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High-precision U–Pb zircon age from the Anfiteatro de Ticó Formation: Implications for the timing of the early angiosperm diversification in Patagonia

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ABSTRACT

The Baqueró Group is one of the most relevant units regarding the study of the early diversification of angiosperms in South America. Whereas the age of the upper part of the Group, namely the Punta del Barco Formation, has been recently dated at 114.67 ± 0.18 Ma, the rest of the unit still lacks precise dating. In this contribution a CA-TIMS U–Pb zircon age of 118.23 ± 0.09 Ma for a tuff interlayered with fossiliferous rocks of the Anfiteatro de Ticó Formation (lower part of the Baqueró Group) is reported. This age constrains the duration of deposition of the Baqueró Group to approximately 4 Ma and provides new evidence for the age interpretation of the previously described angiosperm flora and associated pollen assemblages from this unit, until now interpreted as early Aptian or possibly Barremian in age. The Aptian age of the Baqueró Group allows a better comparison between the paleofloras from this southernmost region.

1. Introduction

One of the most complete and diverse continental paleofloras developed during the Early Cretaceous is recorded in the Patagonian deposits of the Baqueró Group. Megascopic remains, as well as palynological assemblages, were recovered from the three lithostratigraphic units that compose the Group (Anfiteatro de Ticó, Bajo Tigre and Punta del Barco formations). Although these deposits have been studied since early in the last Century new fossil localities and specimens are still being found (Archangelsky and Villar de Seoane, 2005; Del Fueyo and Archangelsky, 2005; Passalia et al., 2010; Carrizo et al., 2011; Del Fueyo et al., 2012, 2013; Vera and Cesari, 2012; among others). The abundant paleobotanical and palynological content, which includes representatives of most of the major groups of plants, was summarized in the works of Archangelsky (2003), Del Fueyo et al. (2007), and Limarino et al. (2012).

Among the most relevant findings made on Baquero Group strata are some of the oldest records of angiosperm pollen and megafloristic remains for Argentina, representing a glimpse of the earliest stages of the flowering plants evolution. Archangelsky and Gamerro (1967) made the first mention of angiosperm pollen (*Clavatipollenites hughesii* Couper) from the Baqueró Group. Afterward, Archangelsky and Taylor (1993) studied in detail a small anther from the Anfiteatro de Ticó Formation which contained *Clavatipollenites* pollen masses. The younger unit of the Group (i.e., the Punta del Barco Formation) also contains angiosperm pollen grains, which were first described by Llorens (2003, 2005). Megascopic angiosperm remains from Baqueró Group were first described by Romero and Archangelsky (1986), who studied five angiosperm leaves collected from Anfiteatro de Ticó Formation outcrops at Estancia Bajo Tigre. Later, Passalia et al. (2003) reported

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a new form of angiosperm leaf from the same unit. In accordance with these results, Limarino et al. (2012) recognized the presence of angiosperm pollen grains throughout the Baqueró Group. Recently, Archangelsky and Archangelsky (2013) made a detailed systematic study of angiosperm pollen grains recovered from the Anfiteatro de Ticó Formation.

The emergence and rapid radiation of angiosperms during the Early Cretaceous is one of the most important events that occurred in the history of the terrestrial ecosystems. The origin and the different stages in the diversification of flowering plants have been the subject of many studies in southern South America since the late nineteenth Century (Passalia et al., 2001; Llorens, 2003; Cúneo and Gandolfo, 2005; Barreda and Archangelsky, 2006; Iglesias et al., 2007; Passalia, 2007; Archangelsky et al., 2009; Vallati, 2010; Perez Loinaze et al., 2012; Archangelsky and Archangelsky, 2013). However, one of the most important problems in the analysis and comparison between different sequences containing angiosperm pollen and megafloristic remains is the poor absolute dating (Hochuli et al., 2006). Integration of high-precision geochronology with the fossil record would address fundamental key-topics in the evolution of the modern ecosystems (Bowring and Schmitz, 2003).

In this work, a new absolute date obtained from a tuff recovered from the lower section of the Anfiteatro de Ticó Formation is presented. Also, the megafloristic content of the dated level, and palynological assemblages recovered from the levels immediately above and below the dated tuff, are given.

2. Geological setting and previous geochronology

The Baqueró Group is a continental – essentially fluvial and lacustrine – succession, which crops out in the central area of the Deseado Massif, and it is mostly composed of clastic and pyroclastic rocks (Cladera et al., 2002). This unit was originally defined as the Baqueró Formation with two members (Archangelsky, 1967). Cladera et al. (2002) proposed a different stratigraphic scheme, where these continental deposits were assigned to a new unit, the Baqueró Group, divided in three formations: Anfiteatro de Ticó, equivalent to the lower member of Archangelsky (1967), and Bajo Tigre and Punta del Barco, corresponding to the upper member of Archangelsky (1967). Recently, Limarino et al. (2012) presented a schematic stratigraphic section for the Baqueró Group (see Fig. 2), and recognized three Depositional Sequences and eight Facies Associations. The Anfiteatro de Ticó Formation, which is the focus of this work, consists of conglomerates, cross-bedded sandstones, fine-grained sandstones, and thin interbedded tuffs (Limarino et al., 2012).

