

BRACKISH TO FRESHWATER DINOFLAGELLATE CYST ASSEMBLAGES FROM THE LA COLONIA FORMATION (PALEOCENE?), NORTHEASTERN PATAGONIA, ARGENTINA



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Abstract. A palynological analysis of the section of La Colonia Formation exposed at Estancia San Miguel yielded conspicuous assemblages of organic-walled dinoflagellate cysts (dinocysts) and green algae. The monotypic palaeoperidinioid dinocyst assemblage of *?Gingiodinium* sp. in the basal beds of this section indicates low-salinity water conditions in a restricted shallow marine paleoenvironment. The green-algae-dominated assemblages together with specimens of *?Morkallacysta* spp., Dinocysts type P and *?Vesperopsis* sp. recorded in the middle and upper part of the San Miguel section indicate brackish to freshwater and freshwater depositional conditions, respectively. The changes in the composition of the palynological assemblages, in agreement with the analysis of the sedimentary facies, reflect a salinity-drop in the water bodies and a progressive upward-shallowing trend. The occurrence of specimens of the neritic open marine *Cribroperidinium* spp., *Apteodinium* sp., *Circulodinium* sp. and *Areoligera* sp. cf. *A. circumseonensis* Fensome *et al.* is here considered as reflecting contemporaneous transported material from the adjacent shelf. The marine part of the La Colonia Formation is associated to Late Cretaceous and Paleocene ages. Nevertheless, palynomorphs together with a stratigraphical criterion suggest an age non older than Paleocene for the deposits of the unit at the San Miguel section.

Keywords. Dinocysts. Green algae. Paleosalinity. Paleocene? Patagonia.

Resumen. ASOCIACIONES DE QUISTES DE DINOFLAGELADOS DE AGUA SALOBRE A DULCE DE LA FORMACION LA COLONIA (PALEOCENO?), NORESTE DE PATAGONIA, ARGENTINA. El análisis palinológico de la Formación La Colonia en la sección aflorante en la Estancia San Miguel proporcionó conspicuas asociaciones de quistes de dinoflagelados (dinoquistes) de pared orgánica y algas verdes. La presencia de una asociación monotípica de dinoquistes palaeoperidinioides de *?Gingiodinium* sp. en los niveles basales de la sección, indica condiciones de baja salinidad del agua, en un paleoambiente marino somero restringido. Asociaciones dominadas por algas verdes junto a especímenes de *?Morkallacysta* spp., Dinocysts type P y *?Vesperopsis* sp. registrados en la parte media y superior de la sección de San Miguel, indican condiciones depositacionales de agua salobre a dulce y dulce, respectivamente. Los cambios en la composición de las asociaciones palinológicas, en concordancia con el análisis de las facies sedimentarias, reflejan una reducción en la salinidad de los cuerpos de agua así como una progresiva continentalización de los ambientes desde la base hacia el techo de la sección. La presencia de especímenes neríticos de mar abierto de *Cribroperidinium* spp., *Apteodinium* sp., *Circulodinium* sp. y *Areoligera* sp. cf. *A. circumseonensis* Fensome *et al.* es aquí interpretado como el reflejo de material contemporáneo, transportado desde la plataforma adyacente. La parte marina de la Formación La Colonia está asociada a edades del Cretácico Tardío y Paleógeno temprano. No obstante, los palinomorfos y criterios estratigráficos sugieren una edad no más antigua que Paleoceno para los depósitos de la unidad en la sección de San Miguel.

Palabras clave. Dinoquistes. Algas verdes. Paleosalinidad. Paleoceno? Patagonia.

DURING the Late Cretaceous–early Paleocene the Atlantic Ocean flooded extensive areas of southern South America (Uliana and Biddle, 1988; Riccardi, 1988; Franzese *et al.*, 2003). These epicontinental seas covered wide areas of northern and central Patagonia (*e.g.*, Nañez and Malumián, 2008) and involved the accumulation of shallow marine deposits. In the northeastern part of Chubut Province these deposits are re-

ferred to the La Colonia Formation. This unit yielded a very rich fossil fauna composed by both continental and marine fossils: mammals, birds, marine and freshwater fish (Pascual *et al.*, 2000), turtles and plesiosaurs (Gasparini and de la Fuente, 2000; Gasparini *et al.*, 2001), which are indicative of the coastal nature of the depositional environments for the La Colonia Formation. Low diversity foraminifera assemblages

–documented by Nañez and Malumián (2008) in the Maastriachian at Bajada Moreno (Northern Patagonia) including deposits of the La Colonia Formation– reflected marginal shallow marine settings.

Studies of the megafloora and palynological records from the La Colonia Formation have been previously published by Archangelsky *et al.* (1999), Archangelsky and Zamaloa (2003), Gandolfo and Cúneo (2005) and Cúneo *et al.* 2013. The main objective of this contribution is to describe for the first time well-preserved brackish to freshwater dinocyst and algae assemblages from the La Colonia Formation exposed at the San Miguel section. These assemblages characterize low-salinity water bodies developed in a low-energy tidal flat environment (Navarro, 2012). Records of brackish and freshwater dinoflagellate cysts are not abundant and, in general, diversity of the assemblages is low whether in ancient or in modern sediments. Certainly, *?Morkallacysta* spp., *?Morkallacysta* sp., Dinocysts type P and *?Vesperopsis* sp. recovered from these strata are one of the very few records from not fully marine pre-Quaternary deposits in Argentina. One specimen of *?Morkallacysta* sp. (as *Peridinium* sp. aff. *P. limbatum* Lemmerman 1899) was recovered in a Danian lacustrine deposit of Patagonia (Scafati *et al.*, 2009) and Prámparo *et al.* (2006; 2008) recorded Late Cretaceous algae assemblages and peridinioid dinoflagellate cysts in deposits from southern Mendoza Province. The assemblages presented herein offer an excellent tool for paleoenvironmental reconstructions in these ?Paleocene nearshore settings exposed in the Telsen area.

