# New fossil record of Lactoridaceae in the Paleogene of southern Patagonia (South America)

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**Abstract:** The new record of the family Lactoridaceae (*Rosannia manika* Srivastava) in Tierra del Fuego, Austral Basin corresponds to a sedimentary succession located at the south of the Irigoyen River, nearby the Cerro Malvinera. The palynology (principally dinoflagellates cysts) of different Paleogene formations (La Barca, Punta Torcida and Puesto José) in the Austral Basin was analyzed to calibrate the age of this outcrop. This result was compared with large datasets of organic dinoflagellate cyst (dinocyst) assemblages from Southern Pacific Ocean shelf sediments and other sections of the world. The majority of the palynomorph taxa from the Cerro Malvinera succession are present in the upper member LB2 of the La Barca Formation and both shared the presence of Lactoridaceae (*Rosannia manika* Srivastava) and the age-diagnostic dinocysts *Pentadinium laticinctum* (First Occurrences 51.95 Ma). An age not older than early Eocene is proposed for the LB2 member of the La Barca Formation and the Cerro Malvinera strata. This data expands the known fossil range of the Lactoridaceae in Patagonia and contributes to elucidate the probably migration routes of this family. A migration via Antarctica is postulated in this paper due to the record of this family in the Maastrichtian (López de Bertodano Formation). Depending on new records, due to the presence of this family in the Colorado Basin in the Danian, a migration route from the north of Patagonia to the south (Austral Basin) it is not discarded.

**Key words**: Lactoridaceae, Paleogene, southern Patagonia, South America.

**Resúmen**: Nuevo registro fósil de Lactoridaceae en el Paleógeno de Patagonia austral (América del Sur). Se presenta un nuevo registro de la familia Lactoridaceae (*Rosannia manika* Srivastava) correspondiente a una sucesión sedimentaria localizada al sur del río Irigoyen, cercano al Cerro Malvinera, Tierra del Fuego, cuenca Austral. Para calibrar la edad del afloramiento se analizó la palinología (principalmente quistes de dinoflagelados) de diferentes formaciones paleógenas (La Barca, Punta Torcida y Puesto José) de la cuenca Austral. Este resultado fue comparado con bases de datos de quistes de dinoflagelados (dinoquistes) correspondientes a sedimentos de plataforma del Océano Pacífico Sur y de otras secciones del mundo. La mayoría de los taxones de palinomorfos de la sucesión de Cerro Malvinera están presentes en el miembro superior LB2 de la Formación La Barca y ambos comparten la presencia de Lactoridaceae (*Rosannia manika* Srivastava) y dinoquistes diagnósticos de edad como *Pentadinium laticinctum* (First Occurrences 51.95 Ma). Se propone una edad no más antigua que Eoceno temprano para el miembro LB2 de la Formación La Barca y los estratos analizados de Cerro Malvinera. Este dato amplia el rango fósil y contribuye a elucidar las rutas de migración probable de la familia Lactoridaceae en Patagonia. La migración vía Antártida es postulada en éste trabajo debido al registro de la familia en el Maestrichtiano (Formación López de Bertodano) Dependiendo de nuevos registros, no se descarta una ruta de migración desde el norte de Patagonia al sur (Cuenca Austral) debido a la presencia de la familia en el Daniano de la Cuenca del Colorado.

**Palabras clave**: Lactoridaceae, Paleógeno, Sur de Patagonia, America del Sur.

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## INTRODUCTION

In this paper we report a new fossil finding of Lactoridaceae tetrads form the Paleogene of southern Patagonia (Austral Basin), southern South America. Lactoridaceae are a monotypic family of shrubby angiosperms represented by a lone species: *Lactoris fernandeziana* Phil., now endemic to the cloud forests of Masatierra Island (= Robinson Crusoe) located at an altitude of 500 m and above (Crawford *et al*., 1991, 1994; Stuessy *et al*., 1997, 1998). The island belongs to the Juan Fernandez Group, located 667 km off the west coast of Chile in the Pacific Ocean.

This species possesses both primitive and highly specialised/reduced characters (Carlquist, 1964). The Lactoridaceae are considerer to form part of an early-branching of angiosperms pertaining to the "paleoherbs" (according to Donoghue & Doyle, 1989), and to understanding of the early angiosperm evolution. It has being assigned to the Order Piperales based on exine structure and wood anatomy, the LauraIes, and the Magnoliales based on cladistic, and chemotaxonomic studies (from Macphail *et al*., 1997 and bibliography cited in this paper). Endress (1994) has summarized features of *Lactoris* which he considers implies a relationship with the Aristolochiales (*Aristolochia*). This is supported by phylogenetic analysis based on nucleotide sequences in the plastid gene rbcL (Chase *et al*., 1993).

Little is known of its reproductive biology. *Lactoris* is anemophilous, a syndrome perhaps reflected by the P/O (pollen/ovule) ratio. Low genetic diversity (isozymes and DNA) supports selfing and implies limited distance wind pollen dispersal. If the primitive angiosperms to which Lactoridaceae is related (Piperales, Magnoliales, Aristolochiales, Laurales; Stuessy *et al.*, 1998) are presumed to be insect pollinated the anemophily is derived (Bernardello *et al*., 1999).

The discovery of fossil pollen of Lactoridaceae in the Upper Cretaceous (lower Turonian-Campanian) of the south-west coast (Orange Basin offshore Namaqualand), South Africa suggests that this family may have been a common element in the Cretaceous Gondwana flora (Zavada & Benson, 1987). The Turonian age for the Lactoridaceae should be cautiously accepted since the type material come from cutting samples (Srivastava & Braman, 2010).

The new register of the family in the area of Cerro Malvinera (Lat. 54°34′55.9′'S, Long. 66°37´22.8"W, Austral Basin) corresponds to a sample in a succession of c. 180 m of black mudstones with minor intercalated sandstone beds, which was correlated to the Paleogene La Barca Formation (Torres Carbonell *et al*., 2008). The outcrops are located to the south of Irigoyen River where the mudstone-dominated succession is adjacent to Upper Cretaceous strata of the Policarpo Formation, but the stratigraphic contacts cannot be observed.

To evaluate the age of the succession at Cerro Malvinera its palynology (principally dinoflagellates cysts) was compared to that of different Paleogene formations (La Barca, Punta Torcida and Puesto José) at its type locality, exposed in the Austral Basin. The results were compared with large datasets of organic dinoflagellate cyst (dinocyst) assemblages from Southern Ocean shelf sediments and from other sections in the World ( Bijl *et al*., 2013, William *et al*., 1998, 1999, 2003).