The first paleontological studies in the area were made by Berry (1924) who, based on megafloristic remains collected from the eastern section of the Meseta Baqueró, suggested an Early Cretaceous age for the Baqueró sequence. Later, Feruglio (1937a, b, 1949) correlated these strata with those of a previously recognized unit (i.e., the "Complejo Porfírico de la Patagonia extra-andina") and, as a consequence, assigned an Upper Jurassic-Early Cretaceous age. In 1967, Archangelsky formally defined the Baqueró Formation, and based on their megafloristic content suggested a Barremian-Aptian age to this unit. Corbella (2001) dated by $^{40}Ar/^{39}Ar$, rocks from the middle section of Punta del Barco (119.65 ± 0.45 Ma) and Anfiteatro de Ticó (118.56 ± 1.40 Ma) formations, restricting the age of the Baqueró Group to the Aptian. Later, Corbella (2005) presented additional ages for the Anfiteatro de Ticó and Punta del Barco formations. The results obtained for the older unit were somewhat comparable to the ones previously reported by Corbella (2001), being 118.56 ± 1.40 Ma with the $^{40}Ar/^{39}Ar$, and 111.80 ± 7.40 Ma by fission track techniques. The age estimation for the Punta del Barco Formation, also made using the fission track technique, had an important degree of uncertainty, with ages ranging from 173 to c. 80 Ma (Corbella, 2005). Recently, Césari et al. (2011) published a CA-TIMS U–Pb zircon age of 114.67 ± 0.18 Ma for an interbedded tuff from the Punta del Barco Formation.

3. Methodology

3.1. Isotopic dating

The dated sample was collected from a tuff level from the lower part of the Anfiteatro de Ticó Formation, cropping out at the Anfiteatro de Ticó locality (48° 30′ 35.24″ S, 69° 14′ 11.47″ W, Fig. 1). The tuff is located approximately 40 m above the contact with the underlying Bajo Grande Formation (Fig. 2). It is a tabular bank, 0.8 m in thickness, containing abundant accretionary lapilli. This deposit covers an irregular surface, interpreted by Limarino et al. (2012) as a low-relief incision carved into lacustrine deposits. The sampled level corresponds to the Stratigraphic Level 5 of the Depositional Sequence 1, as recently proposed by Limarino et al. (2012).

Abundant megafloristic remains and silicified trunks have been recovered from this tuff (Limarino et al., 2012; Vera and Cesari, 2012), which add to the palynological assemblages obtained from the levels immediately above and below, composed by dark gray fine-grained sandstones, rich in organic matter, deposited in a lacustrine environment.

U–Pb dating was done at the Pacific Centre for Isotopic and Geochemical Research housed in the Department of Earth and Ocean Sciences (EOS) at the University of British Columbia. The technique used is a modification of CA-TIMS procedures outlined in Mundil et al. (2004), Mattinson (2005) and Scoates and Friedman (2008). Uncertainties in age are reported at the 95% level of confidence.

3.2. Palynology

Palynological analysis from Anfiteatro de Ticó Formation was carried out on one sample above the level dated (BA Pal 6227) and five samples below this level (BA Pal 6217, 6222–6225). The samples were treated by means of standard techniques for extraction and concentration of palynomorphs. Observations were made with an Olympus BX-51 microscope equipped with a Nikon DS-Fi1 digital camera for photomicrography. Coordinates of the illustrated specimens are cited as England Finder references. The slides are deposited in the Palynological Collection of the Museo Argentino de Ciencias Naturales "Bernardino Rivadavia" (BA Pal).

4. Results

4.1. U–Pb dating

Six zircons from the tuff sample from the lower levels of the Anfiteatro de Ticó Formation were individually analyzed, with U–Pb data listed in Table 1. An age of 118.23 ± 0.09 Ma is based on the weighted average of $^{206}Pb/^{238}U$ dates for the six concordant and overlapping analyses (MSWD = 0.68; Fig. 3; Table 1). Based on this result, the Anfiteatro de Ticó Formation can be assigned to the late Aptian, according to the current Geologic Time Scale (International Chonostratigraphic Chart, 2012).

