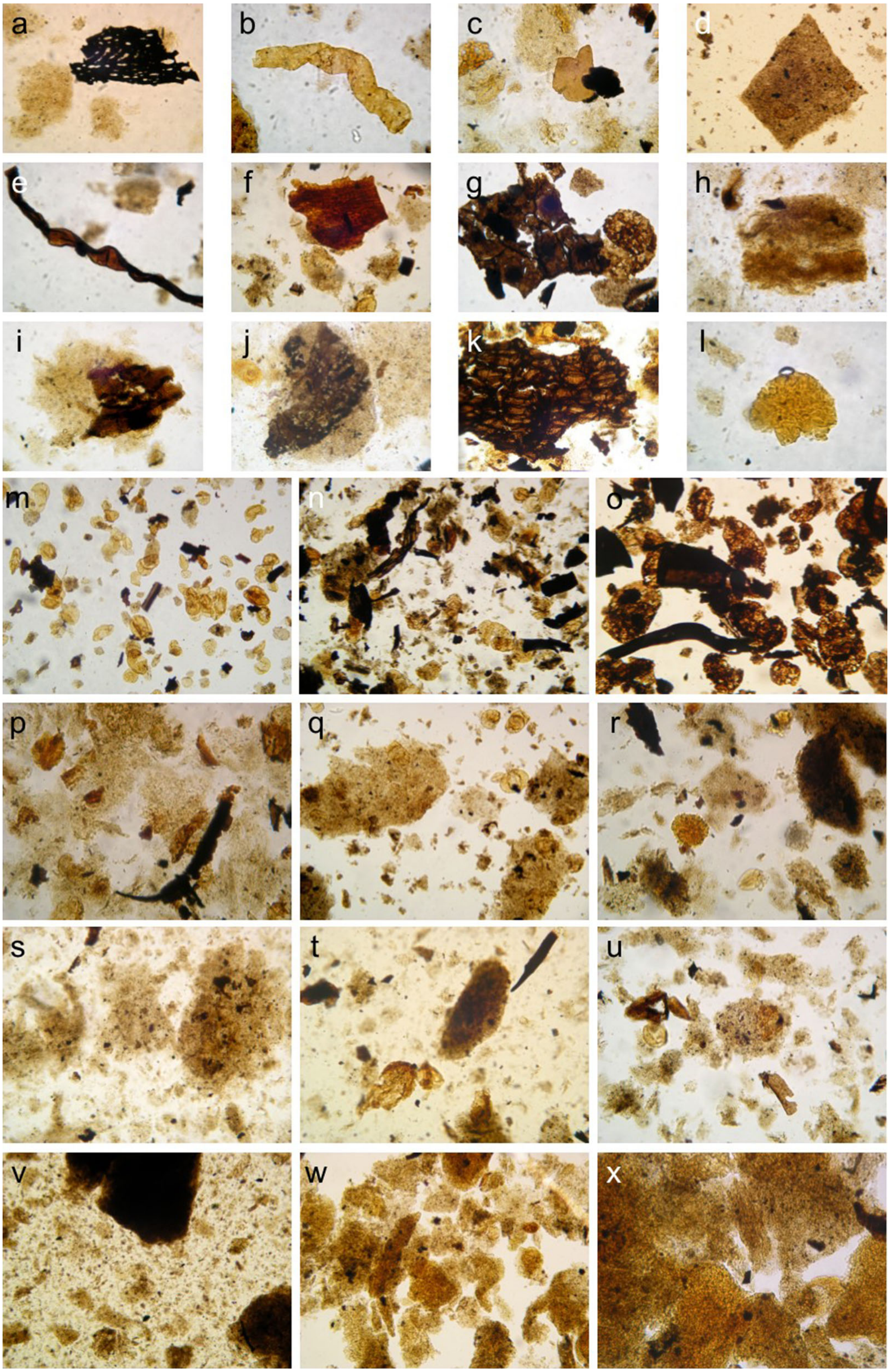
Interpretation Highly degraded AOM points to aerobic degradation and/or to indicate a trend to increasingly reducing conditions where its high percentage is attributed to high dysoxic-anoxic microbial productivity. Tyson (1993) indicates that high percentages of AOM reflect enhanced preservation under reducing conditions and sedimentation from active sources of terrestrial organic matter. This interval can be interpreted as a relatively shallow, high-energy subenvironment with terrestrial organic input and reducing conditions in more profundal conditions in the SCAF paleolake (Fig. 5).