It was also compared with a high-resolution Southern Pacific Ocean dinocyst zonation for the late Palaeocene to late Eocene (58–36 million years ago; Ma). The zonation consists of thirteen dinocyst zones, calibrated to the Geomagnetic Polarity Time Scale (GPTS) of Vandenberghe *et al.* (2012), which can likely be applied, to the entire Southern Ocean (Bijl *et al*., 2013).

The present results expanded the known fossil record of the Lactoridaceae in Patagonia and it is a contribution to elucidate the probably migration routes of this family.

STUDIED LOCALITY AND COMPARED PALEOGENE FORMATIONS

The mountain front of the Fuegian Andes is formed by the Fuegian Thrust–Fold Belt, which constitutes a thin-skinned wedge that involves Upper Cretaceous to Miocene sequences (Klepeis & Austin, 1997; Ghiglione *et al*., 2002; Torres Carbonell *et al*., 2008). The stratigraphic successions involved in the thrust–fold belt correspond to the Magallanes/Austral foreland basin, and the successions have been divided into several unconformity bounded sequences (Olivero & Malumián, 2008) that records the kinematic evolution of the Fuegian Thrust-Fold Belt. During the Paleogene, the foreland successions cropping out at the Atlantic shore include two main tectonically controlled depocenters: a foredeep depocenter with early Eocene deep marine turbidites of the Punta Torcida Formation, and a wedge-top depocenter filled with several Eocene to Oligocene formations (Torres Carbonell *et al*., 2009; Torres Carbonell & Olivero, 2011), of which the mudstones of the Puesto José Formation are of interest for this study. The interpretation of the La Barca Formation is presently not clear, and it was tentatively considered either as part of relatively shallow fandeltaic systems flanking the northern mountain front or as part of a Paleogene-Eocene foredeep system (Olivero *et al*., 2002; Torres Carbonell *et al*., 2009).

The record of the Lactoridaceae family correspond to the Cerro Malvinera locality (54°34′55.9′'S; 66°37′14.4′'W) (Fig. 1). In artificial cuts, south of the Irigoyen River the sedimentary sequence of aproximatly 180 m cor-
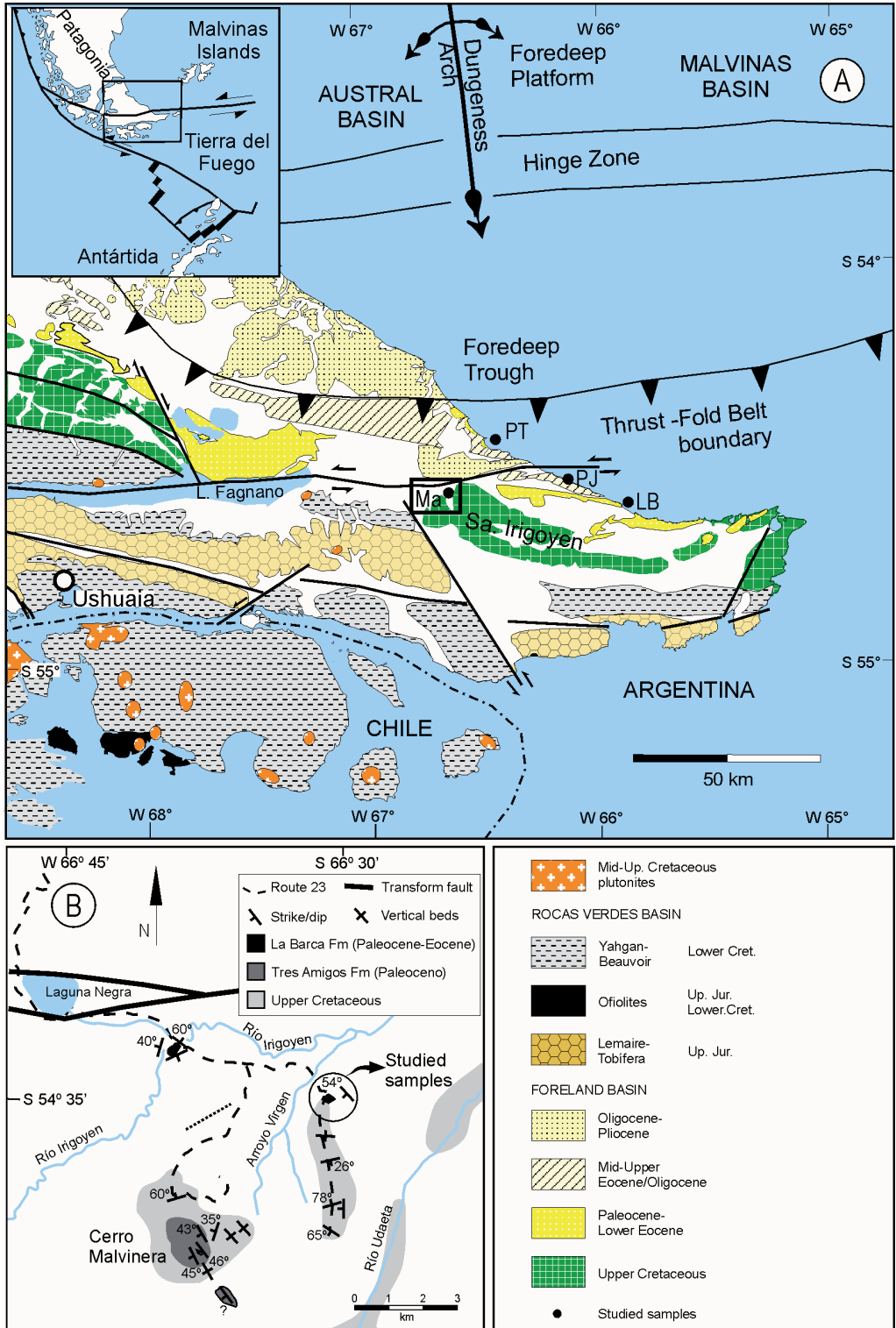
Fig. 1. A. Geological map of Tierra del Fuego province showing sample collection localities. Ma: Cerro Malvineras. LB: La Barca. PJ: Puesto José. PT: Punta Torcida (compiled from Olivero & Malumian, 2008 and Torres Carbonell *et al.*, 2009). B: Location map of Cerro Malvinera.

respond to pelites with thin interbedded sand-stones. The studied samples correspond to the Upper Cretaceous Policarpo Formation and the Paleogene succession. The Cretaceous samples include: samples 684; 685; 686-1, and 686-2 (with *Spiroplectammina spectabilis:* Maastrichtian-Eocene, com. pers., N. Malumián). The Paleogene samples, includes (from top to bottom): samples 687; 687-1; 687-2; 687-3 (with *Rhabdamina*); 687-4; 688 (with Lactoridaceae). Only one out of ten samples was palynologically fertile (sample 688).