4.2. Palynological and megafloristic content

Abundant megafloristic remains were recovered from the same dated tuffaceous strata. Megafossils include the fern fronds *Korallipteris* sp. (="*Gleichenites*" sp.) and "*Phlebopteris–Matonidium–*

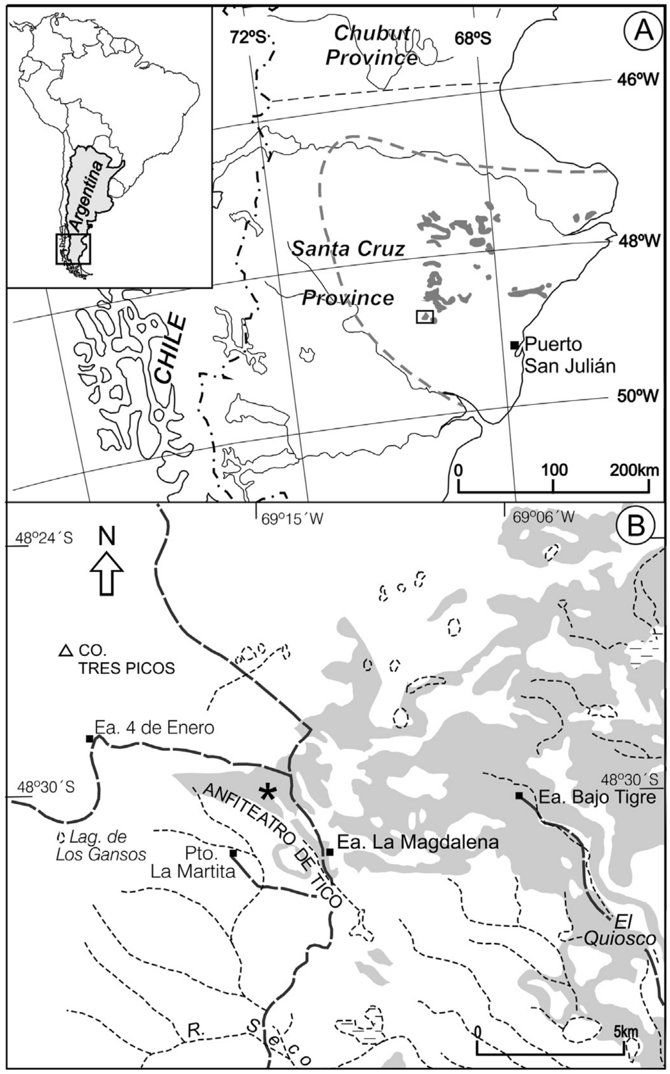

Fig. 1. A. Map showing outcrops of Baqueró Group (gray) in the Deseado Massif Area. B. Detail of the Anfiteatro de Ticó area (rectangle in A). Asterisk denotes the sampling area. Modified from Césari et al. (2011) and Limarino et al. (2012).

Matonia" complex, conifer leaves (*Brachyphyllum* sp.) and silicified trunks (*Brachyoxylon* sp. cf. *B. boureaui* Serra), together with *Taeniopteris* sp. leaves (see Limarino et al., 2012).

Fine-grained sandstones located immediately above the dated tuffaceous level contain masses of charcoalified gleicheniacean stems and petioles with preserved anatomy (Limarino et al., 2012; Fig. 4. 5–6) and a well-preserved palynological assemblage (BA Pal 6227; Table 2). This sample is characterized by the presence of abundant pollen grains of Podocarpaceae e.g., *Gamerroites volkheimeri* Archangelsky, *Microcachrydites antarcticus* Cookson, *Podocarpidites ellipticus* Cookson, *Podocarpidites marwickii* Couper, *Podocarpidites multesimus* (Bolkhovitina) Pocock, *Podocarpidites parviauriculatus* Archangelsky and Villar de Seoane, *Trichotomosulcites microsaccatus* (Couper) Srank (=*Trisaccites microsaccatus*), Araucariaceae (*Balmeiopsis limbatus* (Balme) Archangelsky, *Cyclusphaera psilata* Volkheimer and Sepúlveda, *Cyclusphaera radiata* Archangelsky emend. Del Fueyo, Archangelsky and Archangelsky), and Cheirolepidiaceae (*Classopollis classoides* Plugs, *Classopollis* sp.), with other gymnosperms represented by a minor number of specimens, such as *Alisporites* sp. (Pteridospermophyta) and *Cycadopites follicularis* Wilson and Webster. Among the spores, are recognized *Baculatisporites comaumensis* (Cookson) Potonié (Osmundaceae), *Cibotiidites auriculatus* Archangelsky and Villar de Seoane (uncertain affinity), *Cibotiumspora juncta* (Kara-Murza) Singh (Dicksoniaceae), *Gleicheniidites senonicus* Ross (Gleicheniaceae), *Ruffordiaspora australiensis* (Cookson) Dettmann and Clifford and *Cicatricosisporites cuneiformis* Pocock (Schizaceae). Other components of the assemblage are the abundant angiosperm pollen grains represented by *Clavatipollenites* sp. A (Llorens, 2005), characterized by the presence of short collumelae, with muri wider than lumina, and an irregularly developed colpus; *Clavatipollenites* sp. 1 Archangelsky and Archangelsky, and *Jusinghipollis* sp., with a trichotomocolpate aperture and large columellae (Table 2).