GEOLOGICAL SETTING

The palynological assemblages discussed herein were collected in exposures of the La Colonia Formation in the Telsen area, eastern sector of the Cañadón Asfalto Basin, northeastern

Chubut Province (Fig. 1). The La Colonia Formation overlies in sharp contact the fluvial deposits of the Albian Chubut Group (Navarro and Astini, 2012). Oligocene volcanic bedrocks of the Somuncura Complex (22 Ma; Ardolino and Franchi, 1996) unconformably overlie the La Colonia beds. This stratigraphic succession is extensively exposed in the Telsen area, except towards the north (Cañadón Williams), where the La Colonia deposits are eroded and lie in a low-angle unconformity (Navarro, 2012). The unit was originally described as including a lower continental and a upper marine part (Ardolino and Franchi, 1996). In any event, continental beds of the La Colonia Formation are not exposed in the Telsen area (see Navarro *et al.*, 2012). From a lithologic point of view, the marine deposits of the unit predominantly consist of gray-greenish claystone, with gypsum filling post-depositional cracks, and a veneer conglomerate interpreted as a ravinement surface (Navarro *et al.*, 2008) marking the base. This formation becomes thicker (up to approximately 205 m thick) to the west and to the south. In the Telsen area it never attains a thickness of more than 25 m. The lower part of the La Colonia Formation was described in the vicinity of Telsen and the Bola Morley Hills (Fig. 1). It is characterized by a basal transgressive conglomerate, followed by shoreface to offshore deposits. These deposits include fine sandstones facies with convolute structures overlain by strongly bioturbated siltstone deposits and laminated facies, with alternating hummocky cross-stratified sandstones associated with storm episodes (Navarro *et al.*, 2012). The palynological assemblages herein studied come from Estancia San Miguel, 30 km south of Telsen (Fig. 1). At this locality, the fine-grained lithologies would represent the upper part of the La Colonia Formation (Navarro, 2012). Two well-defined intervals characterize an intertidal-flat zone interpreted for the middle part of the San Miguel section; the lower one, associated with a cyclic coarsening upward pattern –mudstones to fine sandstones– represented by heterolithic facies (flaser, lenticular and wavy lamination) would correspond to a mixed flat (Fig. 2). In turn, the upper interval exhibits banded muddy rhythmites and laminated mudstones, represented by fine heterolithic facies, bioturbated, related to a mud flat (Fig. 2). Toward the uppermost part of the section, the deposits consist of facies with a very fine massive texture –predominantly claystones– probably originated by decantation processes in the water column linked to a supratidal environment (Navarro *et al.*, 2012).

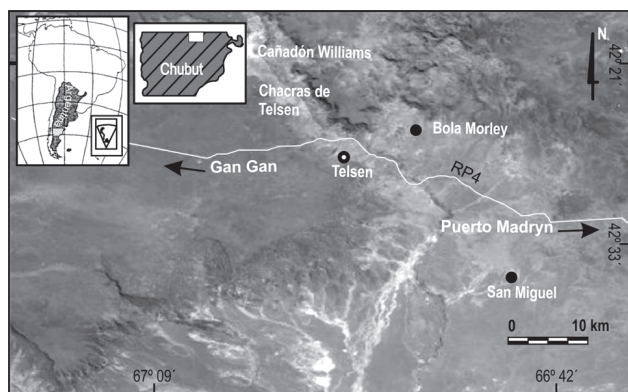


Figure 1. Location map of the Telsen area, Chubut Province, Argentina.

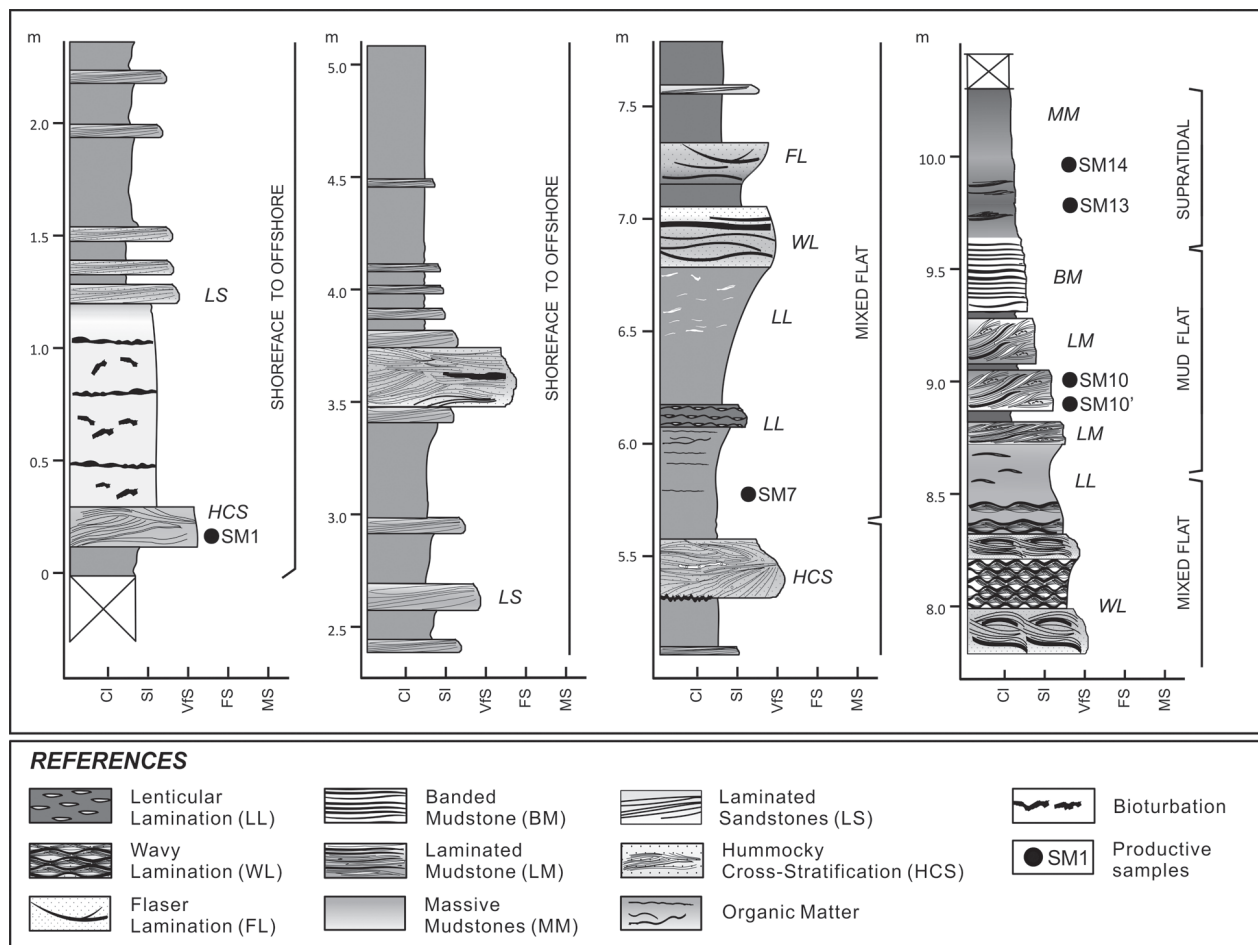


Figure 2. Stratigraphical section of the La Colonia Formation at Estancia San Miguel. Symbol (●) indicates the stratigraphic position of the productive palynological samples.

