
Volume 30, Issue 2, 15 November 2010
ISSN 0895-9811
ELSEVIER
Journal of
South American
Earth Sciences
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Journal of South American Earth Sciences 30 (2010) 97–103

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Journal of South American Earth Sciences

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Age constraints for the northernmost outcrops of the Triassic Cuyana Basin, Argentina

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ARTICLE INFO

Article history:
Received 8 September 2009
Accepted 6 March 2010

Keywords:
U-Pb dating
Palynology
Anisian stage
Cerro Puntudo Formation
Cuyana Basin

ABSTRACT

Age constraints on the Cerro Puntudo Formation at the northernmost exposures of the continental Triassic Cuyana Basin are presented based on palynological data and U-Pb zircon dating. The lacustrine facies of the upper part of the Cerro Puntudo Formation contains a palynological assemblage with low diversity that is dominated by spores of ferns and lycopsids with subordinated inaperturated forms of uncertain affinity. The U-Pb SHRIMP zircon age of 243.8 ± 1.9 Ma (Anisian), obtained from juvenile magmatic zircons in a tuff interbedded in the same beds, provides the first chronostratigraphic date of the Cuyana Basin infilling at its northernmost exposures. According to additional dates already known from the southern part of the basin, a new stratigraphic correlation is proposed thus restricting the first tectono-sedimentary sequence (Synrift I depositional event of Kokogian et al. (1993)) to the Anisian. This depositional event has already been recorded in the Cacheuta and Rincón Blanco sub-basins, but it is for the first time now constrained across the whole basin.

1. Introduction

Triassic sedimentation along the southwestern margin of Gondwana (Argentina and Chile) was controlled by an extensional tectonics with the development of NW–SE trending narrow hemi-grabens. This event occurred approximately at the Permian–Triassic boundary, during the final stages of the Gondwanides event (e.g., Uliana and Biddle, 1988). The Cuyana Basin constitutes one of the most important volcano-sedimentary records that is wide-spread recorded by extensive outcrops along the Precordillera (Mendoza and San Juan provinces). The basin comprises at least two sub-basins and its infilling spans nearly the whole Triassic and has been extensively studied due to its hydrocarbon accumulation (e.g., Kokogian and Mancilla, 1989; Legarreta et al., 1992; Spalletti et al., 2008).

The northernmost exposures of the Cuyana Basin are restricted to the Cerro Puntudo locality on the western flank of the Pre-cordillera in the San Juan province. These exposures record the sedimentation near the northern end of the basin related to a fault tip end (López-Gamundí and Astini, 2004). Due to the lack of continuous outcrops and the scarcity of fossil information, correlations between the Cerro Puntudo succession and southern sections of the Cuyana Basin has relied primarily on lithostratigraphy and equivalent vertical distribution of depositional environments among outcrops (e.g., Strelkov and Álvarez, 1984; López-Gamundí and Astini, 2004). Thus, the presence of a distinctive lacustrine interval in the middle part of the sequence, which was considered the period of the highest accommodation space of the basin, was used to correlate the Cerro Puntudo column with the lacustrine deep deposits that crop out south of Cerro Puntudo at Quebrada del Tigre, on the northern margin of the San Juan River (López-Gamundí and Astini, 2004). Moreover, another correlation with deep lacustrine facies at the Rincón Blanco area (Ciénaga Larga), farther south, was also proposed (López-Gamundí and Astini, 2004).

More recently, U-Pb SHRIMP ages on beds that crop out at the Potrerillos locality have constrained the initial infilling of the basin (Synrift I and the beginning of Synrift II of Kokogian et al., 1993) to the Middle Triassic (Ávila et al., 2006; Spalletti et al., 2008), although correlations between this sections with others non laterally connected along the entire basin still remained debatable.

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doi:10.1016/j.jsames.2010.03.001

The aims of this paper are to present the first precise radiometric data on beds of the northernmost outcrops of the Cuyana Basin at the Cerro Puntudo area and to provide a new chronostratigraphic horizon for correlations along the basin. Palynological data from stratigraphic levels directly below the dated bed could serve as an independent correlation tool for unconnected deposits of the basin as well as for other Triassic successions of western Argentina.