Palynofacies D (sample 3323) (Fig. 4v–x; ESM Figures 1–3) This palynofacies assemblage is dominated by large spongy masses of AOM (88.2 %) (Fig. 4v–x; ESM Figures 1–3). They have a smooth surface and no internal lineations. Small poorly preserved *Botryococcus* colonies are identified (Fig. 4w–x). Opaque lath-shapes or small polygonal phytoclasts reach only 1.4 % and they are mostly included in the AOM masses. Palynomorphs are rare and they are also included in the AOM aggregates (Fig. 4w).

Interpretation The spongy large masses of AOM in association with *Botryococcus* suggest that most of the AOM aggregates result from degradation of this chlorophytic algae. This type of AOM is generally indicative of low energy, stagnant, oxygen-depleted environments (Tyson 1993). The palynofacies characterizes the profundal deposits of the SCAF paleolake (Fig. 5).

Palynostratigraphic analysis

The palynoflora assemblages constitute the unique paleontologic data to establish the age of the Santa Clara Arriba Formation, in addition to its stratigraphic relationships (Stipanicic et al. 2002; Spalletti and


a
b
c
d
e
f
g
h
i
j
k
l
m
n
o
p
q
r
s
t
u
v
w
x

◀**Fig. 4** Microphotographs of the palynofacies and their main components recorded in the SCAF section (Upper Triassic) at the Santa Clara subbasin, Cuyana rift basin, Argentina. **a–l** Main palynological components: **a** Carbonized (charcoal) traqueid fragment and very degraded AOM (MPLP 3324B R25/3) × 40. **b** Tube of probable algal remain (MPLP 3329A E26/5) × 40. **c** Unstructured phytoclast derived from mechanical breakdown of larger plant debris, opaque black debris and granular AOM masses (MPLP 3321E C35/2) × 40. **d** Very degraded phytoclast derived from vascular plant, faint lineation of the organic structure is preserved (MPLP 3331B J25/2) × 10. **e** Fungal structured filament (MPLP 3322B X30/0) × 40. **f** Lath-shaped structured woody particle, very degraded AOM, palynomorph, and opaque black debris (MPLP 3329A Y30/0) × 20. **g** Brown (oxidized) cuticle fragment and palynomorph with pyritic degradation (MPLP 3336C K42/1) × 40. **h** Structured woody phytoclast strongly degraded with partially visible cellular structure (MPLP 3318A H40/0) × 40. **i** Cuticle fragment with epidermal cells of higher plants and very degraded pale yellow granular AOM (MPLP 3326B T26/0) × 40. **j** Very degraded cuticle fragment and very degraded *pale yellow* granular AOM masses (MPLP 3318A H43/3) × 20. **k** Well preserved cuticular fragment (MPLP 3334A C30/0) × 20. **l** *Botryococcus* sp. (MPLP 3324C D28/0) × 40. **m–x** Palynofacies characterization: **m** Palynofacies A (terrestrial source), dominated by palynomorphs, phytoclasts and AOM in small clottes (MPLP 3319B F43/4) × 10. **n** Palynofacies A (terrestrial source) showing palynomorphs and small phytoclasts included in the AOM large masses (MPLP 3334A C37/4) × 10. **o** Palynofacies A (terrestrial source), showing large palynomorphs and carbonized structured vascular plant phytoclasts strongly degraded by pyritic crystals (MPLP 3336C U22/3) × 20. **p** Palynofacies B (mainly terrestrial source) dominated by large masses of granular AOM and common structured phytoclasts and palynomorphs (MPLP 3321E C25/1) × 20. **q** Palynofacies B showing large masses of granular AOM, common well-preserved palynomorphs, and small structured phytoclasts (MPLP 3322B V44/1) × 10. **r** Palynofacies B large masses of fibrous AOM including land plant detritus, very degraded granular AOM, well-preserved palynomorphs and small structured phytoclasts (MPLP 3329A R44/0) × 20. **s** Palynofacies C (mainly aquatic in origin). Dominated by very degraded granular AOM masses, some of them with palynomorphs and phytoclasts included inside (MPLP 3326A Y23/2). **t** Palynofacies C (mainly aquatic in origin) dominated by fibrous and granular AOM, with minor components of phytoclasts and palynomorphs (MPLP 3331A C43/0) × 20. **u**) Palynofacies C (mainly aquatic in origin) granular AOM masses mainly fluffy and clotted granular aspect, scarse structured phytoclasts and palynomorphs (MPLP 3325B Y42/3) × 20. **v** Palynofacies D (lacustrine), dominated by masses of variable size and texture, *dark brown* in color, dense and/or fibrous in aspect being mainly plant-derived palynodebris (MPLP 3323A F39/2) × 10. **w** Palynofacies D (lacustrine) showing AOM granular masses very degraded and *orange* globular masses derived from algal material (MPLP 3323C X31/1) × 10. **x** Palynofacies D (lacustrine) AOM of fibrous aspect derived from plant material and globular *yellow–orange* masses from degraded *Botryococcus* colonies (MPLP 3323C X37/)1 × 20. (Color figure online)