MATERIAL AND METHODS

Samples were taken at regular stratigraphic intervals of 20–30 cm from the base to the top of the San Miguel section, where the La Colonia Formation is exposed. The chemical (palynological) processing of the samples included HCl- and HF- removal of carbonates and silicates. Organic residues were sieved at 10 and 20 μm , stained with Bismarck C and mounted in glycerin jelly. Light microscopy observation was at 600 \times and 1000 \times magnifications using a Nikon Eclipse 600. For the quantitative analysis, more than 300 palynomorphs (dinocysts, algae, spores and pollen grains) were counted in the palynomorph-productive levels, except for sample SM7 in which the palynomorph content was <300, after counting the entire organic residue. Relative frequencies in relation to the total sum of palynomorphs were calculated and the diagram was plotted using the TILIA and TILIA GRAPH

2.0.b.4 package (Grimm, 1991-1993). The dendrogram was generated by a stratigraphically constrained cluster analysis applying the Euclidean Distance coefficient of dissimilarity (CONISS; Grimm, 1991-1993). The nomenclature of dinocysts mentioned in the text follows Fensome and Williams (2004). Images were taken with a Nikon Coolpix 950 digital camera. The microscope coordinates and the *England Finder* reference follow the sample and slide number for each specimen illustrated. Slides containing the illustrated specimens are stored in the Colección Palinológica, Laboratorio de Palinología (INGEOSUR-UNS), Bahía Blanca, Argentina.

RESULTS

Palynological composition

Fifteen samples were collected from the 11 meter-thick

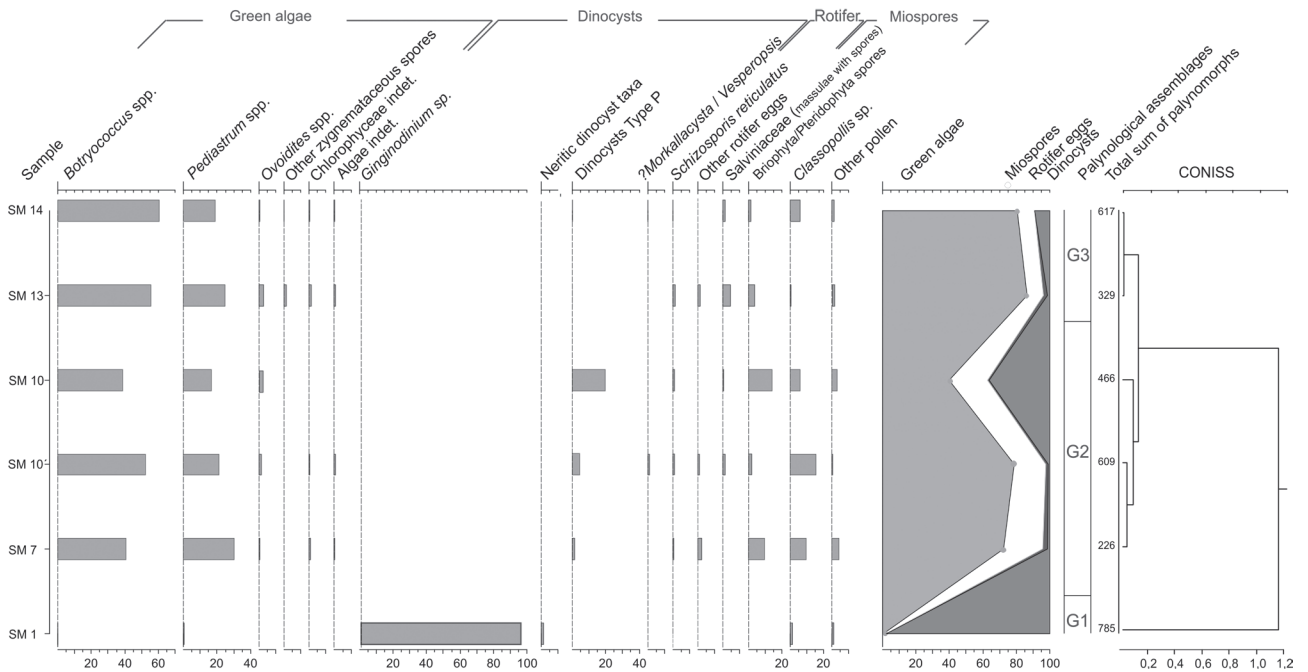


Figure 3. Diagram of relative frequencies of the different palynomorph groups recovered from the La Colonia Formation at the San Miguel section. Neritic dinocyst taxa include specimens of *Cribroperidinium*, *Apteodinium*, *Circulodinium* and *Areoligera*.

San Miguel section of the La Colonia Formation in the Telsen area and 6 of them were palynologically productive. They are mainly composed by organic-walled dinoflagellate cysts, green algae, pollen and spores. Three major groups of palynological assemblages were identified based on both species composition and relative frequencies (Fig. 3). Group 1 (SM1) is a very low-diversity dinocyst assemblage strongly dominated by small, spiny, thin-walled palaeoperidinioid morphotypes (Fig. 4.1–5), most of them included in *?Ginginodinium* sp. with a significant morphological variability (see Systematic Palynology). This almost monotypic assemblage also contains scarce typical neritic (open shallow marine) taxa of *Apteodinium* sp., *Cribroperidinium* spp., *Circulodinium* sp. and *Areoligera* sp. cf. *A. circumsenonensis* Fensome *et al.* 2009 (Figs. 4.6–9).