2. Geological setting

In Southwestern South America several extensional rift-related basins developed during the Triassic. These basins evolved with NNW–SSE trend, along the western Gondwanan margin, as a consequence of a strong fabric control of the basement (e.g., Martínez et al., 2006) and an extensional event associated with the pre-breakup of Pangea (Uliana and Biddle, 1988). The westernmost depocenters documented a connection to the sea, whereas most of the Argentinean Triassic sedimentation was exclusively non-marine (Uliana and Biddle, 1988). The Cuyana Basin was the largest Triassic depocenter of western Argentina and its outcrops are exposed along both flanks of the Precordillera (Fig. 1). This basin includes at least two half-grabens, the southern and northern sub-basins, which suggest different master fault polarities (e.g., Ramos and Kay, 1991; Legarreta et al., 1992; Barredo, 2005). Some authors (e.g., Baldis et al., 1982) have considered that both depocenters represent independent geological histories. However, Strelkov and Álvarez (1984) linked both depocenters by lithological similarities and proposed an equivalent infilling history for the entire Cuyana Basin. In the northern hemigraben, sedimentation is documented by two sedimentary cycles that are also represented in the Uspallata hemigraben and were related to two synrift phases, the Synrift I and II, as was proposed by Kokogian et al. (1993).

The northernmost outcrops of the Cuyana Basin are developed at the Cerro Puntudo area (Fig. 1) and were first recognized by Xicoy (1962). Subsequently, Mombrú (1973) studied the succession and divided the Triassic column into two units, the Cerro Puntudo and El Relincho formations, which discordantly covers the Permo-Triassic Choiyoi Group (Mombrú, 1973; Strelkov and Álvarez, 1984; Sessarego, 1988). The Triassic succession is tectonically truncated at top.

3. Sedimentary cycles of Cerro Puntudo area

The first sedimentary cycle (Cerro Puntudo Formation) begins with a thick package of more than 500 m alluvial fan conglomerates and braid-plain cross-bedded coarse sandstones (Fig. 2). This package is mainly composed of an alternation of massive red clast-supported conglomerates and subordinated sandstones (Fig. 3A). The succession passes upward to a braided fluvial system dominated by red and reddish-brown conglomerates and sandstones that are arranged in lenticular beds with cross-bedded stratification (Fig. 3B). The coarse alluvial fan facies typically display a dispersion of the paleocurrents with mainly a southward direction (Mombrú, 1973; Strelkov and Álvarez, 1984; Sessarego, 1988; López-Gamundí and Astini, 2004). These alluvial deposits suggest an abundant sediment supply and a relatively low accommodation space in the basin (Fig. 2), controlled by tectonic processes during Synrift I initiation (e.g., Kokogian et al., 1993; Prosser, 1993; Gawthorpe and Leeder, 2000; Withjack et al., 2002).

Sheet-floods and an ephemeral fluvial system, characterized by red fine-grained sandstones and white mudstones, are developed over the braided fluvial deposits (Fig. 3C). This fluvial facies can be related with equal rates of sediment supply and generation of accommodation space (Fig. 2) (e.g., Prosser, 1993;

