

Palynostratigraphy of the early Paleogene at the Laguna Manantiales locality, southern Golfo San Jorge Basin, Argentina

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Recibido: 25 de octubre 2023 - Aceptado: 29 de diciembre 2023 - Publicado: 10 de abril 2024

Para citar este artículo: Mirta Elena Quattrocchio, Luis Sebastián Agüero, Ari Iglesias, & María Sol Raigemborn (2024). Palynostratigraphy of the early Paleogene at the Laguna Manantiales locality, southern Golfo San Jorge Basin, Argentina. *Publicación Electrónica de la Asociación Paleontológica Argentina* 24(1): 108–128.

Link a este artículo: <http://dx.doi.org/10.5710/PEAPA.29.12.2023.491>

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ISSN 2469-0228

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PALYNOSTRATIGRAPHY OF THE EARLY PALEOGENE AT THE LAGUNA MANANTIALES LOCALITY, SOUTHERN GOLFO SAN JORGE BASIN, ARGENTINA

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Abstract. This study focuses on the early Paleogene deposits of the southernmost Golfo San Jorge Basin (central Patagonia, Argentina), cropping out at the Laguna Manantiales site. Based on palynological and sedimentological features, a new continental stratigraphic unit, informally named as Laguna Manantiales Strata, is here defined. The sporomorphs recorded evidence of the presence of subtropical forests. The syncolporate pollen grains comparable to those of the modern taxon *Senna pendula*, are mentioned for the first time in Argentina. Based on the record of *Malvacipollis diversus*, *Bombacacidites isoreticulatus*, *Cricotriporites guianensis* and the similarity in the pollen grains composition, the identified palynological assemblage can be correlated to the Patagonian palynofloras from the late Paleocene–early Eocene Ligorio Márquez Formation and the early Eocene Laguna del Hunco site. Thus, the proposed age for the Laguna Manantiales Strata can be constrained between the late Paleocene and the early Eocene. The records of *Huanilipollis cabreræ*, *H. crisci*, and *Mutisiapollis* sp. in Laguna Manantiales Strata, confirm the early development for Mutisioideae for the early Paleogene in Patagonia. The pronounced climatic warming during the late Paleocene and the early Eocene influenced the diversification of Asteraceae in Patagonia.

Key words. Palynomorphs. Paleocene–Eocene. Laguna Manantiales Strata. Patagonia. South America.

Resumen. PALINOESTRATIGRAFÍA DEL PALEÓGENO TEMPRANO EN LA LOCALIDAD DE LAGUNA MANANTIALES, SUR DE LA CUENCA DEL GOLFO SAN JORGE, ARGENTINA. Este estudio se centra en los depósitos del Paleógeno temprano que afloran en el sitio de Laguna Manantiales, extremo sur de la Cuenca del Golfo San Jorge (Patagonia central, Argentina). En base a características palinológicas y sedimentológicas, se define aquí una nueva unidad estratigráfica continental, denominada informalmente Estratos de Laguna Manantiales. El registro de esporomorfos evidencia la presencia de bosques subtropicales. Granos de polen sincolporados comparables a los del taxón actual *Senna pendula* se mencionan por primera vez en Argentina. Considerando el registro de *Malvacipollis diversus*, *Bombacacidites isoreticulatus*, *Cricotriporites guianensis* y la similitud en la composición de los granos de polen con la Formación Ligorio Márquez del Paleoceno tardío–Eoceno temprano y con el Laguna del Hunco del Eoceno temprano, la edad propuesta para los Estratos de Laguna Manantiales puede ser restringida entre Paleoceno tardío y el Eoceno temprano. Los registros de *Huanilipollis cabreræ*, *H. crisci* y *Mutisiapollis* sp. en los estratos de Laguna Manantiales confirman el desarrollo temprano de Mutisioideae para el Paleógeno temprano en la Patagonia. El pronunciado calentamiento climático acaecido durante el Paleoceno tardío y el Eoceno temprano habría influido en la diversificación de Asteraceae en la Patagonia.

Palabras clave. Palinomorfos. Paleoceno–Eoceno. Estratos de Laguna Manantiales. Patagonia. Sudamérica.

DURING THE CENOZOIC, global climate has transitioned from warm states 60–40 My to cool states 10–5 My (e.g., Westerhold *et al.*, 2020). The early Paleogene is marked by long-term warming from the mid Paleocene (~ca. 58 My) to

the early Eocene (e.g., Zachos *et al.*, 2001, 2008; Westerhold *et al.*, 2011, 2020; Littler *et al.*, 2014). Particularly, the Paleocene/Eocene boundary was a period of transient and intense global warming that had a deep effect on middle

and high latitude biotas (*e.g.*, Greenwood *et al.*, 2003; Wilf *et al.*, 2013; Woodburne *et al.*, 2014).

Southern South American paleofloras are unique for understanding the old history of some important native plant groups during this interval, such as the Asteraceae (Barreda *et al.*, 2008; Wilf *et al.*, 2013; Barreda *et al.*, 2015).

Particularly, the early Paleogene succession in the Golfo San Jorge Basin (Fig. 1.1), constitutes the most complete paleoclimatic record to date for the southern mid-paleolatitudes, which come from biotic (mainly macroflora, invertebrates, and vertebrates) and abiotic (clayminerals and paleosols) proxies (Raigemborn *et al.*, 2009, 2014, 2018a, 2018b, 2022; Krause *et al.*, 2010; Woodburne *et al.*, 2014; Zucol *et al.*, 2018; del Río, 2021; Iglesias *et al.*, 2021).

Although there are several records of continental palynofloras for the Paleogene in Patagonia, there are no good records documenting the late Paleocene–early Eocene transition. Furthermore, the southern area of the Golfo San Jorge Basin has been unexplored for palynofloras, with the exception of Zamaloa & Andreis (1995).

This study focuses on the early Paleogene southernmost deposits of the Golfo San Jorge Basin, cropping out at the Laguna Manantiales site (ELM), northern Santa Cruz Province, Patagonia, Argentina (Fig. 1.2). Roughly 5 km towards the northeast of the studied outcrop section, Zamaloa & Andreis (1995) analyzed the palynological assemblage of an exposed 16 m thick section (47° 32' S; 68° 10' W; Fig. 1.3) that they fully assigned to the Salamanca Formation (Danian). Barreda & Palazzesi (2007) included Zamaloa & Andreis (1995) palynological assemblage in the early–middle Eocene based on the high frequencies of megathermal taxa.

The aims of this paper are: i) to present a new early Paleogene section from the southern Golfo San Jorge Basin at the ELM; ii) to carry out the palynostratigraphic analysis of the samples; iii) to compare our results with previous palynological records from Patagonia and other palynofloras from southern South America, Antarctica, Australia, and New Zealand.

GEOLOGICAL SETTING AND SEDIMENTOLOGICAL CONTEXT

The Golfo San Jorge Basin is an extensional intracontinental basin in southern Argentina that is genetically linked to

the Gondwana break-up and encompasses a Cretaceous–Cenozoic infilling (Fitzgerald *et al.*, 1990) (Fig. 1).

The northern region of the Golfo San Jorge Basin (*i.e.*, the north flank and part of the San Bernardo Fold Belt areas in Fig. 1) is well known for its stratigraphic, sedimentologic, and paleontologic features, with several precise dates and some guide levels for the Paleogene (see reviews in Krause *et al.*, 2017; Foix *et al.*, 2022; Iglesias & Brea, 2022). However, the southern part of the basin (*i.e.*, south flank; Fig. 1.2) remains understudied and with sparse geological data (Zamaloa & Andreis, 1995; Raigemborn *et al.*, 2018a, 2018b, 2022; Brea *et al.*, 2021). The stratigraphic information from the northern region of the basin indicates that Cenozoic sedimentation initiated with the early Danian (*ca.* 65.7–63.5 My; Clyde *et al.*, 2014) Salamanca Formation, that corresponds to shallow marine, estuarine, and coastal swamp deposits that represent the late Maastrichtian–early Danian transgression of the Atlantic Ocean (*e.g.*, Andreis *et al.*, 1975; Martínez, 1992; Legarreta & Uliana, 1994; Matheos *et al.*, 2001; Foix, 2009; Raigemborn *et al.*, 2010; Foix *et al.*, 2012; Clyde *et al.*, 2014; Comer *et al.*, 2015; Raigemborn & Beilinson, 2020) (Fig. 2).

The Salamanca Formation contains a diverse and well-preserved gondwanic flora that includes several petrified forests within the formation and correlated units (see review in Iglesias & Brea, 2022).