Zavattieri 2009). Two brief palynologic reports have been previously published on the SCAF (Zavattieri and Batten 1996; Zavattieri 2002). The palynofloral assemblages contain 93 species of spores, pollen grains, and algae (ESM Figure 5; ESM Table 1). The systematic description of the palynomorphs is presently under study. The information presented here, and the specimens figured (ESM Figure 5), should be regarded as a rough guide to characterize the SCAF assemblages and may provide a basis for comparison with other Argentinian and Gondwanan (mainly Australia and New Zealand) palynofloras (ESM Table 1). The SCAF continental diverse microflora is dominated by gymnospermous grains (saccate bi- and monosaccate, sulcate, and polyplicate pollen) and bryophyte and pteridophyte spores (ESM Figures 4, 5). Biostratigraphically significant taxa recorded in the SCAF palynoflora are in grey in the taxonomic listing (ESM Table 1).

Steevesipollenites claviger (ESM Figure 5: 42) recorded in SCAF is a diagnostic species of Carnian—early Norian age recovered in the *Craterisporites rotundus* Zone (de Jersey 1975; de Jersey and Raine 1990). However, *C. rotundus* has not been recorded up to now in the SCAF. ESM Table 1 shows the distribution of the selected and diagnostic species that characterize the *Duplexisporites problematicus* (=*Striatella seebergensis*) and *Polycingulatisporites crenulatus* Zones of eastern Australia and those of *Annulispora folliculosa* Zone of New Zealand, both designated as Carnian–early Norian in age (ESM Figure 5). Absence of the cheirolepidiacean pollen *Classopollis* (=*Corollina*) in this assemblage also suggests that the SCAF type section was deposited before the late Norian because its appearance in Triassic sequences in Argentina is recorded by the late Norian–Rhaetian range (Zavattieri and Batten 1996) (ESM Table 1). Therefore, the SCAF can be assigned preliminary to the late Triassic in age (Carnian-early Norian) based on the similar composition of the continental palynologic zonations from the Australasian Mesozoic. Thus, its deposition is proposed to have occurred before the Patagonian late Triassic palynofloras of the Paso Flores (Zavattieri and Mego 2008) and Comallo (Zavattieri et al. 1994) formations (ESM Table 1). The SCAF palynoflora conforms to the Ipswich phytogeographic province of the Gondwanan Triassic.

