PALYNOLOGY OF EL FOYEL GROUP (PALEOGENE), ÑIRIHUAU BASIN, ARGENTINA

MIRTA E. QUATTROCCHIO, MARCELO A. MARTÍNEZ

Departamento de Geología, Instituto Geológico del Sur, Universidad Nacional del Sur, CONICET, San Juan 670, 8000, Bahía Blanca, Argentina. *mquattro@criba.edu.ar*, *martinez@criba.edu.ar*

MARCOS A. ASENSIO

TECPETROL, Bahía Blanca, Argentina. *marcos.asensio@tecpetrol.com*

M. ELINA CORNOU & DANIELA E. OLIVERA

Departamento de Geología, Universidad Nacional del Sur, San Juan 670, 8000, Bahía Blanca, Argentina. *elina.cornou@uns.edu.ar*, *danielaolivera@yahoo.com.ar*

ABSTRACT – This work aims to analyze the paleovegetation, paleoclimates and paleoceanography of the Paleogene of the Río Foyel section (El Foyel Group), Ñirihuau Basin, Argentina. It comprises Troncoso, Salto del Macho and Río Foyel formations. Sporomorph analysis reflects a regional forest dominated by Nothofagaceae, Myrtaceae, Podocarpaceae and Palmae, developed under a temperate to warm-temperate and humid climate. In the studied section, the relation between terrestrial/marine palynomorphs is considered. In the Troncoso Formation, terrigenous palynomorphs dominate over marine elements. The recurrent presence of gymnosperm pollen with Araucariaceae indicates temperate and humid conditions. The Salto del Macho Formation shows a retraction of the gymnosperm forest, associated with the dominance of *Nothofagus* forest, indicating a temperate and humid condition. In the Río Foyel Formation, the sporomorphs indicate the presence of a temperate to warm-humid forest with subordinate open areas and a remarkable input from the coastal environment. In the same formation, the palynological characteristics, which indicate upward shallowing, allow the identification of parasequences. The bounding surfaces of parasequences are defined as surfaces of flooding which represent a relative sea level rise (marine flooding surfaces). The Río Foyel Formation shows an upward shallowing sequence, indicated by the decrease in abundance and diversity of dinocysts. Different marine flooding surfaces were detected, associated with the diversity and abundance of dinocyst. A comparison of these spore-pollen assemblages with others from Patagonia, using multivariate statistic techniques, yields strong similarities between the Troncoso Formation and the Sloggett Formation (late Eocene to ?early Oligocene); and between Salto del Macho and Río Foyel formations with Loreto Formation (late Eocene-Oligocene) and San Julián Formation in cabo Curioso area (Oligocene).

Key words: Paleogene, Palynology, El Foyel Group, Ñirihuau Basin, Argentina.

RESUMO – Este trabalho visa analisar a paleovegetação, os paleoclimas e a paleoceanografia do Paleógeno da região do Río Foyel (Grupo Foyel), bacia Ñirihuau, Argentina, compreendendo as formações Troncoso, Salto del Macho e Rio Foyel. A análise de esporomorfos mostra a existência de um bosque regional formado principalmente por Nothofagaceae, Myrtaceae, Podocarpaceae e Palmae, desenvolvido sob clima temperado a temperado-quente e úmido. Na região estudada, foi considerada a relação entre os palinomorfos continentais/marinhos. Há predominância de palinomorfos terrígenos sobre elementos marinhos na Formação Troncoso. A recorrência de pólen de gimnospermas como Araucariaceae indica clima temperado a úmido. A Formação Salto del Macho mostra uma regressão do bosque de gimnospermas, relacionada ao avanço do bosque de *Nothofagus*, sugerindo clima temperado-úmido. Na Formação Río Foyel, os esporomorfos demonstram a presença de um bosque temperado a quente-úmido, com áreas abertas subordinadas e um notável *input* do ambiente costeiro. Na mesma formação, as características palinológicas, que indicam rasamento ascendente, permitem a identificação de parasequências. Os limites das parasequências são definidos como superfícies de inundação, as quais representam um aumento relativo do nível do mar (superfícies de inundação marinha). A Formação Río Foyel mostra uma sequência de rasamento ascendente, indicada pela diminuição de dinocistos. Foram detectadas diferentes superfícies de inundação marinha, associadas à diversidade e abundância de dinocistos. A comparação entre estas associações esporopolínicas com outras da Patagônia, realizada através de métodos estatísticos multivariados, revela uma grande semelhança entre a Formação Troncoso (Eoceno médio a superior) e a Formação Slogett (Eoceno superior a ?Oligoceno inferior); e entre as formações Salto del Macho e Río Foyel com associações da Formação Loreto (Eoceno superior-Oligoceno) e a Formação San Julián na área do cabo Curioso (Oligoceno).

Palavras-chave: Paleógeno, Palinologia, Grupo El Foyel, bacia Ñirihuau, Argentina.

INTRODUCTION

This paper focuses on the application of palynological studies to determine relationships between palynomorph concentrations and associations of the biosphere to reconstruct plant associations, oceanic conditions and to interpret climatic trends.

Its goal is to contribute to understand the paleovegetation, paleoclimates and paleoceanographic conditions of El Foyel Group (Paleogene) at the Río Foyel type section, in the Ñirihuau Basin. The Troncoso, Salto del Macho and Río Foyel formations of El Foyel Group are here included.

The major vegetation types may be recognized from the pollen assemblage. Many Tertiary pollen types show affinities with living taxa, hence it should be possible to use the ecological tolerance of today to reconstruct Tertiary climates; though not always satisfactorily due to the fact that ecological tolerances may have changed over the time as suggested by Martin (1987, 1997). Among the most important proxies that were used to detect paleoenvironmental changes are the organic-walled dinoflagellate cysts (dinocysts). Dinocyst assemblages in sediments provide information pertinent to the ecology of the water in which the dinoflagellates lived.

PREVIOUS INVESTIGATIONS ON PALEONTOLOGY

The Río Foyel Formation contains an abundant fauna of marine invertebrates, which have been studied since early 20th century (von Ihering, 1904, 1907, 1914; Gonzalez Bonorino, 1944). In samples from the same section studied here, but from the upper levels, Bertels (1980, 1993, 1994a,b) found strong similarities between the assemblages of foraminifera and those from the Monte León Formation (Santa Cruz Province, Atlantic coast). Based in this bio-correlation, Bertels (1980, 1993, 1994a, b) postulated an Oligocene age for the Río Foyel Formation. Recently, Malumián *et al.* (2008) found moulds of *Transversigerina* cf. *T. transversa* (Cushman) at 18 m from the base of the section under study. This genus appeared in the late Oligocene and the compared species in the early Miocene. Chiesa & Camacho (2001), based on the megafauna, proposed a middle Eocene age for the lower part of this unit.

The megaflora collected by Washburne between 1911 and 1912 in the Ñirihuau Formation was the basis of Berry's (1928) studies about South American flora. Romero & Dibbern (1984) provide a detailed report on the megaflora in the studied area.

Previous palynological studies correspond to the Huitrera, Salto del Macho and Río Foyel formations (Melendi *et al.*, 2003; Barreda *et al.*, 2003; Martínez *et al.*, 2008) and in the "Serie Andesítica" (Sepúlveda, 1980). The Huitrera Formation (Melendi *et al.*, 2003) presents microfloras without *Nothofagidites* of the early Eocene and microfloras with *Nothofagidites* ("brassi" and "fusca" groups) of the middle to late Eocene. Based on the fungal assemblage, Sepúlveda (1980) associated the "Serie Andesítica", in the Cordón

Oriental del Futalaufquen, to the middle Eocene. Other samples from the upper levels of this same section (not studied here) (Barreda *et al.*, 2003) recognize a similar palynological assemblages, but less diverse and they postulated a late Oligocene to early Miocene age taking into account the presence of *Tuberculodinium vancampoae* (Rossignol) Wall. However, this species has already been accurately recognized as corresponding to the early Oligocene (see Head *et al.*, 1989, p. 440). Martínez *et al.* (2008) provide the sedimentology, environmental conditions and an introduction of the plant communities of the Salto del Macho Formation.

STRATIGRAPHY

The fill of the Tertiary Ñirihuau Basin, which is located on the eastern Subandean flank of the Northern Patagonian Cordillera, is characterized by two major volcanic and sedimentary cycles. The Base Cycle (late Paleocene to early Oligocene) involves the Pilcaniyeu Volcanic Belt (Huitrera Formation) and the Cerro Bastión, Río Foyel ("Patagonian") and Rincón de Cholila formations. The Top Cycle (early Oligocene to Pliocene) is represented by the Nahuel Huapi Group and consists, from base to top, of the El Maitén Volcanic Belt (Ventana Formation) and the Ñorquinco, Ñirihuau and Collón Cura formations (Asensio *et al.*, 2010). Structurally, the western part of the basin has taken part in the deformation process that gave rise to the Ñirihuau fold and thrust belt, whereas the eastern border accounts for the basin platform showing poor or no-deformation, with three distinct regions: North (Ñirihuau), South (Ñorquinco) and West (El Bolsón).

El Foyel Group (Asensio *et al.*, 2005) is stratigraphically located between the vulcanite of the Cerro Bastión Formation (middle Eocene, Sepúlveda, 1980) and the vulcanite of the Ventana Formation (late Oligocene, Cazau *et al.*, 1989). It reaches a thickness of more than 1900 m. It appears as if El Foyel Group has a chronostratigraphic range extending from the middle Eocene to the early Oligocene. This entity presents a variable vertical development, as evidenced by the margins of the Foyel River, where the succession reaches a thickness of 2000 m (Asensio *et al.*, 2005).

Río Foyel Section

The outcropping section of the Foyel river margins (42° S) (Figure 1) is central to the stratigraphic analysis of the Ñirihuau Basin. Although it has been known since the 19th century (Roth, 1899; Wherli, 1899), only in 2005 it was substantially studied and valued as having important implications within the sedimentary register of the basin. From the bottom up, it comprises Troncoso, Salto del Macho and Río Foyel formations (Figure 2).

The Troncoso Formation (Asensio *et al.*, 2005) reaches a thickness of 750 m and is constituted mainly of volcaniclastic sandstones and tobaceous clay rocks with intercalation of thick ignimbritic banks. A particularity of this unity is that it presents a divergence between its constitutive layers, which
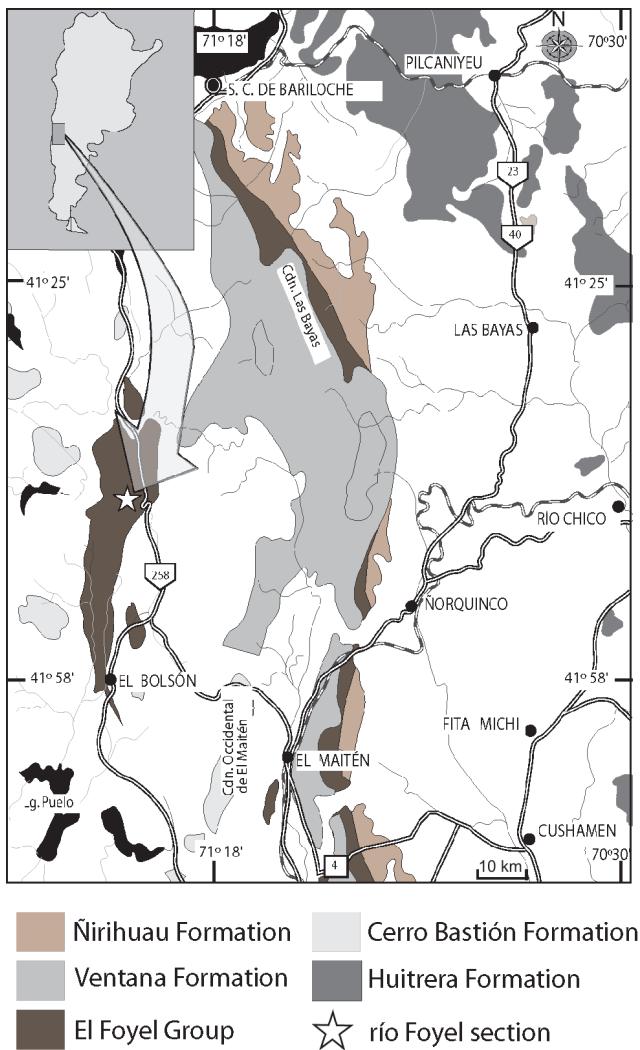
Figure 1. Location map of the study area with indication of the Río Foyel section.