The Salamanca Formation, in the northern region of the basin, is overlaid by fluvial deposits of the late Danian (*ca.* 62.5–61.6 My; Clyde *et al.*, 2014; Comer *et al.*, 2015) Peñas Coloradas Formation or the Selandian? Las Violetas Formation, depending on lateral variations (Raigemborn *et al.*, 2010; Krause *et al.*, 2017; Raigemborn & Beilinson, 2020). The Peñas Coloradas Formation is a fluvial unit that crops out mainly in the north flank of the basin (Fig. 1.2). It corresponds to reddish, cross-bedded sandstones related to sinuous channel fillings and subordinate mudstones deposited in floodplain settings (*e.g.*, Raigemborn & Beilinson, 2020; Foix *et al.*, 2022). The Peñas Coloradas Formation contains permineralized wood, leaves, and palynomorphs (Lema *et al.*, 1999; Ruiz *et al.*, 1999; Brea & Zucol, 2006; Raigemborn *et al.*, 2009; Iglesias *et al.*, 2021). The Las Violetas Formation is a volcanoclastic-rich fluvial unit restricted to the northern margin of the basin. It is

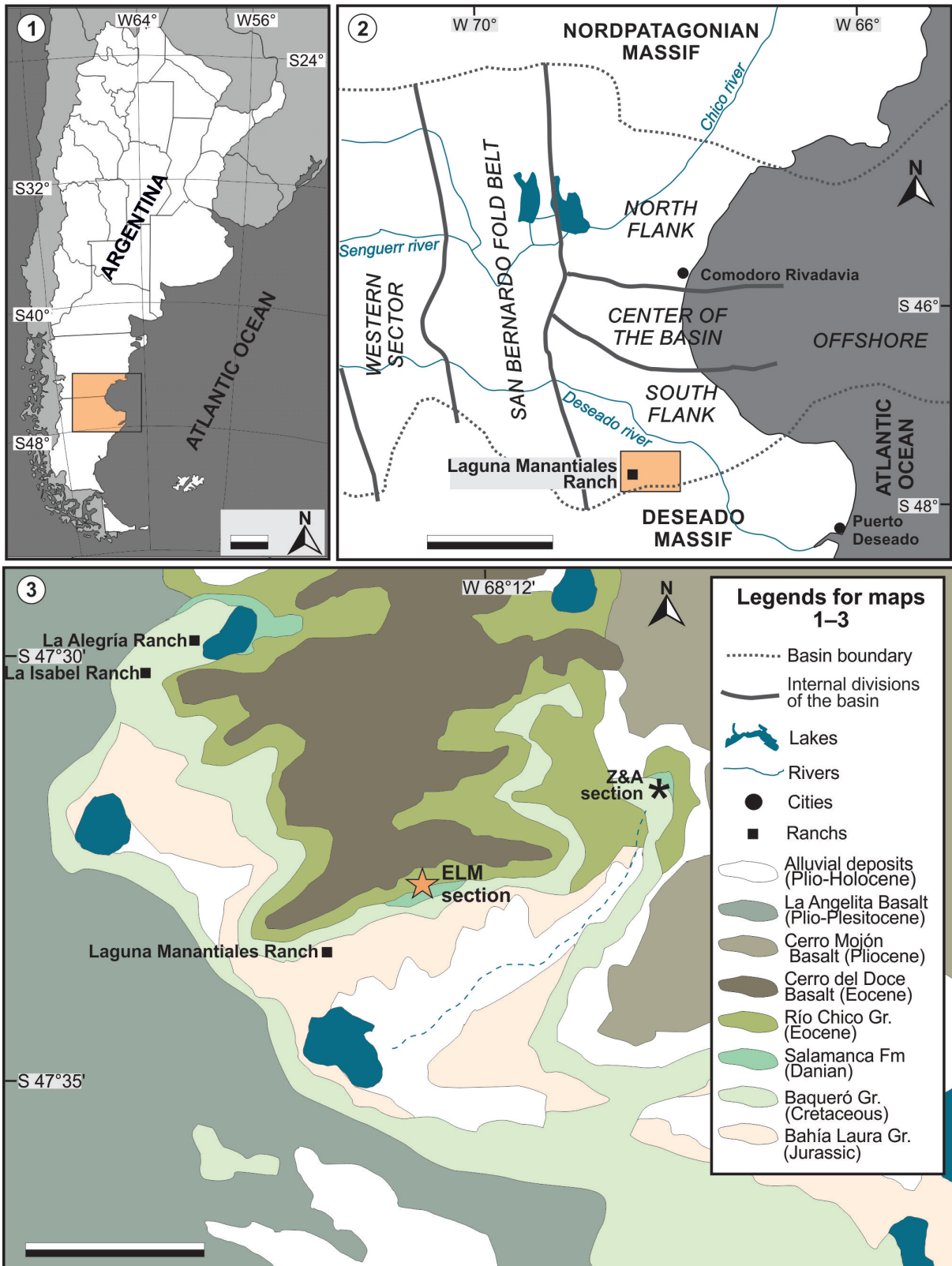


Figure 1. Location maps of the study area. 1, Regional setting for southern South America with the inlet in Fig. 1.2, scale bar= 300 km; 2, Boundaries and internal divisions of the Golfo San Jorge Basin (following Figari *et al.*, 1999), and position of the Laguna Manantiales area delineated in Fig. 1.3, scale bar=100 km; 3, Geology of the study area (modified from Panza *et al.*, 2001 and Raigemborn *et al.*, 2022). The ELM section marks the here studied Laguna Manantiales site. The Z&A section corresponds to the site studied by Zamalao & Andreis (1995). Scale bar= 3 km.

integrated by greenish-grey coarse-grained channel fills and greyish-orange pedogenized fine-grained floodplain deposits that represent a low-sinuosity fluvial system (e.g., Raigemborn & Beilinson, 2020). Unlike the Peñas Coloradas Formation, the Las Violetas Formation is up to now barren of macrofloral records (Iglesias & Brea, 2022). Both the Peñas Coloradas and the Las Violetas formations are overlaid by the early–middle Eocene (ca. 56–46.71 My; Krause *et al.*, 2017) Las Flores Formation, which is broadly characterized by fluvial facies. In the north flank of the basin, this unit is integrated by pinky to grayish or orangey and whitish sandy-gravelly facies interbedded with thin packages of mainly epiclastic fine-grained bodies that represent a moderate -to high- sinuosity fluvial system (Raigemborn *et al.*, 2010, 2014, 2022; Krause & Piña, 2012; Foix *et al.*, 2013, 2015; Raigemborn & Beilinson, 2020). Toward the eastern margin of the San Bernardo Fold Belt, the Las Flores Formation is characterized by epiclastic

and volcanoclastic grayish-greenish homogeneous muddy deposits interpreted as a distal floodplain-dominated sinuous fluvial system (e.g., Raigemborn *et al.*, 2009, 2010; Krause *et al.*, 2017; Raigemborn & Beilinson, 2020). At the southern flank, the Las Flores Formation is identified by the presence of siliciclastic sandy-gravelly facies interbedded with fine-grained facies, all of them altered by pedogenesis to strongly-developed paleosols, which correspond to a distal floodplain-dominated low-sinuosity fluvial system (Raigemborn *et al.*, 2022). Up to now, the paleobotanical record of the Las Flores Formation consists only of phytoliths (Brea *et al.*, 2008; Raigemborn *et al.*, 2009; Zucol *et al.*, 2018; Stiles *et al.*, 2020). Finally, the mid–Eocene (46.71–42.11 My; Dunn *et al.*, 2013; Krause *et al.*, 2017) Koluel-Kaike Formation crops out along the entire margin of the basin (Legarreta & Uliana, 1994; Krause *et al.*, 2010; Raigemborn *et al.*, 2010). This unit is mainly composed of fine-grained eolian-fluvial reworked volcanoclastic sediments, which were strongly pedogenically modified and represent a distal mixed eolian-fluvial depositional system (Krause *et al.*, 2010, 2017; Raigemborn *et al.*, 2010, 2018a, 2022; Raigemborn & Beilinson, 2020). The only paleobotanical remains recorded in this unit consist of a fragment of wood (Brea *et al.*, 2009) and phytoliths (Zucol *et al.*, 2018).

Overall, the stratigraphy and age from the northern region of the basin suggest a temporal gap after the deposition of the Peñas Coloradas and Las Violetas formations (lower–middle Paleocene) and before the beginning of the early Eocene Las Flores Formation (Krause *et al.*, 2017).

This study focuses on the early Paleogene deposits from the southernmost region of the basin, cropping out at ELM near the Laguna Manantiales Ranch site (Fig. 1.2–3). At this locality (Fig. 1.3), the Paleogene deposits constitute a succession of ca. 70 m thick that is unconformably overlying the mid–Cretaceous Baqueró Group and is unconformably overlaid by the late Eocene Cerro del Doce Basalt (Panza *et al.*, 2001) (Fig. 3).

At the ELM, the early Paleogene succession includes a basal section of 21 m thick and an upper section of ca. 50 m thick (Fig. 3). The basal section comprises two parts: 1) the lowermost 0.40 m includes siliciclastic greenish glauconite-rich sandstones that preserve shark teeth, 2) the remaining

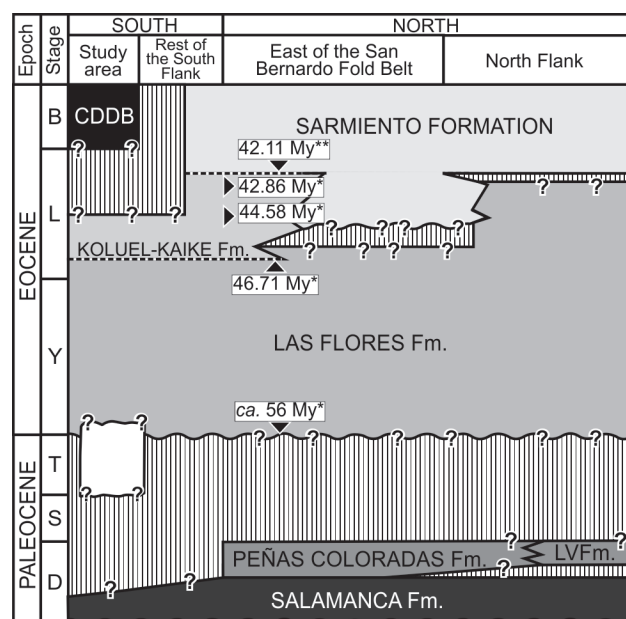


Figure 2. Chronostratigraphic chart of the eastern Golfo San Jorge Basin, including the study area (left), modified from Raigemborn *et al.* (2022). It extends through continental (light and mid gray), marine (dark gray), and basaltic (black) successions from the early Paleocene to the late Eocene. Vertical shading indicates a hiatus. Dashed and wavy lines indicate transitional and erosive contacts, respectively. White area indicates the palynomorphs-rich succession studied in this paper. (*) ages from Krause *et al.* (2017) based on U/Pb dates and paleomagnetic correlations; (**) age from Dunn *et al.* (2013) based on U/Pb dates and paleomagnetic correlations. Stage abbreviations: D, Danian; S, Selandian; T, Thanetian; Y, Ypresian; L, Lutetian; B, Bartonian; LVFm, Las Violetas Formation; CDDB, Cerro del Doce Basalt; LMS, Laguna Manantiales Strata.

ca. 20.10 m are composed of siliciclastic greenish glauconite-rich conglomerates and sandstones with muddy intraclasts that record silicified woods and brownish mixed sandy-muddy and silty facies that commonly preserve leaf compressions, cuticles, and palynomorphs.

