

## Palynostratigraphic study of the Early Cretaceous Río Mayer and Kachaike formations at the Quebrada El Moro Section, Austral Basin, southwestern Argentina

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### ABSTRACT

Palynomorph assemblages have been recovered from the upper levels of the Río Mayer Formation and the basal levels of the Kachaike Formation exposed at the Puesto El Moro Creek, southwest of Santa Cruz Province, Argentina. Forty-five spore species and 25 pollen taxa (including six angiosperms) have been identified. The palynological assemblages of the upper levels of the Río Mayer Formation are dominated by pteridophytic spores, while *Classopollis* is a common element. In the Kachaike Formation, the angiosperm pollen grains are more diverse and abundant than in the underlying unit, and Cheirolepidiaceae pollen continues to dominate. The presence of scarce angiosperm pollen, represented by *Clavatipollenites* sp., allows reference of the assemblage recorded in the upper levels of the Río Mayer Formation to the Aptian *Antulsporites-Clavatipollenites* Zone. In addition, the lower levels of the Kachaike Formation are referred to the late Aptian–early Albian, based on the presence of *Asteropollis asteroides*, *Pennipollis peroreticulatus*, *Clavatipollenites* sp. and scarce tricolpate pollen. From the three major stages of the early angiosperm evolution in southern South America that have been previously recognized, the palynoflora of the upper levels of the Río Mayer Formation can be referred to Stage I (late Barremian–Aptian), whereas the assemblages recognized in the Kachaike strata are comparable to Stage II (latest Aptian–earliest Albian).

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### 1. Introduction

The Austral Basin presents one of the most complete Cretaceous sequences of Argentina, ranging from the Berriasian to the Maastrichtian (Arbe, 2002). These deposits contain rich and diverse fossils, including invertebrates, megafloral remains and terrestrial and marine palynomorphs (Archangelsky et al., 1984; Aguirre-Urreta, 1985, 1986; Riccardi et al., 1987; Riccardi and Medina, 2002; Archangelsky and Archangelsky, 2004; Medina and Riccardi, 2005; Guler and Archangelsky, 2006; Del Fueyo et al., 2007; Passalía, 2007a, b).

The rise and progressive diversification of angiosperms is one of the most important events of the Cretaceous, being well represented in the Austral Basin sequences. The typical Early Cretaceous floras are dominated by ferns, conifers, cycads and bennettites,

while angiosperms represent minor and subordinate components. The origin and early diversification of angiosperms has relevance for understanding the evolution and development of the group in Tertiary and modern communities. Albeit this topic has been focused in several contributions, many questions still remain unresolved (Heimhofer et al., 2005; Hochuli et al., 2006). However, in recent years, several publications dealing with Cretaceous palynofloras and megafloras have added important data for understanding the complex changes that occurred in terrestrial palaeocommunities during the early half of this period (Passalía et al., 2001; Barrera and Archangelsky, 2006; Iglesias et al., 2007; Archangelsky et al., 2008, among others). Recently, Archangelsky et al. (2009) analyzed angiosperm megafloristic and palynological records in central and southern Argentinean basins, recognizing three stages in their evolution in this region of Gondwana. The first stage, dated as late Barremian–Aptian, is characterized by the earliest angiosperm pollen record, represented by the genera *Clavatipollenites*, *Retimonocolpites*, *Monocolpopollenites*, and *Asteropollis asteroides*. The next stage, restricted to the latest Aptian–earliest Albian, is characterized by the appearance of

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*Liliacidites* sp., *Pennipollis peroreticulatus*, *Stellatopollis* and micro-reticulate tricolpate pollen grains. The third stage (middle Albian–Coniacian) is recognized on the basis of an increase in diversity and abundance of angiosperm pollen, and the addition of psilate tricolpate and tricolporoid pollen. These stages are roughly synchronous with those of Australia, Asia, and Europe (Archangelsky et al., 2009).

The aim of this paper is to present further palynological data from the upper levels of the Río Mayer Formation, and from basal levels of the Kachaike Formation exposed at the new locality Puesto El Moro Creek. A stratigraphic analysis, discussion of the age and comparisons with other similar palynological assemblages previously reported for central and southern Argentina is also included.

## 2. Geological setting

The Austral Basin, located in southernmost South America, is a typical back-arc basin. The deposits it contains are mainly composed of marine sediments, ranging from Upper Jurassic to Tertiary (Leanza, 1972; Riccardi and Rolleri, 1980). The Cretaceous strata of the Lago Cardiel area overlie the volcanic Upper Jurassic El Quemado Complex, and include the continental to marine sediments of the Springhill Formation (Berriasian–early Valanginian), marine black shales of the Río Mayer Formation (late Valanginian–early Albian), and shallow marine to continental sandstones and conglomerates of the Kachaike Formation (late Aptian–early Cenomanian).

The Río Mayer Formation (Riccardi, 1971) mainly consists of black shales interpreted as shelf environment deposits. Arbe (1989) divided this unit into a Lower Member, deposited in a deep marine environment, and an Upper Member, deposited in a shallower environment of higher energy.

The first palynological records from this unit are those of Pöthe de Baldis and Ramos (1980), who reported two different assemblages: one in the lower levels of the unit assigned to the Hauterivian–Barremian, and another in the middle levels of the formation dated as Barremian. Later, Pöthe de Baldis and Ramos (1983), based on dinoflagellate assemblages, dated both levels as early Aptian. Following further studies in the unit, a middle–late Aptian age for both assemblages was suggested (Pöthe de Baldis and Ramos, 1988) (Table 1). Recently, Medina et al. (2008), based on data obtained from marine invertebrates and palynofloras (including dinoflagellates), suggested a late Aptian–early Albian age for the

upper levels of the Río Mayer Formation in the Lago Cardiel area (Table 1).

The Kachaike Formation (Riccardi, 1971) is composed of transgressive sequences deposited in a deltaic environment that becomes progressively continental, with fine pyroclastic elements probably derived from the Divisadero Group (Nullo et al., 1999). Based on the ammonite fauna, this unit was assigned to the middle–late Albian or late Aptian–early Albian (Table 2). Based on the presence of the ammonite genus *Borissiakoceras*, Nullo et al. (1999) extended the age of the upper levels of the unit to the early Cenomanian.

On the other hand, palynological assemblages suggest a late Aptian–early Albian age for the Kachaike Formation in its type area (Gamerro in Rebas, 1982; Baldoni et al., 2001). Recently, Guler and Archangelsky (2006), based on dinoflagellate cyst assemblages, suggested an early Albian age for the lower part of this unit. On the other hand, Barreda and Archangelsky (2006), who carried out a palynological study of primitive angiosperm pollen, suggested a late Albian–early Cenomanian age for the upper levels of the Kachaike Formation.