In Group 2 (SM7, SM10'–SM10) and Group 3 (SM13–SM14), typically occurring in the middle and upper parts of the section, green algae are the most frequent and ecologically significant components. Resting stages of colonies of *Botryococcus* Kützing 1849 dominate the assemblages in Groups 2 and 3 (up to approximately 55%, in SM10 and SM13). These algal remains show different morphological types based on their variability in shape, size and pattern of radially arranged

cup. Non-perforate coenobia of *Pediastrum* Meyen 1829 are also an important component of the palynological spectra (up to 30% in sample SM7). Different types of spores of zygnematalean algae were recorded in low proportions (up to 5% in sample SM13), represented by *Ovoidites* spp. and other spores comparable to modern zygospores of *Mougeotia* sp. and *Zygnema* sp. The species *Schizosporis reticulatus* Cookson and Dettman 1959, and other organic-walled microfossils with complex walls attributable to resting rotiferan eggs, comparable with those illustrated by Van Geel (1998) and Borel (2007) complete the assemblages. Differing from Group 3, the palynological spectra of Group 2 contains peridiniacean dinocysts assigned to Dinocyst type P (see Systematic Palynology; Fig. 5.1–3) from samples SM7 to SM10 and a few specimens of *?Morkallacysta* spp. (Figs. 5.4–5, 5.7–8) and *?Morkallacysta* sp. (Fig. 5.9) from sample SM10', stratigraphically very close to SM10. Dinocysts type P are well represented in sample SM10 with frequencies of 20%, while proportions of *Botryococcus* and *Pediastrum* reach values of 38% and 17%, respectively. Sample SM14 –highly dominated by *Botryococcus* and *Pediastrum*– yielded one specimen of a ceratiacean dinocyst tentatively assigned to *?Vesperopsis* sp. (Fig. 5.6).

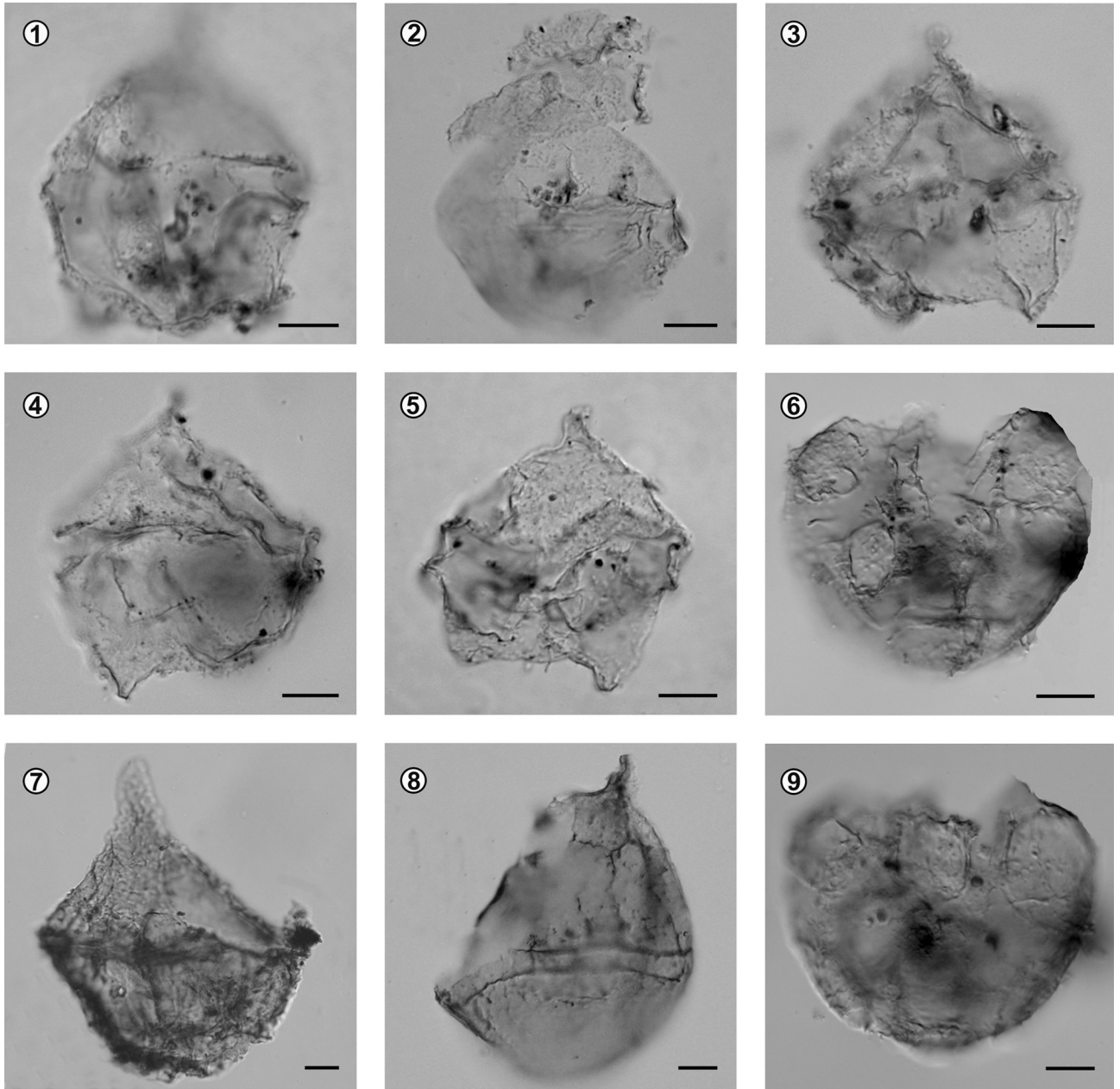


Figure 4. 1–9, Dinocysts recovered from the La Colonia Formation at the base of the San Miguel section. 1–5, *?Ginginodinium* sp., showing an important morphological variation; 1, SM1A2 44/111.5 P44, dorsal view, high focus; 2, SM1B1 16/106 G61/6, dorsal view, high focus, a simple, poly-placoid operculum remains in situ; 3, SM1B1 54/109 S54/2, ventral view, intermediate focus; 4, SM1A1 43.5/108 T44/1, dorsal view, intermediate focus; 5, SM1A2 43/112.5 N34/2, ventral view, intermediate focus. 7, *Cribroperidinium* sp. SM1A1 44/112 P44/2, left lateral view, high focus. 8, *Apteodinium/Cribroperidinium* sp., SM1B1 29/119.5 F29/3, right lateral view, intermediate focus. 6, 9, *Areoligera* sp. cf. *A. circumsenonensis* Fensome et al. SM1B1 36.5/101 K40/1, ventral view; 6, high focus; 9, low focus. Scale bar= 10 μ m.