Figure 2. Study section and stratigraphic distribution of the palynological samples.

can be inferred as resulting from synsedimentary tectonic activity. The contact with the Cerro Bastión Formation is sharp, although in most cases it is blurred by heavily forested areas. The age of this unit has not been established with precision but, as inferred from its stratigraphic relations, it is estimated to extend from the middle Eocene to late Eocene (Asensio *et al.*, 2005).

The Salto del Macho Formation reaches 560 m of thickness and is characterized by having tabular bodies-less than 10 m thick- with a predominance of the conglomeradic facies, among which there is intercalation of sandstone banks and, in lower proportion, carbonaceous shale. As evidenced by the comparison of facies and the stratigraphic relations within the section, it is possible to emphasize that the origin of this dense succession, mainly conglomeradic, is closely related to subaerial hyperconcentrated flows, associated to distal deltaic fans. The tectosedimentary development of the unit is linked with a strong extensional pulse occurred during middle Eocene-lower Oligocene and is related with the tectonics of the Farallón and the Sudamericana Plates (Asensio *et al.*, 2008). The age of this unit as inferred from

its stratigraphic relations extends from the middle Eocene to early Oligocene (Asensio *et al.*, 2005).

The Río Foyel Formation (Pöthe de Baldis, 1984) presents a minimum thickness higher than 600 m and is constituted mainly by black calcareous shales. The age is determined by a sampling $^{87}Sr/^{86}Sr$ of 30, 65 Ma (Griffin *in* Asensio *et al.*, 2010) on the valve of an *Ostrea* and on an andesite dyke that intrudes to the unit and which yielded the value of 31 Ma (K/Ar) (Giacosa *et al.*, 2001). It stands, with a maximum flooding surface, on the conglomerates of the Salto del Macho Formation and could be related to the sandstones of the Ñorquinco Formation (Cazau, 1972).

MATERIAL AND METHODS

Physical and chemical extraction was performed using standard palynological processing techniques (Volkheimer & Melendi, 1976). Twenty-three samples were processed for palynological purpose, and sixteen yielded moderately to poorly preserved palynomorphs. Six from Troncoso Formation only one fertile, one from Salto del Macho Formation and the others from Río Foyel Formation. All figured specimens are lodged in the collections of the Palynological Laboratory (UNSP), Universidad Nacional del Sur, Bahía Blanca, Argentina. In the citation of specimens referred to or illustrated, the sample and slide number (*e.g.* 1980a) are given first and the position on the slide is indicated by an England Finder reference (*e.g.* G36/4). Additionally, the formations are given: Salto del Macho (SM), Troncoso (T), Río Foyel (RF).

The palynologic analysis for biostratigraphic (palynostratigraphic), paleoclimatical and paleoecological approach is based on qualitative and quantitative data. The quantitative analysis comprises a minimum of 100 palynomorphs per sample, excepting those samples in which this was not possible due the scarcity of palynomorphs. These are indicated in Table 1 as "presence". The sporomorphs are arranged in Table 2 according to their botanical affinity.

Hammer's *et al*. (2001) program, *Palaeontological Statistics* (PAST), was used to determine similarities among El Foyel Group and other Danian-Miocene sporomorph assemblages from different units of southern South America, based on presence/absence data.

Each site in the cluster represents a sum of several samples with the exception of Troncoso, Salto del Macho (El Foyel Group) and San Julián formations in cabo Curioso (Santa Cruz Province). Using PAST, the Jaccard Coefficient was applied as a measure of similarity (between 0 to 1 - low to high similarity) between samples. The results of the cluster analyses are presented in dendrograms (Figure 3).
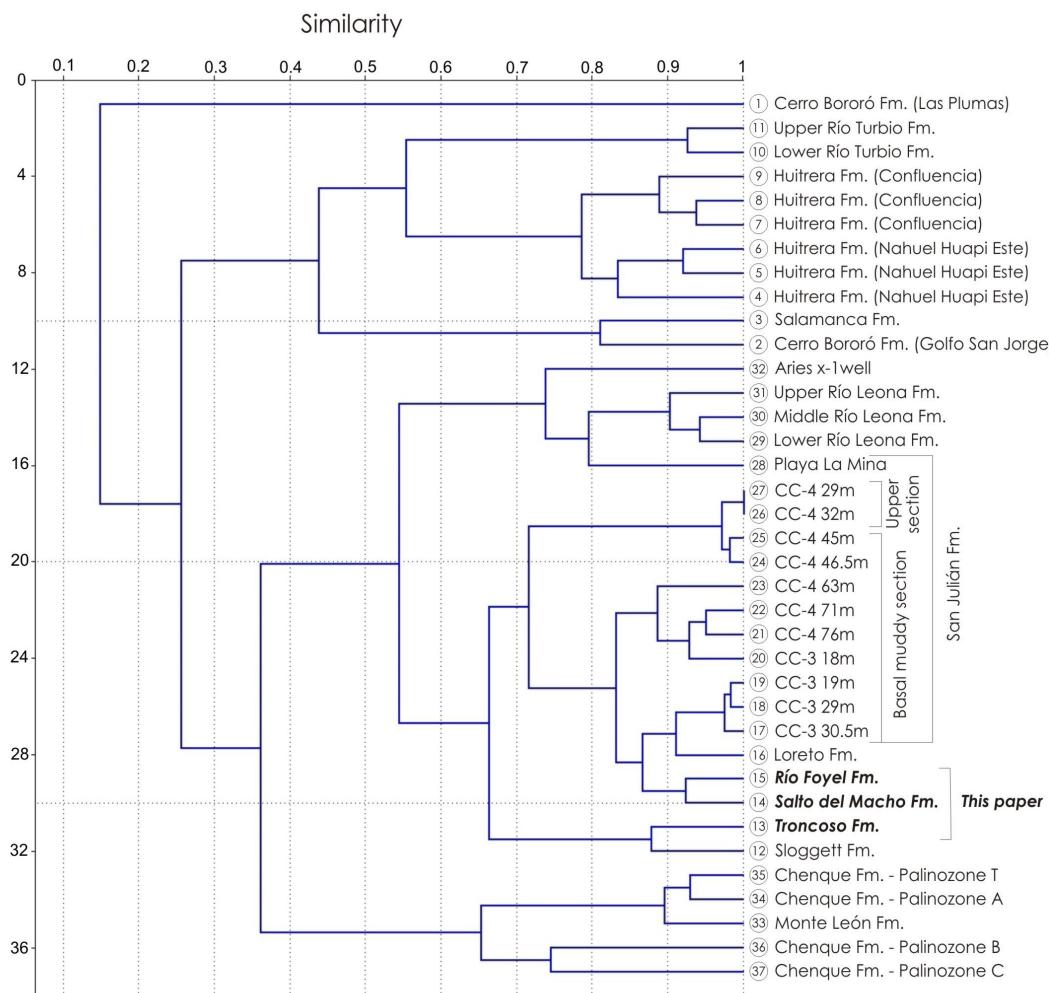
Figure 3. Dendrogram showing the clustering of palynological assemblages from different formations and/or localities, based on Jaccard coefficient and the PAST programme. References: **1**, Volkheimer *et al*. (2007); **2-3**, Archangelsky (1973, 1976); Archangelsky & Romero (1974); Archangelsky & Zamaloa (1986); **4-9**, Melendi *et al*. (2003); **10-11**, following in this paper the Lower and Upper Section (Rio Turbio Formation) recognized by Hünicken (1955); Archangelsky (1972); Romero & Castro (1986); Romero & Zamaloa, 1985; Romero, 1977; **12**, Olivero *et al*., 1998; **13-15**, Asensio *et al*., 2005; this paper; **16**, Fasola (1969); **17-27**, Nañez *et al*. (2009); **28**, Barreda (1997); **29-31**, Barreda *et al*. (2009); **32**, Palamarczuk & Barreda (2000); **33**, Barreda & Palamarczuk (2000a); **34-37**, Barreda (1996); Palamarczuk & Barreda (1998); Barreda & Palamarczuk (2000b) (modified from Nañez *et al*., 2009).

Table 1. Distribution charts of palynomorphs from the río Foyel section.

Formation / Samples → Taxa ↓	Troncoso 2223	Salto del Macho 2267	Río Foyel 2299	2226	2300	2227	2228	2229	2230	2231	2232	2233	2310	2234	2311	2312
PTERIDOPHYTA & BRYOPHYTA																
Azolla sp.		X														
Baculatisporites comaumensis									14		X					
Baculatisporites turbioensis		X														
Baculatisporites sp.						1.2	2.4	X		2.3	X	2.2	1.3			
Biretisporites crassilabratus		3.3				2.4	7.3	X	2.3	9.3	X	9.9		8.5		
Biretisporites sp. 1	1.8	3.3						X								
Cingutriletes australis		X														
Concavisporites sp.													1.3	1.2		
Cyatheacidites annulatus	4.41	1.7		X		10.6	8.5		2.3	2.3	X	3.3			11	1.4
Cyathidites subtilis										2.3						
Deltoidospora australis	9.73	10	X	X		9.4	19.6	X	20.9	11.6	X	8.8	57.3	15.9	12.3	
Deltoidospora minor		5	X			4.7		X				6.6	13.3		1.4	
Deltoidospora spp.					X				11.6						2.7	
Dictyophyllidites harrisii	0.9								2.3							
Gleicheniidites argentinus		1.7					1.2					3.3			2.7	
Hymenophylleaceae	0.9	1.7											4	1.2	5.5	
cf. *Hymenophyllum caudiculatum*									2.3							
Ischyosporites areapunctatis		3.3	X			7	4.9	X	4.6	2.3		6.6	8	9.8	6.8	
Laevigatosporites ovatus		3.3		X			4.9					2.2				
Leptolepidites macroverrucosus										2.3					1.4	
Matonisporites ornamentalis		X														
Muricingulisporis chenquensis		8.3														
Peromonolites vellosus															X	
Polypodiisporites inangahuensis	0.9	1.7		X		3.5	1.2								2.7	3.2
Reticuloidosporites tenellis		1.7														
Indeterminate trilete spore						2.4										3.2
GIMNOSPERMAE																
Araucariacites australis	33.6			X	X	6.1		X	2.3	2.3						1.6
? *Dacrycarpites australis*							1.2								1.4	
Inaperturopollenites spp.	1.8															
Microcachryidites antarcticus		1.7													1.2	
Phyllocladidites mawsonii		1.7		X		11.8	11			11.6		3.3	1.3	6.1		
Podocarpidites marwickii	10.6	6.7	X		X	5.9	4.9	X	4.6	4.6		2.2		11	13.7	1.6
Podocarpidites spp.	0.9						3.7								13.7	
Taxodiaceaepollenites hiatus				X		2.4			2.3	14	X			4.8		
Trisaccites microsaccatum					X											
Algae																
Botryococcus sp.	11.5						1.2									
? *Celyphus rallus*													1.2			
Others																
Foraminiferal test linings							1.2						1.3		1.4	
? Partitomorphitae													4.9			
ANGIOSPERMAE																
Baumannipollis sp.											X					
Chenopodipollis chenopodiaceoides		1.7														
Corsinipollenites atlantica		1.7														
Graminidites sp.	1.8			X		2.4	4.9		2.3			3.3			1.4	
Haloragacidites sp.								X								
Myrtaceidites verrucosus	0.9	1.7		X	X	3.5	4.9	X	2.3	2.3				2.4	4.1	
Myrtaceidites sp. (cf. *Myrceugenia*)							1.2		2.3				1.3		1.4	
Momipites sp.						1.2		X								
Nothofagidites americanus						X										
Nothofagidites anisoechinatus		X														
Nothofagidites dorotensis						X							1.3			
Nothofagidites flemingii		1.7														
Nothofagidites menziesii type						X						2.2			1.4	
Nothofagidites nanus						X										
Nothofagidites rocaensis		11.7		X	X	8.2	2.4		7	14	X	4.4	4	11		
Nothofagidites saraensis	1.8	5	X		X	3.5	2.4					3.3		3.7		4.8
Nothofagidites spp.		11.7				2.4		X	4.7						2.7	11.1
Propylipollis rynthius													1.3			
Proteacidites subscabratus	0.9					X										
Proteacidites symphyonemoides						X										
Proteacidites spp.						1.2										
Pseudowinterapollis couperi						X										
Psilamonocolpites grandis													2.2			
Psilatricolporites salamanquensis											X					
Psilatricolporites spp.						7					X				1.2	
Restioniidites sp.	0.9															

Table 1. Cont.