## 3. Material and methods

The material studied herein was recovered from the Puesto El Moro Creek in the southwest of Santa Cruz Province (49°03'52"S – 72°08'26"W) (Fig. 1). Even though the Río Mayer Formation and the Kachaike Formation in the El Moro Creek are separated by a fault, while in other localities nearby, such as Bajo Comisión and Estancia La Florida, the contact is transitional. This transition is indicated by higher percentages of sand in the lower levels of the Kachaike Formation.

In the area studied, the Río Mayer Formation reaches approximately 72 m in thickness, and is composed of dark, fine-grained deposits of shales and claystones, the latter presenting thin intercalations of limestones, interpreted as offshore platform deposits (Fig. 2). Thick sandstone levels are developed in the uppermost part of this unit. Four productive palynological samples were obtained from the Río Mayer Formation (Fig. 2). The Kachaike Formation reaches 137 m in thickness (Fig. 2), and is covered by debris from the nearby Meseta de la Muerte basalts. In the area studied this unit begins with dark laminated shales, sporadically interrupted by cross-bedded fine sandstones interpreted as distal platform deposits. In the middle levels, sandstone becomes more abundant

**Table 1**  
Comparative chart showing the different ages proposed for the Río Mayer Formation. Listed in the table are the taxa (marine invertebrates and palynomorphs) used in each case for determining a particular age.

	Pöthe de Baldis and Ramos (1980)	Pöthe de Baldis and Ramos (1983)	Pöthe de Baldis and Ramos (1988)	Medina et al. (2008)	This work
Albian				<i>Carpodinium granulatum</i> , <i>Australiceras</i> , <i>Prolixosphaeridium conulum</i> , <i>Tropaeum</i> <i>Leberidocysta</i> sp., <i>Hypacanthoplites</i> ,	
Aptian		<i>Dingodinium sanmartinoi</i> <i>Muderongia tetracantha</i> <i>Peltocrioceras deeckei</i>	<i>Dingodinium sanmartinoi</i> <i>Muderongia tetracantha</i> Zone		<i>Clavatipollenites</i> spp.
Barremian	Association B (middle levels): <i>Trilobosporites trioreticulatus</i> , absence of <i>C. psilata</i> and angiosperm pollen grains Association A (basal levels): <i>Classopollis</i> spp. and <i>Cyclusphaera psilata</i>				
Hauterivian					

**Table 2**  
Different ages proposed for the Kachaiké Formation, including biostratigraphic markers used.

	Leanza (1970), Blasco de Nullo et al., (1980), Medina and Rinaldi (1986), Nullo et al., (1999)	Gamerro in Rebas (1982)	Baldoni et al. (2001)	Aguirre-Urreta (2002)	Barreda and Archangelsky (2006)	Guler and Archangelsky (2006)	This work
Early Cenomanian	Upper levels: <i>Borissiakoaeras</i>				Middle-upper levels: <i>Schrankipollis</i> , <i>Pennipollis</i> , <i>Brenneripollis</i> , <i>Tricolporoidites</i>		
Albian	<i>Parasilesites</i> , <i>Puzosia</i> , Labeceratidae	Absence of tricolpate pollen, <i>Crybelosporites striatus</i> , <i>C. truncatus</i> , <i>Perotrilites majus</i> , <i>Appendicisporites spinosus</i> , <i>Dyoxia armata</i> , <i>Balmeisporites holodictyus</i> , <i>Florentinia radiculata</i> , <i>Callaiosphaeridium asymmetricum</i> , <i>Arcellites nudus</i> , <i>Hystriospheraeridium arundum</i>	<i>Trilobosporites purverulentus</i> , <i>Staplinisporites caminus</i> , <i>Crybelosporites striatus</i> , <i>Odontochitina operculata</i> , <i>Muderongia tetracantha</i> , <i>Litosphaeridium arundum</i>	<i>Sanmartinoceras patagonicum</i> , <i>Lithancylus guanacoense</i>		Lower part: <i>Dinopterygium cladoides</i> , <i>Muderongia tetracantha</i> , <i>Prolixosphaeridium conulum</i>	
Late Aptian							

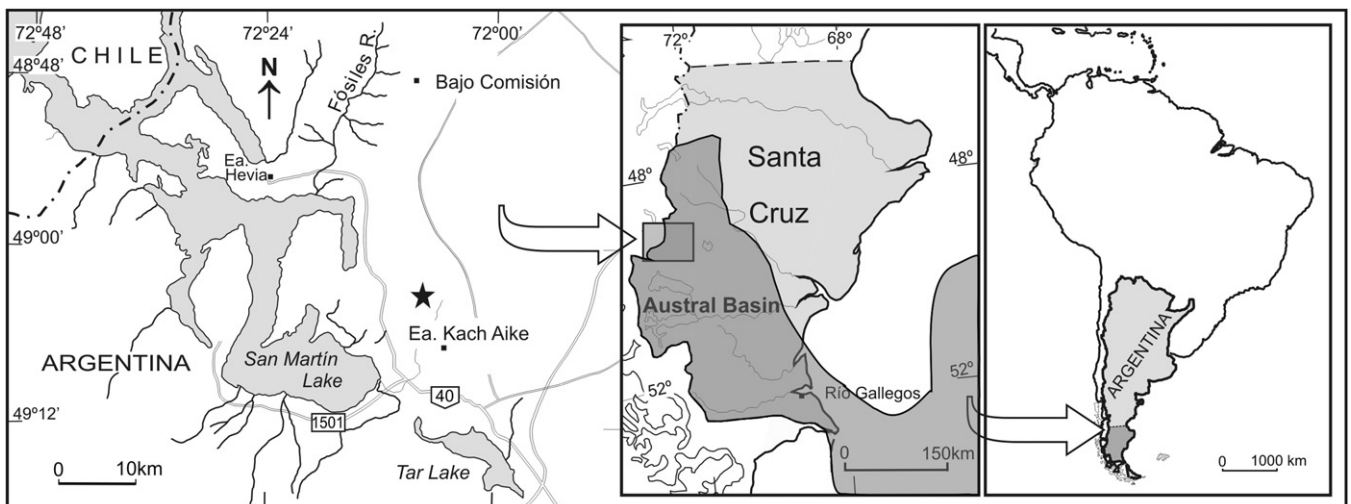
(in both grain size and thickness), and four sedimentary cycles are recognized, each composed of dark laminated shales representing deep facies, and fine sandstones representing shoreface facies (Fig. 2). Finally, in the uppermost levels, well-sorted and thick cross-bedded medium-grained sandstones up to 5–10 m in thickness are interpreted as deposited in a subaqueous platform environment.