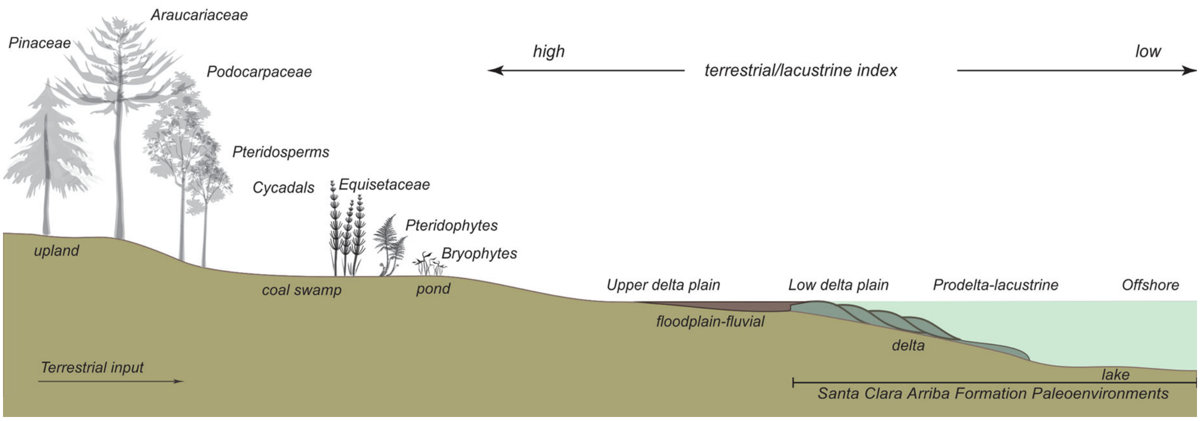


Fig. 5 Diagram (not to scale) of the Santa Clara Arriba paleolake at the Santa Clara subbasin, Cuyana rift basin, interpreted from sedimentary facies association and palynofacies

Discussion

The SCAF deltaic-lacustrine system is interpreted as a shallow lake developed in a shallowing basin as consequence of a declining subsidence. Most likely, this is linked to the post-rift stage of the Cuyana rift that has been recognized basin-wide for the different subbasins during the late Triassic (Kokogian and Mancilla 1989; Barredo et al. 2011).

The SCAF deposits could represent sedimentation in the hinged margin of the Santa Clara subbasin. Therefore, for the SCAF paleolake, relatively low accommodation space led to deposition of the low delta plain facies association linked to a prodelta-lacustrine facies association. The observed succession (arrow, Fig. 2) points to some possible abrupt facies change from the lower delta plain facies association to the prodelta-lacustrine facies association suggesting a modest lake level change from hydrologic changes from increased rainfall. An increased subsidence (possibly linked to tectonic reactivation) leading to water and sediment supply surpassed by the accommodation space might be a possibility that needs to be further explore with regional sedimentology data. More data from other parts of the subbasin are needed to clarify the changes in the sedimentary succession of the SCAF.

Productivity of the lake, as recorded by the total organic carbon (TOC), is moderate to high with dominant land plant contribution, indicating overfilled lake conditions (Bohacs et al. 2000, 2003; Bohacs 2012). The OM preservation was favored by high productivity and low destruction favored by the paleolake stratification or a low dilution factor indicating less fine-grained input. The presence of bioturbation associated with sandy lenses that disrupt the mudrock lamination supports oxygen entering the stratified lake through low-energy turbidity currents or density underflows (Lambert et al. 1976; Buatois and Mángano 2004).

Conclusions

The Santa Clara Arriba unit was a deltaic-shallow stratified lacustrine system developed probably in the hinge margin of one of the subbasins within the Cuyana rift. A general decreasing subsidence surpassed by water and sediment supply may point to an overfilled lake type development (Bohacs et al. 2000, 2003; Bohacs 2012) in an overall shallow post-rift basin that allowed an open drainage.