Formation / Samples — Taxa	Troncoso 2223	Salto del Macho 2297	Río Foyel 2299	2226	2300	2227	2228	2229	2230	2231	2232	2233	2310	2234	2311	2312
ANGIOSPERMAE																
Rhoipites baculatus								X								
Rhoipites minusculus	0.9				X		1.2		2.3	4.6				1.3	3.7	1.4
Rhoipites sp. A	2.65										X					
Rhoipites spp.	2.65															
cf. *Rousea patagonica*		X														
Spinizonocolpites sp.		1.7						X								
Striatricolporites spp.							1.2									
Triatriopollenites bertelsii															1.4	
Triorites minor					X		1.2							2.4	4.1	1.6
Indet. tricolporate pollen grain		1.7				3.5								1.2		
FUNGI																
Desmidiospora willoughbyi	X															
cf. *Diporicellaesporites navicularis*								X								
Diporisporites cf. *psilatus*								X								
Fractisporonites sp.																X
Hilidicellites sp.	X															
Hypoxylonites sp.							X		X					X		
Inapertisporites cystoides																X
Inapertisporites elencantense	X															
Monoporites abruptus	X				X											
Monoporisporites lagenarius								X								
Multicellaesporites sp.					X											
Multicellites sp.												X				
DINOCYSTS																
? *Apteodinium* sp.														1.2		
? *Batiacasphaera baculata*						1.2						5.5				
Batiacasphaera micropapillata	4.4											9.9				
Batiacasphaera spp.			X						4.7			6.6				
? *Cristadinium* sp.					X											
Escharisphaeridia psilata	2.7			X												
Escharisphaeridia spp.	2.7	3.3														
Hystrichostrogylon sp.					X											
Lejeunecysta communis	0.9		X													
Lejeunecysta convexa					X											
Lejeunecysta fallax						1.2										
Lejeunecysta globosa			X						4.7					2.2	2.7	17.5
Lejeunecysta spp.											2.3					
Lingulodinium bergmannii			X	X	X	2.4		X	4.7	7	X	12.1		1.2	12.3	47.6
Lingulodinium hemicystum					X										1.4	
cf. *Selenopemphix nephroides*					X											
Spiniferites sp.															1.4	1.6
Tuberculodinium vancampoae					X	1.2										
Proximate indet. dinocysts				X		1.2		X								6.4

The "non-metric multidimensional scaling" (N-MDS) (Kruskal & Wish, 1976) was used as well, which is based on rank-order of the elements of the similarity matrix, rather than on their absolute values. The procedure is based on a clear assumption: the greater the similarity between two objects, the closer to each other they will appear in the ordination (Kovach, 1989). The results presented in here correspond to the first two axes, which reflect the main variability of the data (Figure 4).

PALEOCOMMUNITIES AND PALEOCLIMATIC INFERENCES

Sporomorphs analysis (Figures 5-7) allows the characterization of the paleofloristic and paleoclimatic scenario of the studied section during the middle Eocene-Oligocene. It reflects a regional forest dominated by Nothofagaceae, Myrtaceae, Podocarpaceae and Palmae, developed under a temperate to warm-temperate and humid climate. The distribution charts of palynomorphs and the list of identified species, and botanical affinities from the río Foyel section are given in Tables 1 and 2, respectively.

In río Foyel section, the species of *Nothofagidites* correspond to *N. saraensis* Menéndez & Caccavari and *N. rocaensis* Romero, which are both similar to the *Nothofagus* "Dombeyi type" and, among others, include the actual *N. dombeyi* (Mirb.) Oerst and *N. antarctica* (Forst.) Oerst. These two species are opposite ecologic indicators. The first corresponds to the evergreen forest and the second to the microtermic and deciduous forest. The paleoenviromental inferences with these morpho-species then are limited.

Morphologically different pollen types are recognizable within the genus *Nothofagus* Blume, but a single pollen type can be found in a number of living species (Dettmann & Pocknall, 1990). This point is important, for the ecological tolerances apply to the species and if the identification is to more than one species, their ecological tolerances may not be the same (Martin, 1997).

Table 2. List of identified species, and botanical affinities.

Fossil taxon	Botanical affinity
Bryophyte and Pteridophyte spores	
Azolla sp.	Azollaceae (*Azolla filiculoides*)
Baculatisporites comaumensis (Cookson) Potonié, 1953	Osmundaceae
Baculatisporites turbioensis Archabgelsky, 1972	?Osmundaceae
Baculatisporites sp. (*in* Barreda *et al.,* 2003)	
Biretisporites crassilabratus Archangelsky, 1972	?Hymenophylleaeceae
Biretisporites sp. 1 (*in* Archangelsky, 1972)	
Cingutriletes australis (Cookson) Archangelsky, 1972	Sphagnales (*Sphagnum*)
Concavisporites sp.	?Filicopsida
Cyatheacidites annulatus Cookson, 1947	Lophosoriaceae (*Lophosoria*)
Cyathidites subtilis Partridge, 1976	Cyatheaceae/Dicksoniaceae
Deltoidospora australis (Couper) Pocock, 1970	Polypodiaceae (*Acrostichum*)
Deltoidospora minor (Couper) Pocock, 1970	Polypodiaceae (*Acrostichum*)
Dictyophyllidites harrisii Couper, 1958	Matoniaceae (*Phlebopteris*)
Gleicheniidites argentinus Volkheimer, 1972	Gleicheniaceae
Hymenophylleaceae	Hymenophylleaeceae
cf. *Hymenophyllum caudiculatum* Mart.	Hymenophylleaeceae
Ischyosporites aerapunctatis (Stuchlik) Barreda, 1996	Dicksoniaceae
Laevigatosporites ovatus Wilson & Webster, 1946	Blechnaceae
Leptolepidites macroverrucosus Schulz, 1967	Dennstaedtiaceae
Matonisporites ornamentalis (Cookson) Partridge *in* Stover & Partrridge, 1973	Dicksoniaceae
Muricingulisporis chenquensis Barreda, 1992	Pteridaceae (*Pteris semiadnata*)
Peromonolites vellosus Partridge, 1973	Blechnaceae
Polypodiisporites inangahuensis (Couper) Potonié, 1956	Polypodiaceae
emend. Pocknall & Mildenhall, 1984	
Reticuloidosporites tenellis Krutzsch, 1959	Polypodiaceae
Gimnosperm pollen	
Araucariacites australis Cookson, 1947	Araucariaceae (*Araucaria*)
? Dacrycarpites australiensis Cookson & Pike, 1953	Podocarpaceae
Microcachryidites antarcticus Cookson 1947 ex Couper, 1953	Podocarpaceae (*Microcachrys*)
Phyllocladidites mawsonii Cookson, 1947	Podocarpaceae (*Dacrydium franklinii*)
Podocarpidites marwickii Couper, 1953	Podocarpaceae
Taxodiaceaepollenites hiatus (Potonie) Kremp	Taxodiaceae
Trisaccites microsaccatum (Cookson) Couper, 1960	Podocarpaceae
Angiosperm pollen	
Baumannipollis sp.	Malvaceae
Chenopodipollis chenopodiaceoides (Martin) Truswell, 1985	Chenopodiaceae
Corsinipollenites atlantica Barreda, 1997	Onagraceae
Graminidites sp.	Poaceae
Haloragacidites sp.	Haloragaceae
Myrtaceidites verrucosus Partridge, 1973	Myrtaceae
Myrtaceidites sp.	Myrtaceae (cf. *Myrceugenia*)
Momipites sp.	Juglandaceae
Nothofagidites americanus Zamaloa, 1992	Nothofagaceae
Nothofagidites anisoechinatus Menéndez & Caccavari, 1975	Nothofagaceae
Nothofagidites dorotensis Romero, 1973	Nothofagaceae
Nothofagidites flemingii (Couper) Potonié, 1960	Nothofagaceae
Nothofagidites menziesii type	Nothofagaceae
Nothofagidites nanus Romero, 1977	Nothofagaceae
Nothofagidites rocaensis Romero, 1973	Nothofagaceae
Nothofagidites saraensis Menéndez & Caccavari, 1975	Nothofagaceae
Propylipollis rynthius (Stover y Partridge) Nañez *et al.*, 2009	Proteaceae
Proteacidites subscabratus (Couper) Harris, 1965	Proteaceae
Proteacidites symphyonemoides Cookson, 1950	Proteaceae
Pseudowinterapollis couperi (Krutzsch) Mildenhall, 1979	Winteraceae
Psilamonocolpites grandis (Van der Hammen) Van der Hammen & García, 1966	Palmae
Psilatricolporites salamanquensis Archangelsky & Zamaloa, 1986	
Restioniidites sp.	Restionaceae
Rhoipites baculatus Archangelsky, 1973	Rutaceae-?Araliaceae
Rhoipites minusculus Archangelsky, 1973	Loganiaceae
Rhoipites sp. A (in Quattrochio, 1980)	Rutaceae
cf. *Rousea patagonica* Archangelsky, 1973	Adoxaceae
Spinizonocolpites sp. (Archangelsky, 1973)	Palmae

Table 2. Cont.

Fossil taxon	Botanical affinity
Angiosperm pollen	
Striatricolporites spp.	
Triatriopollenites bertelsii Archangelsky, 1973	Myricaceae
Triorites minor Couper, 1953	
Fungi	
Desmidiospora willoughbyi (Bradley, 1987) Ethridge Glass *et al.,* 1986	
cf. *Diporicellaesporites navicularis* Katgutkar, 1993	
Diporisporites cf. *psilatus* Kumar, 1990	
Fractisporonites sp.	
Hilidicellites sp.	
Hypoxylonites sp.	
Inapertisporites cystoides (Ambwani) Kalgutkar & Jansonius, 2000	
Inapertisporites elencantense Sepúlveda, 1980	
Monoporites abruptus Sheffy & Dilcher, 1971	
Monoporisporites lagenarius Song & Luo, 1989	
Multicellaesporites sp.	
Multicellites sp.	
Organic walled paleomicroplankton	
?Apteodinium sp.	Dinoflagellata
?Batiacasphaera baculata Drugg, 1970	Dinoflagellata
Batiacasphaera micropapillata Stover, 1977	Dinoflagellata
Batiacasphaera spp.	Dinoflagellata
? Cristadinium sp.	Dinoflagellata
Escharisphaeridia psilata Kumar, 1986	Dinoflagellata
Hystrichostrogylon sp.	Dinoflagellata
Lejeunecysta communis Biffi & Grignani, 1983	Dinoflagellata
Lejeunecysta convexa Matzuoka & Bujak, 1988	Dinoflagellata
Lejeunecysta fallax (Morgenroth) Biffi & Grignani, 1983	Dinoflagellata
Lejeunecysta globosa Biffi & Grignani, 1983	Dinoflagellata
Lingulodinium bergmannii (Archangelsky) Quattrocchio & Sarjeant, 2003	Dinoflagellata
Lingulodinium hemicystum McMinn, 1991	Dinoflagellata
cf. *Selenopemphix nephroides* (Benedek) Benedek & Sarjeant, 1981	Dinoflagellata
Spiniferites sp.	Dinoflagellata
Tuberculodinium vancampoae (Rossignol) Wall, 1967	Dinoflagellata
Algae	
Botryococcus sp.	Chlorococcales
?Celyphus rallus	Rivulariaceae
Others	
Foraminiferal test linings	

The frequent presence of gymnosperm suggests that the parent plants were present in quite large numbers near to the site of deposition. Their anemophilous pollen grains (*Podocarpidites* spp. and *Microcachryidites*) characterize the regional input of palynomorphs in the depositional site.

The Araucariaceae community may have occupied ecotones associated with lowlands (García *et al.*, 2006). Some authors related them even with coastal (Abbink, 1998) and/or swampy (Whitaker *et al.*, 1992) communities. The morphologic and structural features of their pollen grains suggest that they are not suitable for transport over large distances or for eolian dispersion. The presence of araucariacean pollen grains in high proportions may be related to forests of altitude or to relatively lower areas where pollen was transported principally by fluvial currents (Martínez *et al.*, 1996). In this paper due to the increase of Araucariaceae associated with a high frequency of

pteridophytic spores in the regressive events, a lowlands scenario is suggested.

Phyllocladidites mawsonii Cookson is very similar to pollen of *Lagarostrobus franklinii* (Hook) Quinn. Today *L. franklinii* is restricted to high-rainfall areas in western Tasmania, where the annual precipitation is up to 2,500 mm. The habitat is banks of rivers and swampy flats to 750 m.