The palynological samples were treated following standard techniques for extraction and concentration of palynomorphs. Observations were made with an Olympus BX-51 microscope. Photographs were taken with a Nikon DS-Fi1 digital camera. Coordinates of the illustrated specimens are given as England Finder references. The resulting slides are deposited in the Palynological Collection of the Museo Argentino de Ciencias Naturales “Bernardino Rivadavia” (BA Pal). For SEM studies the material was mounted on photographic paper, fixed to a stub and coated with

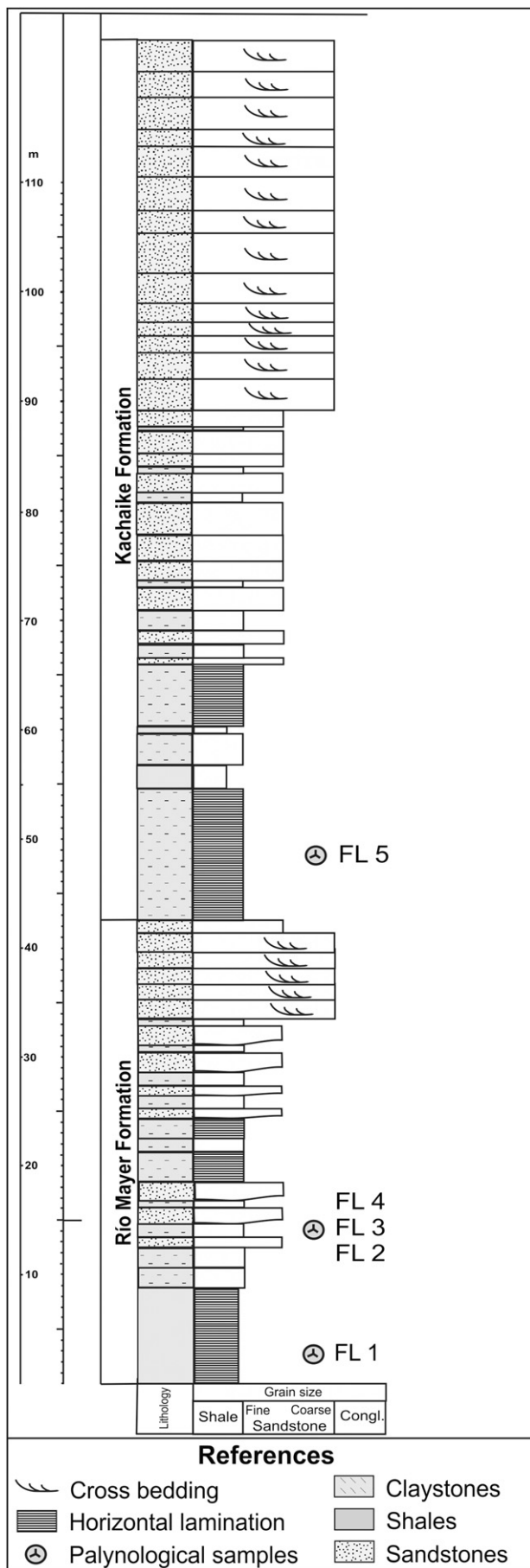
gold–palladium. The stubs are deposited in the Palaeobotanical Collection of the same Museum (BA Pb MEB).

**4. Results**

Well-preserved palynomorphs were obtained from the four palynological samples recovered from the upper levels of the Río Mayer Formation, and one from the lower levels of the Kachaiké Formation. The assemblages contain spores, pollen (including angiosperm pollen grains), dinoflagellate cysts, acritarchs, and algae. Forty-five spore species and 25 pollen taxa, including six angiosperm pollen taxa have been identified from these units. They are listed in Tables 3 and 4 in which their relative abundance and distributions are given. The more unusual or biostratigraphically relevant species are illustrated in Figs. 3 and 4.



**Fig. 1.** Location map of the area studied (★, Puesto El Moro Creek), modified from Barreda and Archangelsky (2006).



In all of the samples of the Río Mayer Formation the pteridophytic spores dominate, reaching 50–61% of the total diversity. The remaining taxa of the association are represented by pollen of the Cheirolepidiaceae (*Classopollis*, 29–45%), bisaccate or trisaccate pollen with affinities with the Podocarpaceae (3.1–5.4%) and Araucariaceae (1.3–6.2%), while angiosperms are extremely rare (0.2–0.6%).

The following species were recognized only in the Río Mayer Formation: *Appendicisporites* sp. cf. *A. pschekhaensis*, *Cibotiumspora jurienensis*, *Ornamentifera* sp. cf. *O. tuberculata*, *Podocarpidites* sp. cf. *P. canadensis*, among others (Tables 3 and 4). The angiosperm pollen grains are represented by small, reticulate columellate–tectate forms, with an aperture marked by an irregular distribution of columellae, or with a well-developed colpus. These specimens were referred to the genus *Clavatipollenites*, whereas a single specimen of reticulate tricolpate pollen grain identified in the unit, was referred to *Tricolpites* sp. 1.

The palynological assemblages recovered from the Kachaika Formation contain the following species not recognized in the Río Mayer Formation: *Aequitriradites verrucosus*, *Appendicisporites* sp. cf. *A. unicus*, *Foraminisporis asymmetricus*, *Gleicheniidites serratus*, *Leptolepidites macroverrucosus*, *Nodosisporites macrobaculatus* and *Vitreisporites pallidus*, among others (Tables 3 and 4). However, the most important difference between the two units is a higher abundance of angiosperm pollen in the Kachaika Formation. This is a result of the increase in abundance and diversity of *Clavatipollenites*, including forms with varied types of reticulum and aperture, ranging from a single leptomate, to monocolpate and trichotomocolpate types. *Asteropollis asteroides*, *Pennipollis peroreticulatus*, *Retimonocolpites* sp., as well as rare reticulate and psilate-tricolpate grains also appear in this unit.

The palynological assemblage of the Kachaika Formation also shows several changes in the proportions of different groups, when compared with the older Río Mayer Formation assemblages. Cheirolepidiaceae pollen grains dominate, reaching 65% of the total association; the spores decrease in abundance (25%), as well as pollen grains related to the Podocarpaceae (2%) and Araucariaceae (1.5%). Angiosperm pollen increases to 1.6% of the total, although it still remains a minor component of the assemblages.