The stratigraphic levels, located below the dated tuff, yielded five palynological assemblages (BA Pal 6217, 6222–6225; Table 2) and mummified cuticles of gymnosperms, such as Bennettitales (cf. *Zamites grandis* (Menéndez) Archangelsky and Baldoni and cf. *Ptilophyllum longipinnatum* Menéndez) and conifers (*Brachyphyllum* sp. cf. *B. irregulare* Archangelsky). These palynological samples have a diversity greater than the one observed in the strata above the tuff (Table 2). Palynological taxa recognized in BA Pal 6227 are also

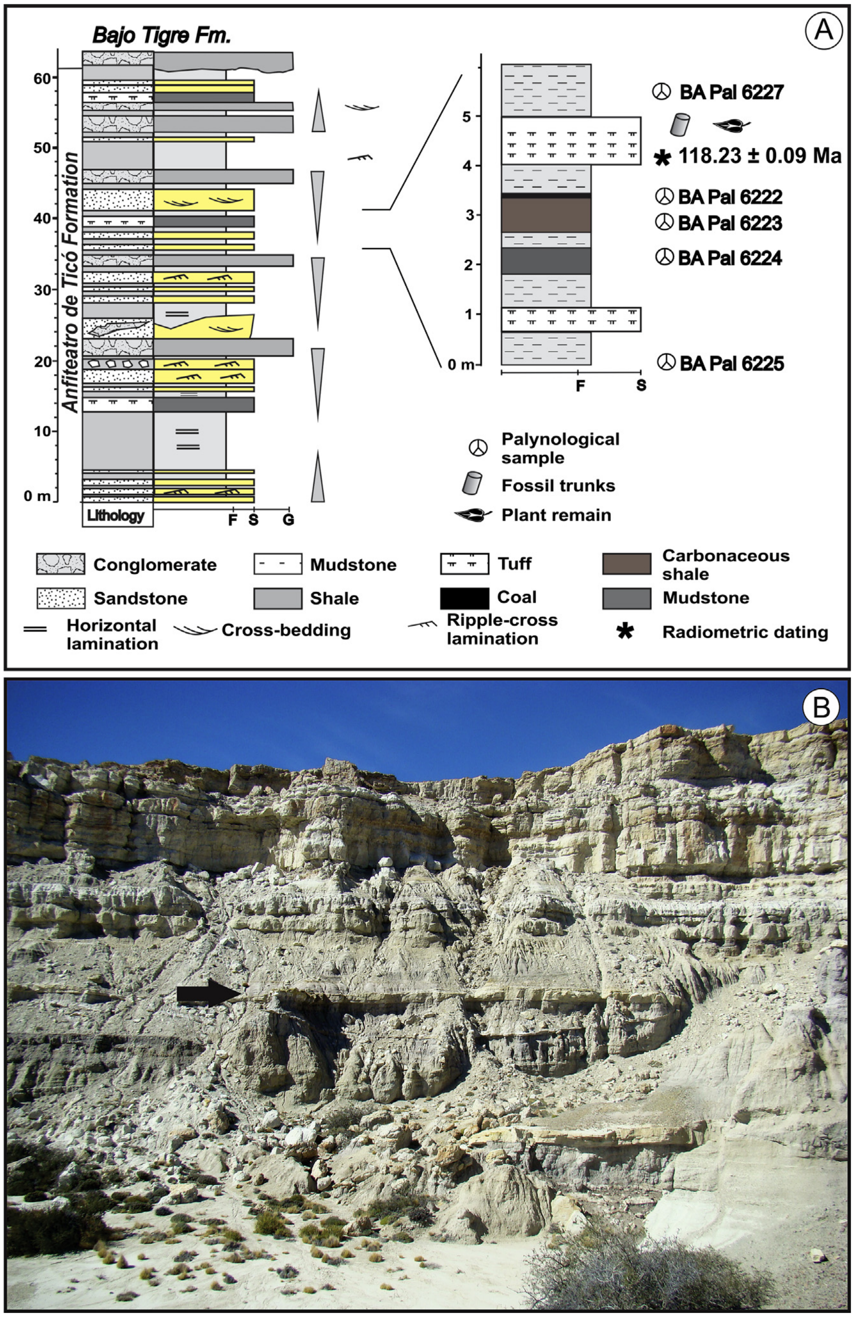

Fig. 2. A. Stratigraphic section of the Anfiteatro de Ticó Formation, showing the dated tuff and provenance of the studied palynological levels. B. View of the Anfiteatro de Ticó Formation in the Anfiteatro de Ticó locality, showing the dated tuff level.