Most of the Myrtaceae pollen corresponds to *Myrtaceidites verrucosus*, a rainforest type (Martin, 1997).

The presence of Palmae, even though palms are found in tropical and subropical climates, in Chile reaches the 35º30'S surviving -15º C during short periods in winter (Ottone, 2009).

Among the pteridophytas *Cyatheacidites annulatus* Cookson and *Deltoidospora minor* Couper and *D. australis* Couper are recognized. Dispersed spores of *Cyatheacidites* are found in rocks of Cretaceous and Cenozoic age, and are virtually identical to those of the living monotypic
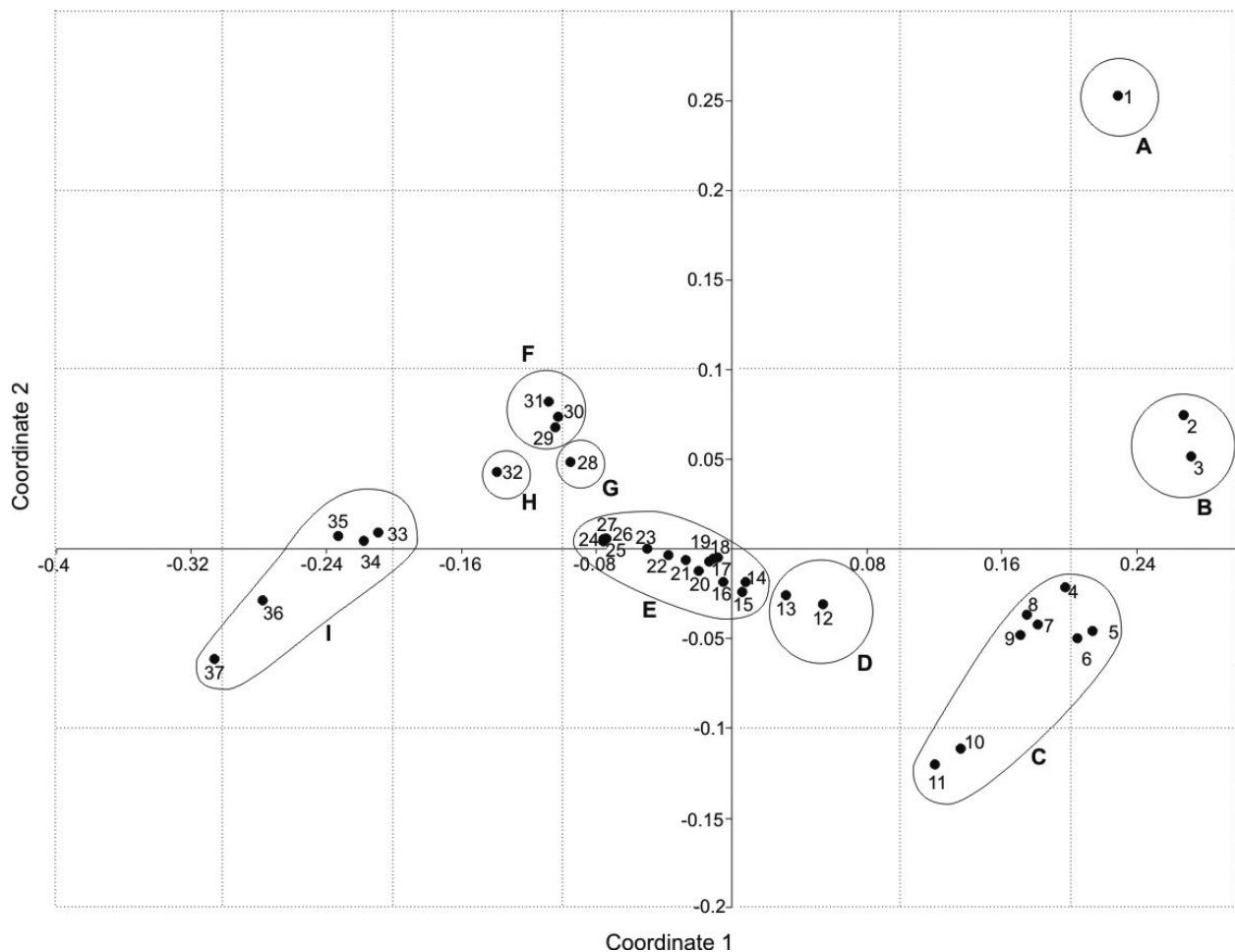
Figure 4. Groupings of palynological assemblages based on the non-parametric multidimensional scalin (N-MDS) technique. **A-B**, Danian, Cerro Bororó and Salamanca formations; **C**, Eocene, Huitrera and Río Turbio formations; **D**, late Eocene-?early Oligocene, Sloggett and Troncoso formations; **E**, Oligocene, Salto del Macho and Río Foyel formations, and "basal muddy section" of the San Julián Formation; **F-G**, late Oligocene, San Julián (Playa La Mina) and Río Leona formations; **H**, late Oligocene-early Miocene (Aries x-1 well); **I**, early-middle Miocene (Monte León and Chenque formations).

fern, *Lophosoria* according to Kurmann & Taylor (1987). Oligocene-early Miocene macrofossils of parts of a fertile frond are assigned to the extant South American species *Lophosoria quadripinnata* (Gmel.) C. Chr. These macrofossils bear the dispersed spore species *Cyatheacidites annulatus* Cookson ex Potonié (Hill *et al.*, 1999). Living *L. quadripinnata* is a large fern, now restricted to South America, where it ranges over more than 70° of latitude and occurs primarily in cloud forest in the tropics and in cool, wet regions further south. It grows in a variety of habitats and readily colonizes disturbed sites such as road cuttings and landslips, and may persist in logged forest, in pastures and in burned areas. *Deltoidospora* spores were found from Eocene-Oligocene polypodiaceous ferns close to *Acrostichum* by Collinson (1978). Anzótegui (2006) recognized a palustrine community with rooted herbaceous: *Acrostichum* cf. *A. aureum* L. in the middle to upper Miocene of the NW of Argentina. Presence of Pteridaceae, *Pteris semiadnata* Phil. (*Muricingulisporis chenquensis* Barreda) was registered. This plant inhabits humid areas, with almost constant rainfall between 5-1370 m.o.s.l. (metres over sea level), in Chile (Rodríguez, 1995).

SEDIMENTARY CYCLES

The palynological data are discussed in order to reconstruct the paleo-oceanographic and paleoclimatic conditions of the studied section.

The parameter used here for the reconstruction of relative sea-level changes is the relation of terrigenous sporomorphs to marine palynomophs (t/m). Within a section, the values of the t/m relation may fluctuate depending on relative sea level changes, phytoplankton productivity or stronger fluvial/eolic input of terrigenous sporomorphs into the basin. They also depend on episodic regional climatic changes, which produce changes in quantitative (and qualitative) sporomorphs input.

When, for example, a progradational package in a highstand systems tract is considered in detail, it is found to consist of a series of smaller packages of beds, each of which shows an upward shallowing, progradational trend. In the terminology of sequence stratigraphy, this group of beds is called a "parasequence".