## 5. Discussion

### 5.1. Palaeoenvironmental inferences

Based on the percentage of different palynomorph groups recorded and their botanical affinities, it is possible to suggest palaeoenvironmental settings for the two units studied. In the Río Mayer Formation, the most abundant components of the community are hygrophilic taxa, such as several fern families: Gleicheniaceae (*Gleicheniidites* sp., *Ornamentifera* sp. and *Clavifera* sp.), Osmundaceae (*Baculatisporites* sp., *Osmundacidites* sp.), Polypodiaceae–Pteridaceae (*Leptolepidites* sp.), and Schizaeaceae (*Appendicisporites* sp., *Cicatricosisporites* sp., *Ruffordiaspora* sp.). Gleicheniaceae spores dominate among the fern spores, reaching 8.4% in the upper levels of the Río Mayer Formation, and sharply decrease to 0.5% in the basal levels of the Kachaika Formation. The plants concerned commonly prefer moist conditions, near to swampy areas. Another component of this hygrophilic community

**Fig. 2.** A stratigraphic log of the Río Mayer and Kachaika formations in Puesto El Moro Creek, illustrating the fossiliferous levels (FL) (FL1: slides BA Pal 6062/63; FL2: slides BA Pal 6064/67; FL3: slides BA Pal 6068/71; FL4: 6072/75; FL5: slides BA Pal 6076/83, BA Pb Pal 369, BA Pb Pal 371).



**Table 3**

Stratigraphic distribution and relative abundance of sporomorph species in the present study (FL1–5) compared to previous Argentinean records (SF–HnF) (○, rare: up to 5 specimens); ●, common (6–15 specimens); ◻, abundant (16–30 specimens); ■, very abundant (more than 30 specimens). RMF, Río Mayer Formation; KF, Kachaïke Formation; SF, Springhill Formation (Baldoni and Archangelsky, 1983; Ottone and Aguirre-Urreta, 2000; Quattrocchio et al., 2006; Berriasian–late Barremian); TF, Anfiteatro de Ticó Formation (Archangelsky, 2003; late Aptian); PBF, Punta del Barco Formation (Llorens, 2003, 2008a, b; late Aptian); RF, Ranquiles Formation (Vallati, 1995; Aptian), LCF, La Cantera Formation (Prámparo, 1990, 1994; late Aptian–early Albian); PCF, Piedra Clavada Formation (Archangelsky et al., 2008; late Aptian–early Albian); PRF, Pampa Rincón Formation (Quattrocchio et al., 2006, late Aptian–early Albian); HtF, Huitrín Formation (Volkheimer and Salas, 1976; earliest Albian); HnF, Huincul Formation (Vallati, 2001, Albian?–Cenomanian). Asterisks represent species not identified in this work but previously reported from the unit (Archangelsky and Llorens, 2003, 2005; Baldoni et al., 2001).

Fossil taxon	RMF				KF	SF	TF	PBF	RF	LCF	PCF	PRF	HtF	HnF
	FL1	FL2	FL3	FL4	FL5									
<b>Bryophytes and pteridophytes</b>														
<i>Aequitriradites superspinulosus</i> Archangelsky and Archangelsky					○	●*	●				●			
<i>Aequitriradites verrucosus</i> (Cookson and Dettmann) Cookson and Dettmann					○	●	●		●					
<i>Appendicisporites</i> sp. cf. <i>A. unicus</i> (Markova) Singh (Fig. 3A)					○									
<i>Appendicisporites</i> sp. cf. <i>A. potomacensis</i> Brenner (Fig. 3B)		○			●*						●			
<i>Appendicisporites</i> sp. cf. <i>A. pschekhaensis</i> (Bolkhovitina) Pocock (Fig. 3C)		○												
<i>Baculatisporites comaumensis</i> (Cookson) Potonié	●	●	●	●	●	●	●							
<i>Baculatisporites kachaikensis</i> Llorens and Archangelsky (Fig. 3D)	●	●	●	●	■									
<i>Ceratosporites equalis</i> Cookson and Dettmann		●	●	●	●*	●	●				●	●		
<i>Ceratosporites</i> sp.	○													
<i>Cibotiumspora jurienensis</i> (Balme) Filatoff (Fig. 3E)	○						●						●	
<i>Cicatricosisporites pseudotripartitus</i> (Bolkhovitina) Dettmann	○				●									
<i>Cicatricosisporites cuneiformis</i> Pocock (Fig. 3F)	○				●									
<i>Cicatricosisporites</i> sp. cf. <i>C. minutaestriatus</i> (Bolkhovitina) Pocock	●		○		○									
<i>Cicatricosisporites</i> sp. cf. <i>C. ticoensis</i> Archangelsky and Gamarro (Fig. 4A)		○	○		○	●	●				●			
<i>Cingulatisporites</i> sp. (Fig. 3G)					○									
<i>Clavifera</i> sp. (Fig. 3I)					○									
<i>Cyathacidites tectifera</i> Archangelsky and Gamarro	●	●	●	●	●		●							
<i>Cyathidites australis</i> Couper					●	●	●						●	●
<i>Cyathidites minor</i> Couper					●	●	●	●	●				●	●
<i>Densoisporites velatus</i> Weyland and Krieger emend. Krasnova	◻	◻	◻	◻	◻	●	●	●						
<i>Densoisporites corrugatus</i> Archangelsky and Gamarro	◻	◻	◻	◻	●*	●	●				●			
<i>Dictyotospores complex</i> Cookson and Dettmann (Fig. 3K)			○	○	○									
<i>Foraminisporis asymmetricus</i> (Cookson and Dettmann) Dettmann (Fig. 3L)					○		●		●	●	●			●
<i>Gleicheniidites senonicus</i> Ross		◻	◻	◻	○	●	●	●					●	
<i>Gleicheniidites serratus</i> Archangelsky and Llorens					●									
<i>Gleicheniidites</i> sp. (Fig. 3J)		○	○	○										
<i>Interulobites</i> sp. cf. <i>I.</i> sp. Archangelsky 1983		●			●				●					
<i>Interulobites</i> sp. cf. <i>I. pseudoreticulatus</i> Archangelsky					○									
<i>Interulobites</i> sp. (Fig. 3H)					○									
<i>Leptolepidites macroverrucosus</i> Schulz (Fig. 3M)					●				●	●			●	●
<i>Muricungulisporis</i> sp. cf. <i>M. annulatus</i> Archangelsky and Gamarro (Fig. 4C)			○		○	●	●							
<i>Neoraistrickia</i> sp.		○	○											
<i>Nodosisporites crenimurus</i> (Srivastava) Davies (Fig. 3O)		○			●*									
<i>Nodosisporites macrobaculatus</i> Llorens and Archangelsky (Fig. 3P)					○									
<i>Ornamentifera</i> sp. cf. <i>O. tuberculata</i> (Grigorjeva) Bolkhovitina (Fig. 4B)	●	●	○											
<i>Osmundacidites wellmanii</i> Couper	●	●	●	●	●*	●			●					
<i>Retitriletes austroclavatidites</i> (Cookson) Döring, Mai, Krutzsch and Schulz	●	●	●	●	●*	●	●				●	●		
<i>Ruffordiaspora australiensis</i> (Cookson) Dettmann and Clifford (Fig. 3Q)	●	●	●	●	●*	●	●			●	●	●	●	
<i>Ruffordiaspora ludbrookiae</i> (Dettmann) Dettmann and Clifford (Fig. 3R)	○				○									
<i>Rugulatisporites</i> sp. (Fig. 3N)		○	○	○										
<i>Staplinisporites caminus</i> (Balme) Pocock		○			○	●	●	●	●	●	●	●	●	●
<i>Stereisporites</i> sp. cf. <i>S. antiquasporites</i> (Wilson and Webster) Dettmann (Fig. 3S)				○										
<i>Taurocusporites segmentatus</i> Stover	●	●	●	●	●	●	●		●	●	●		●	●
<i>Verrucosisporites</i> sp. cf. <i>V. varians</i> Volkheimer (Fig. 3T)			○	○	○				●			●		
<i>Trilites</i> sp. (Fig. 4D)	●													