Palynofloral assemblages are mainly represented by pollen grains of *Classopollis* Pflug 1953, freshwater aquatic pteridophytes (massulae with microspores of Salviniaceae), aquatic bryophytes (Ricciaceae) and other pteridophyte spores (*Echinosporis* sp., *Verrucosiporites* sp., *Clavifera triplex* (Bolkhovitina) Bolkhovitina 1966). Pollen grains related to

Proteaceae (*Triatriopollenites lateflexus* Archangelsky 1973, *Triatriopollenites bertelsii* Archangelsky 1973, *Tripoporollenites ambiguus* Stover and Partridge 1973, *Peninsulapollis gillii* (Cookson) Dettmann and Jarzen 1988), Arecaceae (*Spinizonocolpites hialinus* Archangelsky and Zamaloea 1986), Liliaceae (*Liliacidites vermireticulatus* Archangelsky and Zamaloea

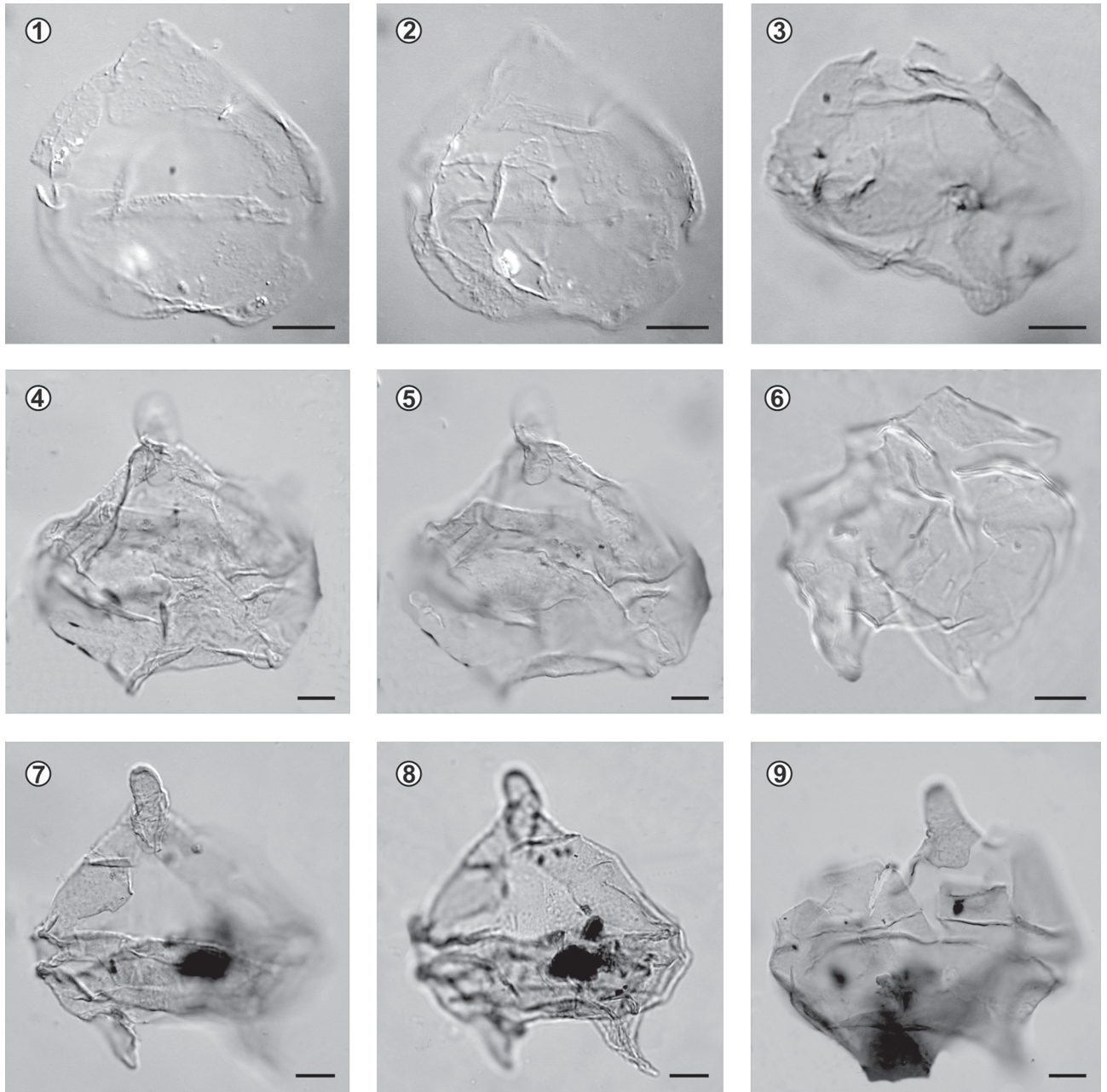


Figure 5. 1–8, Dinocysts recovered from the La Colonia Formation at the middle and upper part of the San Miguel section. 1–2, **Dinocyst type P**, SM10 A 39/104 D39 1, dorsal view; 1, high focus; 2, intermediate focus; precingular detached plates and intercalary sutures are involved in the archeopyle. 3, **Dinocyst type P**, SM10 A 35/114.5 P42/1, general view, apical, intercalary and precingular plates seem to be involved in the archeopyle/. 4–5, 7–8, **?Morkallacysta spp.**, 4–5, SM10 A 27/99.5 C49, ventral view; 4, high focus; 5, low focus; 7–8, SM10 B 60.5/119 F61/4, dorsal view; 7, high focus; 8, low focus, showing a well-defined I3P archeopyle. 9, **?Morkallacysta sp.**, SM10 D 64.5/115.5 K66/3, ventral view, low focus, archeopyle seems to involve one intercalary and three precingular plates I3Pa, precingular plates attached to the anterior margin of the cingulum. 6, **?Vesperopsis sp.**, SM14/08B 44/102.5 B33/3, dorsal view, high focus, showing an apical archeopyle. Scale bar = 10 μ m.

1986), Gunneraceae (*Tricolpites reticulatus* Cookson 1947 ex Couper 1953) and Podocarpaceae (*Podocarpidites* sp.) are subordinated.