Based on stratigraphical position, sedimentological facies, and marine-related fossils in the lowermost level of the section the entire basal section at the area was previously assigned to the Salamanca Formation (Zamaloa & Andreis, 1995; Raigemborn *et al.*, 2018b; Brea *et al.*, 2021). However, this unit is restricted to only the lowermost 0.40 m of the basal section based on the new results provided within the present contribution; and the remaining 20.10 m correspond to a new continental stratigraphic unit that is here informally named as Laguna Manantiales Strata (LMS) (Fig. 3).

The upper section at the ELM corresponds to 36 m thick of intensely pedogenized fine- and coarse-grained siliciclastic facies that were assigned to the Las Flores Formation based on several sedimentological and paleopedological attributes (Raigemborn *et al.*, 2022). The final 15 m of fine-grained volcanoclastic facies can be well constrained to the Koluel-Kaike Formation (Raigemborn *et al.*, 2022; Fig. 3). The LMS represents a sedimentological arrangement that significantly shows dissimilarities to the well-known Golfo San Jorge Basin continental units. Although it can be stratigraphically constrained between the underlayed early Danian Salamanca Formation and the overlayed early–middle Eocene Las Flores Formation, the precise age of the strata remains indeterminate. The present palynological study provides an important piece to improve the floristic knowledge of the Paleocene–Eocene transition for the Golfo San Jorge Basin and its correlation with other Patagonian areas.

MATERIAL AND METHODS

The complete Laguna Manantiales section crops out at 47° 33' 20.0" S; 68° 13' 49.6" W and was stratigraphically sampled regularly for palynological analysis (Figs. 1.3, 3). Palynomorphs were studied from 11 fertile samples that comprised both coarse- and fine-grained lithologies corresponding to greenish trough cross-stratified sandstones, dark and light brown mixed sandstones–mudstones, dark and light brown-laminated siltstones, and light brown

massive siltstones (Fig. 3).

Fresh rock colors were described according to the Munsell notation (Munsell Color firm, 2013). Physical and chemical palynomorph extraction was carried out using standard palynological processing techniques (Volkheimer & Melendi, 1976) at the Palynological Laboratory of the Universidad Nacional del Sur, Bahía Blanca, Buenos Aires Province, Argentina.

The aqueous palynological residue is dehydrated with ethanol in order to be set in UV-curable acrylates TRABASIL NR2 Trabasil® NR2 and Acrysoft® urethane acrylates (Noetinger *et al.*, 2017).

The slides were systematically examined in normal transmitted and incident blue light to characterize the palynofacies (Combaz, 1980). In this contribution, the palynomorphs are documented.

The palynological data were statistically processed using the multivariate statistical programme PAST (Hammer *et al.*, 2001). Based on the presence/absence of the registered taxa, Jaccard similarity index was used to determine the similarity between the palynological assemblage of the LMS (this study) and those of selected formations from the Paleogene. The application of this index results in a similarity matrix with values varying between 0 and 1, where 1 represents the highest similarity and 0 the lowest. In addition, a cluster analysis (Q-mode) was performed using the unweighted pair group method (UPGM) and the Jaccard similarity index. The cophenetic correlation index used in the cluster analysis graphic was defined as the linear correlation coefficient between the cophenetic distances obtained from the dendrogram and the original distances used to construct it. If the magnitude of this value is close to 1, a high-quality resolution is considered (Anderberg, 1973; Kovach, 1989). This technique has been successfully used by several authors (Povilauskas *et al.*, 2008; Cornou *et al.*, 2014; Olivera *et al.*, 2020, among others).

All palynological slides are stored at the Paleobotany Collection of the Museo Provincial Padre Manuel Jesús Molina, Río Gallegos, Santa Cruz Province, Argentina (acronym MPM-Pb).

In the citation of specimens referred to or illustrated, the sample and slide numbers are given first and the position on the slide is indicated by England Finder reference (*e.g.*, G36/4).

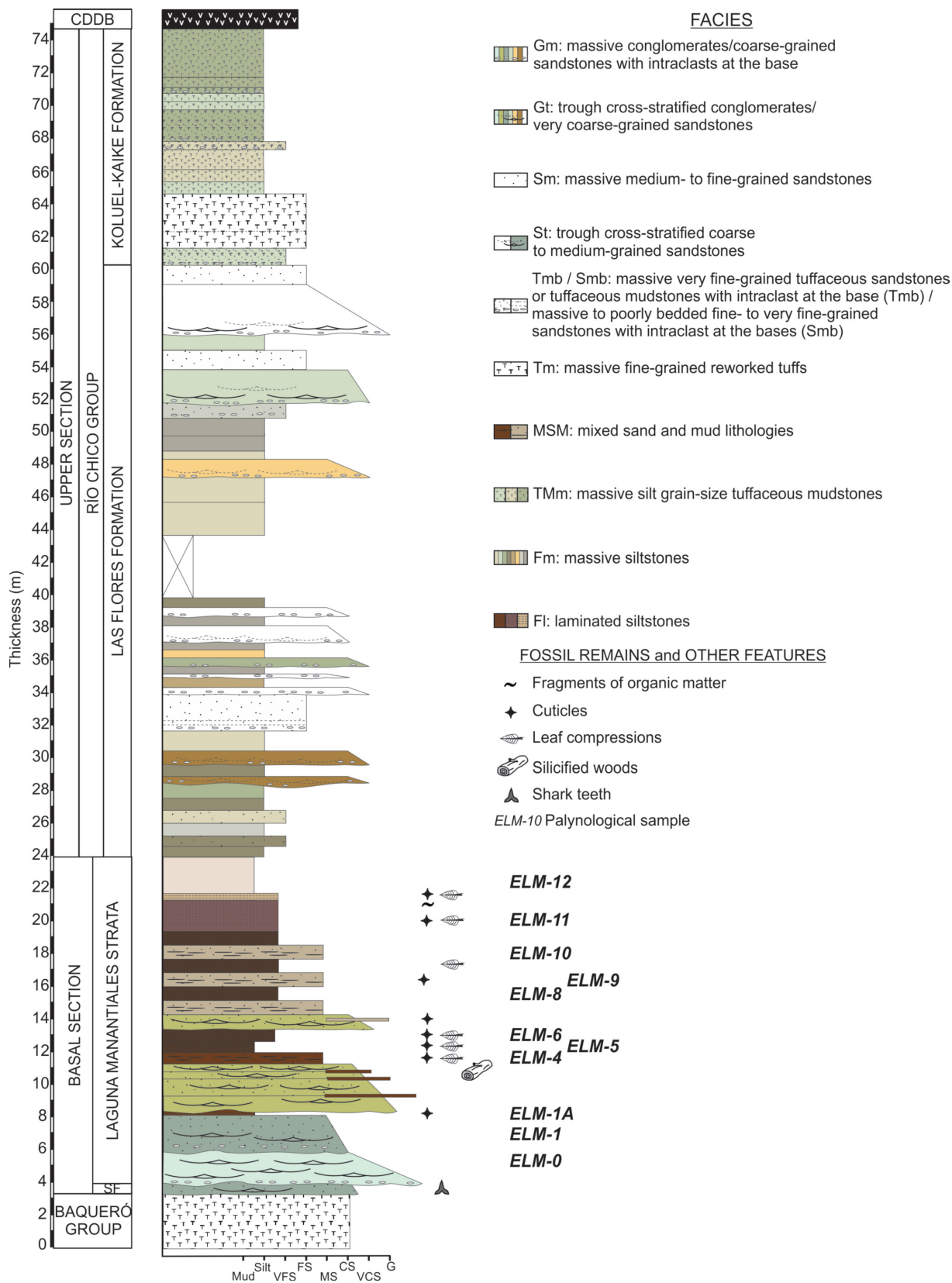


Figure 3. Early Paleogene sedimentary section at ELM. Abbreviations: SF, Salamanca Formation; CDDB, Cerro del Doce Basalt (late Eocene, Bartonian? *sensu* Panza *et al.*, 2001). Facies colors correspond to fresh rock colors.

PALYNOSTRATIGRAPHY

The palynological assemblages of the LMS are reported for the first time and compared with previous studies carried out in the area (Zamaloa & Andreis, 1995), in other lithostratigraphic units from Patagonia and in Gondwana terrains.

Sporomorph analysis at LMS in ELM allowed the characterization of the paleofloristic scenario of the studied section. It reflects a regional forest dominated by Araucariaceae, Nothofagaceae, Podocarpaceae, and Proteaceae, accompanied by ferns belonging to the Schizaeaceae, Polypodiaceae, and Dicksoniaceae families. The angiosperm taxa belonging to Apocynaceae, Arecaceae, Asteraceae, Picrodendraceae, Symplocaceae, between others, are documented.