is represented by spores of Sphaerocarpaceae (*Aequitriradites* sp.), Anthocerotaceae (*Foraminisporis* sp.), Bryopsida (*Interulobites* sp.), and Lycopodiaceae (*Ceratosporites* sp., *Retitriletes* sp.), which are generally found in swampy environments. Cheirrolepidiaceae pollen grains (*Classopollis* sp.) are abundant in both units (more so in the basal levels of the Kachaïke Formation). These thermophilous forms were either shrubs or trees that lived in well-drained soils, in a warm, seasonally dry to semiarid climate (Vakhrameev, 1970; 1981; Batten, 1996). The dominance of *Classopollis* sp., and the decrease in abundance of hygrophilic elements, such as fern, lycophyte and bryophyte spores, suggests a more arid climate in the levels of the Kachaïke Formation studied. In this regard, some authors (Batten, 1996) have pointed out that changes in the abundance of *Classopollis* may not be climate-controlled, being

influenced by a diverse array of factors that can be hard to identify, such as differences in the depositional environment.

The palynofloras of the formations studied show a low percentage of marine elements, reaching up to 5.4% of the total (e.g., dinoflagellates, microforaminifers and acritarchs).

## 5.2. Palynostratigraphy

The upper levels of the Río Mayer Formation yielded few specimens of *Clavatipollenites* and a single reticulate tricolpate grain. Owing to the absence of other angiosperm genera which are usually associated with the oldest tricolpate pollen, this single specimen could be a contaminant. *Clavatipollenites* is common in palynofloras containing early angiosperms, and its first record was reported

**Table 4**

Stratigraphic distribution, relative abundance and previous Argentinean records of pollen grain species in the studied levels. See references in Table 1.

Fossil taxon	RMF				KF	SF	TF	PBF	RF	CF	PCF	PRF	HtF	HnF
	FL1	FL2	FL3	FL4	FL5									
<b>Gymnosperm pollen</b>														
<i>Alisporites similis</i> (Balme) Dettmann					●	●				●				
<i>Callialasporites trilobatus</i> (Balme) Dev					●	●	●		●	●	●	●	●	
<i>Callialasporites</i> sp. (Fig. 4E)	●				●									
<i>Classopollis</i> sp.	■	■	■	■	■	●	●	●	●	●	●	●	●	●
<i>Cyclusphaera psilata</i> Volkheimer and Sepúlveda	□				□	●	●	●				●	●	●
<i>Cyclusphaera radiata</i> Archangelsky (Fig. 4F)			○		○*				?					
<i>Cyclusphaera</i> sp. (Fig. 4G)	●	●	●	●	●									
<i>Gamerroites volkheimeri</i> Archangelsky	○		○	○	●		●							
<i>Gamerroites</i> sp. cf. <i>G. psilasaccus</i> (Archangelsky and Romero) Archangelsky					○									
<i>Microcachryidites antarcticus</i> Cookson			●		●*	●	●	●	●			●	●	●
<i>Podocarpidites ellipticus</i> Cookson		●			●*	●	●	●	●		●			
<i>Podocarpidites marwickii</i> Couper				●	●	●	●	●						
<i>Podocarpidites</i> sp. cf. <i>P. canadensis</i> Pocock (Fig. 4H)				○										
<i>Podocarpidites</i> sp. cf. <i>P. otagoensis</i> Couper					○									
<i>Podocarpidites</i> sp. cf. <i>P. parviauriculatus</i> Archangelsky and Villar de Seoane (Fig. 4I)				○	○		●							
<i>Podocarpidites</i> sp. cf. <i>P. vestitus</i> Archangelsky and Villar de Seoane		○		○			●							
<i>Podocarpidites</i> sp. cf. <i>P. verrucosus</i> Volkheimer (Fig. 4J)					●				●					
<i>Trisaccites microsaccatus</i> (Couper) Couper		○	○		○		●	●		●		●	●	
<i>Vitreisporites pallidus</i> (Reissinger) Nilsson					●	●				●				
<b>Angiosperm pollen</b>														
<i>Asteropollis asteroides</i> Hedlund and Norris (Fig. 4L)					●			●	●	●	●	●	●	●
<i>Clavatipollenites</i> sp. (Fig. 4M, N, P)	○	●	●	●	■	●	●	●	●	●	●	●	●	●
<i>Pennipollis peroreticulatus</i> (Brenner) Friis, Pedersen and Crane (Fig. 4K)					○									●
<i>Retimonocolpites</i> sp. (Fig. 4O)					○			●	●	●	●			●
<i>Tricolpites</i> sp. (Fig. 4Q–S)		○			○						●	●	●	●
Angiosperm tetrad					○									
<b>Algae</b>														
<i>Botryococcus</i> sp.					●									
<i>Mica</i> sp. (Fig. 4T)					○									

from Barremian sediments (Heimhofer et al., 2005; Taylor et al., 2009). However, Brenner (1996) reported the presence of this type of pollen in older sediments from Israel, dated as late Hauterivian. In Argentina, this genus has its older records in late Barremian sequences (Archangelsky et al., 2009).