The AOM was derived from degradation of continental terrigenous and algal material input from proximal environment of the lake supporting a shallow lacustrine depositional setting for facies association b of the SCAF. Palynostratigraphic analysis allowed constraining the relative age of deposition of the SCAF as late Triassic (Carnian-early Norian) and dating the latest deposits of the Cuyana rift basin at the Santa Clara subbasin.

Acknowledgments Authors wish to thank the Suarez family for kindly granting access to their property, and Mr. M. Bourget, Dr. G. Giordano, and Dr. C. Pirrone for field assistance. Funding was provided by PICT 2013-0805 (ACM), PICT 2011-2546 (AMZ), and PICT 2014-0489 (CAB). We thank Dr. Silvia

Barredo and Dr. Mirta Quattrocchio for their constructive and helpful reviews to the manuscript. We also thank Guest Editors M. Rosen and S. Starratt for improving the quality of the manuscript.

References

Baldoni AM (1972) El género *Lepidopteris* (Pteridosperma) en el Triásico de Argentina. Ameghiniana 9:1–16

Barredo S, Chemale F, Marsicano C, Ávila JN, Ottone EG, Ramos VA (2011) Tectono-sequence stratigraphy and U-Pb zircon ages of the Rincón Blanco Depocenter, northern Cuyo Rift, Argentina. Gondwana Res 21:624–636. doi:10.1016/j.gr.2011.05.016

Barrier L, Proust J-N, Nalpas T, Robin C, Guillocheau F (2010) Control of alluvial sedimentation at foreland-basin active margins: a case study from the northeastern Ebro Basin (southeastern Pyrenees, Spain). J Sediment Res 80:728–749

Batten DJ (1982) Palynofacies, palaeoenvironments, and petroleum. J Micropalaeontol 1:107–114

Batten DJ (1996) Palynofacies and palaeoenvironmental interpretation. In: Jansonius J, McGregor DC (eds) Palynology: principles and applications, vol 26A, pp 1011–1064. American Association of Stratigraphic Palynologists Foundation, Lexington, Kentucky

Batten DJ, Stead DT (2005) Palynofacies analysis and its stratigraphic application. In: Koutsoukos EAM (ed) Applied stratigraphy, vol 10. Springer, Berlin, pp 203–226

Benavente CA, Mancuso AC, Cabaleri NG, Gierlowski-Kordesch EH (2015) Comparison of lacustrine successions and their paleohydrologic implications in the two subbasins of the Triassic Cuyana rift, Argentina. Sedimentology 62:1771–1813

Benvenuti M (2003) Facies analysis and tectonic significance of lacustrine fan-deltaic successions in the Pliocene–Pleistocene Mugello Basin, Central Italy. Sediment Geol 157(3–4):197–234

Bohacs KM (2012) Relation of hydrocarbon reservoir potential to Lake Basin type: an integrated approach to unraveling complex genetic relations among fluvial, Lake-Plain, lake margin and lake center strata. In: Baganz OW, Bartov Y, Bohacs K, Nummedal D (eds) Lacustrine sandstones reservoirs and hydrocarbon systems, vol 95, pp 13–56. AAPG Memoir, Tulsa, Oklahoma

Bohacs KM, Carroll AR, Neal JE, Mankiewicz PJ (2000) Lake-basin type, source potential, and hydrocarbon character: an integrated sequence-stratigraphic-geochemical framework. In: Gierlowski-Kordesch EH, Kelts KR (eds) Lake basins through space and time, vol 46, pp 3–34. AAPG Studies in Geology, Tulsa, Oklahoma

Bohacs KM, Carroll AR, Neal JE (2003) Lessons from large lake systems: thresholds, nonlinearity, and strange attractors. In: MA Chan, AW Archer (eds) Extreme depositional environments: mega end members in geologic time, vol 370, pp 75–90. GSA special paper