In this contribution, very well-preserved pteridophyte and bryophyte spores (six taxa), gymnosperm pollen grains (five taxa), angiosperm pollen grains (26 taxa), fungal spores (two taxa), Zygnemataceae spores (two taxa), freshwater dinoflagellate cysts, ?acritarch, and copepod eggs are identified (Figs. 4–6) and summarized in Table 1.

The presence of stratigraphically important sporomorph taxa is discussed below, in alphabetical order:

Bombacacidites isoreticulatus McIntyre, 1965 (Malvaceae, Bombacoideae; Fig. 4.12; ELM-12 in Tab. 1). This species was previously mentioned in Patagonia for the Eocene Río Turbio Formation (Romero & Zamaloa, 1985; Fernandez *et al.*, 2021) and for the Laguna Manantiales section (Zamaloa & Andreis, 1995 as *Intratripopollenites* sp.). Also, Barreda *et al.* (2020) reported *Intratripopollenites* sp. in the early Eocene Huitrera Formation, Chubut Province. *Bombacacidites* sp. was registered for the late Paleocene–early Eocene Ligorio Márquez Formation at Río Zeballos locality, Argentina (Macphail *et al.*, 2013). *B. isoreticulatus* is known for Argentina and New Zealand during the warm peaks of the Eocene (Fernández *et al.*, 2021; and references therein). Contreras *et al.* (2013) defined *Bombacacidites* sp. A in Antarctica for the Early Eocene Climatic Optimum and postulated that this species is similar to *Intratripopollenites notabilis* (Harris) Stover, 1973 (in Stover & Partridge, 1973) and *B. isoreticulatus*.

Cricotriporites guianensis Leidekmeyer, 1966 (Gentianales,

Apocynaceae; Figs. 4.20, 6.7). This species was found in several ELM levels (Tab. 1). Its first appearance is in the early Eocene (55.8–48.6 My) and last appearance in the Late Miocene (11.6–5.3 My) (GBIF Secretariat, 2023). It was previously mentioned in Argentina for the late Paleocene–early Eocene Maíz Gordo Formation of the Salta Basin (Volkheimer *et al.*, 1984; Quattrocchio & del Papa, 2000), in the Late Miocene Chiquimil Formation in Catamarca Province (Mautino & Anzótegui, 2002) and in the Late Miocene Barranca Final Formation of the Colorado Basin (Guler *et al.*, 2001). *Dacrycarpites australiensis* Cookson & Pike, 1953 (Figs. 4.2, 6.3) is a common pollen grain in the Cenozoic of the southern Hemisphere (Zamaloa & Romero, 2005 and references therein). It was registered for the late Paleocene–early Eocene Ligorio Márquez Formation at the Río Zeballos locality, Argentina (Macphail *et al.*, 2013) and for the Danian Lefipan Formation (Barreda *et al.*, 2012).

Dacrydiumites praecupressinoides (Couper) Truswell, 1983 is recorded in Patagonia since the Upper Cretaceous, varying in abundance throughout the Paleogene to the Neogene (Raine *et al.*, 2011). Within the Paleogene, it is present in the Danian Salamanca Formation (Clyde *et al.*, 2014), the late Paleocene–early Eocene Ligorio Márquez Formation at the Río Zeballos locality (as *Dacrydiumites florinii* Cookson & Pike, 1953; Macphail *et al.*, 2013), and the Eocene La Marcelina Formation, Santa Cruz Province (Noetinger *et al.*, 2023).

Dyadosporites subovalis (Sheffy & Dilcher) Kalgutkar & Jansonius, 2000 (hyphomycete; Fig. 5.1). This taxon corresponds to a fungal spore that is recorded for the middle Eocene in the Gulf of Mexico Basin of the USA (Sheffy & Dilcher, 1971) and the Patagonian Tertiary Troncoso Formation of the Ñirihuau Basin (Martínez *et al.*, 2016).

Favitricolporites australis Archangelsky, 1973 (Fig. 4.13). This Patagonian species was defined for the Danian Salamanca and Cerro Bororó formations for the northern flank of the Golfo San Jorge Basin (Archangelsky, 1973). It was also recorded for the early to late Eocene Huitrera Formation (Melendi *et al.*, 2003), for the Tertiary Salto del Macho Formation of the Ñirihuau Basin (Cornou *et al.*, 2014), and for the Eocene La Marcelina Formation (Noetinger *et al.*, 2023).

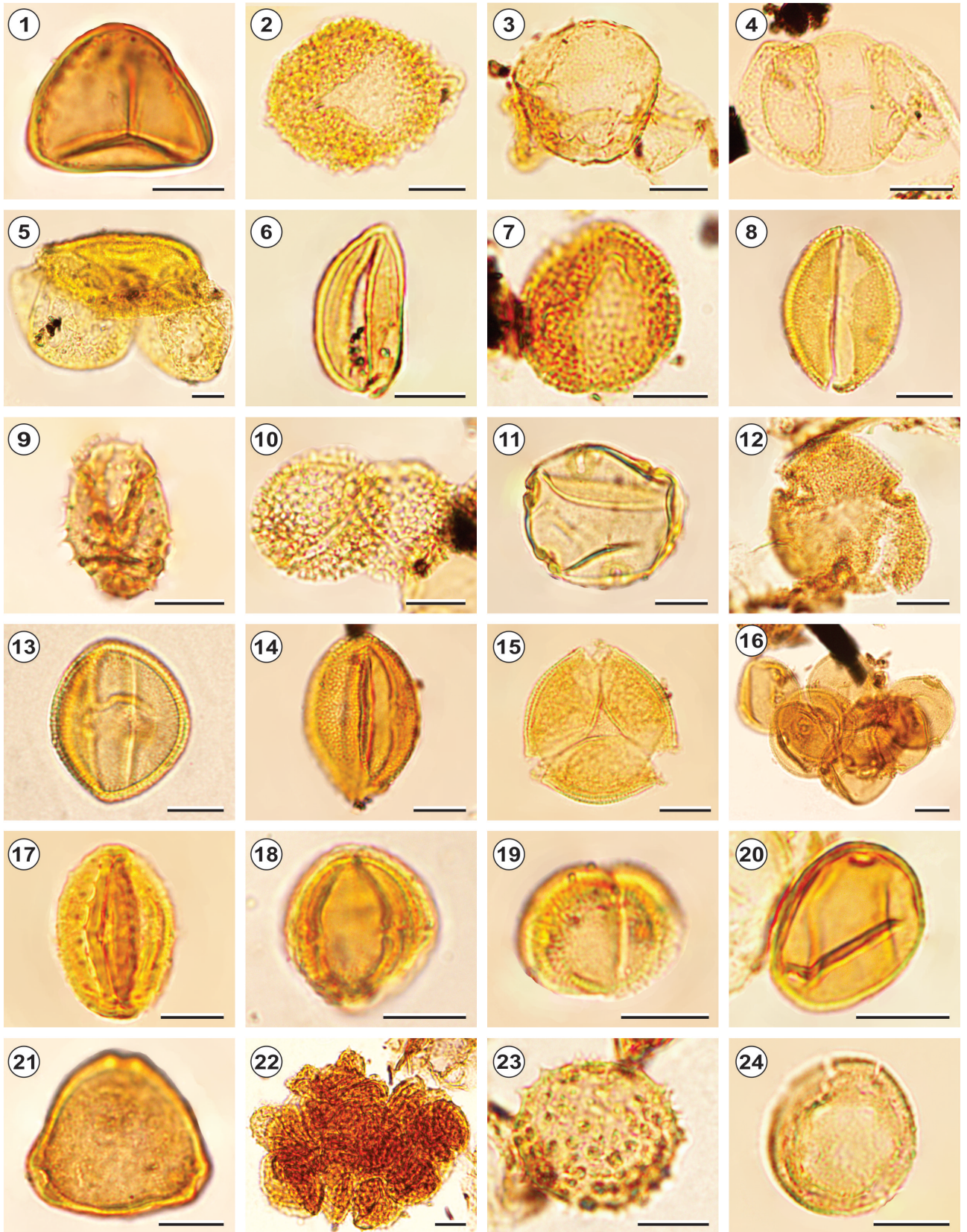


Figure 4. Selected sporomorphs from LMS (see also Tab. 1). **1**, *Deltoidospora minor* (Couper) Pocock, 1970 (Slide 5221B; B46/3); **2**, *Dacrycarpites australiensis* Cookson & Pike, 1953 (Slide 5219D; B27/1); **3–4**, *Podocarpidites elegans* Romero, 1977 (Slide 5218D; D41/1); **5**, *Podocarpidites marwickii* Couper, 1953 (Slide 5221E; R45/1); **6**, *Arecipites (Monosulcites) waitakiensis* (McIntyre) Mildenhall & Pocknall, 1989 (Slide 5221B; H71); **7**, *Clavatipollenites hughesii* Couper, 1958 (Slide 5215b; J61/1); **8**, *Liliacidites vermireticulatus* Archangelsky & Zamalao, 1986 (Slide 5212c; H52); **9**, *Spinizonocolpites* sp. (Slide 5521b; G46/2); **10**, *Albertipollenites anguloluminosus* (Anderson) Archangelsky, 1973 (Slide 5220b; F41/4); **11**, *Nothofagidites rocaensis* Romero, 1973 (Slide 5212c; H56); **12**, *Bombacacipites isoreticulatus* McIntyre, 1965 (Slide 5221b; G62/4); **13**, *Favritricolporites australis* Archangelsky, 1973 (Slide 5212e; G56/1); **14**, *Rhoipites baculatus* Archangelsky, 1973 (Slide 5212e; R50); **15**, *Syncolporites* sp. (Slide 5212e; B62); **16**, *Symplocopollenites austellus* Partridge (in Stover & Partridge, 1973) (Slide 5521b; K55/4); **17**, *Mutisiapollis* sp. (Slide 5212e; U52/1); **18**, *Huanilipollis cabreræ* Barreda & Palazzesi (in Barreda *et al.*, 2008) (Slide 5212e; Y56/3); **19**, *Huanilipollis crisci* Barreda & Palazzesi (in Barreda *et al.*, 2008) (Slide 5212c; F53); **20**, *Cricotriporites guianensis* Leidelmeyer, 1966 (Slide 5216b; Z47/2); **21**, *Myricipites harrisii* (Couper) Dutta & Sah, 1970 (Slide 5521b; J48/3); **22–23**, *Malvacipollis diversus* Harris, 1965 (Slide 5221b; H58/1. Slide 5216b; V48/1); **24**, *Polyporina romeroi* Archangelsky, 1973 (Slide 5220b; F41/2). Scale bar= 10 µm.

