

Early Cretaceous dinoflagellate cysts from the southern border of the Neuquén Basin, Estancia Santa Elena locality, Argentina*

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Abstract: An assemblage of dinoflagellate cysts is reported from the Lower Member (Pilmatué Member) of the Agrio Formation (late Valanginian-Hauterivian) of the southern Neuquén Basin, Argentina. Thirty species are recognized and the new species *Oligosphaeridium quattrocchioae* and *Muderongia sarjeantii* described. The studied assemblage is compared with other Early Cretaceous assemblages from central western Argentina, Patagonia, the South Atlantic Malvinas Plateau, the Antarctic Peninsula and Australia. The marine dinoflagellate cyst assemblage of the Agrio Formation at the Estancia Santa Elena locality has cosmopolitan character, with a predominance of European and Tethyan species.

Key words: palynology, dinoflagellate cysts, taxonomy, Cretaceous, Argentina, Neuquén Basin, Agrio Formation.

Resumen: Quistes de dinoflagelados del Cretácico Temprano del borde austral de la Cuenca Neuquina, de la localidad de Estancia Santa Elena, Argentina. Se describe una asociación de quistes de dinoflagelados del Miembro Inferior (Miembro Pilmatué) de la Formación Agrio (Valanginiano tardío–Hauteriviano) de la parte austral de la Cuenca Neuquina, Argentina. Se reconocen 30 morfotipos y se describen las nuevas especies *Oligosphaeridium quattrocchioae* y *Muderongia sarjeantii*. La asociación estudiada se compara con otras asociaciones de quistes de dinoflagelados del centro oeste de Argentina, de Patagonia, el Plateau de las Malvinas en el Atlántico Sur, la Península Antártica y Australia. La asociación de quistes de dinoflagelados tiene carácter cosmopolita, con predominio de formas europeas y tethianas.

Palabras clave: Palinología, quistes de dinoflagelados, taxonomía, Cretácico, Argentina, Cuenca Neuquina, Formación Agrio.

INTRODUCTION

The main objective of this paper is to present and illustrate new data on marine dinoflagellate cyst assemblages of the Lower Member (Pilmatué Member) of the Agrio Formation. An assemblage of continental palynomorphs, described earlier (Volkheimer & Prámparo, 1984) from the Agrio Formation of the same locality, bearing the *Cyclusphaera psilata*-*Classopollis* assemblage and *Balmeiopsis limbatus*, is characteristic for the phytogeographic Southern Gondwana province (Brenner, 1976) and specially for the *Cyclusphaera psilata* subprovince of southwestern Gondwana (Volkheimer, 1980).

The material studied is from outcrop samples of the Lower Member (Pilmatué Member) of the Agrio Formation, of which the lowermost 144m

crop out at Estancia Santa Elena (Figs. 1 and 2). Well-preserved assemblages of dinoflagellate cysts are present only in the lowermost 25m of the section. Between 25 and 87m the preservation is poor, and in the uppermost part of the section (from 87 to 144m) it is very poor. The general stratigraphic setting is presented on Table 1 and the stratigraphic levels bearing the dinoflagellate cyst assemblages are displayed in Table 2.

The Agrio Formation was proposed by Weaver (1931), for the strata deposited on the top of the sandstones of the Early Cretaceous (Valanginian) Mulichinco Formation and beneath the Rayosa Formation. He divided the Agrio Formation into a lower part composed by "Marine Black Shales", a middle part of sandstones resistant to erosion (the "Avilé Sandstone") and an upper part composed of "Marine Black shales", "Shallow Water Bivalve Beds" and "Gypsum" (Correlation Chart in Weaver, 1931). The latter two units became known as "Huitriniano" (Groeber, 1946) and finally as the "Huitrín Formation" (Digregorio, 1972).

* In Memory of Dr. William Antony Swithin Sarjeant

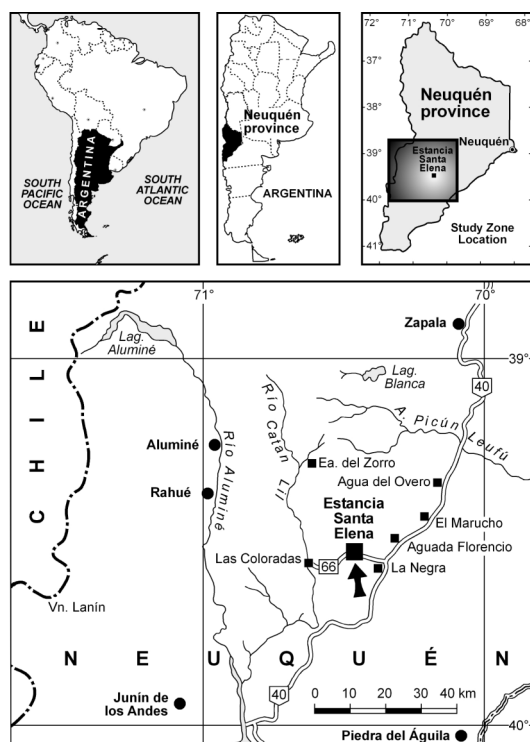


Fig. 1. Location map. / Mapa de ubicación.