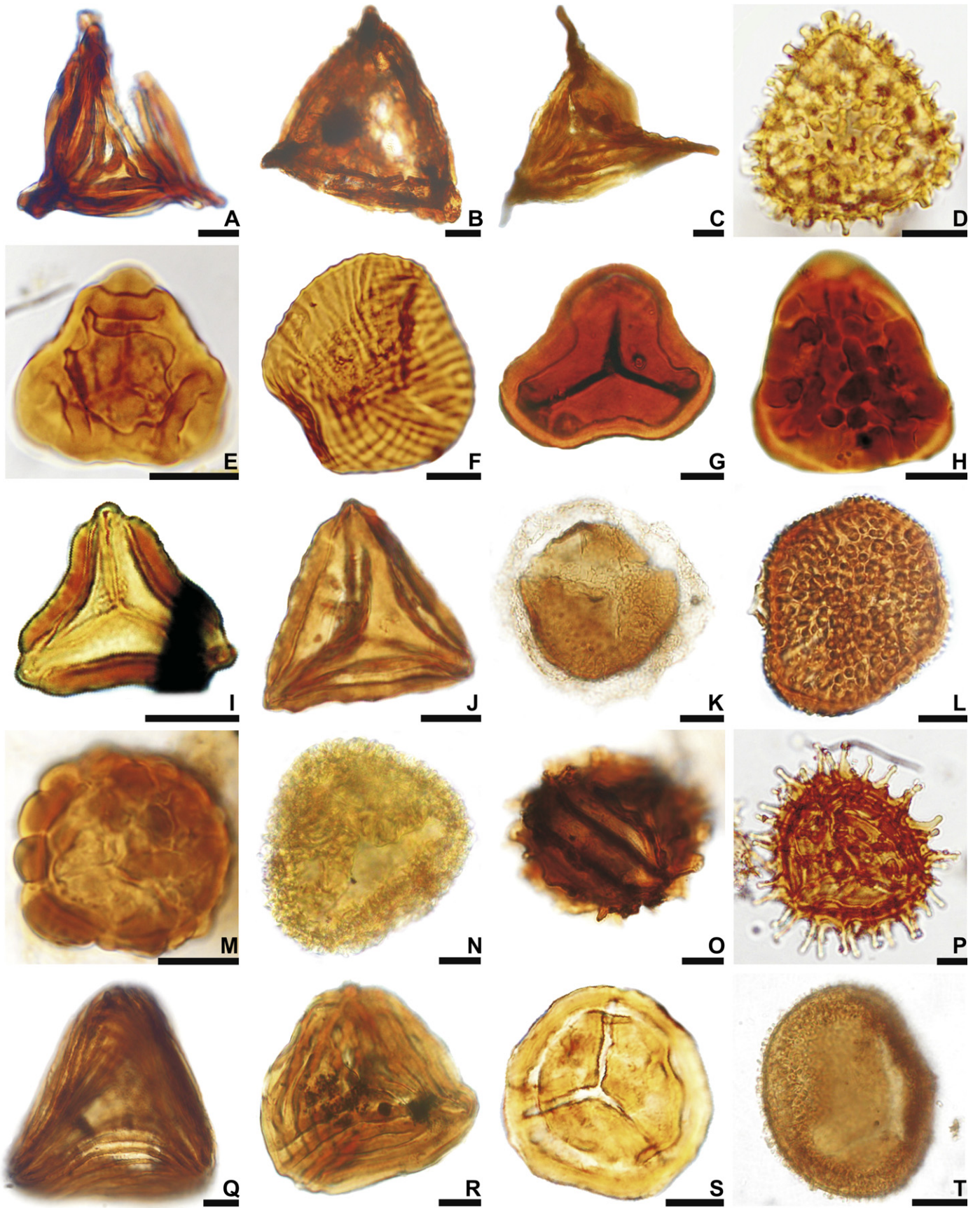
The palynofloras recovered from the upper levels of the Río Mayer Formation can be compared with the *Antulsporites-Clavatipollenites* Zone proposed for southern Argentina, which is characterized by the first appearance of angiosperm pollen and dated as Aptian (Archangelsky et al., 1984).

Most species recognized in the basal levels of the Kachaike Formation are long-ranging and, thus, poor stratigraphic markers. Since angiosperm pollen grains have a better biostratigraphic resolution, they are used here for the palynostratigraphic interpretations. *Asteropollis asteroides* has a wide distribution in post-Aptian sequences (Laing, 1975; Doyle and Robbins, 1977; Srivastava, 1977; Singh, 1983). The acolumellate pollen *Pennipollis peroreticulatus* is generally regarded as a stratigraphic marker of Aptian strata (Doyle, 1992; Schrank, 1987; Penny, 1986, 1991). Noteworthy is the fact that Penny (1986) and Brenner and Bickoff (1992) identified the oldest records of this species in late Barremian assemblages. *Pennipollis peroreticulatus* was identified only in the basal levels of the Kachaike Formation. The first appearance of

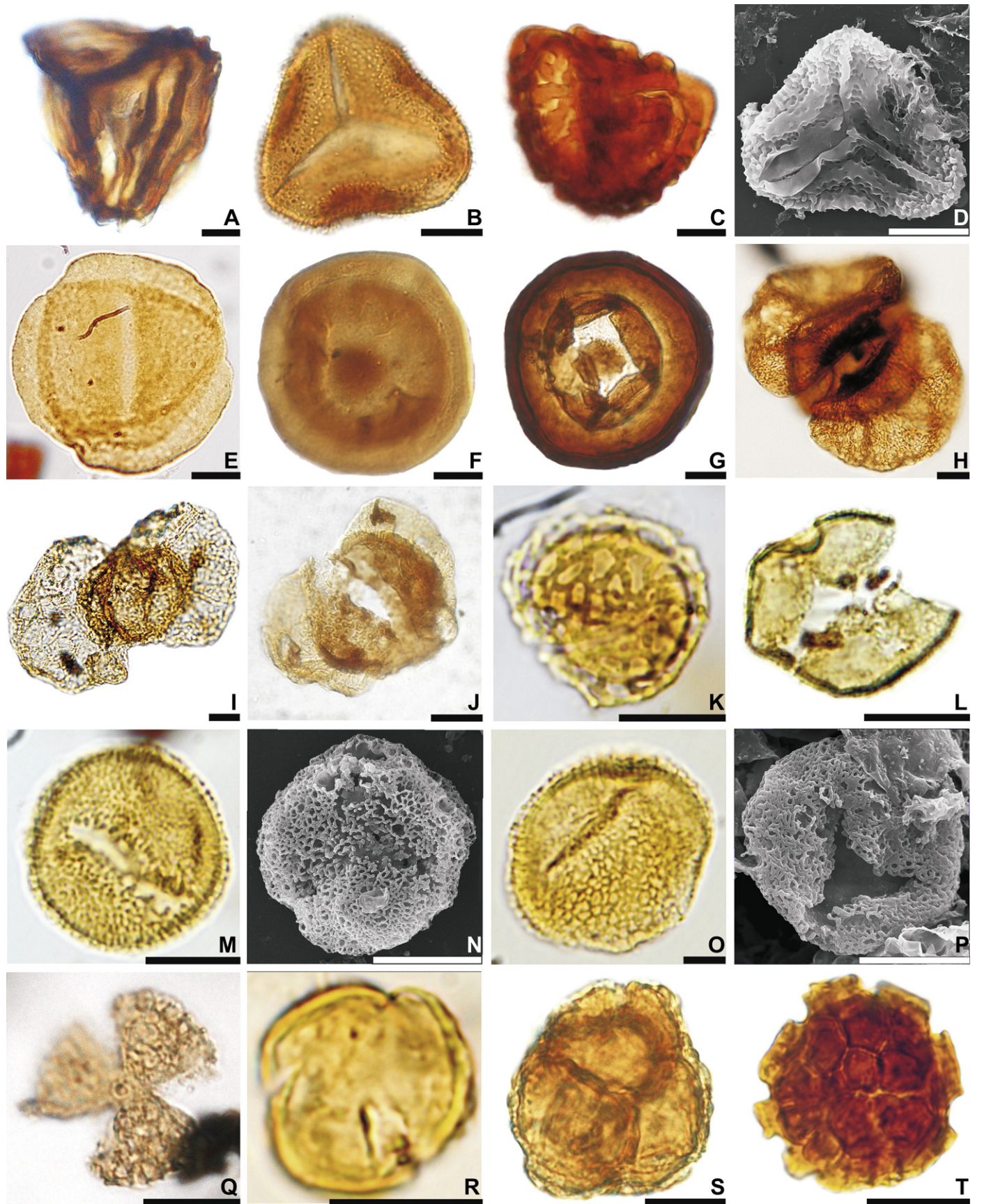
this species is diachronous in Argentina: it was recorded in the north (San Luis Basin) in the late Aptian–earliest Albian La Cantera Formation, and in the south (Neuquén and Austral basins) in late Albian–Cenomanian strata (Barreda and Archangelsky, 2006). The first appearance of tricolpate pollen, representing ancestral members of the basal eudicots, is recorded in palynological assemblages of mid and high latitudes in Australia, Europe and North America in early Albian deposits (Dettmann, 1973; Burger, 1990; Hochuli et al., 2006; Heimhofer et al., 2007). However, in equatorial regions, the first record of tricolpate pollen is reported earlier, in early Aptian sediments (Müller, 1966; Jardine et al., 1974; Brenner and Bickoff, 1992). In these palynological assemblages, the tricolpate pollen types are rare, showing relatively low diversity and abundance throughout the early–middle Albian (Heimhofer et al., 2007).