Huanilipollis cabreræ Barreda & Palazzesi (in Barreda *et al.*, 2008) (Asteraceae, Mutisioideae; Fig. 4.18). This Patagonian species was originally defined for the Miocene Chenque Formation, southeastern Chubut Province, Argentina (Barreda *et al.*, 2008; Tellería *et al.*, 2023) and was also recorded for the early Eocene palynoflora from the Laguna del Hunco site (Barreda *et al.*, 2020).

Huanilipollis crisci Barreda & Palazzesi (in Barreda *et al.*, 2008) (Asteraceae, Mutisioideae; Fig. 4.19). This species was previously defined in Patagonia, but is only known from the Miocene Chenque Formation (Barreda *et al.*, 2008).

Liliacidites regularis Archangelsky, 1973 (Arecaceae). This Patagonian species is known from the late Maastrichtian to the Danian for the north flank of the Golfo San Jorge Basin (Archangelsky, 1973; Scafati *et al.*, 2009; Barreda *et al.*, 2012; Vallati *et al.*, 2016). It was also recorded in the Eocene Río Turbio Formation (Fernández, 2018). *Liliacidites* cf. *L. regularis* was cited for the late Paleocene–early Eocene Ligorio Márquez Formation at Río Zeballos, Argentina (Macphail *et al.*, 2013).

Malvacipollis diversus Harris, 1965 (Picrodendraceae; Figs. 4.22–23, 6.9). This species is very common (80% of the sporomorph assemblage in ELM-12) and it was also

registered in other several ELM levels (Tab. 1). It is well known for its record in the Gippsland Basin (southeastern Australia), indicating the upper part of the *Lygistepollenites balmei* Zone to the *Proteacidites asperopolus* Zone (corresponding to a time range from the late Paleocene to the early Eocene); and becomes more common in the early Eocene *Malvacipollis diversus* Zone (Stover & Partridge, 1973; Partridge *et al.*, 2006). At the Gippsland Basin, the top of the *P. asperopolus* Zone (early Eocene) is delimited by the essentially contemporaneous termination of both *Intratrirporopollenites notabilis* (*i.e.*, *B. isoreticulatus* following Contreras *et al.*, 2013) and *M. diversus* (Stover & Partridge, 1973, p. 241). Following Stover & Partridge (1973), the Gippsland Basin spore–pollen zonation is most applicable in dominantly continental to marginal marine sections, thus may also be applicable for the present work. *Malvacipollis diversus* is assigned to the Picrodendraceae (Grímsson *et al.*, 2019), a family which has an almost worldwide Paleocene–Eocene pollen record (Australia, New Zealand, Europe, and North America). There is not a single fossil record of Picrodendraceae from Africa and India (Grímsson *et al.*, 2019 and references therein). Within South America, *M. diversus* was previously mentioned for Patagonia in the Laguna

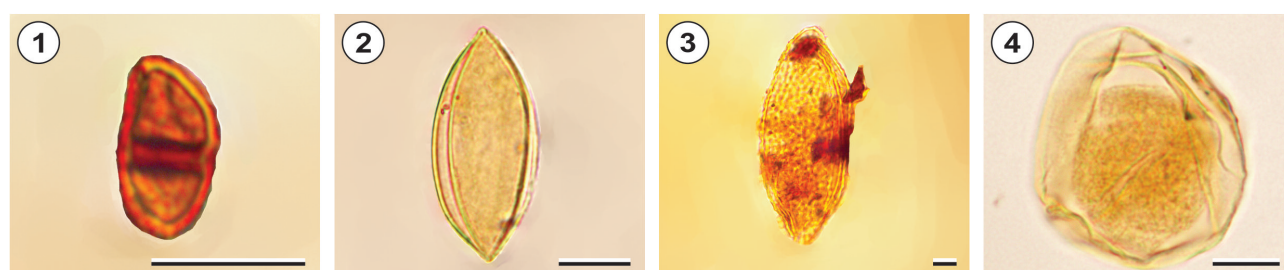


Figure 5. Selected palynomorphs from LMS (see also Table 1). **1**, *Dyadosporites subovalis* (Sheffy & Dilcher) Kalgutkar & Jansonius, 2000 (Slide 5215a; F51/4); **2**, Zygnemataceae spore type 1 (Slide 5216b; W 66/3); **3**, Zygnemataceae spore type 2 (Slide 5212c; H53/4); **4**, Freshwater dinoflagellate cyst (Slide 6389b; G58/2). Scale bar= 10 µm.

TABLE 1 – Distribution of palynomorphs in the Laguna Manantiales Strata, ELM section, southern Golfo San Jorge Basin, Argentina.

Fossil Taxon	Botanical affinity	Slide	6389	5212/ 6390	5213/ 6391	5214	5215	5216	5217	5218	5219	5220	5221
		Samples	ELM-0	ELM-1	ELM-1A	ELM-4	ELM-5	ELM-6	ELM-8	ELM-9	ELM-10	ELM-11	ELM-12
Bryophyte/Pteridophyte													
<i>Biretisporites crassilabratius</i> Archangelsky, 1972	Schizaeaceae			X									
<i>Cingutrilletes australis</i> (Cookson) Archangelsky, 1972	Sphagnaceae				X								
<i>Deltoidospora australis</i> (Couper) Pocock, 1970	Polypodiaceae												X
<i>Deltoidospora minor</i> (Couper) Pocock, 1970	Polypodiaceae												X
<i>Ischyosporites areapunctatis</i> (Stuchlik) Barreda, 1996	Dicksoniaceae			X									
<i>Retitrlletes austroclavatidites</i> (Cookson) Döring <i>et al.</i> , 1963	Lycopodiaceae						X						
Gymnosperm pollen													
<i>Dacrycarpites australiensis</i> Cookson & Pike, 1953	Podocarpaceae						X		X				X
<i>Dacrydiumites praecupressinoides</i> (Couper) Truswell, 1983	Podocarpaceae (<i>Dacrydium</i> group B, <i>Dacrydium cupressinum</i>)						X		X				
<i>Microcachrydites antarcticus</i> Cookson, 1947	Podocarpaceae (<i>Microcachrys tetragona</i>)												X
<i>Podocarpidites elegans</i> Romero, 1977	Podocarpaceae									X			
<i>Podocarpidites manwickii</i> Couper, 1953	Podocarpaceae		X	X	X			X	X	X	X	X	X
Angiosperm pollen													
<i>Albipollenites anguloluminosus</i> (Anderson) Archangelsky, 1973	Unknown				X								
<i>Arecipites (Manosulcites) waitakiensis</i> (McIntery) Mildenhall & Pocknall, 1989	Arecaceae												X
?Arecaceae	?Arecaceae												X
<i>Bombacacidites isoreticulatus</i> McIntyre, 1965	Malvaceae, Bombacoideae (<i>Ceiba</i>)												X
<i>Chenopodipollis</i> spp.	Chenopodiaceae		X	X									
<i>Clavatiipollenites hughesii</i> Couper, 1958	Chloranthaceae (? <i>Ascarina</i>)						X						
<i>Cricotriporites guianensis</i> Leidelmeyer, 1966	Gentianales, Apocynaceae (<i>Mandevilla angustifolia</i>)						X		X				X
<i>Favritricolporites australis</i> Archangelsky, 1973	Unknown										X		
<i>Huanipollis cabrerarae</i> Barreda & Palazzesi (in Barreda <i>et al.</i> , 2008)	Asteraceae, Mutisioideae, Nassauviaceae (<i>Holochilus</i> , <i>Jungia</i> , <i>Proustia</i>)							X					
<i>Huanipollis crisci</i> Barreda & Palazzesi (in Barreda <i>et al.</i> , 2008)	Asteraceae, Mutisioideae, Nassauviaceae (<i>Triplilion</i>)										X		

TABLE 1 – Continuation.