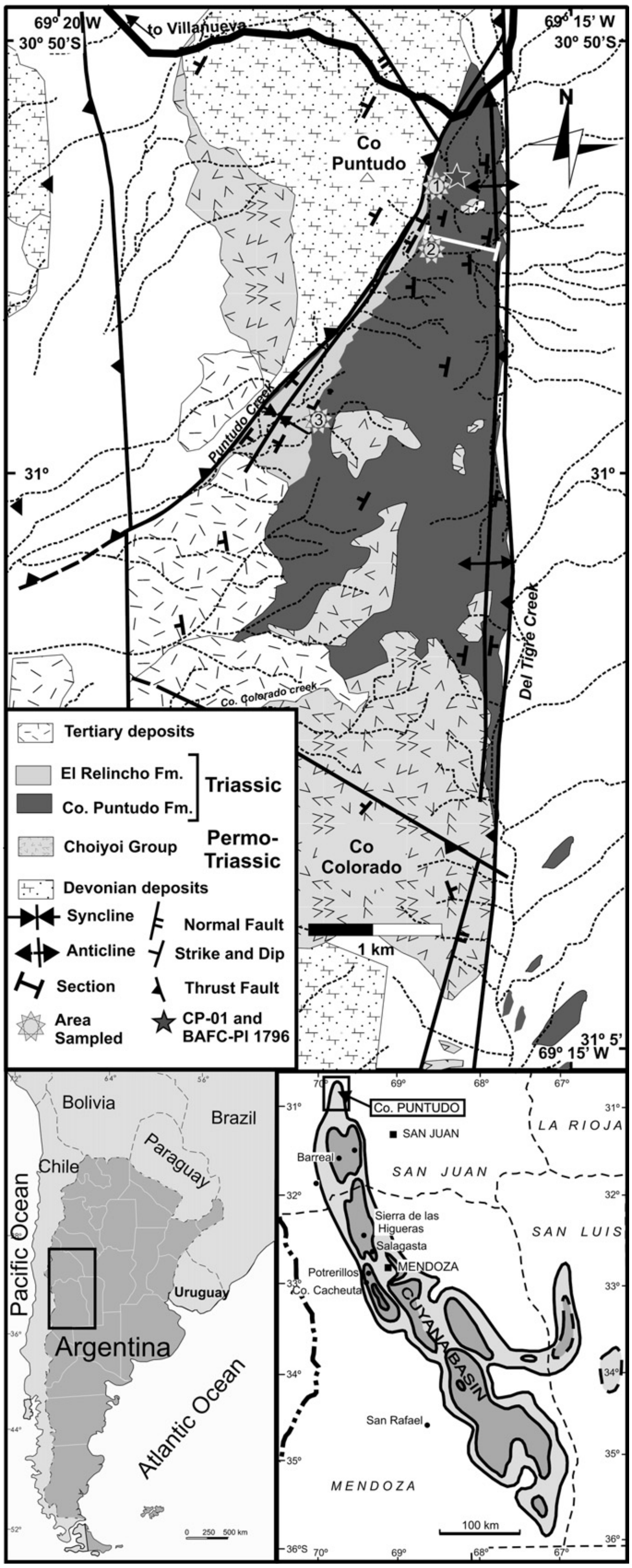

Fig. 1. Location map of Cuyana Basin, and the geologic map of the Cerro Puntudo area (modified from Stipanicic and Marsicano, 2002; Krapovickas et al., 2008). The star marks shows the area sampled and the location of the dating (CP-01) and palynological samples (BAFC-Pl 1796).

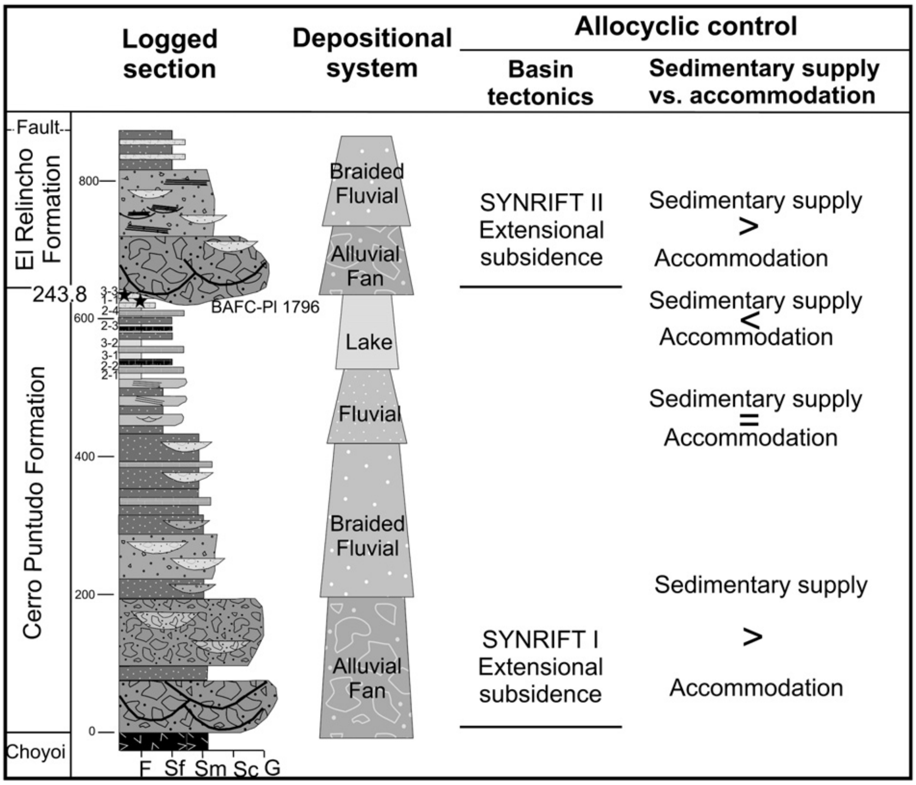

Fig. 2. A generalized lithostratigraphic section of the area between Cerro Puntudo and Cerro Colorado, showing a logged section, depositional characteristics, and allocyclic control. The star marks show the levels of the dating and palynological samples. The pair of numbers indicates the area and the level where the samples were collected. F: mudrock, Sf: fine sandstone, Sm: medium sandstone, Sg: coarse sandstone, G: grave.