present here, along with *Aequitriradites verrucosus* (Cookson and Dettmann) Cookson and Dettmann, *Aequitriradites spinulosus* (Cookson and Dettmann) Cookson and Dettmann, *Antulsporites baculatus* (Archangelsky and Gamerro) Archangelsky and Gamerro, *Appendicisporites unicus* (Markova) Singh, *Callialasporites trilobatus* (Balme) Dev, *Callialasporites dampieri* (Balme) Dev, *Capsispora vulcanica* Llorens, *Coptospora foveolata* Archangelsky and Villar de Seoane, *Cyatheacidites tectifera* Archangelsky and Gamerro, *Singhia multicostata* (Brenner) Lima, *Triporoletes reticulatus* (Pocock) Playford, *Trilobosporites apiverrucatus* Couper, *Trilobosporites purverulentus* (Verbitskaya) Dettmann, *Trilobosporites trioreticulosus* Cookson and Dettmann, *Densoisporites corrugatus* Archangelsky and Gamerro, *Densoisporites velatus* (Weyland and Krieger) emend. Krasnova, *Foraminisporis dailyi* (Cookson and Dettmann) Dettmann, and *Foraminisporis asymmetricus* (Cookson and Dettmann) Dettmann, among others. Angiosperms are also present in this level, with both taxa identified above the tuff deposit, as well as *Retimonocolpites* sp. A (Llorens, 2005), characterized by an elliptical amb with acute ends and thin muri, which can be partially lost. However, it is important to note that this latter taxon, along with *Clavatipollenites* sp. A, is present in different stratigraphic levels of the Baquero Group strata, from basal sections of the Anfiteatro de Ticó Formation, to the younger Punta del Barco Formation (Llorens, 2005).

5. Discussion

The Baqueró Group is important to understanding the Cretaceous communities not only by its abundant and very well

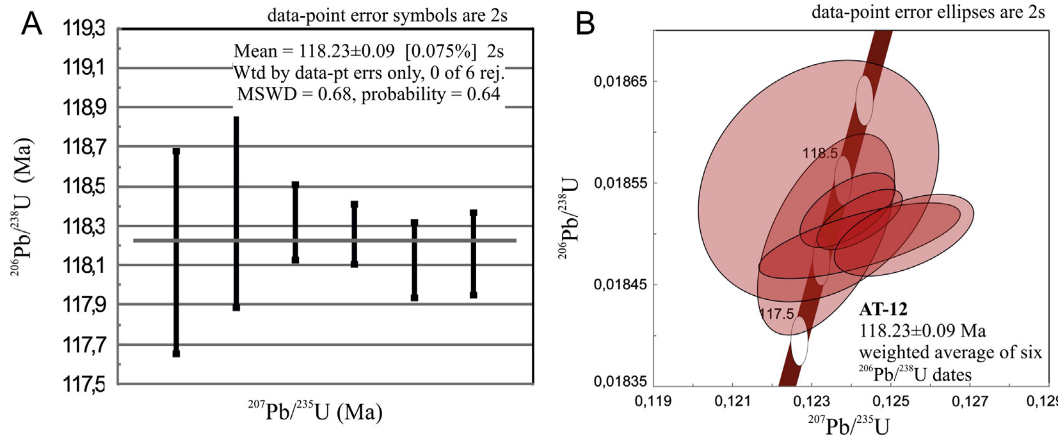

Fig. 3. U–Pb concordia plot and $^{206}Pb/^{238}U$ histogram showing data from six analysed zircon grains.

preserved paleobotanical and palynological records, but also for being one of the few Lower Cretaceous lithostratigraphic units dated with high-precision geochronology. An age of 118.23 ± 0.09 Ma obtained from the lower levels of the Anfiteatro de Ticó Formation, along with the CA-TIMS U–Pb age recently obtained for the Punta del Barco Formation (Césari et al., 2011) constrains sedimentation of the Baqueró Group to the late Aptian.

This new isotopic dating is comparable than the $^{40}Ar/^{39}Ar$ age of 118.56 ± 1.4 Ma obtained by Corbella (2001) for the Anfiteatro de Ticó Formation, and more precise than the age of 111.8 ± 7.4 Ma obtained later by the same author by fission track on zircon crystals (Corbella, 2005).

5.1. Calibrating the angiosperm pollen record of the Baqueró Group

Recently, Archangelsky et al. (2009) recognized three stages in the evolution of the Cretaceous angiosperms in southern South América, based on megafloristic and palynological records from central and southern Argentinean basins. The first stage, dated as late Barremian-Aptian, is characterized by the earliest angiosperm pollen grains, represented by the genera *Clavatipollenites*, *Retimonocolpites*, *Monocolpopollenites*; and *Asteropollis asteroides* Hedlund and Norris, and was divided in two phases. The angiosperm pollen record from the Anfiteatro de Ticó Formation was referred by these authors to the "early" Stage I, whereas, what was recovered from Punta del Barco Formation, was referred to the "later" Stage I, where the diversity of angiosperm pollen grains was slightly higher (Archangelsky et al., 2009). However, after the results presented by Limarino et al. (2012) and current studies revising the taxonomic treatment of the angiosperm pollen content of both, Anfiteatro de Ticó and Punta del Barco formations, such distinction between "early" Stage I and "late" Stage I is not supported. Furthermore, differences in the palynological composition of both units, as pointed out in previous studies, are probably related (at least partially) to dissimilar environmental conditions of preservation rather than to stratigraphic differences. The less productive samples in the younger unit coincide with an increase in volcaniclastic sediments (Limarino et al., 2012).