Fossil Taxon	Botanical affinity	Slide Samples	5212/ 6390 ELM-1	5213/ 6391 ELM-1A	5214 ELM-4	5215 ELM-5	5216 ELM-6	5217 ELM-8	5218 ELM-9	5219 ELM-10	5220 ELM-11	5221 ELM-12
<i>Liliacidites regularis</i> Archangelsky, 1973	Areaceae								X			X
<i>Liliacidites vermiculatus</i> Archangelsky & Zamaloa, 1986	Areaceae		X									
<i>Malvacipollis diversus</i> Harris, 1965	Picodendraceae			X			X		X		X	X
<i>Myricipites harrisi</i> (Couper) Dutta & Sah, 1970	Casuarinaceae/Myricaceae		X					X				
<i>Mutisiapollis</i> sp.	Asteraceae, Mutisioidaeae, Mutisieae		X									
<i>Nothofagidites rocaensis</i> Romero, 1973	Nothofagaceae		X			X						
<i>Polyporina romerai</i> Archangelsky, 1973	Unknown									X		
<i>Proteacidites</i> spp.	Proteaceae							X	X			
<i>Retricolporites chubutensis</i> Archangelsky, 1973	Rutaceae		X									
<i>Retricolporites</i> sp.	Unknown											X
<i>Rhoipites baculatus</i> Archangelsky, 1973	Rutaceae		X								X	
<i>Rousea microreticulata</i> Archangelsky & Zamaloa, 1986	Unknown		X									
<i>Spinizonocolpites</i> sp.	Areaceae (<i>Nypa</i>)										X	
<i>Symplocolpitenites australis</i> Partridge (in Stover & Partridge, 1973)	Symplocaceae (<i>Symplocos</i>)											X
<i>Syncolporites</i> sp.	Fabaceae-Caesalpinioideae (<i>Senna pendula</i>)		X									
<i>Tricolporites valvatus</i> Harris, 1972	Unknown					X						X
Fungi												
<i>Dyadosporites subovalis</i> (Sheffy & Dilcher) Kalgutkar & Jansonius, 2000	Hyphomycete					X						
Indeterminate fungal spore												
Algae												
Zygnemataceae												
Zygnemataceae spore type 1			X	X			X		X			
Zygnemataceae spore type 2			X								X	X
Dinoflagellate cysts												
Freshwater dinoflagellate cysts			X	X								
?Acritarch										X		
Copepod eggs												
Type 388 Hoomistra, 1984	Unknown		X									

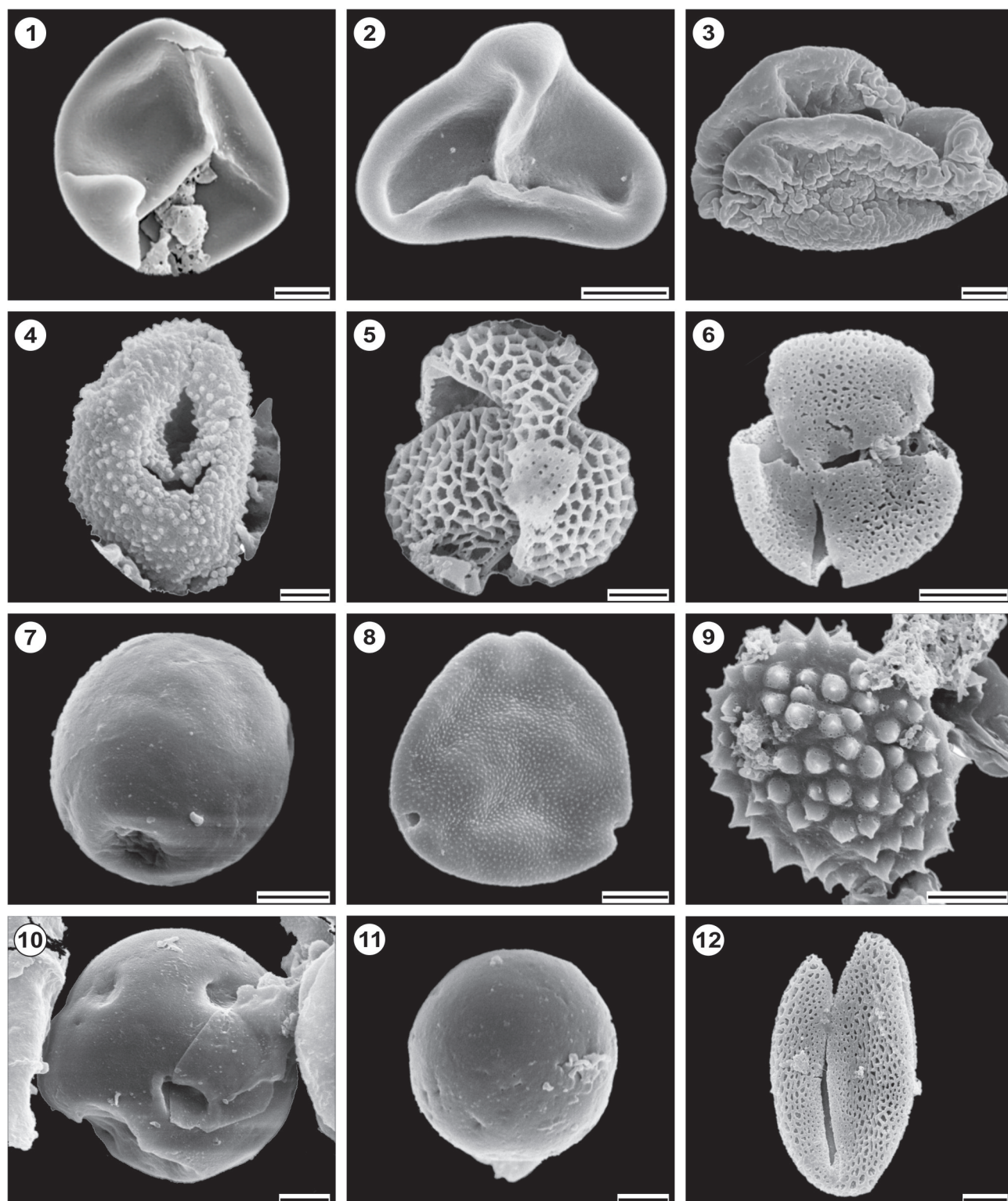


Figure 6. Scanning electron microscopy (SEM) of selected palynomorphs from LMS (see also Tab. 1). **1**, *Deltoidospora australis* (Couper) Pocock, 1970 (Sample ELM-12), scale bar= 5 μ m; **2**, *Biretisporites crassilabratu*s Archangelsky, 1972 (Sample ELM-12), scale bar= 5 μ m; **3**, *Dacrycarpites australiensis* Cookson & Pike, 1953 (Sample ELM-12), scale bar= 5 μ m; **4**, ?Arecaceae (Sample ELM-12), scale bar= 2 μ m; **5**, *Albertipollenites anguloluminosus* (Anderson) Archangelsky, 1973 (Sample ELM-12), scale bar= 5 μ m; **6**, *Retitricolporites* sp. (Sample ELM-12), scale bar= 5 μ m; **7**, *Cricotriporites guianensis* LeideImeyer, 1966 (Sample ELM-12), scale bar= 5 μ m; **8**, *Myricipites harrisii* (Couper) Dutta & Sah, 1970 (Sample ELM-12), scale bar= 5 μ m; **9**, *Malvacipollis diversus* Harris, 1965 (Sample ELM-12), scale bar= 5 μ m; **10**, *Polyporina romeroi* Archangelsky, 1973 (Sample ELM-12), scale bar= 5 μ m; **11**, Fungal spore (Sample ELM-12), scale bar= 2 μ m; **12**, Zygnemataceae spore type 2 (Sample ELM-12), scale bar= 5 μ m.

Manantiales area (Zamaloa & Andreis, 1995) and the late Paleocene–early Eocene Ligorio Márquez Formation, Patagonian Chile (Yabe *et al.*, 2006; Carvajal, 2013; Encinas *et al.*, 2019). *Mutisiapollis* sp. (Asteraceae, Mutisioideae; Fig. 4.17). The genus was recorded for the late Paleocene–early Eocene Ligorio Márquez Formation at the Argentinean Río Zeballos locality (Tab. 2) by Macphail *et al.* (2013) but proper descriptions are still needed (Tellería *et al.*, 2023).

Podocarpaceae are very common in the ELM palynofloras, with *Dacrycarpites australiensis*, *Dacrydiumites praecupressinoides*, *Microcachryidites antarcticus* Cookson, 1947, *Podocarpidites elegans* Romero, 1977 (Fig. 4.3–4), and *Podocarpidites marwickii* Couper, 1953 (Fig. 4.5).

Retitricolporites chubutensis Archangelsky, 1973 (Rutaceae). This Patagonian species is known from the Maastrichtian to the Oligocene (Melendi *et al.*, 2003 and references therein).

This is the first mention of *Syncolporites* sp. (*Senna pendula* (Willd.) Irwin & Barneby, 1982) (Fabaceae–Caesalpinioideae). This is an isolated pollen grain, isopolar, angulaperturate, syncolporate, with straight colpi, small apocolpium and a wide vestibulum. The amb is triangular, with convex sides. The exine is scabrate. Measurements are: sexine (columella and tectum): 1 µm; nexine: 0.5 µm; equatorial diameter: 31 µm (one specimen). The pollen grains of *Senna pendula* are described in Ybert *et al.* (2017, p. 59). We include this specimen in *Syncolporites* because it has the diagnostic characters of the morphogenus: “pollen syncolporate (tricolporate with the colpi united in the polar regions)” (Jansonius *et al.*, 2002, p. 5511).

Symplocoipollenites austellus Partridge (in Stover & Partridge, 1973) (Symplocaceae; Fig. 4.16). This species was defined for the Late Miocene Gippsland Basin of southwestern Australia (Stover & Partridge, 1973). Baldoni & Askin (1993) mentioned *Symplocoipollentias* sp. cf. *S. austellus* in the Maastrichtian Lefipan Formation, Chubut Province, Argentina.

Tricolporites valvatus Harris, 1972 is known for the Eocene Huitrera Formation (Melendi *et al.*, 2003).

Other long ranging gondwanic species such as *Cingutritetes australis* (Cookson) Archangelsky, 1972 (Sphagnaceae), *Myricipites harrisii* (Couper) Dutta & Sah, 1970 (Casuarinaceae–Myricaceae; Figs. 4.21, 6.8),

Retitritetes austroclavatidites (Cookson) Döring *et al.*, 1963 (Lycopodiaceae) and *Rhoipites baculatus* Archangelsky, 1973 (Rutaceae; Fig. 4.14) are also present.