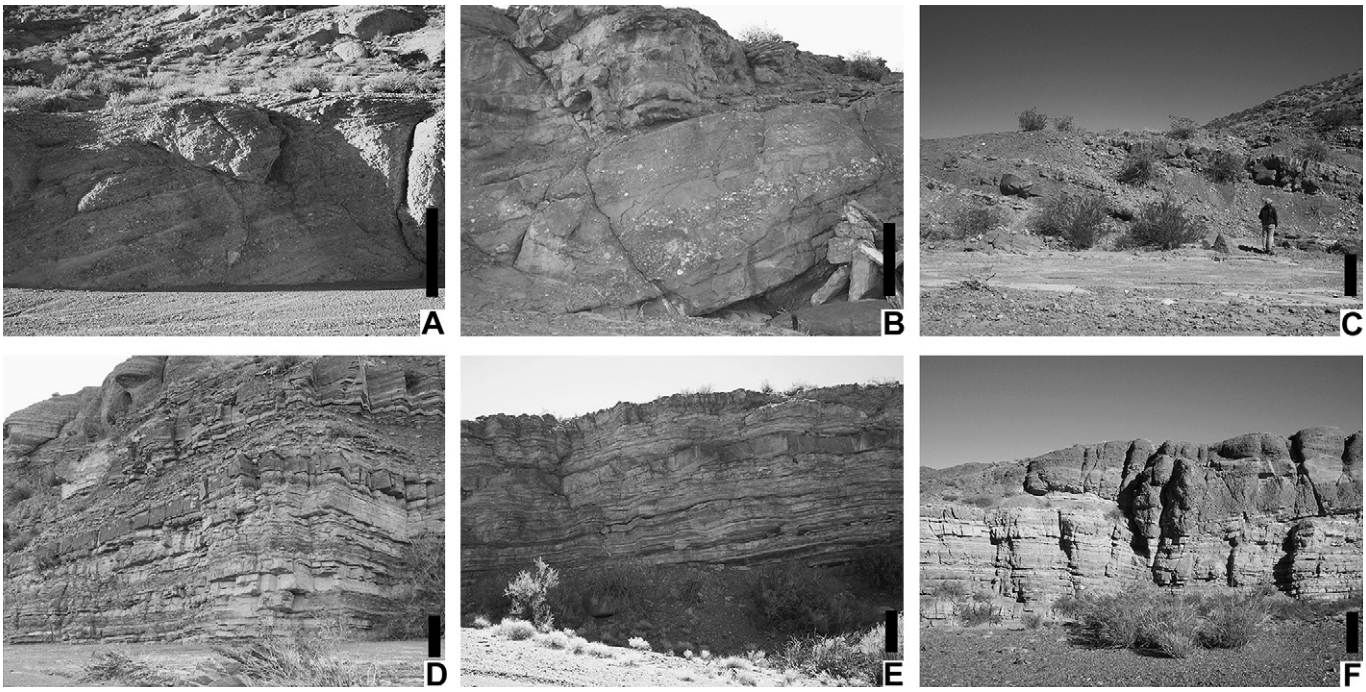

Fig. 3. Field photographs of the main sedimentary deposits. (A) Alternation of massive red clast-supported conglomerates and subordinated sandstones at the base of the Cerro Puntudo Formation. (B) Lenticular beds of conglomerates and sandstones of the Cerro Puntudo Formation. (C) Red fine-grained sandstones and white mudstones of braided fluvial system of the Cerro Puntudo Formation. (D) Well-stratified gray limestones, stromatolitic limestones, reddish brown mudstones, red fine-grained sandstones, and green tuffs of the upper part of the Cerro Puntudo in the northwest. (E) Reddish brown mudstones, red fine-grained sandstones, and green tuffs of the upper part of the Cerro Puntudo in the southeast. (F) Erosive unconformity between lacustrine deposits of the Cerro Puntudo Formation and the clast-supported conglomerate of the El Relincho Formation. Scale bar = 1 m.

Gawthorpe and Leeder, 2000; Withjack et al., 2002). Near the Cerro Puntudo, the upper part of this first sedimentary cycle comprises 75 m thick of well-stratified gray limestones, stromatolitic limestones, reddish brown mudstones, red fine-grained sandstones, and green tuffs deposited in a shallow carbonate-rich lake (Figs. 2 and 3D). To the southeast, the lacustrine deposits are dominated by siliciclastic facies made of reddish brown mudstones, red fine-grained sandstones, and green tuffs (Fig. 3E), with a paleocurrent pattern from the south. These fine facies suggest that the rate of sediment supply to the basin was lower than the generation of accommodation space (Fig. 2) (e.g., Prosser, 1993; Gawthorpe and Leeder, 2000; Withjack et al., 2002).