## La Barca Formation (Olivero *et al.*, 2002)

The La Barca Formation,  only recognized at the type locality (Fig.1), c. 220 m, includes a lower member LB1, of tuffaceous sandstones and intercalated carbonaceous siltstones; and an upper member LB2 of black mudstones (Olivero & Malumián, 2008). In the La Barca Formation a restricted horizon of the lower member LB1 (100 m) bears a mostly cosmopolitan Midway Type assemblage dominated by buliminids; the assemblage includes the dominant *Bulimina karpatica*, and exceptional endemic species such as *Buliminella isabelleana* and *Antarcticella* sp., both known from Antarctica and very common and widespread in Patagonia. LB2 (120 m) contains only scarce agglutinated foraminifera, dominated by *Spiroplectammina spectabilis* (Malumián & Caramés, 2002; Olivero & Malumián, 2008).

There has not been register diagnostic megafauna in the La Barca Formation. The associations of dinocysts (*Palaeocystodinium golzowense* and *Glaphyrocysta* sp.) of the member LB1 are poor preserved. In LB2 member only *Palaeocystodinium golzowense* was recognized (Olivero *et al.*, 2002). A Late Paleocene age was proposed for LB2 member (Olivero *et al.*, 2002).

The studied samples in this paper correspond to LB2 member: 80 m (372-19) and 180 m (372-25) above the sample with Paleocene forams of the LB1 member.

## Punta Torcida Formation (Olivero & Malumián, 1999)

The type section of the Punta Torcida Formation, including the members PTa, PTb, PTc, and unnamed strata, is exposed at the eponymous area (Olivero & Malumián, 1999; Jannou & Olivero, 2001). The lower PTa member (> 74 m) is composed of dark gray mudstones with thin sandstone beds; the PTb member (58 m), mudstones with small sandstone lenses, both mem-bers include levels with high radiolarian content; and the PTc member (83 m) mudstones (Olivero & Malumián, 1999). The upper unnamed strata (ca. 200 m) consist of turbidites and tuffaceous mudstones (Olivero & López, 2001; Olivero *et al.*, 2002, 2004).

The formation contains abundant ostracods (Jannou, 2009) foraminifera and radiolarians. Most of the benthic foraminifera were described from the Agua Fresca Formation in the pioneer work in Austral Basin of Todd & Kniker (1952) and include common endemic species such as *Antarcticella ceccioni*. Planktonic foraminifera indicate an early Eocene age and the benthonic ones are mostly dominated by agglutinated forms typical of turbiditic settings (Olivero & Malumián, 1999). The radiolarians are correlated with the RP 10 Zone of the South Pacific calibrated between 51 to 47 Ma (Hollis, 1997) by Jannou (2014).

## Puesto José Formation (Torres Carbonell *et al.*, 2009)

The Puesto José Formation is a very thick (e. 1600 m), monotonous mudstone-dominated succession (Torres Carbonell *et al.*, 2009) exposed on the Atlantic shore in the Cape José area (Fig. 1) between Puesto José (54°34'S; 66°06'W) and Puesto La Chaira (54°33'S; 66°09'W). The lower section (370 m) is composed of grey massive pelite, the middle section (655 m) of mudstones with fine sandstone lenses and the upper (575 m) of  grey mudstones with fine to medium sandstone intercalations.

Based on the foraminifer content, this Formation is equivalent with the Oligocene "capas" de la Estancia María Cristina and Puesto Herminita (Scarpa & Malumián, 2008), and with the 'Glauconítico A' and 'Margosa Superior' in the subsurface of the Austral Basin (cf. Malumián & Olivero, 2006; Malumián *et al.*, 2008).

In the type section the last occurrence datum of *S. angiporoides* restrict the age of the strata below this level to the early Oligocene (30 Ma) Torres Carbonell *et al.*, 2009.

## MATERIAL AND METHODS

The palynomorphs were recovered from outcrop samples corresponding to different Paleogene formations of the Austral Basin (Table 1). Age control was provided principally by foraminifera, dinoflagellates and spore and pollen species whose time distributions are significant.

Due to the characteristics of the analyzed for-

Table 1: Studied samples, Paleogene of Austral Basin.

| Formation/locality | Co. Malvinera | La Barca (LB2 member) | Punta Torcida | Puesto José |
|---|---|---|---|---|
| Outcrop samples/ (Palynological samples) | 688 (3121) | 372-25 (4045) 372-19 (4046) | 506 (4047) 50B (4048) | 133 (4049). POI120-1 (4050) |

mations, with common reworked material during different phases of the episodic evolution of the thrust-fold belt only the palynomorphs in a good state of preservation were considered.

The material physically or chemically altered was considered reworked from older deposits.

Physical and chemical extraction was carried out using standard palynological processing techniques (Volkheimer & Melendi, 1976), which involve treatment with hydrochloric and hydrofluoric acids. A brief oxidation (two minutes or less) in nitric acid was realized.  The residue was sieved through a 10 μm mesh to concentrate the palynomorphs. All figured specimens are lodged in the collections of the Palynological Laboratory, Universidad Nacional del Sur, Bahía Blanca, Argentina. In the citation of specimens referred to or illustrated, the sample and slide number is given first and the position on the slide indicated by an England Finder reference (e.g. G36/4).

## List of identified palynomorphs

### Spores

*Baculatisporites comaumensis* (Cookson) Potonié 1956

*Biretisporites crassilabratus* Archangelsky 1972 (Fig. 3J)

*Cingutriletes australis* (Cookson) Archangelsky 1972

*Corrugatisporites argentinus* Archangelsky 1972

*Cyathidites paleospora* (Martin) Alley & Broadbridge 1992 (Fig. 3K)

*Cingutriletes australis* (Cookson) Archangelsky 1972 (Fig. 3L)

### Gymnosperm pollen

*Araucariacites australis* Cookson 1947

*Dilwynites granulatus* Harris 1965

*Microcachryidites antarcticus* (Cookson) Couper 1953

*Phyllocladidites mawsonii* (Cookson ) Couper 1953 (Fig. 4B)

*Podocarpidites* spp.

### Angiosperm pollen

*Diporites aspis* Pocknall & Mildenhall 1984

*Nothofagidites fortispinulosus* Menéndez & Caccavari de Filice 1975 (Fig. 4A)

*Nothofagidites* spp.