RESULTS AND DISCUSSION

The palynological association here recognized for the LMS is comparable to those identified in other Paleogene Patagonian units, like the Cerro Bororó, Huitrera, La Marcelina, Ligorio Márquez, Río Turbio, and Salamanca formations and to those recorded in the Gippsland Basin in southeastern Australia. The complete list of shared taxa can be found in Table 2, the similarity matrix (Jaccard similarity index) in Table 3, and the dendrogram generated by the cluster analysis in Figure 7. In the following paragraphs, the shared taxa (ST) and the similarity values (SV) after the Jaccard index estimation are indicated.

About Asteraceae: the novelty of the pollen records of *Huanilipollis cabreræ*, *H. crisci*, and *Mutisiapollis* sp. for the LMS in the present contribution corresponds to the oldest evidence confirming the early Paleogene development of the Mutisioideae in Patagonia.

At present times, three Asteraceae clades included in the Mutisioideae (Mutisieae, Nassauvieae, and Onoserideae) are distributed in South America and some Mutisieae are distributed in southern Africa (Tellería *et al.*, 2023). *Huanilipollis* may find affinities with Nassauvieae; meanwhile, *Mutisiapollis* finds affinities with Mutisieae (Tab. 1). The pronounced climatic warming during the late Paleocene toward the Early Eocene Climatic Optimum seems to have been an important influence on the diversification of the Asteraceae (Barreda *et al.*, 2015; Tellería *et al.*, 2023).

The Huitrera Formation (Río Pichileufú flora, middle Eocene, 47.74 ± 0.05 My; Wilf, 2012) is known for the oldest macrofossil of Asteraceae, based on an outstandingly preserved capitulescence that could represent the ancestor of Mutisioideae–Carduoideae and the associated pollen *Mutisiapollis telleriae* (Barreda *et al.*, 2012).

Previous Paleocene–Eocene record of Asteraceae includes fossil species that were assigned to Mutisioideae (*Mutisiapollis telleriae* and *Huanilipollis cabreræ*) (Tellería *et al.*, 2023) and Dicomeae (“*Tubulifloridites viteauensis*” *sensu* Zavada & de Villiers, 2000) from the Eocene from of South Africa (Zavada & de Villiers, 2000; Scott *et al.*, 2006).

TABLE 2 – Taxa identified and their distribution in the main basins of Patagonia.

Age	Danian	late Paleocene–early Eocene	early Eocene	early–middle Eocene	middle to late Eocene	Eocene
Formation	Salamanca (Archangelsky, 1973; Clyde <i>et al.</i> , 2014)	Cerro Bororó (Archangelsky, 973)	Ligorio Márquez (Carvajal, 2013)	Ligorio Márquez (Macphail <i>et al.</i> , 2013)	Gippsland Basin, Australia (Stover & Partridge, 1973)	Huitrera (Barreda <i>et al.</i> , 2020) LH
						Huitrera (Melendi <i>et al.</i> , 2003) PJ/NHE
						Laguna Manantiales Strata (Zamaloa & Andreis, 1995)
						Huitrera (Melendi <i>et al.</i> , 2003) CON
						Río Turbio (Archangelsky, 1972; Romero, 1977; Romero & Zamaloa, 1985; Fernández, 2018)
						La Marcelina (Noetinger <i>et al.</i> , 2023)
Taxon						
<i>Biretisporites crassilabratius</i>			X			X
<i>Cingutrietes australis</i>	X		X			X
<i>Deltoidospora australis</i>					X	cf.
<i>Deltoidospora minor</i>	X		X			X
<i>Ischyosporites areapunctatis</i>	X			X		X
<i>Retrietes austroclavatioides</i>	X				X	X
<i>Dacrycarpites australiensis</i>	X		X			X
<i>Dacrydiumites praecupressinoides</i>	X		X		X	X
<i>Microcachrydites antarcticus</i>	X		X		X	X
<i>Podocarpidioides elegans</i>	X				X	X
<i>Podocarpidioides marwickii</i>	X		X		X	X
<i>Albertipollenites anguloluminosus</i>	X		X		X	X
<i>Arecipites (Monosulcites) waitakiensis</i> ³					X	X
?Arecaceae						
<i>Bombacacidites isoreticulatus</i>			cf.		X	X
<i>Chenopodipollis</i> spp. ³				cf.		
<i>Clavatipollenites hughesii</i>						
<i>Cricotriporites zgulanensis</i> ²					X	
<i>Favritricolporites australis</i>	X		cf.			X
<i>Huanillipollis cabreræ</i> ⁴						
<i>Huanillipollis crisc[†]</i>					X	
<i>Liliacidites regularis</i>	X			cf.		X
<i>Liliacidites vermiculatus</i>	X		X			X
<i>Malvacipollis diversus</i>	X				X	X
<i>Myricipites harrisi</i>	X					X
<i>Mutisiapollis</i> sp.				X		
<i>Nothofagidites rocaensis</i>						X
<i>Nothofagidites fusca</i> group	X		X		X	X

TABLE 2 – Continuation.

Age	Danian	late Paleocene–early Eocene	early Eocene	early–middle Eocene	middle to late Eocene	Eocene
Formation	Salamanca (Archangelsky, 1973; Clyde <i>et al.</i> , 2014)	Cerro Bororó (Archangelsky, 973)	Ligorio Márquez (Carvajal, 2013)	Ligorio Márquez (Macphail <i>et al.</i> , 2013)	Gippsland Basin, Australia (Stover & Partridge, 1973)	Huitrera (Barreda <i>et al.</i> , 2020) LH
						Huitrera (Melendi <i>et al.</i> , 2003) PJ/NHE
						Huitrera (Melendi <i>et al.</i> , 2003) P/NHE
						Laguna Manantiales Strata (Zamaloa & Andreis, 1995)
						Huitrera (Melendi <i>et al.</i> , 2003) CON
						Río Turbio (Archangelsky, 1972; Romero, 1977; Romero & Zamaloa, 1985; Fernández, 2018)
						La Marcelina (Noetinger <i>et al.</i> , 2023)
Taxon						
<i>Polyporina romeroi</i>	X	X	cf. X	X	X	X
Proteaceae	X	X	X	X	X	X
<i>Retitricolporites chubutensis</i>	X	X	X	X	X	X
<i>Retitricolporites</i> sp.				X	X	
<i>Rhoipites baculatus</i>	X	X	cf. X	X	X	X
<i>Rousea microreticulata</i>	X	X	cf. X	X	X	X
<i>Spinizonocolpites</i> sp.						
<i>Symplocolpitenites austellus</i> *						
<i>Syncolporites</i> sp.*					X	
<i>Tricolporites valvatus</i>						

Abbreviations: LH, Laguna del Hunco; PJ, Pampa de Jones; NHE, Nahuel Huapi Este; CON, Confluencia. Comparable taxa are indicated with cf. *Indicates first mention. References: ¹Askin (1994); ²Quattrocchio & del Papa (2000); ³With previous Danian records (e.g., Ruiz & Quattrocchio, 1997); ⁴Earlier register.

The comparison of the present palynoflora with the late Paleocene–early Eocene Ligorio Márquez Formation from Patagonia at the Argentinean Río Zeballos locality (Macphail *et al.*, 2013) and at the Chilean Ligorio Márquez Mine site (Carvajal, 2013) revealed a quite similar palynological association, with SC: 18 and SV: 0.47.

With the Danian Salamanca Formation, there are several species in common (Archangelsky, 1973; Clyde *et al.*, 2014) with SC: 18 and SV: 0.47; however, the Eocene species present in the LMS analyzed section have not been recorded in the Danian unit (e.g., Asteraceae, *Bombacacidites isoreticulatus*, *Cricotriporites guianensis*, and *Malvacipollis diversus*).

The Río Turbio Formation (Archangelsky, 1972; Romero, 1977; Romero & Zamaloa, 1985; Fernández, 2018) is very similar to the LMS studied section, with SC: 17 and SV: 0.44. No species of Asteraceae are recorded in the Río Turbio Formation.

Compared to the Eocene La Marcelina Formation that crops out in the Deseado Massif, Santa Cruz Province, Argentina (Noetinger *et al.*, 2023), LMS is quite similar, with SC: 15 and SV: 0.39. Nevertheless, the absence of three taxa present in LMS stand out: *Bombacacidites isoreticulatus*, *Malvacipollis diversus*, and *Cricotriporites guianensis*.

The early Eocene Laguna del Hunco (LH) fossil site, northwestern Chubut Province, Argentina (42° 27'2.6" S; 70° 2' 45.95" W) holds one of the best preserved and most diverse paleofloras worldwide (early Eocene: 52.22±0.22 My; Wilf, 2012). Among other Eocene Patagonian palynofloras, the assemblage is similar to that of LH, Pampa de Jones (PJ)/Nahuel Huapi Este (NHE) and Confluencia (CON). All these localities belong to the Huitrera Formation, with ages ranging from ca. 54.2 My (PJ) and 52.2 My (LH) to middle Eocene or younger (Barreda *et al.*, 2020). Several species of LH are registered in LMS (SC: 13; SV: 0.34) and the presence of *Huanilipollis cabreræ*

TABLE 3 – Similarity matrix (Jaccard similarity index) showing the similarity measures between the palynological assemblage of the Laguna Manantiales strata (this study) and those of selected formations from the Paleogene.