The second sedimentary cycle, represented by the El Relincho Formation, starts at the point where the lacustrine deposition is replaced by the deposition of alluvial fan facies with an exposed thickness of approximately 50 m. An erosive unconformity, produced by a lowering in the base level, separates the volcano-sedimentary units of the Cerro Puntudo and El Relincho formations (Fig. 3F). The El Relincho succession is dominated by green clast-supported conglomerates exhibiting pyroclastic clasts of the Cerro Puntudo Formation, and a pyroclastic and siliciclastic matrix mixture. The succession passes upward to 150 m of reddish brown, cross-bedded, coarse- to medium-grained sandstones deposited in a braided fluvial setting (Fig. 2). The alluvial–fluvial facies show an abrupt sediment supply in a relatively low accommodation space of the basin (Fig. 2), which was possibly controlled by tectonic processes during Synrift II initiation (e.g., Kokogian et al., 1993; Prosser, 1993; Withjack et al., 2002).

3.1. Paleontological content

The Triassic succession at the Cerro Puntudo area is nearly devoid of fossil remains. Mombrú (1973) briefly mentioned the presence of vertebrate fragments in tuffaceous levels near the top of the Cerro Puntudo Formation, a specimen that is at present lost. Invertebrates are represented exclusively by traces in fluvial and lacustrine facies, which included representatives of the *Skolithos* and *Scoyenia* ichnofacies (Krapovickas et al., 2008). Plant material is also very scarce in the sequence and is mainly represented as rhizoliths in the aerobic lacustrine facies. Only vegetal debris is present in the uppermost lacustrine levels due to the high supply of pyroclastic material (Mancuso et al., 2006; Mancuso, 2009).

Palynological sampling was conducted in three different areas (areas sampled are shown in Fig. 1), one black shale level in the Area 1, four black to brown shale levels in the Area 2, and three black to brown shale levels in the Area 3, all from the lacustrine deposit of the Cerro Puntudo Formation. One sample (1–1), close to the top of this deposit and just beneath the dated tuff, has yielded palynomorphs (BAFC-Pl 1796). This sample includes scarce kerogen, composed of opaque phytoclasts, wood fragments, and regularly preserved miospores (Fig. 4). The sparse and low diverse palynological assemblage is dominated by a few specimens of spores, with subordinated inaperturated forms of uncertain affinity (see list in Appendix 1). Due to carbonization, the palynomorphs are difficult to observe in detail. However, scarcity of the material was a major obstacle in trying to lighten the color of the palynomorphs by oxidants agents. Oxidation is a critical procedure that could result in irreversible damage of an assemblage like the present, composed of very few specimens. The palynoflora of the Cerro Puntudo Formation is quite dissimilar, in terms of composition, diversity and abundance, with coeval microfloras of Argentina (Zavattieri and Batten, 1996).

4. U-Pb geochronology

The studied sample corresponds to a tuff collected from the upper section of the lacustrine facies of the first sedimentary cycle (Cerro Puntudo Formation) (Fig. 2), near the Cerro Puntudo (Fig. 1). The zircons were separated by conventional procedures, using heavy liquids and a magnetic separator after being concentrated by hand panning. The most clear and inclusion-free zircons from the sample were handpicked for U-Pb sensitive high-resolution ion microprobe (SHRIMP) analyses. Handpicked zircons were mounted on epoxy discs along with zircon standards that were ground. The zircons were microphotographed in transmitted and reflected light, and imaged using a scanning electron microscope (SEM) and cathodoluminescence (CL). Then the mounts were cleaned and gold coated in preparation for the SHRIMP analysis. Analytical methods and data treatment can be found elsewhere (Williams, 1998). U-Pb data were reduced using Isoplot EX version 3.0 (Ludwig, 2003) (Table1).

The selected sample (CP-01) is an acid tuff interlayered within the lacustrine phase of the upper portion of the Cerro Puntudo section. The analyzed zircons are euhedral and inclusion-free crystals. The crystals are interpreted as igneous zircons formed during the tuff formation. Six spot analyses in six zircon crystals (Fig. 5), from 2 zircons (zircon 3 and 6) are excluded for age calculation. For this rock, the four youngest zircons yielded a $^{206}Pb/^{238}U$ age of 243.8 $\pm$ 1.9 Ma. The age is interpreted as the magmatic age of the volcanism associated with lake sediments (Fig. 6).

5. Correlations across the Cuyana Basin

Correlations among unconnected exposures of the Cuyana Basin were extensively based on fossil remains (mainly floral content), lithology, and distribution of equivalent depositional environments (e.g., Yrigoyen and Stover, 1970; Strelkov and Álvarez, 1984; Spalletti et al., 1999; Barredo and Ramos, 2010).