Therefore, based on the angiosperm pollen identified, we provisionally assign the upper levels of the Río Mayer Formation to Stage I of the angiosperm evolution proposed for Patagonia by Archangelsky et al. (2009), dated as late Barremian–Aptian, and palynologically characterized by the appearance of the genus *Clavatipollenites*. The basal levels of the Kachaike Formation show, on the other hand, several *Clavatipollenites* types, together with *Asteropollis asteroides*, *Pennipollis peroreticulatus* and tricolpate

**Fig. 3.** A, *Appendicisporites* sp. cf. *A. unicus* (Markova) Singh, BA Pal 6080 (FL5):V27/4. B, *Appendicisporites* sp. cf. *A. potomacensis* Brenner, BA Pal 6065 (FL2):V30/0. C, *Appendicisporites* sp. cf. *A. pschekhaensis* (Bolkhovitina) Pocock, BA Pal 6067 (FL2):G27/2. D, *Baculatisporites kachaikeensis* Llorens and Archangelsky, BA Pal 6069 (FL3):G27/2. E, *Cibotiumspora juriensis* (Balme) Filatoff, BA Pal 6062 (FL1):T38/3. F, *Cicatricosisporites cuneiformis* Pocock, BA Pal 6083 (FL5):W54/0. G, *Cingulatisporites* sp., BA Pal 6080 (FL5):S49/3. H, *Interulobites* sp., BA Pal 6076 (FL5):H34/3. I, *Clavifera* sp., BA Pal 6076 (FL5):S50/2. J, *Gleicheniidites* sp., BA Pal 6069 (FL3):C37/1. K, *Dictyosporites complex* Cookson and Dettmann, BA Pal 6081 (FL5):D49/1. L, *Foraminisporis asymmetricus* (Cookson and Dettmann) Dettmann, BA Pal 6079 (FL5):E52/3. M, *Leptolepidites macroverrucosus* Schulz, BA Pal 6076 (FL5):W42/2. N, *Rugulatisporites* sp., BA Pal 6065 (FL2):Z36/2. O, *Nodosisporites crenimurus* (Srivastava) Davies, BA Pal 6066 (FL2):G45/3. P, *Nodosisporites macrobaculatus* Llorens and Archangelsky, BA Pal 6082 (FL5):R38/2. Q, *Ruffordiaspora australiensis* (Cookson) Dettmann and Clifford, BA Pal 6071 (FL3):N46/4. R, *Ruffordiaspora ludbrookiae* (Dettmann) Dettmann and Clifford, BA Pal 6063 (FL1):V42/3. S, *Stereisporites* sp. cf. *S. antiquasporites* (Wilson and Webster) Dettmann, BA Pal 6072 (FL4):H35/1. T, *Verrucosisporites* sp. cf. *V. varians* Volkheimer, BA Pal 6070 (FL3):W41/4. Scale bar represents 10 µm.









pollen. Based on these records, the basal levels of the Kachaike Formation are assigned to Stage II of angiosperm evolution in Patagonia (Archangelsky et al., 2009), dated as latest Aptian–earliest Albian.

### 5.3. Comparison with other Cretaceous palynofloras of Argentina

Medina et al. (2008) reported palynological assemblages from the upper levels of the Río Mayer Formation and recognized two angiosperm pollen genera: *Clavatipollenites* and *Asteropollis*. Notably, tricolpate pollen grains were not recognized in the study (Medina et al., 2008). On the other hand, studies on the basal and mid levels of this unit (Pöthe de Baldi and Ramos, 1980, 1983, 1988) did not reveal angiosperm pollen grains (see Table 1).

Baldoni et al. (2001) analyzed palynofloras from the Kachaike Formation in the Arroyo Caballo Muerto area, approximately 10 km south of El Moro Creek, and recognized only one species of *Clavatipollenites*. Recently, Barreda and Archangelsky (2006) studied angiosperm pollen from the Kachaike Formation at the Bajo Comisión locality, and identified the species *Pennipollis peroreticulatus* in the middle and upper levels of the unit. In the present study, the range of this species is extended to the basal levels of the Kachaike Formation.

The palynofloras reported here can be compared with other assemblages of similar age recognized in several regions of Argentina, including the Neuquén (Huincul and Ranquiles formations), Austral (Piedra Clavada, Pampa Rincón and Springhill formations), San Luis (La Cantera Formation) and Baqueró (Anfiteatro de Ticó and Punta del Barco formations) basins.

The latest Aptian–early Albian Piedra Clavada Formation (Archangelsky et al., 2008), shares an important number of species with the sequences considered herein (see Tables 3 and 4). In particular, the presence of several angiosperm pollen genera (i.e., *Pennipollis*, *Asteropollis*) in the Kachaike Formation, also recorded in the Piedra Clavada assemblages, suggests a close relationship between these two units.