In the Río Foyel Formation, homogeneous pelite deposits were identified; the parasequences are identified on the basis of the biofacies characteristics, which indicate upward swallowing.
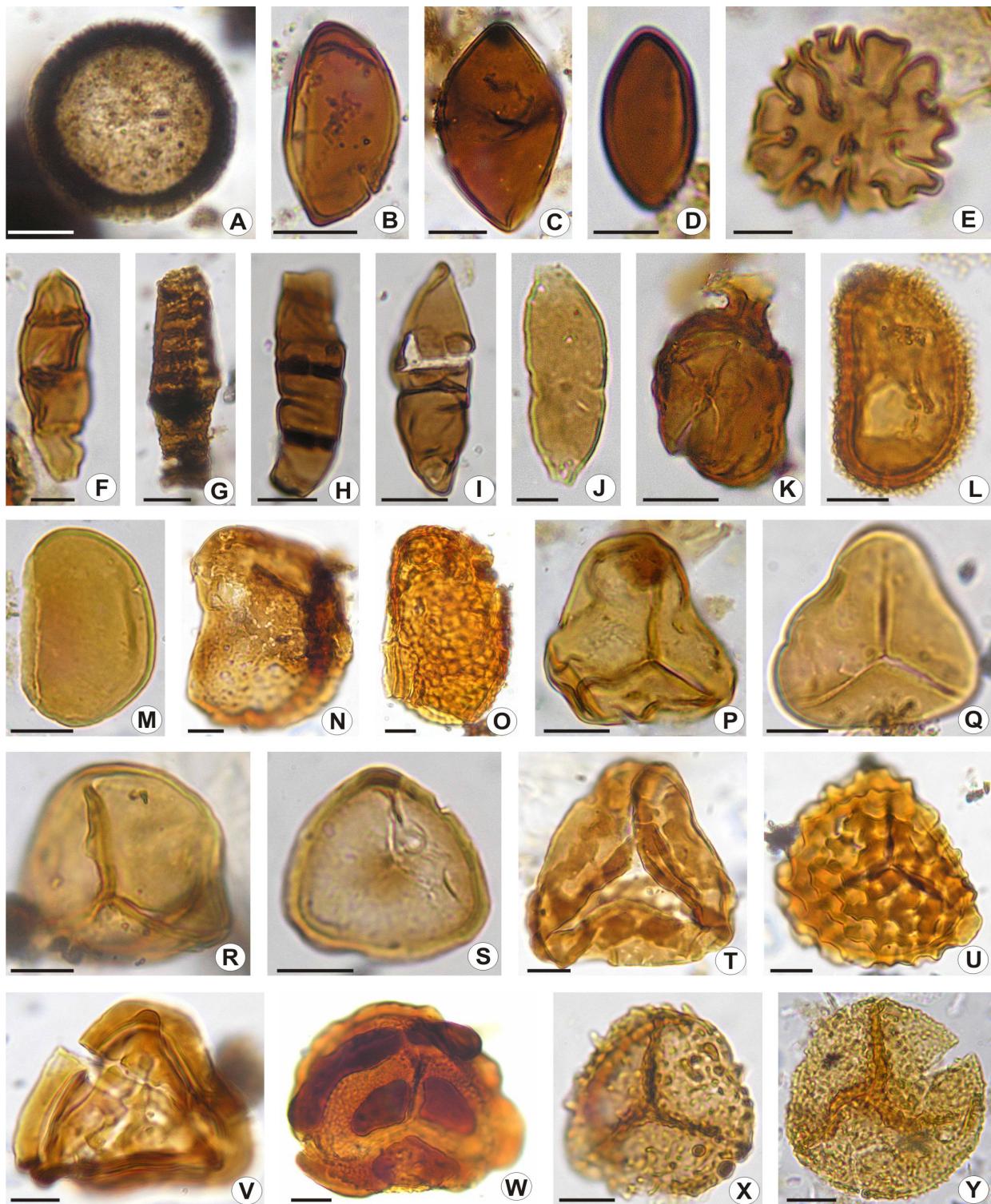
Figure 5. A, *Inapertisporites cystoides* (Ambwani) Katgutkar & Jansonius, UNSP RF 2312b: X6. **B**, *Hypoxylonites* sp., UNSP RF 2230c: P32. **C**, *Monoporites abruptus* Sheffy & Dilcher, UNSP T 2223b: P66/1. **D**, *Inapertisporites elencantense* Sepúlveda, UNSP T 2223b: Z56/4. **E**, *Desmidiospora willoughbyi* (Bradley) Ethridge Glass, Brown & Elsik, UNSP T 2223b: L19/4. **F**, *Multicellaesporites* sp., UNSP RF 2300c: T9. **G**, *Fractisporonites* sp., UNSP RF 2312b: W5/4. **H**, *Multicellaesporites* sp., UNSP SM 2297b: X51/2. **I**, *Hilidicellites* sp. UNSP T 2223c: V55. **J**, *Diporisporites* cf. *D. psilatus* Kumar, UNSP RF 2229c: V57. **K**, *Monoporisporites lagenarius* Song & Luo, UNSP RF 2229c: X64/4. **L**, *Peromonolites vellosus* Partridge in Stover & Partridge, UNSP RF 2311: V6. **M**, *Laevigatosporites ovatus* Wilson & Webster, UNSP RF 2228c: X28/3. **N**, *Reticuloidosporites tenellis* Krutzsch UNSP SM 2297b: R49. **O**, *Polypodiisporites inangahuensis* (Couper) Potonié emend. Pocknall & Mildenhall, UNSP RF 2311c: F45. **P**, *Cyathidites subtilis* Partridge, UNSP RF 2231c: S65/3. **Q**, *Deltoidospora minor* (Couper) Pocock, UNSP SM 2297b: K48/4. **R**, *Biretisporites crassilabratus* Archangelsky, UNSP SM 2297b: B30/4. **S**, *Cingutriletes australis* (Cookson) Archangelsky, UNSP SM 2297b: J54. **T**, *Matonisporites ornamentalis* (Cookson) Partridge, in Stover & Partridge, UNSP SM 2297b: R52/1. **U**, *Ischyosporites areapunctatis* (Stuchlik) Barreda, UNSP SM 2297b: V9. **V**, *Muricingulisporis chenquensis* Barreda, UNSP SM 2297b: W53/1. **W**, *Cyatheacidites annulatus* Cookson, UNSP SM 2297b: V56. **X**, *Baculatisporites turbioensis* Archangelsky, UNSP SM 2297b: R58. **Y**, *Baculatisporites* sp., UNSP RF 2228c: S44. Scale bars = 10 μm, except in D, E, F, J = 5 μm.
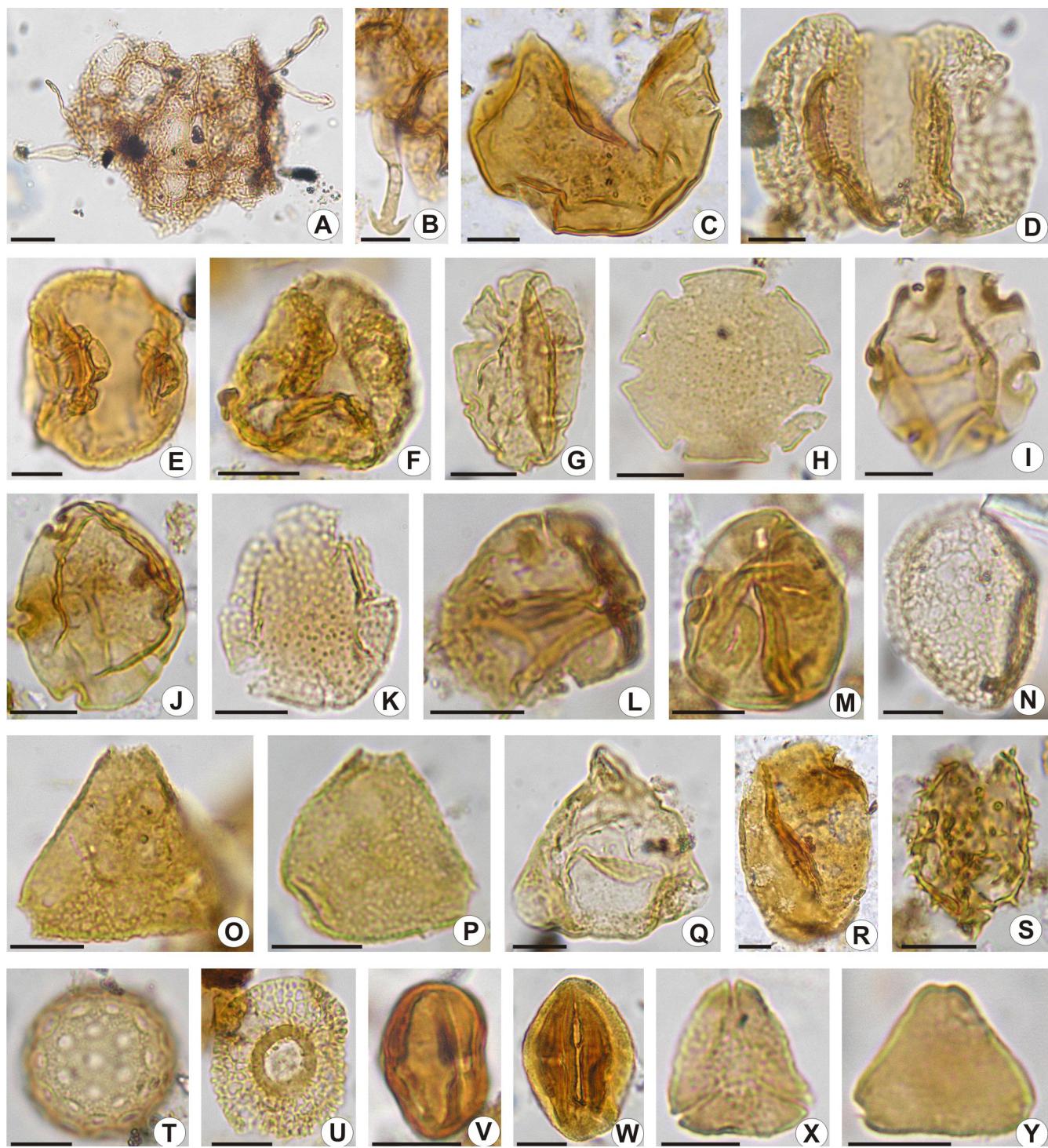
Figure 6. A-B, *Azolla* sp.: **A**, UNSP SM 2297: N36/2. **B**, Detail of *Glochidium*, UNSP SM 2297b: V20/2. **C**, *Taxodiaceaepollenites hiatus* (Potonié) Kremp, UNSP RF 2231c: D17. **D**, *Podocarpidites marwickii*, UNSP SM 2297: S11/3. **E**, *Phyllocladidites mawsonii*, UNSP SM 2297b: T30/1. **F**, *Trisaccites micosaccatum* (Cookson) Couper, UNSP RF 2300c: U9/3. **G**, *Nothofagidites* cf. *N. dorotensis* Romero, UNSP RF 2300c: Y50/1. **H**, *Nothofagidites fuegiensis* Menéndez & Caccavari, UNSP RF 2300d: X52/4. **I**, *Nothofagidites rocaensis* Romero, UNSP SM 2297b: Y58/2. **J**, *Nothofagidites saraensis* Menéndez & Caccavari, UNSP RF 2228c: O9/4. **K**, *Nothofagidites* "menziesii type" UNSP SM 2297b: N25/2. **L**, *Nothofagidites* sp. UNSP RF 2300c: W37/1. **M**, *Haloragacidites* sp., UNSP RF 2229c: U13. **N**, cf. *Rousea patagonica* Archangelsky, UNSP SM 2297: B29/4. **O**, *Proteacidites symphyonemoides* Cookson, UNSP RF 2300c: R12/1. **P**, *Proteacidites* sp. UNSP RF 2300d: A32. **Q**, *Corsinipollentites atlantica* Barreda, UNSP SM 2297b: R49. **R**, *Psilamonocolpites grandis* (Van der Hammen) Van der Hammen & García, UNSP RF 2233c: O46. **S**, *Spinizonocolpites* sp. UNSP RF 2229c: N30. **T**, *Chenopodipollis chenopodiaceoides* (Martin) Truswell, UNSP SM 2297b: X23/3. **U**, *Pseudowinterapollis couperi* (Krutzsch) Mildenhall, UNSP RF 2300c: B12. **V**, *Rhoipites minusculus* Archangelsky, UNSP RF 2234c: V21/1. **W**, *Rhoipites baculatus* Archangelsky, UNSP RF 2229c: U42. **X**, *Myrtaceidites verrucosus* Partridge, UNSP SM 2297b: S20/2. **Y**, *Triorites minor* Couper, UNSP RF 2300d: W44/3. Scale bars = 10 μm, except in A = 20 μm.
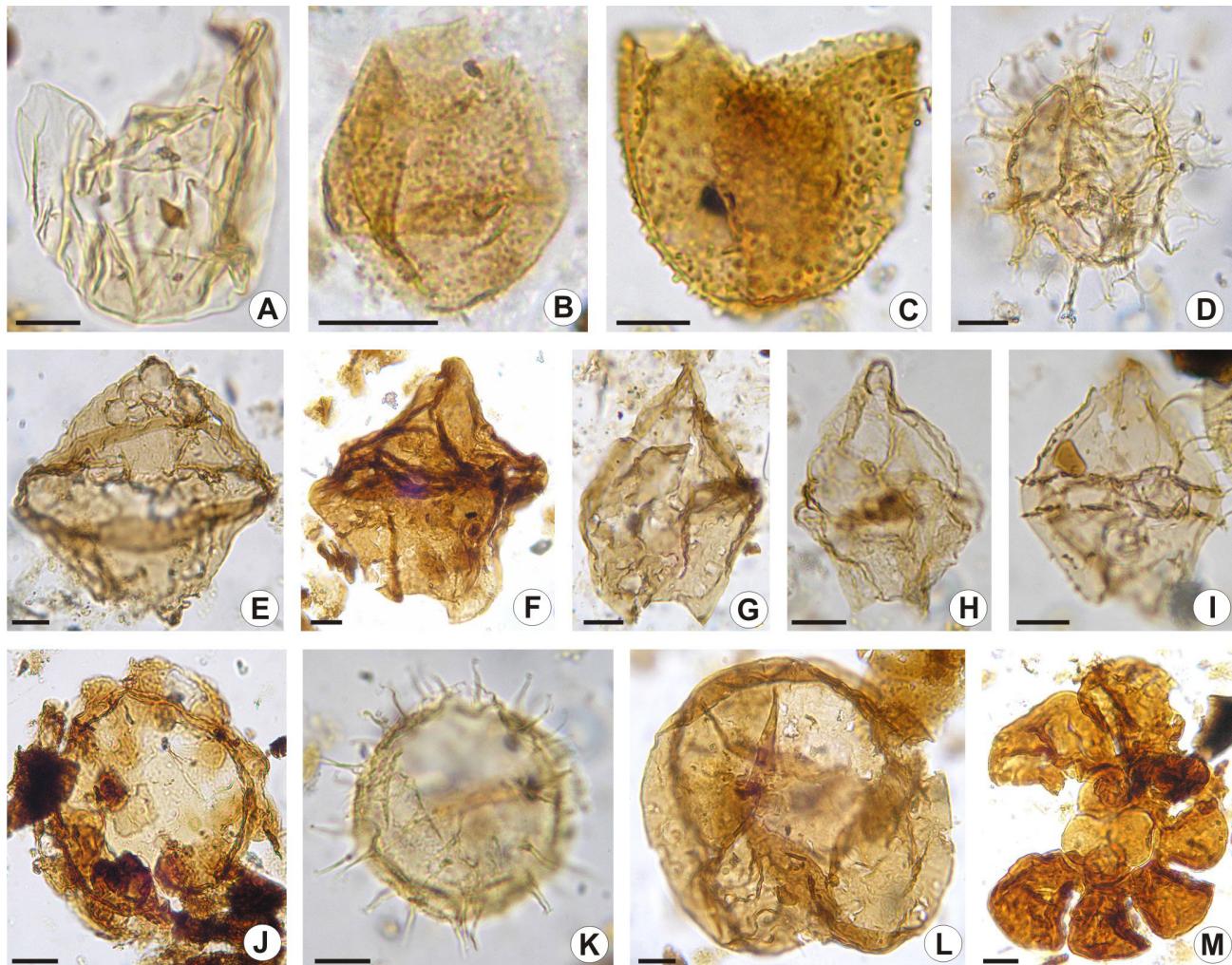
Figure 7. A, *Escharisphaeridia psilata* Kumar, UNSP T 2223c: T15. **B**, *Batiacasphaera micropapillata* Stover, UNSP RF 2233c: Z46. **C**, *?Batiacasphaera baculata* Drugg, UNSP RF 2228c: H24/3. **D**, *Hystrichostrogylon* sp., UNSP RF 2300d: O35/2. **E**, *Lejeunecysta globosa* Biffi & Grignani, UNSP RF 2299b: K16/3. **F**, *Lejeunecysta fallax* (Morgenroth) Biffi & Grignani, UNSP RF 2227c: U61/2. **G**, *Lejeunecysta communis* Biffi & Grignani, UNSP RF 2299b: G37/4. **H**, *Lejeunecysta convexa* Matsuoka & Bujak, UNSP RF 2300c: B53. **I**, *?Cristadinium* sp., UNSP RF 2300c: Y30/2. **J**, *Tuberculodinium vancampoae* (Rossignol) Wall, UNSP RF 2300c: Z52. **K**, *Lingulodinium bergmannii* (Archangelsky) Quattrocchio & Sarjeant, UNSP RF 2300c: Z26. **L**, cf. *Selenopemphix nephroides* (Benedek) Benedek & Sarjeant, UNSP RF 2227c: K33/3. **M**, Foraminiferal test linings UNSP RF 2228c:V43/4. Scale bars = 10 μm

These results are only an approach to this concept, due to limited fertile sampling. The bounding surfaces of parasequences are defined as surfaces of flooding which represent a relative sea level rise (marine flooding surfaces) (Figure 8).