*Proteacidites* sp. (in Fasola 1969) (Fig. 4C)

 *Rosannia manika* Srivastava emend. Srivastava & Braman 2010 (Fig. 4D)

*Rosannia* cf. *R. manika* (Fig. 4E-F)

### Dinoflagellates

*Achilleodinium latispinosum* (Davey & Williams 1966) Bujak *et al*., 1980 (Fig. 2A)

 cf. *Adnatosphaeridium* sp. *A* (in Bijl *et al*., 2013) (Fig. 2B)

*Apectodinium homomorphum* (Deflandre & Cookson) Lentin  (Fig. 2C)

& Williams, 1977 emend. Harland, 1979

*Batiacasphaera rifensis* Slimani *et al*., 2008 (Fig. 2D)

*Batiacasphaera micropapillata* Stover 1977 (Fig. 2E)

*Cleistosphaeridium diversispinosum* Davey *et al*. 1966 emend. Eaton *et*

*al*., 2001 (Fig. 2F)

*Deflandrea fuegiensis* Menéndez 1965 (Fig. 2G)

*Dracodinium waipawaense* (Wilson) Costa & Downie 1979 (Fig. 2H)

*Habibacysta* sp.

*Hystrichosphaeridium tubiferum* (Ehrenberg) Deflandre 1937 emend. Davey & Williams 1966 (Fig. 2I)

*Impagidinium maculatum* (Cookson & Eisenack) Stover & Evitt 1978 (Fig. 2J)

*Isabelidinium bakeri* (Deflandre & Cookson) Lentin & Williams 1977 (Fig. 2K)

*Lejeunecysta fallax* (Morgenroth 1966) Artzner & Dörhöfer 1978 (Fig. 2L)

*Lejeunecysta* cf. *pulcra* Biffi & Grignani 1983

*Lingulodinium bergmannii* (Archangelsky) Quattrocchio & Sarjeant 2003(Fig. 2M)

*Magallanesium* sp. (Fig. 2N)

*Membranisphoridium perforatum* Wilson 1988 (Fig. 2Ñ, Fig. 3A)

*Oligosphaeridium complex* (White) Davey & Williams 1966 (Fig. 3B)

*Operculodinium azcaratei* Troncoso & Doubinger 1980 (Fig. 3C)

*Palaeocystodinium golzowense* Alberti 1961 (Fig. 3D)

*Pentadinium laticinctum*  Gerlach 1961 emend. Benedek *et al*., 1982 (Fig. 3E)

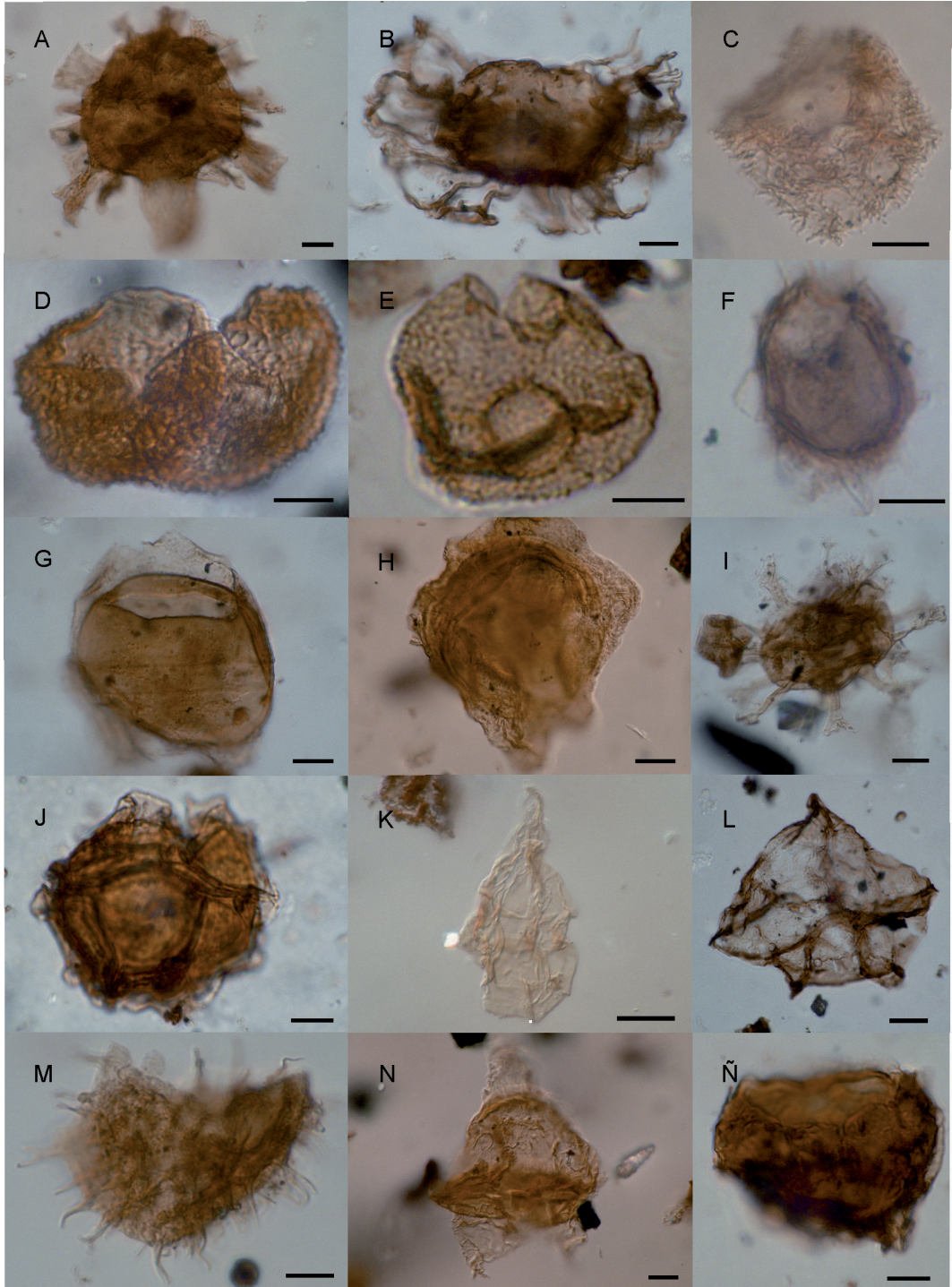*Phthanoperidinium coreoides* (Benedek) Lentin