	A	B	C	D	E	F	G	H	I	J	K
A	1										
B	0.211	1									
C	0.474	0.182	1								
D	0.105	0	0.222	1							
E	0.342	0.235	0.348	0.133	1						
F	0.289	0.357	0.381	0.071	0.333	1					
G	0.316	0.111	0.364	0.333	0.471	0.353	1				
H	0.342	0.313	0.348	0.063	0.529	0.6	0.389	1			
I	0.447	0.190	0.458	0.105	0.5	0.4	0.45	0.429	1		
J	0.395	0.278	0.435	0.056	0.4	0.444	0.35	0.4	0.6	1	
K	0.474	0.368	0.5	0.1	0.348	0.45	0.364	0.476	0.522	0.571	1

Abbreviations: A, Laguna Manantiales Strata (this study); B, Cerro Bororó Fm.; C, Ligorio Márquez Fm.; D, Gippsland Basin; E, Huitrera Fm. (Laguna del Hunco); F, Huitrera Fm. (Pampa de Jones/Nahuel Huapi Este); G, Laguna Manantiales Strata (Zamaloa & Andreis, 1995); H, Huitrera Fm. (Confluencia); I, Río Turbio Fm.; J, La Marcelina Fm.; K, Salamanca Fm.

stands out. For LMS, the absence of pollen grains of Myrtaceae (*Myrtaceidites* sp.) and Ulmaceae (*Ulmoideipites patagonicus* Archangelsky, 1973), among other families, stands out.

Zamaloa & Andreis (1995) only studied the palynological record of a single rich level that may be close stratigraphically to the here named ELM-11 to ELM-12 and assigned to the Salamanca Formation (see Fig. 3). Barreda & Palazzesi (2007) included the Zamaloa & Andreis (1995) palynological assemblage, with high frequencies of megathermal taxa (Juglandaceae, Tiliaceae-Bombacaceae, Chloranthaceae, and Araceae) within the early–middle Eocene. As the present work is carried out in the framework of a palynofacial study, all lithologies were sampled. We only recorded the Asteraceae family at the two lowermost levels (ELM-0 and ELM-1; see Fig. 3). The palynological association studied is very similar to that of Zamaloa & Andreis (1995), in this paper considered the top of LMS, with SC: 12 and SV: 0.31, emphasizing the absence of Asteraceae taxa.

The presence of *Nothofagidites rocaensis* (Fig. 4.11) is recorded from the Late Cretaceous (Ruiz *et al.*, 1999). For the Eocene Huitrera Formation in northern Patagonia, Melendi *et al.* (2003) recorded early Eocene microfloras ($^{40}\text{Ar}/^{39}\text{Ar}$ age of 54.24 ± 0.45 My; Wilf *et al.*, 2010) without *Nothofagidites* at the PJ/NHE locality (SC: 11; SV: 0.28) and other middle to late Eocene microfloras with notable presence of *Nothofagidites* ('*brassii*' and '*fusca*' groups) at the Confluencia locality (SC: 13; SV: 0.34) (Quattrocchio *et al.*, 2011). Both localities are near each other (less than 40 km apart), indicating that differences in *Nothofagus* abundances are due to rapid climate and/or landscape changes during the Eocene (Wilf *et al.*, 2010). Comparing LMS with the early Eocene Huitrera Formation (PJ/NHE) and with the middle to late Eocene Huitrera Formation (CON), all assemblages share long ranging species (*e.g.*, *Deltoidospora minor* and *Dacrycarpites australiensis*) and few angiosperm species (*e.g.*, *Favritcolporites australis* and *Tricolporites valvatus*).

Compared with the Gippsland Basin in southeastern Australia (Stover & Partridge, 1973; Partridge *et al.*, 2006), the SC: 4 and SV: 0.10 are highlighted (Tab. 2), along with the presence of two taxa with a well-defined age range: *Bombacacidites isoreticulatus* and *Malvacipollis diversus*.

CONCLUSIONS

The presence of freshwater algae spores (Zygnemataceae) characterizes almost all the analyzed section (Tab. 1). In ELM-1 the Zygnemataceae are associated with thin-walled freshwater dinoflagellate cysts.

The sporomorph record provides evidence that subtropical forests thrived in the surrounding areas, based on plant taxa now restricted to these environments.

Most palynomorphs recovered here can provide only a broad guide to the age of the fossil-bearing deposits, as they have long stratigraphic distributions. However, there are some species with restricted biochron (*e.g.*, *Bombacacidites isoreticulatus*, *Cricotriporites guianensis*, and *Malvacipollis diversus*).

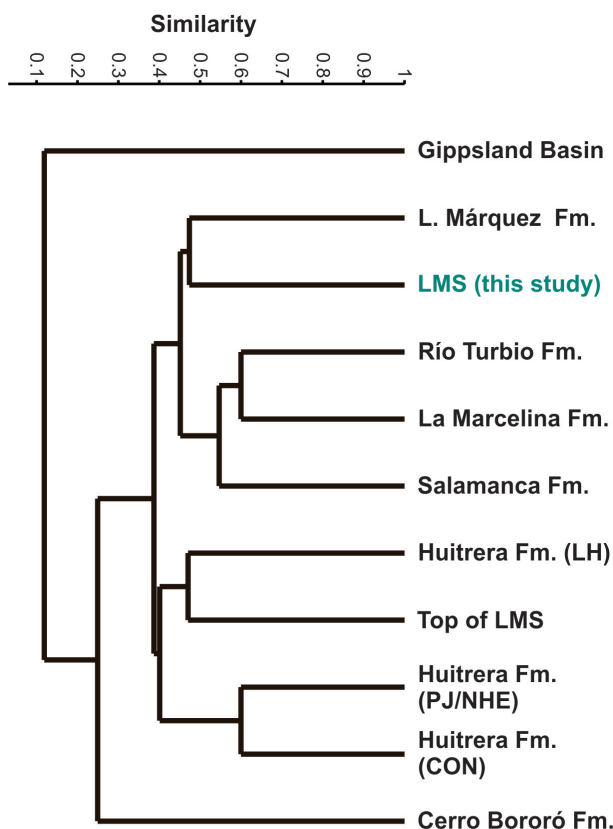
Regarding the Asteraceae, the presence in this work of *Huanilipollis cabreræ*, *H. crisci*, and *Mutisiapollis* sp. confirms the early Paleogene development of the Mutisioideae in the early Paleogene of Patagonia. The new stratigraphic range of *Huanilipollis cabreræ* is late Paleocene–early Eocene to Miocene. The presence of *Huanilipollis crisci* constitutes the earliest record of this species.

The syncolporate pollen grains of the modern taxon *Senna pendula* are mentioned for the first time for Argentina.

From the comparison of the present palynoflora with the Ligorio Márquez Formation (late Paleocene–early Eocene) Patagonia, Argentina–Chile (Carvajal, 2013; Macphail *et al.*, 2013), both yielded a quite similar palynological association.

Several species of Laguna del Hunco (early Eocene) are registered in LMS and the presence of *Huanilipollis cabreræ* stands out.

Due to the presence of late Paleocene–early Eocene marker species (*i.e.*, *Bombacacidites isoreticulatus*, *Cricotriporites guianensis*, and *Malvacipollis diversus*) and the similarity in pollen grains composition with the Ligorio Márquez Formation and Laguna del Hunco flora (Huitrera Formation), the proposed age for LMS can be well constrained between



Cophenetic correlation coefficient: 0.8968

Figure 7. Dendrogram generated by Jaccard similarity index unweighted pair group method cluster analysis showing the comparison between the palynological assemblage of the LMS (this study) and those of selected formations from the Paleogene. Abbreviations: L. Márquez, Ligorio Márquez Formation; LMS, Laguna Manantiales Strata; LH, Laguna del Hunco; Top of LMS, Zamaloa & Andreis (1995); PJ, Pampa de Jones; NHE, Nahuel Huapi Este; CON, Confluencia.

the late Paleocene and the early Eocene.

The Zamaloa & Andreis (1995) palynological level is correlated here with the ELM-11 and ELM-12 levels of the upper section of the LMS.

The LMS presents both a singular palynological signature and certain sedimentological characterization that allows us to consider it as a new continental stratigraphic unit for the Golfo San Jorge Basin, stratigraphically positioned between the Danian Salamanca Formation and the early–middle Eocene Las Flores Formation. Further radiometric data and other paleontological records would help to constrain the age here proposed for this sedimentological package of such important climatological and biological Paleocene–Eocene transition.

ACKNOWLEDGEMENTS

Financial and logistical support for these studies was provided by the projects PIP 100523 and 00391 of the CONICET, the PI+D N890 of the UNLP (to MSR), and the project 24/H156 of the Secretaría de Ciencia y Tecnología of the UNS (Director: Dr. Marcelo A. Martínez). The authors would like to thank Lic. Pablo Díaz for valuable help at all stages of preparation of the palynological samples, Lucía Gómez Peral, Leandro Martín Pérez, Mariana Brea, Caroline Strömberg and Georgina Erra for assistance during fieldwork, and Mauricio Ibañez for up to now unpublished age analysis. Special thanks to Dr. Luis Palazzesi and Dr. Lilia Mautino for assisting with pollen grains identifications: Asteraceae (LP) and Fabaceae-Caesalpinioideae (LM). Finally, thanks to the Secretaría de Cultura from the Santa Cruz Province and Laguna Manantiales Ranch owners for permitting access to the outcrops. The author would like to thank the anonymous reviewers for their careful reading of the manuscript and their many insightful comments and suggestions, which significantly improved this paper.

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doi: 10.5710/PEAPA.29.12.2023.491

Recibido: 25 de octubre 2023

Aceptado: 29 de diciembre 2023

Publicado: 10 de abril 2024



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