In the studied section, the relation between terrestrial/ marine palynomorphs in Troncoso Formation indicates the general dominance of terrigenous over marine elements. The frequent presences of gymnosperm pollen (46%) with Araucariaceae (33.6%) dominate the spectrum, indicating temperate-humid conditions. The abundance of bryophytic/ pteridophytic spores in general denotes humid local condition, and the pteridophytic polypodiaceous ferns close to *Acrostichum* (*Deltoidospora*) reflect palustrine communities.

The dinocysts assemblage corresponds to only proximate cysts (*Escharisphaeridia* spp.) indicative of near shore conditions. The presence of Algae corresponds to *Botryococcus* sp. Colonies of *Botryococcus* are common in littoral areas where they accumulate in quiet and wind-protected sections (Tyson, 1995) with freshwater influence.

In Salto del Macho Formation, there is a retraction of the gymnosperm forest, associated with the dominance of *Nothofagus* Forest (30%), indicating temperate-humid condition. The pteridophytic spores (45%) correspond in particular to *Muricingulisporis chenquensis* (Pteridaceae). These plants inhabit humid areas, with almost constant rainfall.

The assemblage of dinocysts corresponds to *Escharisphaeridia* spp., indicative of a littoral marine environment. Similar conditions are inferred from 13 fertile samples of Salto del Macho Formation, in the same section, by Cornou *et al.* (2012).

In Río Foyel Formation, in the lower part of the section (from sample F21 to F23), only the "presence" (see Material and Methods) of palynomorph is registered (Pteridophytic, Gymnosperm, Nothofagaceae, Loganiaceae, Myrtaceae and dinocysts). In F23 the presence of *Tuberculodinium vancampoae* (R. Rossignol) Wall, suggest an estuarine and inner neritic environments, with warm-temperate to warm water temperatures (Wall *et al.*, 1977; Harland, 1983).

Samples F24 to F27, show an upward shallowing sequence,
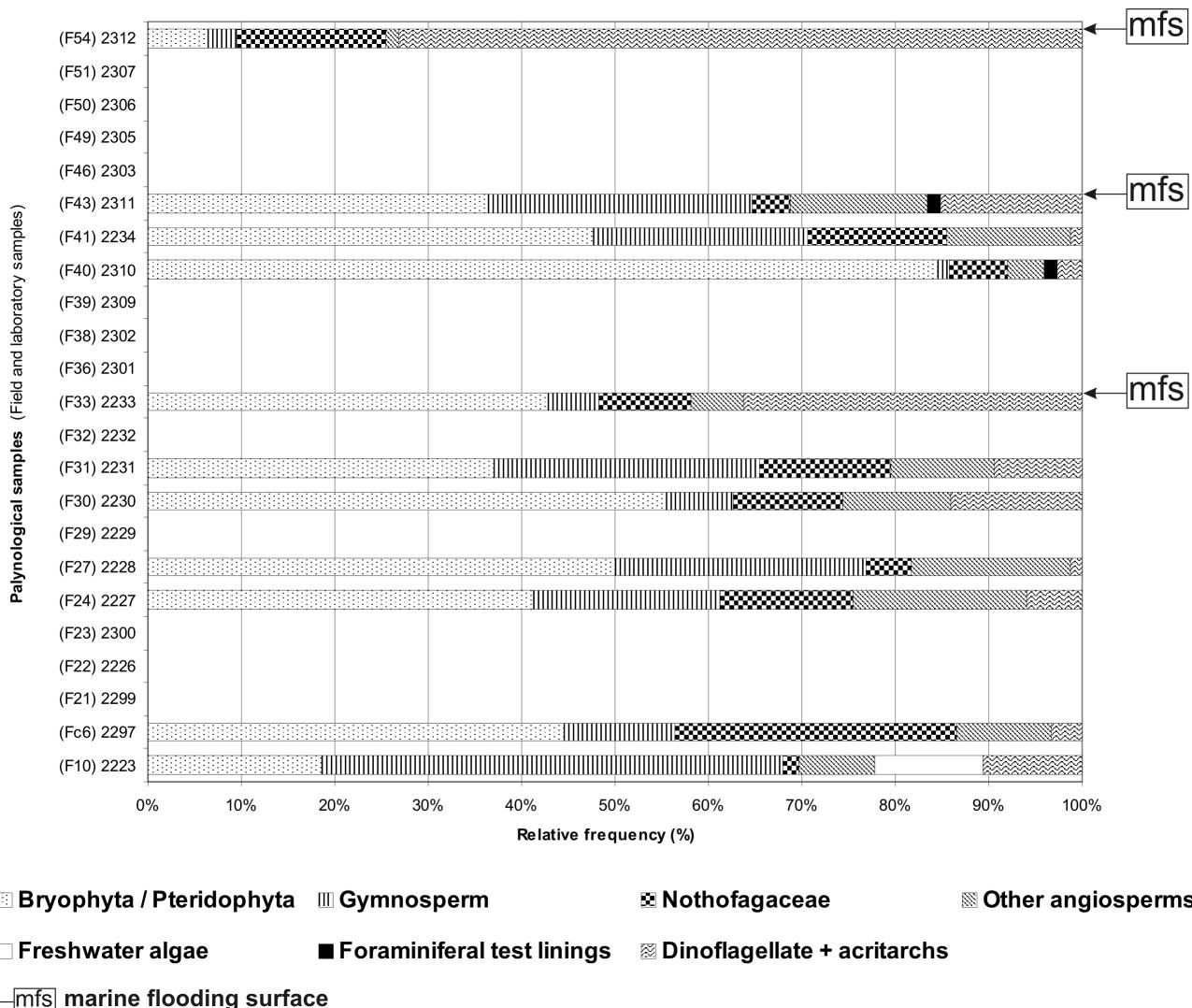
Figure 8. Relation between terrestrial and marine palynomorphs (suprageneric groups). Only stratigraphic levels with quantitative analysis are documented.

indicated by the decrease of dinocysts (6% in F24 to 1.2% in F27). The pteridophytic dominate the spectrum (41.2% in F24 to 50% en F27). In the regression (F27), the Araucariaceae (6.1%) income is associated with a decrease of the Nothofagaceae (14.1% in F24 to 4.8% in F27) and an increase of the Myrtaceae (3.5% in F24 to 6.1% in F27). *Phyllocladidites mawsonii* Cookson ex Couper have the same representativity (aproximatly 11% in both samples). This pulse could be associated with temperate to warm-humid climatic condition.

In F30, again, a marine influence is registered (dinocysts 14.1% with *Batiacasphaera* spp., *Lejeunecysta globosa* Biffi & Grignani and *Lingulodinium bergmannii* Archangelsky), associated with the income of Palmae (4.6%), Nothofagaceae (11%), Myrtaceae (4.6%) and Poaceae (4.6%). The pteridophytic spores still dominate the spectrum (55.7%). Probably, this sample reflects warm conditions.

In sample F31, there is a relative decrease of marine influence (9.3%, only *Lejeunecysta* spp. and *Lingulodinium bergmannii* are registered). An increase of gymnosperm

pollen (28%) of the montane forest indicates either less humid conditions or the generation of an altitude gradient. Due to a register of humid indicators as *Phyllocladidites mawsonii* (11.6%), Nothofagaceae (14%), and pteridophytic spores (37%), the latter could be the most valid explanation.

Probably, marine flooding surface could be detected in F33 where dinocyst reach 36.3%, with ?*Batiacasphaera baculata* Drugg, *B. micropapillata* Stover, *Lejeunecysta globosa* and *Lingulodinium bergmannii*. There is a register of Pteridophyta (42.9%), Nothofagaceae (9.9%) associated with gymnosperm pollen (5%), Palmae (2.2%) and Poaceae (3.3%). The presence of Palmae suggests relatively warm conditions.

A regressive event (dinocysts: 2.7% only *Lejeunecysta globosa* is registered) is present in F40, where the pteridophytic spores (85.2%) correspond to pteridophytic polypodiaceous ferns close to *Acrostichum* (*Deltoidospora*) and reflect the presence of palustrine environments. The Nothofagaceae (6.3%), *Phyllocladidites mawsonii* (1.3%) and Proteaceae (6.3%) indicate humidity.

A regressive event is also registered at F41 (dinocysts: 2.4% only *Apteodinium* sp. and *Lingulodinium bergmannii* are registered), where the pteridophytic spores reach 47.6%, associated with an increase of the gymnosperm forest (23%). Nothofagaceae (14.7%) and Loganiaceae (3.7%) are registered.

At F43, a marine flooding surface (dinocysts 15% with *Lingulodinium bergmannii*, *L. hemicystum* McMinn and *Spiniferites* sp.) could be detected, associated with gymnospermous pollen from the montane forest (28%).

In F54, the maximum marine flooding surfaces of the studied section are registered (dinocysts: 73.1%, with *Lejeunecysta globosa* and *Lingulodinium bergmannii* in high percentages). The Nothofagaceae (15.9%) have their highest representation associated to the minimum of the pteridophytic spores (6.4%) of the profile.

DISCUSSION

The microfloristic assemblages of El Foyel Group (Troncoso, Salto del Macho and Río Foyel formations), were compared to the following stratigraphic units and localities (Figure 9): Salamanca-Cerro Bororó (Danian,
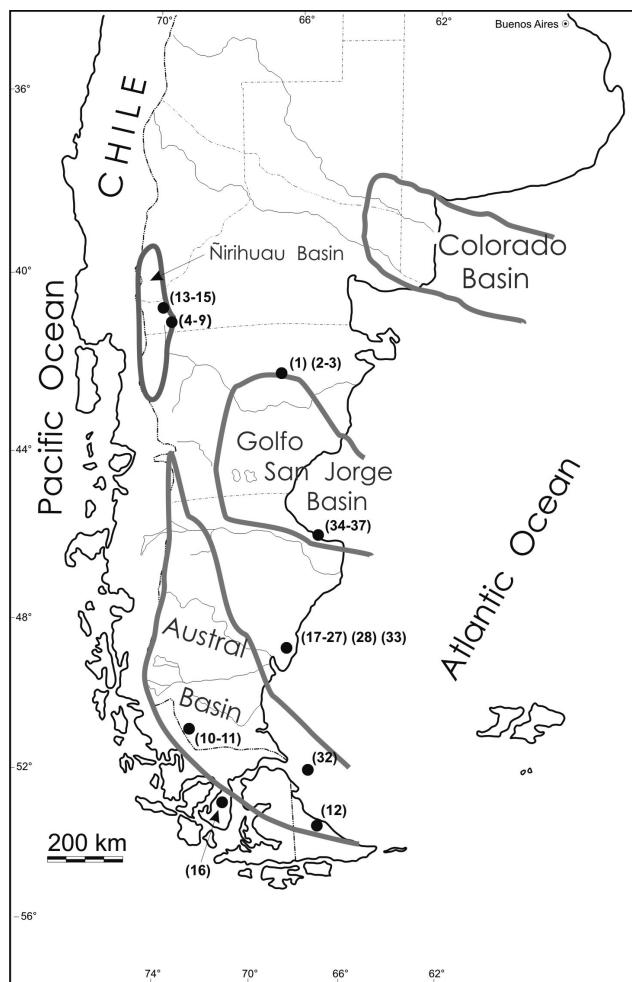
Figure 9. Map of Argentina indicating the sedimentary basins and localities compared in the text. For references of plotted numbers, see Figure 3.

Chubut Province), Huitrera (Eocene, Río Negro and Neuquén provinces), Río Turbio (Eocene, Santa Cruz Province), Sloggett (late Eocene-?early Oligocene, Tierra del Fuego) and Loreto (late Eocene-Oligocene; Magallanes, Chile) formations; El Foyel Group (Troncoso, Salto del Macho and Río Foyel formations, this paper), San Julián (Oligocene, "basal muddy section" and Playa La Mina, Santa Cruz Province); borehole Aries x-1, Tierra del Fuego (late Oligocene-early Miocene); Río Leona (early late Oligocene) and Monte León and Chenque (early-middle Miocene, Chubut Province) formations.