Bordas LS (1944) Peces triásicos de la Quebrada de Santa Clara. Physis 19:453–460

Bos IJ (2010) Architecture and facies distribution of organic-clastic lake fills in the fluvio-deltaic Rhine-Meuse System, The Netherlands. J Sediment Res 80:339–356

Buatois LA, Mángano MG (2004) Animal-substrate interactions in freshwater environments: applications of ichnology in facies and sequence stratigraphic analysis of fluvio-lacustrine successions. In: McIlroy D (ed) The application of ichnology to palaeoenvironmental and stratigraphic analysis. Geological Society, London, pp 311–333

Chebli GA, Ploszkiewicz JV, Azpiroz GM (2001) El Sistema Triásico y los hidrocarburos. In: Artabe A, Morel E, Zamuner A (eds) El Sistema Triásico en la Argentina, Fundación Museo de La Plata “Francisco Pascasio Moreno”, La Plata, pp 283–315

Cohen AS (1990) Tectono-stratigraphic model for sedimentation in Lake Tanganyika, Africa. In: Katz BJ (ed) Lake Basin exploration: case studies and modern analogs, vol 50, pp 137–150. AAPG Memoir, Tulsa, Oklahoma

Combaz A (1964) Les palynofaciès. Revue du Micropaleontologie 7:205–218

Cortés JM, González Bonorino G, Koukharsky MML (2003) Hoja Geológica 3369-03 Yalguaráz. Subsecretaría de Minería de la Nación, Servicio Geológico Minero Argentino, Provincias de San Juan y Mendoza República Argentina, p 95

De Jersey NJ (1975) Miospore zones in the Lower Mesozoic of southern Queensland. In: Campbell KSW (ed) Gondwana geology. Australian National University Press, Canberra, pp 159–172

De Jersey NJ, Raine JI (1990) Triassic and earliest Jurassic miospores from the Murihiku supergroup, New Zealand. N Z Geol Surv Paleontol Bull 62:1–164

Gierlowski-Kordesch E, Kelts K (1994) Global geological record of Lake Basins. Cambridge University Press, Cambridge, p 427

Goddard (1980) Geological rock color chart. Rock-color chart committee. Geological Society of America

Groeber P, Stipanicic PN (1953) Triásico. In: Groeber P, Stipanicic PN, Mingramm (eds) A.R.G.: Mesozoico. Geografía de la República Argentina, vol 2, no 1, pp 13–141. Sociedad Argentina de Estudios Geográficos GAEA

Hamblin AP (1992) Half-graben lacustrine sedimentary rocks of the lower Carboniferous Strathlorne formation, Horton Group, Cape Breton Island, Nova Scotia, Canada. Sedimentology 39:263–284

Hammer Ø, Harper DAT, Ryan PD (2001) PAST: Paleontological statistics software package for education and data analysis. Palaeontol Electr 4(1) [online content]. http://palaeoelectronica.org/2001_1/past/issue1_01.html

Harrington HJ (1971) Descripción geológica de la Hoja 22c Ramblón. Provincias de Mendoza y San Juan. Boletín n° 114. Dirección Nacional de Geología y Minería, Argentina, p 81

Horton BK, Schmitt JG (1996) Sedimentology of a lacustrine fan-delta system, Miocene Horse Camp Formation, Nevada, USA. Sedimentology 43:133–155

Johnson TC, McCave IN (2008) Transport mechanism and paleoclimatic significance of terrigenous silt deposited in varved sediments of an African rift lake. Limnol Oceanogr 53:1622–1632

Kokogian DA, Mancilla O (1989) Análisis estratigráfico secuencial de la Cuenca Cuyana. In: Chebli GA, Spalletti LA (eds) Cuencas sedimentarias Argentinas. Serie Correlación Geológica, vol 6. Universidad Nacional de Tucumán, San Miguel de Tucumán, pp 169–201