The tectono-sedimentary phase of a rift basin may be represented by one or more complete/incomplete rift stages, with a stratigraphic succession of fluvial to lacustrine conditions resulting from a complex interaction of fault propagation, climate, and sea/lake level (e.g., Gawthorpe and Leeder, 2000). Similar tectono-sedimentary evolution has been proposed to chrono-correlate the Cuyana Basin sub-basins which underwent at least two rift stages or tectono-sedimentary phases that were controlled by the fault propagation in the basin itself (e.g., Kokogian et al., 1993; Barredo, 2005). In the southernmost part of the Cuyana Basin, the Synrift I of Kokogian et al. (1993) includes the alluvial fan deposits of the Río Mendoza Formation covered by the fluvial/lacustrine rocks of the Cerro de Las Cabras Formation. Consistently, in the Cerro Puntudo section the first depositional cycle (Synrift I) is represented by coarse alluvial fan deposits and braided/ephemeral fluvial facies overlain by calcareous-rich lacustrine deposits, all included in the Cerro Puntudo Formation (Fig. 2). In the Potrerillos area, the beginning of the second synrift phase (Synrift II) is marked by a tectonic reactivation of the basin. This reactivation is recorded by the deposition of coarse fluvial deposits at the base of the Potrerillos Formation that overlie the lacustrine facies of the Cerro de Las Cabras Formation (Kokogian et al., 1993).

A recent radiometric age documented at the Potrerillos area (southern sub-basin) has yielded an age of 243 $\pm$ 5 Ma for the base of Cerro de Las Cabras Formation (Ávila et al., 2006) and it is chronostratigraphically equivalent to the age of 243.8 $\pm$ 1.9 Ma obtained herein for the lacustrine facies near the top of the Cerro Puntudo Formation. It is important to remark that both dates were obtained from beds that correspond to the lacustrine facies of the