From the analysis of the similarity matrix and of the dendrogram (Figure 3), achieved by application of "cluster analysis", it is evident that the higher values of similarity (close to 1) are between the samples of the Salto del Macho and Río Foyel formations and between Loreto (Fasola, 1969) and San Julián formations in CC3 (Nañez *et al.*, 2009). A second level of similarity is represented between the samples 21, 22 y 23 (FSJ in CC4), associated with the sample 20 (San Julián in CC3).

There is a close similarity between Troncoso and Sloggett formations assigned to the late Eocene-?early Oligocene. The Sloggett Formation is characterized by temperate to temperate-cold climate, very humid and without modern families, such as Poaceae, Onagraceae and Asteraceae (Olivero *et al.*, 1998).

Just as (similarity lower than 0.6) of the Salto del Macho, Troncoso and Río Foyel formations, with the San Julian Formation in Playa La Mina from the late Oligocene (Sample 28), Río Leona Formation (samples 29-31) from the late early Eocene and Aries x-1 (sample 32) from the late Oligocene-early Miocene.

Chenque and Monte León (Miocene) formations present values lower than 0.4 and, with the formations corresponding to the Eocene (Huitrera and Río Turbio formations) and to the Danian (Salamanca and Cerro Bororó formations), the values are lower than 0.3.

By means of the N-MDS (Figure 4), it was possible to determine that the samples are mainly grouped according to the analyzed formations. There are six clearly distinct groups, corresponding to the interval Paleocene-Miocene. (A-B) Danian, Cerro Bororó and Salamanca formations; (C), Eocene, Huitrera and Río Turbio formations; (D), late Eocene-?early Oligocene, Sloggett and Troncoso formations; (E), Oligocene, Salto del Macho and Río Foyel formations, and "basal muddy section" of the San Julián Formation; (F-G), late Oligocene, San Julián Formation (Playa La Mina) and Río Leona Formation; (H), late Oligocene - early Miocene (Aries x-1 well); (I), early-middle Miocene (Monte León and Chenque formations).

Then, both the Cluster Analysis and the N-MDS techniques (Figures 3, 4) yielded the same levels of similarity between the samples, which evidences a real difference between the different palynofloras here analyzed.

As in many other paleogene associations of the Patagonia

(Romero, 1986a, b; Baez *et al.*, 1990; Markgraf *et al.*, 1996), the analyzed formations have podocarpaceae linked to forms which are currently restricted to Tasmania and New Zealand (*Phyllocladidites*, *Dacrycarpites* and *Microcachryidites*), associated to the Nothofagaceae, which are currently part of the Subantartic region. In general, this flora is characterized by Nothofagaceae, Podocarpaceae and, in lower proportion, by Araucariaceae, Myrtaceae and Proteaceae, and they do not present the diversity of angiosperms that appears in the late Oligocene.

In the late Oligocene, a community dominated by Myrtaceae, Palmae and Araucariaceae trees with Podocarpaceae and Nothofagaceae is recognized in San Julián Formation, at Playa La Mina, Santa Cruz Province (Barreda, 1997). However, the presence of small amounts of Anacardiaceae, Malvaceae, Symplocaceae, Ephedraceae, Poaceae, Asteraceae and Chenopodiaceae suggests the development of local open vegetation. The spore-pollen assemblage suggests warm and humid conditions. All of these families are present in the río Foyel section, with the exception of the local open vegetation.

As Barreda *et al.* (2003) pointed, the almost total absence of herbaceous and shrubby angiosperms in the río Foyel section (upper levels assigned to late Oligocene-early Miocene) is not consistent with the families observed in contemporary formations of the Atlantic coast. Most probably, the reason is that the paleoclimatic conditions allowed a nearly exclusive development of forest on the western side of Patagonia, while near the Atlantic coast some areas with open vegetation began to spread. Pollen assemblages from the Río Foyel Formation (northwestern area) are probably coeval or slightly older (Pöthe de Baldis, 1984; Barreda *et al.*, 2003).

Barreda *et al.* (2003) provides a detailed discussion on the marine transgression in the Ñirihuau Basin. A marine connection with the Pacific Ocean is proposed for the río Foyel section (Malumián *et al.*, 2008; Asensio *et al.*, 2010), due to the presence of crystalline gypsum internal moulds, of both specimens and chambers of *Transversigerina* cf. *T. transversa*. Palaeoenvironmentally, *Transversigerina* is a foraminifera genus type of deep water environment, with a tendency towards upper and middle bathyals environments, which is compatible with that of other species present in large numbers in the upper levels of the Río Foyel Formation, such as *Sphaeroidina bulloides* d'Orbigny. A closed species is *T. tenua* (Cushman & Kleinpell), which characterizes the "Patagonian" in the Atlantic coast. In Chile, as opposed to Ñirihuau basin, *T. transversa* is abundant and frequent in Cholchol Formation, Temuco Basin SE of Temuco and Hueyusca Formation, Catamutún Basin, NE of Osorno, (*cf.* Marchant, 1990). These formations were assigned to the late middle Miocene.

Dinoflagellate assemblages exhibit similarities with those identified in the "Patagonian" deposits outcropping at the southern side of San Jorge Gulf (Barreda & Palamarczuk, 2000b), but there are no published registers of dinoflagellate coming from the Pacific Ocean at Ñirihuau Basin latitude.

CONCLUSIONS

The Age of El Foyel Group has not been established with precision and generates a lot of controversy. The present statistical results refine the stratigraphic model of Asensio *et al.* (2005), inferred from stratigraphic relations and absolute data.

In the Río Foyel Formation, homogeneous pelite deposits were registered; this palynological study allows to recognizing parasequences, identifiable on the basis of the biofacies characteristics, which indicate upward shallowing. The bounding surfaces of parasequences are defined as surfaces of flooding which represent a relative sea level rise (marine flooding surfaces) through the profile.

In general, in the Río Foyel Formation the regression events are indicated by the decrease on abundance and diversity of dinocysts and the dominance of pteridophytic spores and the gymnospermous pollen. In general, the increase of the Araucariaceae pollen corresponds to the decrease of the Nothofagaceae pollen.

The marine influence is registered by an increase on the abundance and diversity of dinocysts. In this event the Nothofagaceae, Myrtaceae, Palmae and Poaceae increase in abundance. Marine flooding surface could be detected through the Río Foyel Formation, associated with the dominance of the Nothofagaceae over the gymnospermous pollen; with the exceptions of F43, where the gymnosperm pollen dominate over the Nothofagaceae, probably due to the generation of an altitude gradient.

A comparison of these spore-pollen assemblages with others from Patagonia, using multivariate statistical techniques, yields strong similarities between the Troncoso Formation and the Sloggett Formation (late Eocene-?early Oligocene); and between Salto del Macho and Río Foyel formations with Loreto Formation (late Eocene-Oligocene) and San Julián Formation in cabo Curioso area "basal muddy section" (Oligocene).

ACKNOWLEDGEMENTS

REFERENCES

Abbink, O.A. 1998. Palynological investigations in the Jurassic of the North Sea region. *Laboratory of Paleobotany and Palynology, Contributions Series*, **8**:1-192.

Anzótegui, L. M. 2006. *Paleofloras del Mioceno en Los Valles Calchaquies, Noroeste de Argentina*. Facultad de Ciencias Exactas y Naturales y Agrimensura, Universidad Nacional del Nordeste, Ph.D. thesis, 266 p.

Archangelsky, S. 1972. Esporas de la Formación Río Turbio (Eoceno). Provincia de Santa Cruz. *Revista del Museo de La Plata (Nueva Serie)*, *Paleontología*, **6**:65-100.

Archangelsky, S. 1973. Palinología del Paleoceno de Chubut. I. Descripciones sistemáticas. *Ameghiniana*, **10**:339-399.

Archangelsky, S. 1976. Palinología del Paleoceno de Chubut. III. Análisis numérico. *Ameghiniana*, **13**:169-184.

Archangelsky, S. & Romero, E. J. 1974. Polen de gimnospermas (coníferas) del Cretácico superior y Paleoceno de Patagonia. *Ameghiniana*, **11**:217-236.

Archangelsky, S. & Zamaloa, M.C. 1986. Nuevas descripciones palinológicas de las formaciones Salamanca y Bororó, Paleoceno de Chubut (República Argentina). *Ameghiniana*, **23**:35-46.

Asensio, M.A.; Cornou, M.E.; Malumián, N.; Martínez, M.A. & Quattrocchio, M.E. 2010. Formación Río Foyel, Oligoceno de Cuenca de Ñirihuau: la transgresión pacífica en la Cordillera Norpatagónica. *Revista de la Asociación Geológica Argentina*, **66**:399-405.

Asensio, M.; Zavala, C. & Arcuri, M. 2005. Los sedimentos terciarios del Río Foyel, Provincia de Río Negro, Argentina. *In*: CONGRESO GEOLÓGICO ARGENTINO, 16, 2005. *Actas*, La Plata, p. 271-276.

Asensio, M.; Zavala, C.A. & Cazau, L.B. 2008. Análisis tectosedimentario de la Formación Salto del Macho, Cuenca de Ñirihuau. Argentina. *In*: CONGRESO DE EXPLORACIÓN Y DESARROLLO DE HIDROCARBUROS, 7, 2008. *Actas*, Mar del Plata, p. 565-574.

Báez, A.M.; Zamaloa, M.C. & Romero, E. 1990. Nuevos hallazgos de microfloras y anuros paleógenos en el noroeste de Patagonia: implicancias paleoambientales y paleobiogeográficas. *Ameghiniana*, **27**:83-94.

Barreda, V.D. 1996. Bioestratigrafía de polen y esporas de la Formación Chenque, Oligoceno tardío?-Mioceno de las provincias de Chubut y Santa Cruz, Patagonia, Argentina. *Ameghiniana*, **33**:35-96.

Barreda, V. 1997. Palinoestratigrafia de la Formación San Julián en el área de Playa La Mina (Provincia de Santa Cruz), Oligoceno de la Cuenca Austral. *Ameghiniana*, **34**:283-294.

Barreda, V.D. & Palamarczuk, S. 2000a. Palinomorfos continentales y marinos de la Formación Monte León en su área tipo, provincia de Santa Cruz, Argentina. *Ameghiniana*, **31**:3-12.

Barreda, V.D. & Palamarczuk, S. 2000b. Estudio palinoestratigráfico del Oligoceno tardío-Mioceno en secciones de la costa patagónica y plataforma continental argentina. *In*: F.G. Aceñolaza & R. Herbst (eds.) *El Neógeno de Argentina*, INSUGEO, Serie Correlación Geológica, 14, p. 103-138.

Barreda, V.D.; García, V.; Quattrocchio, M. & Volkheimer, W. 2003. Edad y paleoambiente de la Formación Río Foyel, Cuenca Ñirihuau, provincia de Río Negro, Argentina. *Revista Española de Micropaleontología*, **35**:229-239.

Barreda, V. D.; Palazzesi, L. & Marenssi, S. 2009. Palynological record of the Paleogene Río Leona Formation (southernmost South America): stratigraphical and paleoenvironmental implications. *Review of Palaeobotany and Palynology*, **154**:22-33. *doi:10.1016/j.revpalbo.2008.11.005*

Bertels, A. 1980. Estratigrafía y foraminíferos (Protozoa) bentónicos de la Formación Monte León (Oligoceno) en su área tipo, Provincia de Santa Cruz, República Argentina.

In: CONGRESO ARGENTINO DE PALEONTOLOGÍA Y BIOESTRATIGRAFÍA, 2/CONGRESO LATINOAMERICANO DE PALEONTOLOGÍA, 1, 1978. *Actas*, Buenos Aires, p. 213-273.

Bertels, A. 1993. Foraminíferos bentónicos (Protozoa) de las "Lutitas de Río Foyel" (Oligoceno medio bajo), Provincia de Río Negro, República Argentina. *Revista Española de Micropaleontología*, **25**:23-58.

Bertels, A. 1994a. Los foraminíferos planctónicos (Protozoa) de las "Lutitas de Río Foyel" (Oligoceno medio bajo), Cuenca Ñirihuau-Ñorquinco-Cushamen, Provincia de Río Negro, Argentina. *Ameghiniana*, **31**:187-194.

Bertels, A. 1994b. Foraminíferos (Protozoa) y paleoambientes de las "Lutitas de Río Foyel" (Oligoceno medio bajo), Cuenca Ñirihuau-Ñorquinco-Cushamen, Provincia de Río Negro, República Argentina. *Revista Española de Micropaleontología*, **26**:99-108.