Fig. 2. A. *Achilleodinium latispinosum*: 4048c:C65/2. B. cf. *Adnatosphaeridium* sp. A: 4047c:D43/3. C *Apectodinium homomorphum*: 4048a:D49. D. *Batiacasphaera rifensis*: 4046a:R39. E. *Batiacasphaera micropapillata*: 4045c: H34/3. F. *Cleistosphaeridium diversispinosum*: 4048c:F60/4. G. *Deflandrea fuegiensis*: 4048a:N39. H. *Dracodinium waipawaense*: 4047c: K61/3. I. *Hystrichosphaeridium tubiferum*: 4048c: E36. J. *Impagidinium maculatum*: 4048a: Q69/2. K. *Isabelidinium bakeri:* 4046a: E37/3. L. *Lejeunecysta fallax*: 4049a: K62/2. M. *Lingulodinium bergmannii*: 4048c:F60/1. N. *Magallanesium* sp.: 4046a:G33. Ñ. *Membranisphoridium perforatum*: 4048c:G67/2. Scale bars = 10μm.
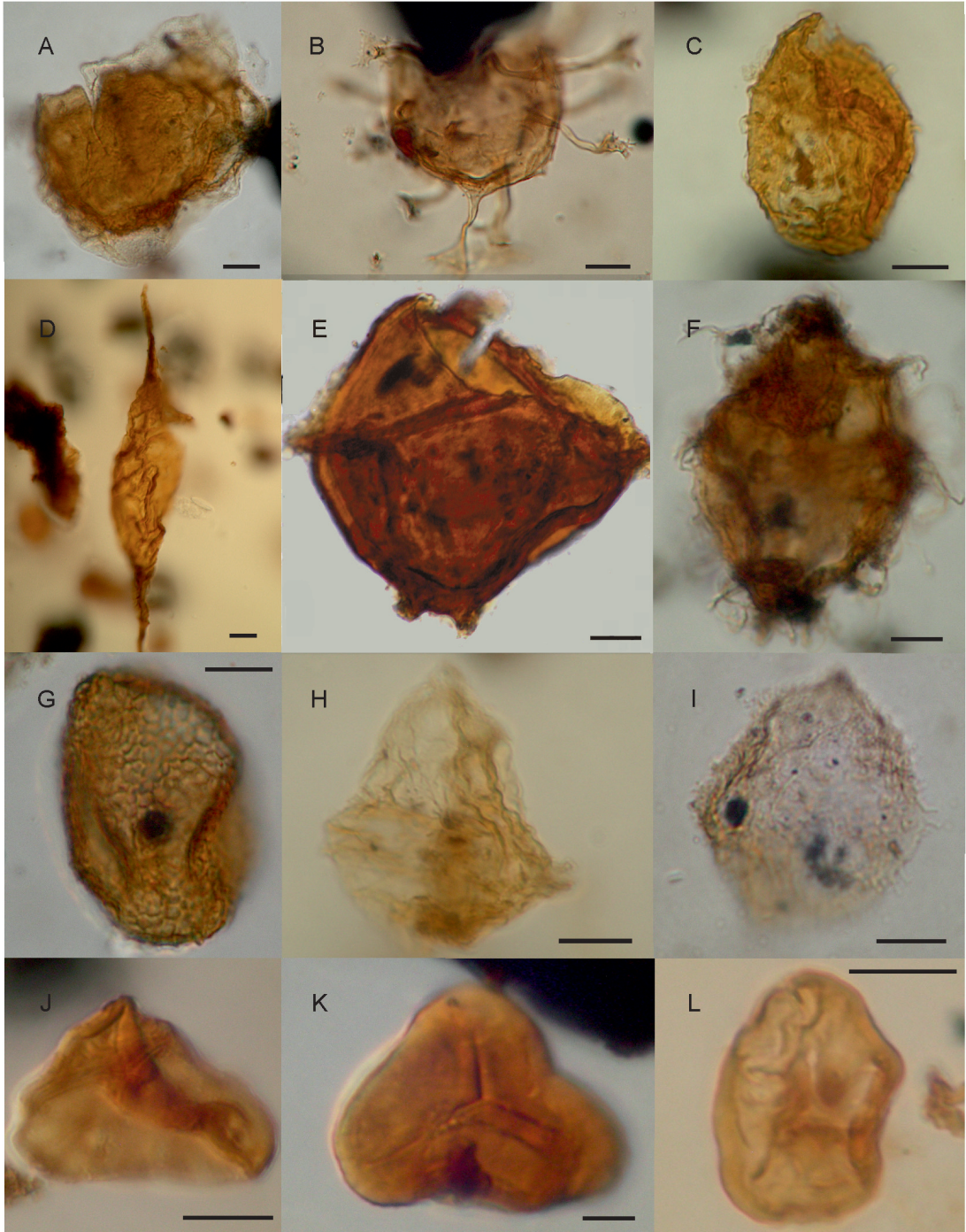
Fig. 3. A. *Membranisphoridium perforatum*: 4047c: E60. B. *Oligosphaeridium complex*: 4048c: V69/3. C. *Operculodinium azcaratei*: 4046a: U50. D. *Palaeocystodinium golzowense*: 4046a: M36/3. E. *Pentadinium laticinctum*: 3121/2: T33. F. *Phthanoperidinium coreoides*: 4049a: K62/2. G. *Pyxidinopsis waipawaensi*: 4048a: M33. H. *Volkheimeridium lanterna*: 4046b: P44. I. *Vozzhennikovia apertura*: 4048a: U58/4. J. *Biretisporites crassilabratus*: 4046a: G35. K. *Cyathidites paleospora*: 4046a: P48. L. *Cingutriletes australis*: 4045a: P50/3. Scale bars= 10µm.

& Williams 1976 emend. Benedek & Sarjeant 1981 (Fig. 3F)

*Pyxidinopsis waipawaensi* Wilson 1988 (Fig. 3G)

*Spiniferites ramosus* (Ehrenberg) Mantell 1854

*Volkheimeridium lanterna* (Cookson & Eisenack) Quattrocchio & Sarjeant 2003(Fig. 3H)

*Vozzhennikovia apertura* (Wilson 1967) Lentin & Williams 1976 (Fig. 3I)

**Acritarchs**
*Pterospermella* sp.

SYSTEMATIC DESCRIPTION

The original diagnosis of the genus *Rosannia* as *R. manika*, were based on a misinterpretation of its morphological characteristics (Srivastava, 1968). The genus was erroneuously diagnosed as a monad. *Rosannia* would have priority over *Lactoripollenites* Zavada & Benson, 1987. Gamerro & Barreda (2008) found fossil tetrads of Lactoridaceae and informally named as '*Lactoris* type' pending an emended diagnosis of *Rosannia* based on the type material. It was done in Srivastava & Braman (2010). Then this material is assigned here to the genus *Rosannia*.