Kokogian D, Spalletti L, Morel E, Artabe A, Martínez R, Alcober O, Milana J, Zavattieri A, Papú O (1999) Los depósitos continentales triásicos. In: Caminos R, Panza J (eds) Geología Regional Argentina, Instituto de Geología y Recursos Minerales, Anales, vol 29, pp 377–398

Kroonenberg SB, Alekseevski NI, Aliyeva E, Allen MB, Aybulatov DN, Baba-Zadeh A, Badyukova EN, Davies CE, Hinds DJ, Hoogendoorn RM, Huseynov D, Ibrahimov B, Mamedov P, Overeem I, Rusakov GV, Suleymanova S, Svitoch AA, Vincent SJ (2005) Two deltas, two basins, one river, one sea: the modern Volga Delta an as analogue of the Neogene productive series, South Caspian Basin. In: Bhattacharya JP Giosan L (eds) River deltas—concepts, models, and examples, vol 83, pp 231–256. SEPM special publication

Lambert AM, Kelts K, Marshall NF (1976) Measurements of density underflows from Walensee, Switzerland. Sedimentology 23:87–195

Larsen D, Smith GA (1999) Sublacustrine-fan deposition in the oligocene creede formation, Colorado, USA. J Sediment Res 69:675–689

Legarreta L, Kokogian DA, Dellapé DA (1992) Estructura terciaria de la Cuenca Cuyana: ¿Cuánto de inversión tectónica? Revista de la Asociación Geológica Argentina 47:83–86

Liu S, Yang S (2000) Upper Triassic-Jurassic sequence stratigraphy and its structural controls in the western Ordos Basin, China. Basin Res 12:1–18

López-Arbarello A, Zavattieri AM (2008) Systematic revision of *Pseudobeaconia* Bordas, 1944 and *Mendocinichtys* Whitley, 1953 (Actinopterygii “Perleidiformes”) from the Triassic of Argentina. Palaeontology 51:1025–1052

Makaske B (2001) Anastomosing rivers: a review of their classification, origin, and sedimentary products. Earth Sci Rev 53:149–196

Martin RE (1999) Taphnomy. Cambridge University Press, Melbourne, pp 110–160

Nadon GC (1994) The genesis and recognition of anastomosing fluvial deposits: data from the St. Mary River Formation, southwestern Alberta, Canada. J Sediment Res B64:451–463

Nesossi DA (1945) Contribución al conocimiento geológico de Santa Clara. Provincias de Mendoza y San Juan (Zona limítrofe). Ph.D. Thesis. Universidad de Buenos Aires

Noffke N, Gerdes G, Klenke T, Krumbein WE (2001) Microbially induced sedimentary structures—a new category within the classification of primary sedimentary structures. J Sediment Res 71:649–656

Rajchl M, Ulicný D, Mach K (2008) Interplay between tectonics and compaction in a rift-margin, lacustrine delta system: miocene of the Eber Graben, Czech Republic. Sedimentology 55:1419–1447

Rolleri EO, Criado Roqué P (1968) La Cuenca Triásica del Norte de Mendoza. Terceras Jornadas Geológicas Argentinas, Actas I:1–76

Römer AS (1966) Las capas triásicas del “Gondwana” en la historia de la evolución de los vertebrados. Revista del Museo de Ciencias Naturales Bernardino Rivadavia, vol I, p 5. Buenos Aires

Sabato L, Bertini A, Masini F, Albianelli A, Napoleone G, Pieri P (2005) The lower and middle Pleistocene geological record of the San Lorenzo lacustrine succession in the Sant’ Arcangelo Basin (southern Appennines, Italy). Quat Int 131:59–69

Soreghan MJ, Cohen AS (1996) Textural and compositional variability across littoral segments of Lake Tanganyika: the effect of asymmetric basin structure on sedimentation in large rift lakes. AAPG Bull 80:382–409

Spalletti LA (1999) Cuencas triásicas del oeste argentino: origen y evolución. Acta Geológica Hispánica 32:29–50