On the other hand, Archangelsky et al. (2009) suggested that the early diversification of angiosperms at mid and high latitudes in both hemispheres occurred roughly synchronously. Hughes (1994) recognized six phases on the evolution of early angiosperms during the middle Hauterivian to the early Aptian of Southern England. Pollen grains with trichotomocolpate apertures are first recorded in phase 3 in Hughes scheme (1994), being referred to the early Barremian. Contrasting with this, oldest trichotomocolpate pollen grains from Argentina are recorded in the Anfiteatro de Ticó Formation (late Aptian in age), suggesting that diversification and appearance of the different pollen types may have been not synchronous in both hemispheres. The lack of precise dating of early angiosperm-bearing floras precludes a more exhaustive study about evolutionary and dispersion patterns of this group of plants. Furthermore, palynological lists which include *Asteropollis* spp. and/or *Clavatipollenites* spp. may be containing trichotomocolpate pollen grains which, in absence of a more detailed systematic treatment, may be being obscured, resulting difficult to identify in the literature.

Early angiosperm pollen types belonging to *Clavatipollenites* complex have been also recognized in subsurface samples from both San Jorge Gulf Basin (Pozo D-129 Formation) and Austral Basin (i.e., Springhill and Pampa Rincón formations) (Vallati, 1996; Palamarczuk et al., 2000; Quattrocchio et al., 2006). The age of these angiosperm records are probably older (Barremian-early Aptian) than the ones from the Baqueró Group. However, more accurate comparisons with these associations are difficult to perform because a little consensus on the classification criteria for the primitive angiosperm pollen grains coupled with the lack of detailed systematic work of these associations. Considering this, it is difficult to compare some Lower Cretaceous angiosperm records that have been poorly described and/or illustrated, being necessary future detailed studies to achieve a comparative study of different microflora.

The Ranquiles Member (=Quili Malal Member) of the Rayoso Formation (Aptian) and the La Cantera Formation (late Aptian) are two other Argentinean units which contain early angiosperm pollen grains. These units share two angiosperm genera (*Clavatipollenites* and *Retimonocolpites*) with the Baqueró deposits, but differ mainly by having diverse species of *Afropollis* (Prámparo, 1990, 1994, 1999; Vallati, 1995). Both units have been referred to the Stage II of Archangelsky et al. (2009), and probably represent deposits slightly younger than the Baqueró Group.

The Cerro Negro Formation at the South Shetland Islands was often considered coeval with the Anfiteatro de Ticó Formation (e.g., Hernández and Azcárate, 1971; Archangelsky and Césari, 2004). The former unit presents a rich paleoflora, which differs from the Anfiteatro de Ticó mainly by the absence of angiosperms (Vera, 2010; Césari et al., 2011). Hathway (1997) and Hathway et al. (1999) published $^{40}Ar/^{40}Ar$ ages (120.3 ± 2.2 Ma, 119.4 ± 0.6 Ma, 119.1 ± 0.8 Ma, 119 ± 3.0 Ma) for the Cerro Negro Formation, and

Table 1
U–Pb isotopic data on chemically abraded zircon from the Anfiteatro de Ticó Formation, at the Anfiteatro de Ticó locality.

Sample	Wt. mg	Compositional parameters								Radiogenic isotope ratios								Isotopic ages					
		U ppm	$\frac{Th}{U}$	Pb ppm	$^{206}Pb^* \times 10^{-13}$ mol	Mol % $^{206}Pb^*$	$\frac{Pb^*}{Pb_c}$	Pb_c (pg)	$\frac{^{206}Pb}{^{204}Pb}$	$\frac{^{208}Pb}{^{206}Pb}$	$\frac{^{207}Pb}{^{206}Pb}$	% Err	$\frac{^{207}Pb}{^{235}U}$	% Err	$\frac{^{206}Pb}{^{238}U}$	% Err	Corr. coef.	$\frac{^{207}Pb}{^{206}Pb}$	±	$\frac{^{207}Pb}{^{235}U}$	±	$\frac{^{206}Pb}{^{238}U}$	±
(a)	(b)	(c)	(d)	(c)	(e)	(e)	(e)	(e)	(f)	(g)	(g)	(h)	(g)	(h)	(g)	(h)		(i)	(h)	(i)	(h)	(i)	(h)
AT-12																							
B	0.004	192	0.703	4.2	0.6065	97.19%	11	1.44	657	0.225	0.048362	0.983	0.123356	1152	0.018499	0.438	0.548	117.02	23.17	118.11	1.28	118.16	0.51
C	0.004	189	0.677	4.1	0.5984	97.67%	13	1.17	795	0.215	0.048150	1966	0.123164	2024	0.018552	0.524	0.240	106.64	46.43	117.94	2.25	118.50	0.61
D	0.005	182	0.776	4.1	0.6455	97.35%	12	1.45	696	0.248	0.048513	0.716	0.123900	0.799	0.018523	0.162	0.587	124.35	16.85	118.60	0.89	118.32	0.19
E	0.005	158	0.698	3.4	0.5716	98.14%	17	0.89	993	0.224	0.048656	0.634	0.124206	0.714	0.018514	0.131	0.664	131.31	14.91	118.88	0.80	118.26	0.15
G	0.002	157	0.762	3.7	0.2896	95.60%	7	1.10	420	0.245	0.048711	1573	0.124205	1684	0.018493	0.165	0.699	133.95	36.96	118.88	1.89	118.13	0.19
H	0.003	145	0.704	3.2	0.3456	97.65%	13	0.68	788	0.228	0.049140	1073	0.125335	1156	0.018498	0.178	0.525	154.52	25.11	119.90	1.31	118.16	0.21