Berry, E.W. 1928. Tertiary fossil plants from the Argentine Republic. *Proceedings of the United States National Museum*, **73**:1-27.

Cazau, L. 1972. Cuenca de Ñirihuau-Ñorquinco-Cushamen. *In*: A.F. Leanza (ed.) *Geología Regional Argentina*, Academia Nacional de Ciencias de Córdoba, p. 427-740.

Cazau, L.; Mancini, D.; Cangini, J. & Spalletti, L. 1989. Cuenca del Ñirihuau. *In*: G.A. Chebli & L.A. Spalletti (eds.) *Cuencas Sedimentarias Argentinas*, Serie Correlación Geológica, 6, p. 299-318.

Chiesa, J.O. & Camacho, H.H. 2001. Invertebrados marinos eocenos de la parte inferior de la Formación Río Foyel, provincia de Río Negro, Argentina. *Revista Española de Paleontología*, **16**:299-316.

Collinson, M.E. 1978. Dispersed fern sporangia from the British Tertiary. *Annals of Botany*, **42**:233-250.

Cornou, M.E.; Martínez, M.A.; Quattrocchio, M.E. & Asensio, M.A. 2012. Estudio palinológico de esporas de la Formación Salto del Macho, Paleógeno de la Cuenca de Ñirihuau, Argentina. *Ameghiniana*, **49**:1-11. *doi:10.5710/AMGH.v49i1(322)*

Dettmann, M.E. & Pocknall, D.T. 1990. *Nothofagidites* Erdtman ex Potonié, 1960; a catalogue of species with notes on the palaeogeographic distributions of *Nothofagus* Bl. (southern beech). *New Zealand Geological Survey, Palaeontological Bulletin*, **60**:1-79.

Fasola, A. 1969. Estudio palinológico de la Formación Loreto (Terciario medio), provincia de Magallanes, Chile. *Ameghiniana*, **6**:3-49.

García, V.M.; Quattrocchio, M.E.; Zavala, C.A. & Martínez, M.A. 2006. Palinofacies y paleoclima del Grupo Cuyo (Jurásico medio) en la Sierra de Chacaico, Cuenca Neuquina, Argentina. *Revista Española de Micropaleontología*, **38**:269-288.

Giacosa, H.; Heredia, N.; Césari, O.; Zubia, M.; González, R. & Faroux, A. 2001. *Descripción geológica de la Hoja 4172-IV, San Carlos de Bariloche, Provincias de Río Negro y Neuquén*, Buenos Aires, Servicio Geológico Minero Argentino, Instituto de Geología y Recursos Minerales (Boletín 279).

González Bonorino, G. 1944. Descripción geológica y petrográfica de la Hoja 41b "Río Foyel" (Terr. Río Negro). *Boletín de la Dirección de Minas, Geología e Hidrología*, **56**:1-124.

Hammer, Ø.; Harper, D.A.T. & Ryan, P. D. 2001. PAST: Paleontological Statistics Software Package for Education and Data Analysis. *Palaeontologia Electronica*, **4**:1-9. *doi. org/palaeo-electronica.org/2001_1/past/issue1_01.htm*

Harland, R. 1983. Distribution maps of recent dinoflagellate cysts from the North Atlantic and adjacent seas. *Palaeontology*, **26**:321-387.

Head, M.J.; Norris, G. & Mudie, P.J. 1989. Palynology and dinocyst stratigraphy of the Upper Miocene and lowermost Pliocene, ODP Leg 105, Site 646, Labrador Sea. *Proceedings of the Ocean Drilling Program, Scientific Results*, **105**:423-451.

Hill, R.S.; Macphail, M.K. & Jordan, G.J. 1999. Tertiary History and Origins of the Flora and Vegetation. *In*: J.B. Reid; R.S. Hill; M.J. Brown & M.J. Hovenden (eds.) *The Vegetation of Tasmania*, Australian Biological Research Study, p. 39-63.

Hünicken, M. 1955. Depósitos Neocretácicos y Terciarios del extreme SSO de Santa Cruz. *Revista del Instituto Nacional de Investigaciones de las Ciencias Naturales y Museo Argentino de Ciencias Naturales "Bernardino Rivadavia"*, **4**:1-161.

Kovach, W.L. 1989. Comparisons of multivariate analytical techniques for use in Pre-Quaternary plant paleoecology. *Review of Paleobotany and Palynology*, **60**:255-282. *doi:10.1016/0034-6667(89)90046-8*

Kruskal, J.B. & Wish, M. 1976. Multidimensional scaling. *In*: J.L. Sullivan & R.G. Niemi (eds.) *Quantitative Applications in the Social Sciences*, Sage University Papers, Beverly Hills, p. 7-11.

Kurmann, M.H. & Taylor, T.N. 1987. Sporoderm ultrastructure of *Lophosoria* and *Cyatheacidites* (Filicopsida): systematic and evolutionary implications. *Plant Systematic and Evolution*, **157**:85-94.

Malumián, N.; Asensio, M.; Cornou, E.; Martínez, M. & Quattrocchio, M.E. 2008. Formación Río Foyel: la transgresión pacífica en la Cordillera Norpatagónica. *In*: CONGRESO GEOLÓGICO ARGENTINO, 17, 2008. *Actas*, Jujuy, p. 861-862.

Marchant, M. 1990. Foraminíferos miocénicos de los estratos de Pupunahue (Provinca de Valdivia: 10º Región): Determinación de la edad probable y Paleoambiente. *In*: SIMPOSIO SOBRE EL TERCIARIO DE CHILE, 2, 1990. *Actas*, Concepción, p. 177-188.

Markgraf, V.; Romero, E. & Villagrán, C. 1996. History and paleoecology of South American *Nothofagus* forests. *In*: T. Veblen, R. S. Hill & J. Read (eds.) *The Ecology and Biogeography of Nothofagus forests*, Yale University, p. 354-386.

Martin, H.A. 1987. The Cainozoic history of the vegetation and climate of the Lachlan River Region, New South Wales. *Proceedings of the Linnean Society of New South Wales*, **109**:214-257.

Martin, H.A. 1997. The use of Ecological Tolerances for the Reconstruction of Tertiary Paleoclimates. *Australian Journal of Botany*, **45**:475-492.

Martínez, M.A.; García, V.M. & Quattrocchio, M.E. 1996. Análisis de componentes principales aplicado el estudio palinológico del Jurásico medio de Cuenca Neuquina, Argentina. *In*: CONGRESO GEOLÓGICO ARGENTINO, 12/CONGRESO DE EXPLORACIÓN DE HIDROCARBUROS, 3, 1996. *Actas*, Buenos Aires, p. 171-179.

Martínez, M.A.; Ferrer, N. & Asensio, M. 2008. Primer registro de algas dulceacuícolas del Paleógeno de la Cuenca de Ñirihuau, Argentina: descripciones sistemáticas y análisis palinofacial. *Ameghiniana*, **45**:719-735.

Melendi, D.L; Scafati, L.H. & Volkheimer, W. 2003. Palynostratigraphy of the Paleogene Huitrera Formation in N-W Patagonia, Argentina. *Neues Jahrbuch für Geologie und Paläontologie, Abhandlungen*, **228**:205-273.

Nañez, C.; Quattrocchio, M.E. & Ruiz, L. 2009. Palinología y micropaleontología de las formaciones San Julián y Monte León (Oligoceno - Mioceno temprano) en el subsuelo de Cabo Curioso, provincia de Santa Cruz, Argentina. *Ameghiniana*, **46**:669-693.

Olivero, E.B.; Barreda, V.D.; Marenssi, S.A.; Santillana, S.N. & Martinioni, D.R. 1998. Estratigrafía, sedimentología y palinología de la Formación Sloggett (Paleógeno continental), Tierra del Fuego. *Revista de la Asociación Geológica Argentina*, **53**:504-516.

Ottone, E.G. 2009. La flora cretácica de Cuenca Neuquina. *Revista de la Asociación Geológica Argentina*, **65**:373-386.

Palamarczuk, S. & Barreda, V.D. 1998. Bioestratigrafía en base a quistes de dinoflagelados de la Formación Chenque (Mioceno), provincia del Chubut, Argentina. *Ameghiniana*, **35**:415-426.

Palamarczuk, S. & Barreda, V.D. 2000. Palinologia del Paleógeno tardío-Neógeno temprano, pozo Áries x-1, plataforma continental Argentina, Tierra de Fuego. *Ameghiniana*, **37**:221-234.

Pöthe de Baldis, E.D. 1984. Microfloras Cenozoicas. *In*: CONGRESO GEOLÓGICO ARGENTINO, 10, 1984. *Relatorio*, San Carlos de Bariloche, p. 393-411.

Rodríguez, R. 1995. Pteridophyta. *In*: C. Marticorena & R. Rodríguez (eds.) *Flora de Chile*, Ediciones Universidad de Concepción, 1:119-309.

Romero, E.J. 1977. *Polen de gimnospermas y fagáceas de la Formación Río Turbio (Eoceno), Santa Cruz, Argentina*. Buenos Aires, Fundación para la Educación, la Ciencia y la Cultura, 219 p.

Romero, E.J. 1986a. Fossil evidence regarding the evolution of *Nothofagus* Blume. *Annals Missouri Botanical Garden*, **73**:276-283.

Romero, E.J. 1986b. Paleogene phytogeography and climatology of South America. *Annals Missouri Botanical Garden*, **73**:449-461.

Romero, J.E. & Castro, M.T. 1986. Material fúngico y granos de polen de angiospermas de la Formación Río Turbio (Eoceno), provincia de Santa Cruz, República Argentina. *Ameghiniana*, **23**:101-118.

Romero, E.J. & Dibbern, M.C. 1984. Floras fósiles cenozoicas. *In*: CONGRESO GEOLÓGICO ARGENTINO, 9, 1984. *Relatorio*, San Carlos de Bariloche, p. 373-382.

Romero, J.E. & Zamaloa, M.C. 1985. Polen de angiospermas de la Formación Río Turbio (Eoceno), provincia de Santa Cruz, Argentina. *Ameghiniana*, **22**:43-51.

Roth, S. 1899. Reconocimiento de la región andina de la República Argentina. Apuntes sobre la geología y paleontología de Río Negro y Neuquén. *Revista Museo de La Plata*, **9**:141-197.

Sepúlveda, E. 1980. Estudio palinológico de sedimentitas intercaladas en la "Serie Andesítica Andina", cordón occidental del Futalaufquen, Chubut. Parte I: restos de hongos. *Revista de la Asociación Geológica Argentina*, **35**:248-272.

Tyson, R.V. 1995. *Sedimentary organic matter: organic facies and palynofacies*. London, Chapman & Hall, 615 p.

Volkheimer, W. & Melendi, D. 1976. Palinomorfos como fósiles guías (3ra. Parte). Técnicas de laboratorio palinológico. *Revista Minera, Geología y Mineralogía, Sociedad Argentina de Minería y Geología*, **34**:19-30.

Volkheimer, W.; Scafati, L. & Melendi, D. L. 2007. Palynology of a Danian warm climatic wetland in central northern Patagonia, Argentina. *Revista Española de Micropaleontología*, **39**:117-134.

von Ihering, H. 1904. Nuevas observaciones sobre moluscos cretáceos y terciarios de Patagonia. *Revista del Museo de La Plata*, **11**:229-243.

von Ihering, H. 1907. Les Mollusques fósiles du Tertiaire et du Crétacé supérieur de Argenine. *Anales Museo Nacional de Buenos Aires*, **15**:1-611.

von Ihering, H. 1914. Catálogo de molluscos cretáceos e terciarios de Argentina de colleção do Autor. *Revista Museu Paulista*, **1**:9-100.

Wall, D.; Dale, B.; Lohman, G. P. & Smith, W. K. 1977. The environmental and climatic distribution of dinoflagellate cysts in modern marine sediments from regions in the North and South Atlantic oceans and adjacent seas. *Marine Micropaleontology*, **2**:121-200. *doi:10.1016/0377-8398(77)90008-1*

Wehrli, L. 1899. Rapport preliminaire sur mon expedition géologique dens la Cordillera Argentina Chilene du 40º et 41º latitude sud (Región du Nahuel Huapí). *Revista del Museo de La Plata*, **9**:221-242.

Whitaker, M. F; Giles, M. R. & Cannon, S. J. C. 1992. Palynological review of the Brent Group, UK Sector, North Sea. *Geological Society of London, Special Publication*, **61**:169-202.