*Rosannia manika* (Srivastava) Srivastava & Braman 2010

**Description**: Pollen grains shed in permanent tetrads, radiosymmetric. Individual grains monoporate, ana-ulcerate, slightly constricted proximally but distally flared; pore large situated at the distal end of an individual grain (diameter: 9 $\mu$m) with a conspicuos ridge adjacent to the aperture. Exina of two layers, aproximatly 1,5 $\mu$m thick. Sexine thicker than nexine; perforate-granulate. Infratectal ornamentation microreticulate, lumina size less than 1 $\mu$m. Sexine calymmate ( the sexine is continuous around the tetrad whereas the food layer continues around each monad of the tetrad and absent from the proximal hemisphere and the equatorial region of each pollen grain), about 1 $\mu$m, tectate, tectum thin, bacules short and wide , baculate and foot layers separate at the base of the pore forming a large cubiculum (term proposed in Srivastava & Braman, 2010); endopore not seen. Nexine less than 0.5 $\mu$m.

**Measurements**: Equatorial diameter 27 $\mu$m (2 specimens).

**Studied material**: 3121B: H32/1(Cerro Malvinera locality). 4045a: F50/3 (La Barca

Formation).

**Localities**: Cerro Malvinera and La Barca.

**Other records in Argentina.**

Gamerro & Barreda (2008) compared there material with *Rosannia manika* Srivastava from Pedro Luro Formation (Maastrichtian?-Danian) of central Argentina (Ruiz & Quattrocchio, 1997) but they said that it was impossible to achieve an accurate comparison because there are not description. A description of the material from Pedro Luro Formation is given in this paper as *Rosannia* cf. *manika* (Srivastava) Srivastava & Braman 2010.

*Rosannia* cf. *manika* (Srivastava) Srivastava & Braman 2010
(Fig. 4 E-F)

**Description**: Pollen grains shed in permanent tetrads, radiosymmetric. Individual grains monoporate, ana-ulcerate, slightly constricted proximally but distally flared; pore large situated at the distal end of an individual grain (diameter: 8-10 $\mu$m). Exine of two layers, 1 $\mu$m thick. Sexine thicker than nexine; perforate- scabrate. Sexine calymmate (the sexine is continuous around the tetrad whereas the food layer continues around each monad of the tetrad and absent from the proximal hemisphere and the equatorial region of each pollen grain). Nexine very thin, dificult to distinguish except in the equatorial region of each grain.

**Measurements**: Equatorial diameter 28-37 $\mu$m (9 specimens).

**Studied material**: 2972/4: E 31/4: 37 $\mu$m. 2972/7: K 41/4 :34 $\mu$m.

**Type locality:** Puerto Belgrano Nº 20 borehole (813,8-813,9 m depth). Colorado Basin (Argentina). Pedro Luro Formation.

**Age**: On the basis of foraminiferal, dinoflagellates and nannoplankton dating, the age of studied level is Upper Danian (Quattrochio & Sarjeant, 1996).

**Remarks**: We compare and not assigned to *R. manika* due to in the present material the infratectal ornamentation microreticulate characteristic of the species is not observed. The sexine is thinner (1.0 $\mu$m) in the studied material in relation to the type species (1.5 $\mu$m). This material shows a close resemblance to *Lactoris* type of Gamerro & Barreda (2008) and *Lactoripollenites africanus* Zavada & Benson (1987), sharing a similar morphology. The distal aperture is clearly defined in one of the specimen of Pedro Luro Formation, characteristic not observed in
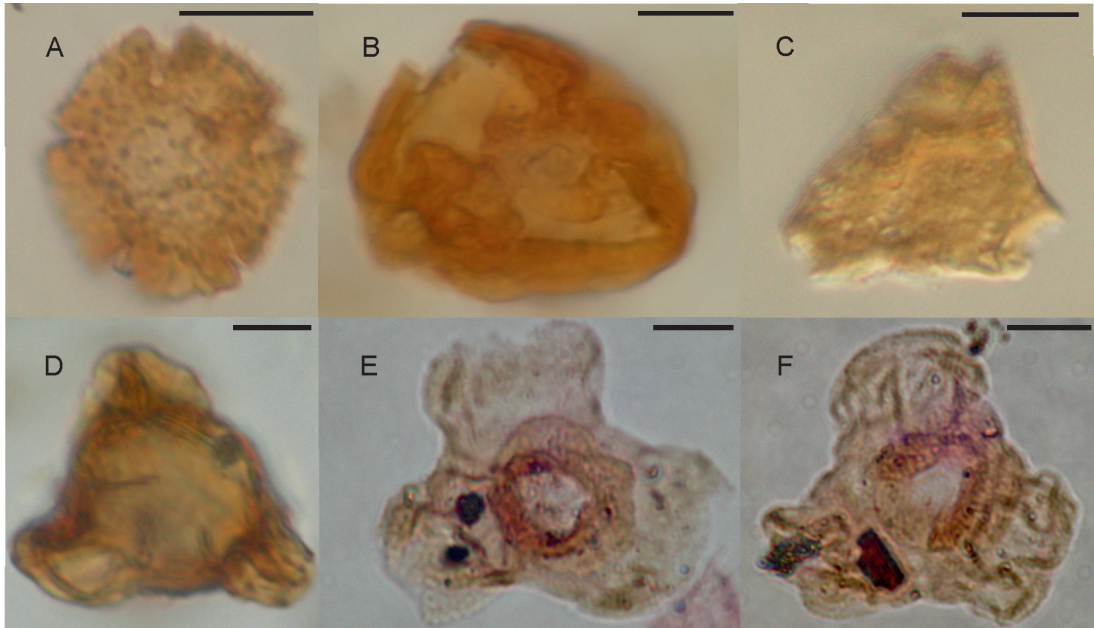
Fig. 4. A. *Nothofagidites fortispinulosus*: 4045a: S41/2. B. *Phyllocladidites mawsonii*: 4045a: X39/4. C. *Proteacidites* sp. : 4045a: L36/2. D. *Rosannia manika*: 4045a: F50/3. E-F: *Rosannia* cf. *manika*: 2972/7: K41/4. 2972/4: E31/4. Scale bars= 10μm.

*Lactoris* type (Gamerro & Barreda, 2008). *Lactoripollenites* from Australia (Macphail *et al.*, 1999) differs in having a thick exine (1,5-2 μm) and larger size (40-56 μm) than the present material (28-37 μm).

DISCUSSION

The new register of the Lactoridaceae in the area of Cerro Malvinera expanded the known fossil range of this family in Patagonia. To evaluate the age of the succession at Cerro Malvinera its palynology was compared to that of different Paleogene formations (La Barca, Punta Torcida and Puesto José) at its type locality, exposed in the Austral Basin. Several dinocyst events were recognized in the compared Paleogene formations. The first occurrences (FO) and last occurrences (LO) of these events are documented in Table 2. Magnetostratigaphycally calibrated ages of key dinocysts species in the Southern Ocean (Bijl *et al.*, 2013) and from other sections in the world recognized in these formations are given.