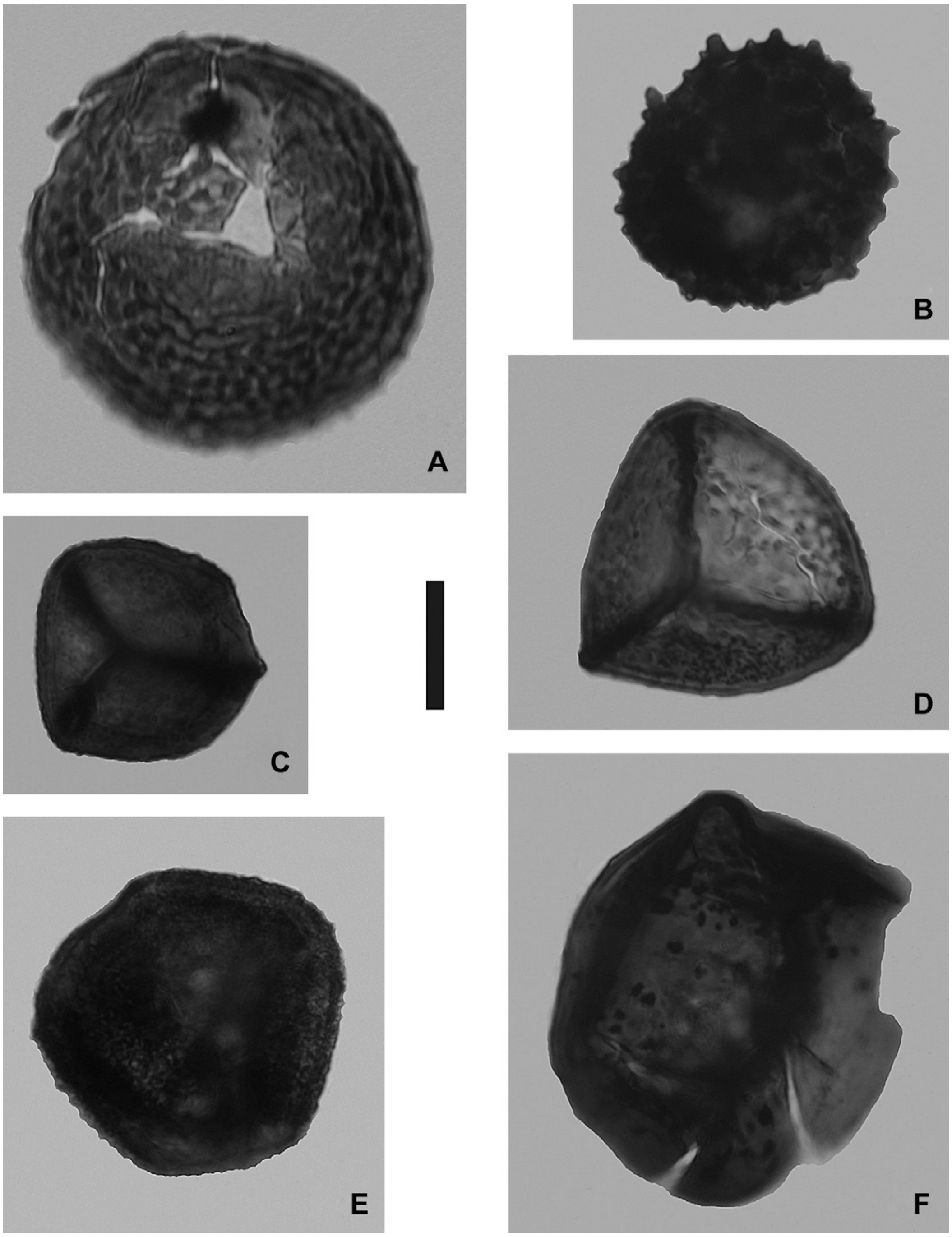

Fig. 4. (A) *Rugulatisporites* sp? BAFC-Pl 1796(1) K52/0. (B) *Verrucosisporites* sp. BAFC-Pl 1796(1) D48/0. (C) *Densoisporites* sp. BAFC-Pl 1796(2) W44/4. (D) *Converrucosisporites* sp. BAFC-Pl 1796(2) S34/4. (E) *Lundbladispora* sp. BAFC-Pl 1796(1) W31/3. (F) Inaperturated form of uncertain affinity BAFC-Pl 1796(1) S27/4. Scale bar = 15 μm.

first sedimentary cycle in both depocenters. Moreover, previous dates (235 ± 5 and 240 ± 10 Ma K-Ar) obtained from basaltic sills emplaced in the Cerro de La Cabras Formation at Paramillos de Uspallata (Ramos and Kay, 1991) are consistent with and Anisian age for the unit. Additionally, a second new age (239.2 ± 4.5 Ma) was recently obtained from overlying beds at the base of the Potrerillos Formation (Spalletti et al., 2008), thus constraining the age of the beginning of this second synrift phase in the basin. In the Cerro Puntudo area, the reactivation (beginning of Synrift II) is marked by the abrupt interruption of the lacustrine deposition and the instauration of an alluvial fan/braided fluvial setting (El Relincho Formation) (Fig. 2). In the Rincón Blanco area, situated farther south to Cerro Puntudo and also in the San Juan province, a similar facies arrangement is observed. Thus, the lacustrine facies of the top of the Cerro Amarillo Formation (Synrift I) are unconformably covered by the fanglomerates of the Panul Formation, indicating the beginning of the Synrift II (Barredo, 2005). In both Rincón Blanco and Cerro Puntudo localities, the lake deposits of the Synrift I were related to a semiarid climate period which enhanced the deposition of carbonates (Barredo, 2005).

Therefore, the new radiometric age presented herein can be precisely correlated with that from the Potrerillos area at the

Table 1
U-Pb SHRIMP Zircon results for sample CP-01.

Grain. Spot	[a]$\%^{206}Pb_c$	ppm U	ppm Th	$^{232}Th/^{238}U$	ppm $^{206}Pb^*$	$^{238}U/^{206}Pb^*$	% err	$^{207}Pb^*/^{206}Pb^*$	% err	$^{207}Pb^*/^{235}U$	% err	$^{206}Pb^*/^{238}U$	% err	err corr	(2) $^{206}Pb/^{238}U$	±
CP01-01	0,000	443	183	0,413	14,9	25,4	1,5	0,0524	1,8	0,284	2,3	0,0393	1,5	0,65	248	4
CP01-02	0,000	143	92	0,643	4,8	25,8	1,1	0,0497	5,1	0,266	5,2	0,0387	1,1	0,21	245	3
CP01-03	0,094	683	593	0,868	44,1	13,3	0,5	0,0539	1,6	0,559	1,7	0,0752	0,5	0,29	469	2
CP01-04	0,205	209	141	0,674	6,9	26,0	0,6	0,0487	3,4	0,258	3,4	0,0385	0,6	0,17	244	1
CP01-05	0,226	255	160	0,630	8,4	26,2	0,7	0,0492	3,9	0,259	4,0	0,0382	0,7	0,17	242	2
CP01-06	0,211	388	224	0,578	13,6	24,5	0,5	0,0482	1,9	0,271	2,0	0,0408	0,5	0,23	259	1

Errors are 1-sigma; Pb_c and Pb^* indicate the common and radiogenic portions, respectively. Error in Standard calibration was 0.57% (not included in above errors but required when comparing data from different mounts).
[a] Common Pb corrected by assuming $^{206}Pb/^{238}U$-$^{207}Pb/^{235}U$ age-concordance.