Age of the studied section

The age of the La Colonia Formation was originally believed to be Senonian (Wichmann, 1927). Nakayama *et al.* (1978) referred it to the Salamanquense (Danian) and, Lapido

and Page (1978) tentatively assigned an outcrop west from Telsen to the Paleocene. A Senonian pre-Campanian age was proposed for the continental lower and middle part of the La Colonia Formation, mainly based on stratigraphical relationships. Based on micropaleontological data, foraminifera and ostracods, a Campanian/ Maastrichtian age was indicated for the upper marine deposits of the unit (Ardolino and Franchi, 1996 and references cited therein). Based on foraminiferal assemblages, Nañez and Malumíán (2008) assigned a Maastrichtian age for the marine layers of the La Colonia Formation at the Bajada Moreno section, 100 km south of Telsen. There are no previous biostratigraphical studies in the Telsen area and the palynological assemblages recovered in this study suggest a strong coastal character for the San Miguel section and consequently, the lack of age diagnostic marine dinocyst taxa. Nevertheless, the occurrence of *Areoligera* sp. cf. *A. circumsenonensis* at the base of the San Miguel section constrains the age of the assemblages to the Late Cretaceous–early Paleogene in agreement with Fensome *et al.* (2008; 2009). These authors described and discussed a plexus of morphologies within the genus *Areoligera* Lejeune-Carpentier 1938 in Late Cretaceous and early Paleogene assemblages from the Scotian Margin, offshore eastern Canada. However, in the earliest records of *Areoligera* spp. in high latitudes of the Southern Hemisphere occur at 57.3 Ma, *i.e.*, the Danian (Brinkhuis *et al.*, 2003). Another datum is the abundance of pollen grains of *Classopollis* (Cheirolepidiaceae) throughout the section (more than 30% of total terrestrial palynomorphs in some samples, see Fig. 3). We cannot be certain that this abundance correlates with a true peak of *Classopollis* in the San Miguel section, or with the peak of *Classopollis* characterizing the earliest Danian assemblages in complete sequences of the Cretaceous–Paleogene transition in southern South America (Barreda *et al.*, 2012). Thus, and even though the age of the marine part of the La Colonia Formation is probably Late Cretaceous–early Paleogene, we do not discard an age not older than Paleocene for these deposits at the San Miguel section, that also represent the uppermost part of the unit in the Telsen area (Navarro *et al.*, 2012).

PALEOENVIRONMENTAL INTERPRETATION

Based on the distribution of dinoflagellate cysts in modern marine sediments, Wall *et al.* (1977) showed that species diversity increases in an inshore-offshore direction. However,

local effects of salinity, temperature and nutrient availability may modify this basic pattern of distribution, and cyst diversity strongly depends on ecosystem stress (Bradford and Wall, 1984; Pross and Brinkhuis, 2005; Prauss, 2006). High relative and/or high absolute abundance of morphologically related forms per unit time reflects (sub) optimal environmental conditions and/or wider tolerance towards certain environmental conditions for such taxa (Sluijs and Brinkhuis, 2009).

The ?*Gingiodinium* sp. cyst assemblage strongly dominates sample SM1, reducing diversity in this sample to an almost monotypic level. This lead us to suggest that this taxon was presumably tolerant to extremely reduced-salinity conditions and/or salinity-related changes typical of a very shallow marine coastal environmental. The over-representation of these palaeoperidinioid cysts –reflected by a “peak” of ?*Gingiodinium* sp. cysts– suggests salinity-related stressed shallow marine waters, even when other factors (*e.g.*, nutrient availability, water chemistry, temperature) controlling the environmental stress of the ecosystem might also be involved. Nearshore environments are stressful to most forms and tend to be colonized by a small number of eurytopic taxa (Tyson, 1995). Prauss (2006) recorded a prominent peak of peridinioids, tentatively placed in ?*Gingiodinium* sp., at the Cenomanian/Turonian Boundary Event at Wunstorf in northwestern Germany. He attributed this presence to reduced salinity and cooler waters. The conspicuous assemblage from the San Miguel section is associated to very fine-grained hummocky cross-stratified sandstone. Hence, it is possible to assume that restricted shallow marine water conditions would have prevailed where the tempestite was deposited. The few specimens of neritic taxa such as *Apteodinium* sp., *Cribroperidinium* spp., *Circulodinium* sp. and *Areoligera* sp. cf. *A. circumsenonensis* reflect transport from the adjacent shelf.

The abundance of freshwater algae (*Botryococcus* and *Pediastrum*) and the presence of zygnematalean algae characterize the middle and upper parts of the San Miguel section. *Botryococcus* is a euryhaline alga widespread in brackish water basins, thriving even in lagoons (Guy-Ohlson, 1992; Medeañic, 2006). According to different authors, this is an oligotrophic to mesotrophic alga (Komarek and Marvan, 1992; Chmura *et al.*, 2006; Tell and Zamaloa, 2004). However, it was also reported in eutrophic environments (Tyson, 1995). In general, *Botryococcus* and *Pediastrum* are not simultaneously abundant (Tyson, 1995) because of their different eco-

logical requirements; *Pediastrum* is a freshwater taxon, strongly sensitive to changes in salinity and clearly prefers a higher load of nutrients.

In the middle part of the sections, Group 2 (SM7, SM10–SM10') includes green algae assemblages associated with the thin-walled Dinocysts type P; a few specimens of ?*Morkallacysta* spp., and a significant increase in the proportions of bryophyte and pteridophyte spores. Some of the Dinocysts type P (Fig. 5.1–3) resemble specimens of *Saepodinium* Harris 1974 from Australian non-marine Paleocene deposits (Harris, 1974) and *Holmwoodinium* sp. cf. *H. notatum* Batten 1985 which appear in low-salinity to freshwater palynological assemblages in the Lower Cretaceous of Great Britain (Batten, 1985). Dinocysts type P may be compared also with the cysts of *Peridinium* Ehrenberg 1832 from sedimentary sequences in southeastern Buenos Aires Province –related to the Holocene transgression– such as the Hinojales and Ballenera sections (Borel *et al.*, 2003; Borel, 2007). These *Peridinium* cysts record their peaks in the brackish intervals of these sections, and disappear where freshwater algae (*Zygnematales*, *Pediastrum*) reach their maximum frequencies, indicating brackish instead of freshwater conditions. The genus *Morkallacysta* Harris 1974 was recorded in middle to late Paleocene non-marine lacustrine mudstones from Australia (Harris, 1974). A sedimentological analysis reveals that these Group 2 palynomorphs come from the upper interval of an intertidal flat environment defined in the middle part of the San Miguel section. Changes in the hydrodynamic conditions and decrease in the depositional energy (presumably in response to more sheltered morphological conditions) are indicated by the gradual vertical changes of the sedimentary environments from a mixed flat to a mud flat (Navarro, 2012). Thus, it seems that assemblages of Group 2 would have thrived in low-energy brackish or brackish to freshwater bodies that occurring in the mudflat.