In comparing the palynomorphs of Cerro Malvinera with those recorded in La Barca, Punta Torcida and Puesto José formations (Table 3) it should be noted that the majority of taxa of this profile are present in La Barca Formation (7 species in common). Four species are shared with Punta Torcida Formation and only two with Puesto José Formation.

Cerro Malvinera samples and La Barca Formation share the presence of : *Rosannia manika* Srivastava & Braman (Lactoridaceae); in the sporomorphs group: *Biretisporites crassilabratus*, *Araucariacites australis*, *Podocarpidites* spp. and *Nothofagidites* spp. and in the dinoflagellate group: *Lingulodinium bergmannii* (Paleocene-middle Eocene) and *Pentadinium laticinctum* (FO 51.95-LO 11.2 ).

With Punta Torcida Formation shared the presence of *Araucariacites australis*, *Podocarpidites* spp., *Lingulodinium bergmannii* and *Spiniferites ramosus*. And with Puesto José Formation only *Biretisporites crassilabratus* and *Nothofagidites* spp.

In Table 3 the list of palynomorphs recognized in the different formations is given. Taking into account the dinocysts species some stratigraphic considerations about the analyzed formations are given.

La Barca Formation is considered to be Late Paleocene in previous studies (Olivero *et al.*, 2002) due to the presence of *Paleocystodinium golzowense*. According to Bijl *et al.*, 2013 this species has its LO 51. 50 Ma in the South Pacific Ocean and in other oceans FO 54.31 Ma (Table 2). Also this species is present in Austral Basin,

Table 2: Magnetostratigraphically calibrated ages of key dinocyst species in the Southern Ocean and from other sections in the World ( Bijl *et al*., 2013, William *et al*.,  1998, 1999, 2003).

| Dinocyst species | South Pacific Ocean | | Other oceans | |
|---|---|---|---|---|
| | FO Error | LO Error | FO Error | LO Error |
| *Apectodinium homomorphum* | 58.20 0.65 | 48.80 0.20 | | |
| *Batiacasphaera micropapillata* | | | 41.0 | 3.0 |
| *Cleistosphaeridium diversispinosum* | 49.30 0.20 | 38.30 0.30 | | |
| *Deflandrea antarctica* | 58.20 0.30 | | ?55 | |
| *Dracodinium waipawaense* | 53.40 0.10 | 50.00 0.40 | 53.40 0.10 | 51.30 0.10 |
| *Hystrichosphaeridium tubiferum* | | | 117.48 | 46.00 |
| *Membranophoridium perforatum* | 51.80 0.20 | 45.50 0.20 | | |
| *Palaeocystodinium golzowense* | | 51.50 0.20 | 54.31 | 9 |
| *Pentadinium laticinctum* | | | 51.95 | 11.21 |
| *Vozzhennikovia apertura* | 65.10 0.40 | | Transantarctic flora | |

Chile in the Chorrillo Chico Formation in the Late Paleocene associated with *Palaeoperidinium pyrophorum* (Late Campanian–Late Selandian) and in the lower part (early Eocene) of Agua Fresca Formation (Quattrocchio, 2009). The presence of *Palaeocystodinium golzowense* from PP18 sample upwards in the Agua Fresca Formation (early to middle Eocene) is considered reworking (Quattrocchio, 2009). Other species are *Operculodinium azcaratei*, *Volkheimeridium lantern,* which were cited for Chorrillo Chico and Agua Fresca formations, Paleocene- middle Eocene of Chile (Quattrocchio, 2009).

Due to the presence of *Pentadinium laticinctum* (FO 51.95 Ma– LO 11.21 Ma in other oceans) an age not older than early Eocene is proposed for La Barca Formation in the studied sample of LB2 member.

Punta Torcida Formation includes the quasi-globally recorded of the genus *Apectodinium homomorphum* (FO 58.20 Ma) associated with the P/E boundary. *Cleistosphaeridium diversispinosum* (FO 49.30 Ma early Eocene), *Achilleodinium latispinosum* (early Eocene), *Deflandrea fuegiensis*, *Habibacysta* sp. *Impagidinium maculatum* (Eocene), *Lingulodinium bergmannii* (Paleocene-Eocene), *Oligosphaeridium complex* (FO 135.2 Ma-LO 48.5 Ma), *Membranophoridium perforatum* (FO 51.80 Ma - LO 45.50 Ma), *Operculodinium azcaratei* (present in Chorrillo Chico and Agua Fresca Formations, Chile (Paleocene-middle Eocene), *Vozzhennikovia apertura* (Paleoceno-Oligoceno) are also identified. An age not older than early Eocene is proposed due to the presence of *Cleistosphaeridium diversispinosum* (FO 49.30 Ma., early Eocene),

*Achilleodinium latispinosum* (early Eocene) and *Impagidinium maculatum* (Eocene). The presence of *Oligosphaeridium complex* suggests an age not younger than early Eocene and *Membranophoridium perforatum* proposes an age not younger than middle Eocene. The assemblage of Punta Torcida resembles those of Agua Fresca Formation in Punta Prat locality (Quattrocchio, 2009), specially its lower and middle part.

An age not older than middle Oligocene is proposed for the studied samples from Puesto José Formation due the presence of *Phthanoperidinium coreoides,* which it is associated with *Leujenecysta fallax (*middle Eocene to middle Miocene).

**Migration routes**

The discovery of fossil pollen of Lactoridaceae in the Late Cretaceous (early Turonian-Campanian) deposits of the south-west coast (Orange Basin offshore Namaqualand), South Africa suggests that this family may have been a common element in the Cretaceous Gondwana flora (Zavada & Benson, 1987). Due to the type material was documented from cutting samples; the Turonian age for the Lactoridaceae should be cautiously accepted (Srivastava & Braman, 2010).

Different explanations have been postulated about the migratory routes of the family now restricted to a volcanic island in the Pacific Ocean (Macphail *et al*., 1999; Gamerro & Barreda, 2008; Srivastava & Braman, 2010). In Australia, pollen grains of one or more closely related species of *Lactoripollenites* Zavada &

Table 3: List of palynomorphs recognized in the analyzed formations.