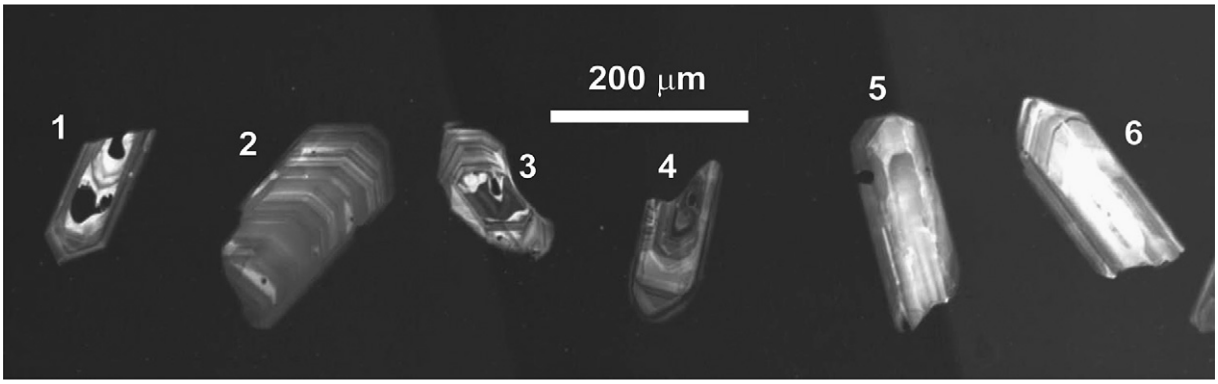

Fig. 5. Cathodoluminescence image of a dated igneous zircon of the CP-01 sample.

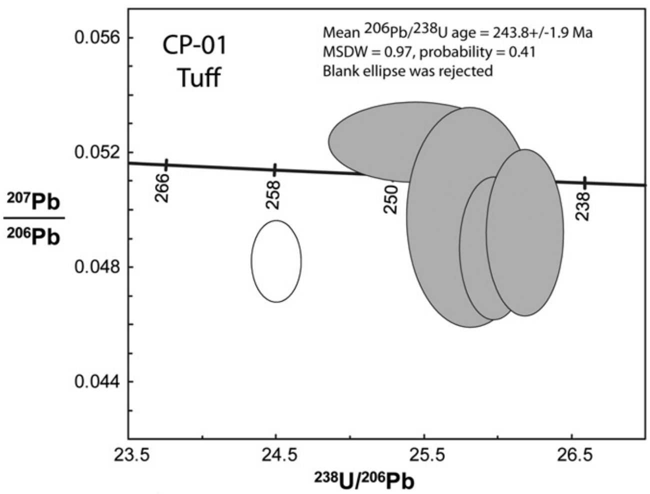

Fig. 6. U-Pb sensitive high-resolution ion microprobe (SHRIMP) zircon concordia diagram for tuff interlayed in the upper portion of the Cerro Puntudo section (sample CP-01).

southernmost outcrops of the Cuyana Basin. Both ages correspond to equivalent facies at the top of the first sedimentary cycle of the basin infilling thus constraining the deposition of the Synrift I of Kokogian et al. (1993) to the base of the Anisian and its consistent to the date obtained for the beginning of the second Synrift phase at the Anisian–Ladinian boundary (Spalletti et al., 2008). Therefore our results confirm the Anisian age for the deposition of the lacustrine beds at the top of the Synrift I succession and allow correlating this age along the whole Cuyana Basin.

The palynological record of the Cerro Puntudo Formation documented herein is proposed to be coeval with the well known palynofloras already known from the lacustrine levels of the Cerro de Las Cabras Formation at the Potrerillos area which suggested that the deposition of the unit occurred during Anisian times (Zavattieri and Batten, 1996; Zavattieri, 2002).

Acknowledgments

We are very thankful to Ivo A. Dussin (UFRGS) for his assistance during fieldwork and further discussions. We also acknowledge the valuable suggestions of both reviewers, A.M. Zavattieri (CRICyT-CONICET) and P. Pazos (UBA-CONICET), which improved the submitted version of the Ms. This study was financially supported by the PIP CONICET 5120 (EGO) and 5222 (W.Volkheimer), UBACyT X133 (CAM), PROSUL 490340/06-07 (Cesar Schultz) and PICT 32236 (AMC). Additional financial support was provided by the Consejo Nacional de Investigaciones Científicas y Técnicas (CONICET).

Appendix 1

List of taxa recorded in the palynological sample BAFC-Pl 1796

Pteridophyta
- *Anapiculatisporites* sp?
- *Biretisporites* sp?
- *Clavatisporites* sp.
- *Converrucosisporites* sp. (Fig. 4D)
- *Neoraistrickia* sp.
- *Punctatisporites* sp.
- *Rugulatisporites* sp? (Fig. 4A)
- *Verrucosisporites* sp. (Fig. 4B)

Lycophyta
- *Densoisporites* sp. (Fig. 4C)
- *Lundbladispora* sp. (Fig. 4E)

Uncertain affinity
- Inaperturated forms

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