Note. (a) A, B etc. are labels for fractions composed of single zircon grains or fragments; all fractions annealed and chemically abraded after Mattinson (2005) and Scoates and Friedman (2008); (b) Nominal fraction weights estimated from photomicrographic grain dimensions, adjusted for partial dissolution during chemical abrasion; (c) Nominal U and total Pb concentrations subject to uncertainty in photomicrographic estimation of weight and partial dissolution during chemical abrasion; (d) Model Th/U ratio calculated from radiogenic $^{208}Pb/^{206}Pb$ ratio and $^{207}Pb/^{235}U$ age; (e) Pb* and Pbc represent radiogenic and common Pb, respectively; mol % $^{206}Pb^*$ with respect to radiogenic, blank and initial common Pb; (f) Measured ratio corrected for spike and fractionation only. Mass discrimination of 0.23%/amu based on analysis of NBS-982; all Daly analyses; (g) Corrected for fractionation, spike, and common Pb; up to 1 pg of common Pb was assumed to be procedural blank: $^{206}Pb/^{204}Pb = 18.50 \pm 1.0\%$; $^{207}Pb/^{204}Pb = 15.50 \pm 1.0\%$; $^{208}Pb/^{204}Pb = 38.40 \pm 1.0\%$ (all uncertainties 1-sigma). Excess over blank was assigned to initial common Pb with Stacey and Kramers (1975) model Pb composition at 118 Ma; (h) Errors are 2-sigma, propagated using the algorithms of Schmitz and Schoene (2007) and Crowley et al. (2007); (i) Calculations are based on the decay constants of Jaffey et al. (1971). $^{206}Pb/^{238}U$ and $^{207}Pb/^{206}Pb$ ages corrected for initial disequilibrium in $^{230}Th/^{238}U$ using Th/U [magma] = 3; (j) Corrected for fractionation, spike, and blank Pb only. EARTH TIME U–Pb synthetic solutions analysed on an on-going basis to monitor the accuracy of results. Isotopic dates are calculated the decay constants λ238 = 1.55125E-10 and λ235 = 9.8485E-10 (Jaffey et al., 1971).

Table 2
Stratigraphic distribution of the palynomorphs identified in the Anfiteatro de Ticó Formation.