| Formations/Locality | LaBarca | | PuntaTorcida | | PuestoJosé | | Co.Malvinera |
|---|---|---|---|---|---|---|---|
| Samples | 4045 | 4046 | 4047 | 4048 | 4049 | 4050 | |
| **Spores** | | | | | | | |
| *Baculatisporites comaumensis* | | x | | x | | | |
| *Biretisporites crassilabratus* | | x | | | | x | x |
| *Cingutriletes australis* | x | x | | | | | |
| *Corrugatisporites argentinus* | | | | | x | | x |
| *Cyathidites paleospora* | | x | | | | | |
| *Deltoidospora australis* | | x | | | | | |
| **Gymnosperm pollen** | | | | | | | |
| *Araucariacites australis* | x | x | | x | x | | x |
| *Dilwynites granulatus* | | | x | | | | |
| *Microcachryidites australis* | | x | | | | | |
| *Phyllocladidites mawsonii* | x | x | | | | | |
| *Podocarpidites* spp. | | | | x | | | x |
| **Angiosperm pollen** | | | | | | | |
| *Diporites aspis* | x | x | | | | | |
| *Nothofagidites fortispinulosus* | x | x | | | | x | |
| *Nothofagidites* spp. | | | | | | | x |
| *Proteacidites* sp. | x | x | | x | | | |
| *Rosannia manika* | x | | | | | | x |
| **Dinoflagellates** | | | | | | | |
| *Achilleodinium latispinosum* | | | x | x | | | |
| cf. *Adnatosphaeridium* sp. *A* | | | x | | | | |
| *Apectodinium homomorphum* | | | | x | | | |
| *Batiacasphaera rifensis* | | x | | | | | |
| *Batiacasphaera micropapillata* | x | x | | | | | |
| *Cleistosphaeridium diversispinosum* | | | x | x | | | |
| *Deflandrea fuegiensis* | | | x | x | | | |
| *Dracodinium waipawaense* | | | x | | | | |
| *Habibacysta* sp. | | | | x | | | |
| *Hystrichosphaeridium tubiferum* | | | x | | | | |
| *Impagidinium maculatum* | | | | x | | | |
| *Isabelidinium bakeri* | | x | | | | | |
| *Lejeunecysta fallax* | x | | | | | | |
| *Lejeunecysta* cf. *pulcra* | | | x | | | | |
| *Lingulodinium bergmannii* | x | x | | x | | | x |
| *Magallanesium* sp. | | x | | | | | |
| *Membranisphoridium perforatum* | | | x | x | | | |
| *Oligosphaeridium complex* | | | x | x | | | |
| *Operculodinium azcaratei* | | x | | x | | | |
| *Palaeocystodinium golzowense* | x | x | | | | | |
| *Pentadinium laticinctum* | x | | | | | | x |
| *Phthanoperidinium coreoides* | | | | | x | | |
| *Pyxidinopsis waipawaensi* | | | | x | | | |
| *Spiniferites ramosus* | | | | x | | | x |
| *Volkheimeridium lanterna* | | x | | | | | |
| *Vozzhennikovia apertura* | | | | x | | | |
| **Acritarchs** | | | | | | | |
| *Pterospermella* sp. | | | | | | | x |

Benson, 1987 have been recorded since 1970 in marine and terrestrial sediments, which range in age from Campanian to early Oligocene (Macphail *et al*., 1999). Macphail *et al*. (1999) considered that the Lactoridaceae could have entered Australia through the north from Africa during the middle-late Campanian. None of the Southeast Australian specimens of Lactoridace were an exact match for the South African and it could be presume that *Lactoris fernandeziana* is merley the sole survivor of a much larger clade (Mcphail com.pers.).

Lactoridaceae is also present in in the Danian and early Miocene of South America (Ruiz & Quattrocchio, 1997; Gamerro & Barreda, 2008, Barreda *et al*., 2012) and the Senonian of India (Prasad *et al*., 1995; Prasad & Pundeer, 2002), which was connected with Africa in the Senonian (Srivastava, 1988; Briggs, 2003). Africa and South America had land connections by the Río Grande Rise and the Walvis Ridge then the migrations of Lactoridaceae in the late Cretaceous throughout the Atlantic Ocean could be possible (Gamerro & Barreda, 2008). Gamerro and Barreda (2008) also postulated a migration via Antarctica due to the record of this family (Lactoridaceae *s.l.* A. Partridge, pers. comm. in Gamerro & Barreda 2008) in the Maastrichtian (López de Bertodano Formation). The southernmost extreme of South America (Patagonia) remained connected to the present Antarctic Peninsula at least up until about 30 Ma., that was part of the landscape up to the first part of the Paleogene, and quite probably also including part of the remaining Antarctic continent (Pascual & Ortiz-Jaureguizar, 2007) . Secular variation of neodymium isotope ratios at Agulhas Ridge (Southern Ocean, Atlantic sector) suggests  an early middle Eocene (approximately 41 Ma) for the opening of the Drake Passage (Scher & Martin, 2006)

The migration from North to South America is also possible (Gamerro & Barreda, 2008). By the beginning of the Late Cretaceous, the volcanic and diastrophic processes that finally led to the differentiation of the Caribbean region and Central America built up transient geographic connections that permitted the initiation of an overland inter-American exchange that included dinosaurian titanosaurs from South America and hadrosaurs from North America. Marsupials (polydolopimorphian marsupials) were assumed to have differentiated in South America prior to new discoveries from the North American Late Cretaceous (Pascual & Ortiz-Jaureguizar, 2007). But the lack of fossils of Lactoridaceae in north-

ern and central South America indicates that this route (North American) could be less probably (Gamerro & Barrera, 2008).

The route followed by this family to its present distribution is explained in Gamerro & Barreda (2008, p. 48). The youngest record is in the early Miocene (Austral Basin) in Argentina. Gamerro & Barreda (2008) considered that *Lactoris* migrated to the west (Robinson Crusoe Island) before the Andean maximum uplift in the middle-late Miocene.

A migration via Antarctica is postulated in this paper due to the record of this family in the Maastrichtian (Lopez de Bertodano Formation). The southernmost extreme of South America (Patagonia) remained connected to the present Antarctic Peninsula at least up until about 41 Ma. Depending on new records due to the presence of this family in the Colorado Basin in the Danian, a migration route from the north of Patagonia to the south (Austral Basin) it is not discarded.

CONCLUSION

The majority of palynomorph taxa from the Cerro Malvinera succession are present in the upper member LB2 of the La Barca Formation and both shared the presence of Lactoridaceae (*Rosannia manika* Srivastava) and the age-diagnostic dinocysts *Pentadinium laticinctum* (First Occurrences 51.95 Ma).  An age not older than early Eocene is proposed for the studied samples of LB2 member of the La Barca Formation and the Cerro Malvinera strata.

These data expands the known fossil record of the Lactoridaceae in Patagonia and contributes to elucidate the probably migration routes of this family. A migration via Antarctica is postulated in this paper due to the record of this family in the Maastrichtian (Lopez de Bertodano Formation). The southernmost extreme of South America (Patagonia) remained connected to the present Antarctic Peninsula at least up early middle Eocene (approximately 41 Ma). Depending on new records  due to the presence of this family in the  Colorado Basin in the Danian,  a migration route from the north of Patagonia to the south (Austral Basin) it is not descarded.

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