Quattrocchio et al. (2006) studied core samples from the Pampa Rincón Formation (late Aptian–early Albian), where they identified scarce tricolpate pollen grains, a result comparable to that presented here for the Kachaike Formation (see Tables 3 and 4). The palynoflora from the basal levels of the latter shares some species with the palynological assemblages described by Volkheimer and Salas (1976) for the upper levels of the Huitrín Formation (dated as earliest Albian). The most conspicuous similarity between both units is the presence of tricolpate pollen grains.

The absence of tricolpate pollen grains in the La Cantera Formation, dated as earliest Albian by Prámparo (1990, 1994), marks an important difference between it and the basal levels of the Kachaike Formation (see Tables 3 and 4). However, the former unit has yielded several angiosperm pollen taxa that are absent from the assemblages reported here, such as *Stellatopollis*, *Afropollis* and *Schrankipollis*.

The Huincul Formation (Albian?–Cenomanian; Vallati, 2001), shares with the samples studied here the presence of *Clavatipollenites*, *Pennipollis* and *Tricolpites*, along with some spore species (see Tables 3 and 4). However, these palynofloras differ from those recorded in the basal levels of the Kachaike Formation

by containing more diverse and abundant angiosperm pollen (e.g., *Psilatricolpites* sp., *Rousea* sp., *Gemmatricolpites* sp., among others).

The palynofloristic assemblages from the Anfiteatro de Ticó and Punta del Barco formations, dated as late Aptian (Corbella, 2001), share many species with the samples discussed herein (see Tables 3 and 4). For the time being, *Clavatipollenites* represents the only palynological evidence of angiosperms in the Anfiteatro de Ticó Formation (Archangelsky, 2003), as in the upper levels of the Río Mayer Formation. On the other hand, the overlying Punta del Barco Formation is characterized by a more diverse assemblage of angiosperm pollen. However, tricolpate pollen grains, identified in the basal levels of the Kachaike Formation, are absent from the Punta del Barco Formation (Llorens, 2003).

Vallati (1995) recovered a rich palynoflora from the Aptian Ranquiles Formation. This unit differs from the upper levels of the Río Mayer Formation by containing a higher diversity of angiosperm pollen grains, and from the basal levels of the Kachaike Formation by the absence of tricolpate pollen.

Palynological assemblages studied from the Springhill Formation lack angiosperm pollen grains (Baldoni and Archangelsky, 1983; Ottone and Aguirre-Urreta, 2000; Quattrocchio et al., 2006). However, in a sample from a well drilled in the offshore Gallegos area, and referred to the same unit, Archangelsky and Archangelsky (2004) noted the presence of *Clavatipollenites*. This unit shares many species with the assemblages studied here, but differs by its scarcity of angiosperm pollen (see Tables 3 and 4).

## 6. Conclusions

The palynological content of the upper levels of the Río Mayer Formation and the basal levels of the Kachaike Formation at Puesto El Moro Creek, allowed the identification of 45 spore species and 25 pollen taxa. Among the latter, six angiosperm genera (as well as one indeterminate angiosperm pollen tetrad) were recognized. Pteridophytic spores dominate in the upper levels of Río Mayer Formation and *Classopollis* is also a common component, while the remaining elements are subordinate. Scarce angiosperms, represented by *Clavatipollenites* were identified. On the other hand, the palynological assemblages recovered from the Kachaike Formation contain additional species that are absent from the Río Mayer Formation. However, the greatest difference between both units is underscored by the relative abundance of different pollen and spore groups. In the younger strata (lower levels of the Kachaike Formation), the angiosperm pollen is more diverse and abundant. Furthermore, the Cheiralepidiaceae dominate the palynoflora of the Kachaike Formation, while spores, as well as the remaining floristic elements, decrease in abundance.

The comparison with palynological assemblages found in other sections of the Austral Basin suggests an Aptian age for the upper levels of the Río Mayer Formation, and a late Aptian–early Albian age for the basal levels of the Kachaike Formation at the Puesto El Moro Section. Moreover, the palynoflora of the Río Mayer deposits from this section can be referred to Stage I of the angiosperm evolution (late Barremian–Aptian) proposed by Archangelsky et al. (2009), whereas the assemblages recognized in the Kachaike strata are comparable to Stage II (latest Aptian–earliest Albian).

**Fig. 4.** A, *Cicatricosisporites* sp. cf. *C. ticoensis* Archangelsky and Gamarro, BA Pal 6067 (FL2):W54/4. B, *Ornamentifera* sp. cf. *O. tuberculata* (Grigorjeva) Bolkhovitina, BA Pal 6069 (FL3):R29/1. C, *Muricungulisporis* sp. cf. *M. annulatus* Archangelsky and Gamarro, BA Pal 6079 (FL5):H33/1. D, *Trilites* sp., BA Pb Pal 371 (FL5). E, *Callialasporites* sp., BA Pal 6079 (FL5):W44/3. F, *Cyclusphaera radiata* Archangelsky, BA Pal 6079 (FL3):N35/2. G, *Cyclusphaera* sp., BA Pal 6069 (FL3):W49/0. H, *Podocarpidites* sp. cf. *P. canadensis* Pocock, BA Pal 6070 (FL3):O35/2. I, *Podocarpidites* sp. cf. *P. parviauriculatus* Archangelsky and Villar de Seoane, BA Pal 6071 (FL3):S48/3. J, *Podocarpidites* sp. cf. *P. verrucosus* Volkheimer, BA Pal 6083 (FL5):R28/1. K, *Pennipollis peroreticulatus* (Brenner) Friis et al., BA Pal 6076 (FL5):U52/3. L, *Asteropollis* sp., BA Pal 6076 (FL5):129/5.5. M, *Clavatipollenites* sp., BA Pal 6076 (FL5):C41/3. N, *Clavatipollenites* sp., BA Pb Pal 371 (FL5). O, *Retimonocolpites* sp., BA Pal 6076 (FL5):N50/4. P, *Clavatipollenites* sp., BA Pb Pal 369 (FL5). Q, *Tricolpites* sp. 1, BA Pal 6064 (FL2):M40/4. R, *Tricolpites* sp. 2, BA Pal 6076 (FL5):V43/3. S, angiosperm tetrad, BA Pal 6076 (FL5):M46/2. T, *Mica* sp., BA Pal 6076 (FL5):K33/3. Scale bar represents 10  $\mu$ m.

Finally, the appearance of tricolpate pollen in the Austral Basin seems to have stratigraphic significance by confirming that this took place near the Aptian/Albian boundary. This agrees with data from other regions where this pollen type has its first records in the earliest Albian.

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