BA Pb	6227	6222	6223	6224	6225
Spores					
Aequitriradites spinulosus			X	X	
Aequitriradites verrucosus			X	X	
Appendicisporites unicus			X	X	
Baculatisporites comaumensis	X		X	X	
Biretisporites sp. cf. *B. potoniaei* in Llorens 2008			X	X	X
Biretisporites sp.			X	X	
Capsispora vulcanica			X	X	X
Ceratosporites equalis	X			X	X
Ceratosporites sp. A in Llorens 2008					
Cibotiidites auriculatus	X			X	
Cibotiumspora juncta	X			X	X
Cicatricosisporites cuneiformis	X				
Cicatricosisporites hughesii			X	X	
Cicatricosisporites sp. cf. *C. abacus*	X		X		
Cicatricosisporites sp. cf. *C. mediostriatus*	X				
Cicatricosisporites sp. cf. *C. minutaestriatus*				X	
Clavifera sp. cf. *C. triplex*	X			X	X
Concavissimisporites punctatus	X		X	X	
Concavissimisporites sp. cf. *C. crassatus*				X	
Coptospora foveolata					X
Coptospora sp.			X		X
Crybelosporites sp.			X	X	X
Cyatheacidites tectifera		X	X	X	
Cyathidites australis	X		X	X	
Cyathidites concavus	X				
Cyathidites minor	X		X	X	
Cyathidites rafaelii			X	X	
Densoisporites corrugatus			X		
Densoisporites velatus	X		X		X
Densoisporites sp.				X	
Dictyophyllidites sp.				X	
Dictyotosporites complex			X		
Divisisporites sp. cf. *D. enormis*			X		
Foraminisporis asymmetricus				X	
Foramisnisporis dailyi				X	
Foveotriletes sp.	X				
Gleicheniidites aptianus				X	
Gleicheniidites rigidus			X		
Gleicheniidites senonicus	X	X	X	X	X
Gleicheniidites sp. A in Archangelsky and Seoane 1992					X
Gleicheniidites sp.					X
Interolubites sp. cf. *I. triangularis*			X		
Laevigatosporites ovatus			X	X	
Leptolepidites major			X		
Microfoveolatosporis sp.		X	X	X	
Muricingulisporis annulatus					X
Nevessisporites simiscalaris			X		
Obtusisporis concavus	X			X	
Obtusisporis convexus				X	
Obtusisporis obtusangulus				X	X
Osmundacidites wellmanii	X			X	
Peromonolites sp.			X		
Retitriletes douglasii				X	X
Retitriletes sp. cf. *R. nodosus*			X		
Retitriletes sp.			X		
Rotverrusporites labratus			X		
Ruffordiaspora australiensis	X		X	X	
Sotasporites sp. cf. *S. elegans*			X		
Staplinisporites caminus					X
Staplinisporites sp. cf. *S. mathurii*				X	X
Stoverisporites lunaris			X	X	X
Taurocusporites segmentatus			X		X
Taurocusporites sp.			X		X
Trilobosporites apiverrucatus			X		
Trilobosporites purverulentus			X		
Trilobosporites trioreticulosus			X		
Triporoletes reticulatus			X		
Tuberculatosporites sp.			X		
Pollen grains					
Balmeiopsis limbatus				X	X
Callialasporites trilobatus f. dampieri			X		
Callialasporites trilobatus f. trilobatus				X	
Classopollis classoides	X	X	X	X	X
Classopollis simplex	X		X	X	X
Classopollis triangulatus	X		X	X	
Classopollis spp.	X				
Cycadopites follicularis			X		
Cycadopites nitidus			X		
Cyclusphaera patagonica				X	
Cyclusphaera psilata	X		X	X	X
Cyclusphaera radiata	X		X	X	X
Cyclusphaera sp. 1			X	X	X
Cyclusphaera sp. 2	X	X	X	X	X
Dacrydiumites sp.			X		
Gamerroites volkheimeri	X		X	X	X
Gamerroites sp. cf. *G. psilasaccus*	X		X	X	
Microcachrydites antarcticus			X		X
Microcachrydites cesariae			X	X	X
Podocarpidites canadensis	X			X	X
Podocarpidites ellipticus	X		X	X	
Podocarpidites herbstii	X			X	
Podocarpidites granulatus			X	X	
Podocarpidites marwickii	X		X	X	X
Podocarpidites microreticuloidata			X	X	
Podocarpidites minusculus			X	X	X
Podocarpidites multesimus	X		X	X	
Podocarpidites parviauriculatus	X			X	X
Podocarpidites vestidus			X	X	
Singhia multicostata			X		
Trichotomosulcites microsaccatus	X			X	X
Viretrisporites signatus	X			X	X
Angiosperm pollen grains					
Undetermined monocolpate grain				X	
Clavatipollenites sp. A in Llorens 2005	X		X	X	
Clavatipollenites sp. 1 in Archangelsky and Archangelsky 2013	X				
Jusinghipollis sp.	X		X	X	
Retimonocolpites sp. A in Llorens 2003			X		
Algae					
Botryococcus sp.	X		X		
Ovoidites parvus			X		
Ovoidites reticulatus			X	X	
Ovoidites sp. cf. *O. grandis*			X		
Retirotundia pseudoreticulata				X	

assigned this unit to the early Aptian. Therefore, it is confirmed that the Cerro Negro Formation is older than the Anfiteatro de Ticó Formation as was suggested by Césari et al. (2011). The total absence of angiosperms at high latitudes during the early Aptian support the hypothesis of an equatorial origin of flowering plants, which later migrated towards the poles (see Barret and Willis, 2001, and cites therein).

6. Conclusion

In this work, the age of the Anfiteatro de Ticó Formation is estimated using the CA-TIMS U–Pb zircon method. An interbedded tuff yielded an age of 118.23 ± 0.09 Ma, which indicates that this unit was deposited during the late Aptian. Since the uppermost unit of the Baqueró Group, the Punta del Barco Formation, has an age estimated of 114.67 ± 0.18 (Césari et al., 2011), the deposition of the Baqueró Group was restricted to the late Aptian, during approximately 4 Ma, as was previously suggested (Césari et al., 2011). The ages obtained for the Baqueró Group are important because they precisely constrain the time of the earliest stage in the angiosperm diversification in southern South América, and the paleofloristic and paleoenvironmental context in which this event took place. Moreover, the new age for the Anfiteatro de Ticó Formation reinforces an equatorial origin and posterior migration towards higher latitudes of angiosperms.

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Appendix A. Supplementary data

Supplementary data related to this article can be found at http://dx.doi.org/10.1016/j.jsames.2013.08.005.

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