From the uppermost part of the section, assemblages of Group 3 (SM13–SM14) are almost entirely composed by *Pediastrum* and *Botryococcus*, except by low proportions of zygnematalean spores, rotiferan eggs and ?*Vesperopsis* sp. This assemblage is associated to massive mudstones (Navarro *et al.*, 2012) and reflects freshwater bodies in a mudflat environment, far from tidal influence. Ceratiacean dinocysts occur in both modern and fossil freshwater and marine palaeoenvironments. Among them, *Vesperopsis* Bintl *emend* Mao *et al.*

1999 occurs in low salinity water conditions assemblages from Cretaceous deposits, in which it sometimes predominates (Bintl, 1984; Mao *et al.*, 1999; Sha *et al.*, 2008).

Marshy vegetation is mainly represented by pollen of *Classopollis*, a genus commonly inhabiting nearshore marine-lagoon environments (Doyle *et al.*, 1982). Swampy areas surrounding the water bodies would have been colonized by aquatic bryophytes, pteridophytes and zygnematalean algae.

Summarizing, brackish and/or freshwater dinoflagellate cyst and algae assemblages characterize different low-salinity water bodies developed in a tidal flat environment. Low-energy depositional processes reflected by the predominance of fine textures –mainly mudstones– throughout the San Miguel section suggest environments associated to a muddy coast and isolated from direct open marine hydrodynamic influence.

SYSTEMATIC PALYNOLOGY

Division DINOFLAGELLATA (Bütschli) Fensome, Taylor,

Norris, Sarjeant, Wharton and Williams, 1993

Clase DINOPHYCEAE Pascher, 1914

Subclass PERIDINIPHYCIDAE Fensome, Taylor, Norris,

Sarjeant, Wharton and Williams, 1993

Order PERIDINIALES Haeckel, 1894

Suborder PERIDINIINEAE (Autonym)

Family PERIDINIACEAE Ehrenberg, 1831

Subfamily PALAEOPERIDINIOIDEAE (Vozzhennikova)

Bujak and Davies, 1983

Genus *Ginginodinium* Cookson and Eisenack, *emend.*

Lentin and Williams 1976

Type species. *Ginginodinium spinulosum* Cookson and Eisenack, 1960; p. 7, pl. 2, fig. 9. ?Late Albian-Cenomanian, Gingin, Perth Basin, Australia.

?*Ginginodinium* sp.

Figures 4.1–5

Description. Small subpentagonal (40–52 µm wide, 42–60 µm long; 25 specimens measured) extremely thin-walled Peridiniacean (palaoperidinioid) cysts present one apical horn and two weakly asymmetrical antapical horns, the left one being slightly larger. Acavate or weakly cornucavate, a few specimens show the endophragm separated from the periphragm in the apical horn. Surface is densely covered with short spines, sometimes showing spine alignments, but specimens do not display parasutural features with the exception of

the cingulum and in rare cases the archeopyle. In the few cases in which the archeopyle could be observed, it seems to result from the loss of the 1a–3a intercalary and the 3", 4" and 5" precingular plates; operculum may be simple, free (3I3P) (Fig. 4.2) or attached in most of the cases (3I3P)a (Figs. 4.1, 4.3–5).

Comments. The specimens of ?*Gingiodinium* sp. herein described show significant morphological variations and share features with more than one palaeoperidinioid genus, though they do not fit exactly within any of them. The overall morphology of the specimens resembles *Gingiodinium evittii* Singh 1983, but *G. evittii* is clearly cornucavate and, moreover, the archeopyle in species of *Gingiodinium* results from the loss of the three intercalary and three precingular plates, with the latter attached posteriorly, 3I3Pa. *Laciniadinium* McIntyre 1975 is spherical to rhombic and has a combination intercalary and precingular archeopyle with the operculum attached to the cingulum, (3I3P)a. *Luxadinium* Brideaux and McIntyre 1975 has a combination archeopyle (3I3P) or 3I3P with operculum free but differs from ?*Gingiodinium* sp. by being circumcavate or bicavate; our specimens are preferably acavate or slightly cavate apically. *Palaeoperidinium* (Deflandre) Evitt et al. 1998 and *Saeptodinium* differ mainly by having a A3I3P transapical archeopyle.

Order PERIDINIALES Haeckel, 1894
Suborder PERIDINIINEAE (Autonym)
Family PERIDINIACEAE Ehrenberg, 1831
Subfamily INCERTA

Dinocyst type P

Figures 5.1–3

Description. Cysts type P include translucent extremely thin-walled palaeoperidinioid cysts (25–40 µm wide, 27–45 µm long; 15 specimens measured) with a weakly granulate surface and incipient development of one apical and two symmetrical short antapical horns. The archeopyle seems to be formed by the loss of precingular, intercalary and/or apical plates, but it could not be definitely defined; most of the specimens are poorly preserved, most of them folded and, in the few cases where the archeopyle was observed, the number and plate series involved were not consistent. Characteristic omphali (biopolymeric accumulation bodies) are always present inside and located at the cingulum level.

Comments. The overall outline of some specimens of Dinocysts type P (Fig. 5.1–2) suggests a resemblance to *Saeptodinium gravattensis* Harris 1974 from non-marine Paleocene deposits in Australia (Harris, 1974). However, *S. gravattensis* displays a two layered-wall and the archeopyle was not identified. Other specimens of Dinocyst type P (Fig. 5.3) might be compared with those illustrated by Batten and Lister (1988) as *Holmwoodinium* sp. cf. *H. notatum*, although the presence of two short antapical horns is not consistent in the latter and the archeopyle is formed essentially by apical and intercalary plates (Batten, 1985; Batten and Lister, 1988), rather than precingular, intercalary and apical plates as in the case in Dinocysts type P. These inconspicuous forms with generally poorly developed parasutural diagnostic features are typical of the *Peridinium* cysts from Holocene and modern lacustrine sediments in Argentina (Boltovskoy, 1973, 1975, 1976; Borel et al., 2006).

Genus *Morkallacysta* Harris, 1974

Type species. *Morkallacysta pyramidalis* Harris, 1974; p. 163, pl. 1, figs. 5–11. Palaeocene, Victoria, Australia.

?*Morkallacysta* spp.

Figures 5.4–5, 5.7–8

Description. Three well-preserved specimens assigned to the genus ?*Morkallacysta* have a strong peridinioid shape with a densely granulate autophragm, with one apical and two antapical horns and the archeopyle formed by the loss of one intercalary and three precingular plates, (I3P). One specimen shows a more rounded outline and short antapical horns 5 µm long (Fig. 5.4–5) and the two other specimens are markedly pentagonal with longer acuminate antapical horns 10 µm long (Figs. 5.7–8); both types with an (I3P) archeopyle.