Spalletti LA (2001) Evolución de las cuencas sedimentarias. In: Artabe AE, Morel EM, Zamuner AB (eds) El Sistema Triásico en la Argentina, Fundación Museo de La Plata “Francisco Pascasio Moreno”, La Plata, pp 81–101

Spalletti LA, Zavattieri AM (2009) El sistema lacustre de la Formación Mollar en el depocentro triásico de Santa Clara (provincia de Mendoza, Argentina). Andean Geol 36:236–263

Stappenbeck R (1910) La Precordillera de San Juan y Mendoza. Ministerio de Agricultura de la Nación. Sección Geología, Mineralogía y Minería, Anales, vol 4, no 3, pp 1–187. Buenos Aires

Stipanicic PN (1947) Estudio geológico, estratigráfico y tectónico de la Precordillera, al este del río de Los Patos en Sorocayense (San Juan). Tesis Doctoral. Universidad de Buenos Aires. Buenos Aires (Inédito)

Stipanicic PN (1983) The Triassic of Argentina and Chile. In: Moullade M, Nairn ED (eds) The phanerozoic geology of the World II, pp 181–199. The Mesozoic, B. Elsevier, Amsterdam

Stipanicic PN (2001) Antecedentes geológicos y paleontológicos. In: Artabe A, Morel E, Zamuner AB (eds) El Sistema Triásico en la Argentina. Fundación Museo de La Plata “Francisco Pascasio Moreno”, La Plata, pp 1–12

Stipanicic PN, Zavattieri AM, Marsicano C (2002) Grupo Peñasco. In: Stipanicic PN, Marsicano C (eds) Léxico Estratigráfico de la Argentina, VIII Triásico, Asociación Geológica Argentina. Series B, vol 26, pp 210–212

Stoner S, Holbrook J (2010) Geometric trends for floodplain lakes in high-accommodation floodplains and architecture of floodplain lake partitioning crevasse channels and splay deltas: AAPG Student Expo Article 90113, Houston, Texas

Strelkov E, Alvarez L (1984) Análisis estratigráfico y evolutivo de la cuenca triásica mendocina-sanjuanina. 9° Congreso Geológico Argentino, Actas, vol 3, pp 115–130. San Carlos de Bariloche

Sturm M, Matter A (1978) Turbidites and varves in Lake Brienz (Switzerland): deposition of clastic detritus by density currents. In: Matter A, Tucker M (eds) Modern and ancient lake sediments, vol 2, pp 147–168. Special Publication, International Association of Sedimentologists

Tyson RV (1993) Chapter 5: palynofacies analysis. In: Jenkins DG (ed) Applied micropaleontology. Kluwer Academic Publishers, Amsterdam, pp 153–191

Volkheimer W, Melendi DL (1976) Palinomorfos como fósiles guía: técnicas del laboratorio palinológico. Revista Minera de Geología y Mineralogía, Sociedad Argentina de Minería y Geología 34:19–30

Zavattieri AM (2002) Microfloras. In: Stipanicic PN Marsicano CA (eds) Léxico Estratigráfico de la Argentina, Volumen VIII: Triásico. Asociación Geológica Argentina, Series B, vol 26, pp 318–323

Zavattieri AM, Batten DJ (1996) Chapter 20B. Miospores from Argentinian Triassic deposits and their potential for intercontinental correlation. In: Jansonius J, McGregor DC (eds) Palynology: principles and applications, vol 2, pp 767–778. American Association of Stratigraphic Palynologists Foundation

Zavattieri AM, Mego N (2008) Palynological record of the Paso Flores Formation (Late Triassic) on the southeastern side of the Limay River, Patagonia, Argentina. Ameghiniana 45:483–502

Zavattieri AM, Volkheimer W, Rosenfeld U (1994) Palynology and facies of the Late Triassic of Comallo (Northern Patagonia, Argentina). Zentralblatt für Geologie und Paläontologie, Teil I:133–154