Comments. The specimens were placed in *Morkallacysta* questionably because of the debatable nature of the archeopyle in this genus. Harris (1974) originally described a triangular archeopyle, without reference to the plates involved in it. Stover and Evitt (1978) considered a 3I archeopyle and Lentin and Williams (1976) an A3I3Pa one (as invalid genus). Fensome et al. (1993) interpreted an (I3P)a archeopyle. Yet, there is no formal description of the archeopyle for this genus. Although our specimens exhibit most of the features of *Morkallacysta*, they show a clear I3P archeopyle with a free

operculum. *Morkallacysta* spp. show an overall resemblance with the type species *M. pyramidalis*, but mainly differ by the hypotract morphology; in the latter, the antapical horns markedly diverge laterally. Dinoflagellate cysts assigned to *Peridinium* sp. aff. *P. limbatum* (Scafati *et al.*, 2009, fig. 7, C,D) recovered from the Danian Bororó Formation approximately 100 km south from the deposits studied herein are quite similar to some specimens of ?*Morkallacysta* spp. (Fig. 5.7–8) from sample SM10'. These dinocysts attributed to *Peridinium* are part of a subtropical palynobiota that probably developed in a shallow, low-energy, freshwater lacustrine environment in a marine littoral setting, along with brackish coastal swamps (Scafati *et al.*, 2009). The specimens from the La Colonia Formation presumably correspond to two different morphospecies, but the lack of better-preserved specimens precludes an exhaustive description.

?*Morkallacysta* sp.

Figure 5.9

Description. Other two palaeoperidinioid specimens were tentatively placed in ?*Morkallacysta* sp. They are characterized by a moderately large pentagonal autophragmal body (85 µm wide; a single specimen measured), a pronounced apical horn with rounded tips (15 µm long), and two acuminate antapical horns (5 µm long). The number of plates involved in the archeopyle is not completely clear. One to three intercalary and three precingular plates appear to form the archeopyle, with the precingular ones posteriorly attached, *i.e.*, 3I3Pa (Fig. 5.9). Although the overall morphology of the specimens suggests that they fit in *Morkallacysta*, as in the case discussed previously, the genus is still missing a formal definition of the archeopyle.

Order GONYAULACALES Taylor, 1980

Suborder GONYAULACINEAE Autonym

Family AREOLIGERACEAE Evitt, 1963

Genus ***Areoligera*** Lejeune-Carpentier, 1938

Type species. *Areoligera senonensis* Lejeune-Carpentier, 1938; p. 164-166, text-figs. 1-3. Late Cretaceous, Belgium.

Areoligera* sp. cf. *A. circumsenonensis

Fensome, Williams and MacRae, 2009

Figures 4.6, 4.9

Comments. The two specimens of *Areoligera* sp. recovered from the basal SM1 sample are too poorly preserved to identify specifically beyond doubt. Specimens have encircling complex arrangement (*sensu* Fensome *et al.* 2009), with penitabular annulate process complexes and resemble *A. circumsenonensis* in carrying predominantly isolated processes. Nevertheless, poor preservation prevents observing the distal end of the processes. In addition, the low relief ornamentation observed in our specimens was not described for that species. In the other two close species, *i.e.*, *A. gippingensis* Jolley 1992 and *A. cf. coronata* *sensu* Williams and Downie 1966 (“*A. circumcoronata*” in Fensome and Williams, 2005) processes show trabecular and membranous connections respectively.

Suborder CERATIINEAE Fensome, Taylor, Norris, Sarjeant,

Wharton and Williams, 1993

Family CERATIACEAE Willey and Hickson, 1909

Genus ***Vesperopsis*** Bint *emend.* Mao, Wan and Qiao, 1999

Type species. *Vesperopsis mayi* Bint, 1986; p. 156-157, pl. 5, figs. 8, 9, 12-14; pl. 6, figs. 6-8, text-fig. 5. Late Albian, Kansas, EEUU.

?*Vesperopsis* sp.

Figure 5.6

Description. ?*Vesperopsis* sp. has a very thin hyaline autophragm with a smooth to slightly rough surface. The acuminate apex forms a low apical horn; the two hypocystal subequal horns (one antapical and one postcingular) are moderately prominent with rounded ends and two lateral bulges. However, with the only specimen available it is impossible to recognize whether the lateral horns are in a cingular or precingular position, although according to Mao *et al.* (1999) this group has precingular lateral horns. The archeopyle is apical (tA) with a ventrally attached operculum.

Comments. The assignment is questionable because the unique specimen recovered from the La Colonia Formation is broken and shows a strong dorso-ventral compression that preclude accurate observation of the cyst features. Nevertheless, because of its low lateral horns ?*Vesperopsis* sp. might be compared with *Vesperopsis fragilis* (Harding) Harding 1990. However, the hypocystal horns in the latter are unequal and poorly developed. *V. nebulosa* Bint 1986 has hypocystal horns of the same size, but the lateral horns are well developed compared to those of ?*Vesperopsis* sp.

CONCLUSIONS

Conspicuous dinoflagellate cyst assemblages from the La Colonia Formation in the Telsen area proved to be useful for paleoenvironmental interpretations. A monotypic assemblage composed by ?*Gingiodinium* sp. characterizing the basal level indicates stressed shallow restricted marine conditions, mainly associated to low salinity and/or changes in the salinity of water surface. It shows a peak of palaeoperidinioid dinocysts in response to salinity-related stressed conditions.

High relative frequencies of green algae, mostly *Botryococcus* and *Pediastrum*, associated with Dinocysts type P and a few specimens of *Morkallacysta* spp. in the middle part of this section suggest the development of low-energy brackish or brackish to freshwater bodies related to a mudflat paleoenvironment. Dinocysts of ?*Morkallacysta* are important paleoenvironmental markers for the Paleocene? in northeastern Patagonia.

Assemblages dominated by the chlorophytes *Pediastrum* and *Botryococcus* associated with zygnematalean algae and ?*Vesperopsis* sp. –recorded in the upper part of this section—are indicative of freshwater depositional conditions associated to a supratidal paleoenvironment.

The progressive upward-shallowing trend identified in the San Miguel section on the basis of sedimentological analysis is characterized by a salinity-drop in the depositional environments.

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