The area sampled is located within the geologic map “Hoja 37c-Catán Lil, Neuquén province” of the Servicio Geológico Nacional (Leanza & Leanza, 1979). The main unconformities which produced major order break-ups during the evolution of the Mesozoic sedimentary infill of the Neuquén Basin, were studied by Leanza (2009). In this southernmost area of the basin he considered the Intravalangian Movements, producing the Huncálican (Catanililican) Unconformity.

A synthesis of the biostratigraphy of the Agrio Formation, based on ammonites, palynomorphs and calcareous nannofossils, was given by Aguirre-Urreta *et al.* (1999). The ammonites from the Agrio Formation indicate a late Valanginian to early Barremian age (Table 1). The position of the Agrio Formation in the context of facies evolution of the Mesozoic Neuquén Basin was given in Leanza *et al.* (2000) and Lazo (2006) studied the taphonomy of the Pilmatú Member macrofauna (= Lower Member) of the Agrio Formation. The biofacies and sea level changes of the Pilmatú Member were analysed by Lazo (2007). His studies on the biofacies are based on corals, serpulids, bivalve mollusks and gastropods, which are the principal components of the benthonic macrofauna of this member.

Lazo *et al.* (2009) presented an integrated biostratigraphy of the Agrio Formation at its type locality (Bajado del Agrio). They correlated biostratigraphically the local section with the European standard zonations.

Concheyro *et al.* (2009) studied the micropaleontology of the Agrio Formation in different areas of the Neuquén Basin. They found that in central and southern positions of the Neuquén Basin the age of calcareous nannofossil assemblages is Late Valanginian – Late Hauterivian and that the benthic microfauna indicates frequent eustatic variations (from shelves to shallow marine) with conditions of normal salinity.

Ottone (2009) gave a thorough review of the paleoenvironmental and paleoclimatic significance of the Cretaceous flora of the Neuquén Basin, principally based on the palynologic record, considering 191 papers related to the subject.

The sequence stratigraphy of the Agrio Formation was first interpreted by Legarreta & Gulisano (1989) and followed by the facies and sequence analysis in the central and southern Neuquén Basin of Brinkmann (1994). Volkheimer & Prámparo (1984) studied the terrestrial palynoflora associated with the dinoflagellate cysts of Estancia Santa Elena and Volkheimer & Sarjeant (1993) described *Systematophora rosenfeldii* from this locality.

Dinoflagellate cysts from other localities were studied by Quattrocchio & Volkheimer (1990), providing a range chart with 11 species of dinoflagellate cysts from the Agrio Formation) and Peralta (1996, 1997, 2000), who described and/or illustrated in her doctoral thesis (1997) 43 species of dinoflagellate cysts from the Lower Member of the Agrio Formation. The palynostratigraphic value of terrestrial species and communities was assessed by Volkheimer & Sepúlveda (1976) and Volkheimer & Pöthe de Baldís (1976). Peralta & Volkheimer (1997) discussed the palaeoenvironmental aspects of the Agrio Formation north of the Picun Leufú–Plottier High, inferred from dinoflagellate cyst assemblages, by considering the absolute abundances of individuals of a total spectrum of 24 species of dinoflagellate cysts. These same authors (Peralta & Volkheimer, 2000) studied Early Cretaceous sea level variations, as reflected by changes in dinoflagellate cyst assemblages and organic matter components north of the Picun Leufú–Plottier High (Cerro Negro de Covunco locality, with 36 dinoflagellate cyst species present in the stratigraphic levels analyzed).

Ottone & Aguirre-Urreta (2000), through a comparative analysis of dinoflagellate cysts and ammonites, proposed the existence of a marine link between the Austral and Neuquén basins

TABLE 1. Stratigraphic chart of the Early Cretaceous. Southern Neuquén Basin. Adapted from Leanza (1999). / Cuadro estratigráfico del Cretácico Temprano. Sur de la Cuenca Neuquina. Adaptado de Leanza (1999).

LOWER CRETACEOUS	ALBIAN	<i>Principal Miranic unconformity</i>		~100 Ma	
		Lohan Cura Fm.	Cullin Grande Mb. ----- Puesto Quiroga Mb.		
	APTIAN	<i>Intermediate Miranic unconformity</i>		~125 Ma	
		La Amarga Fm.	Piedra Parada Mb. ----- B. de Caichigue Mb. ----- Puesto Antigüal Mb.		
	HAUTERIVIAN	<i>Initial Miranic unconformity</i>		~132 Ma	
		MENDOZA GROUP	Agrio Fm.	<i>Transition zone</i>	
	<i>Catanilic unconformity</i>		~137 Ma		
	Bajada Colorada Fm.				
	BERRIASIAN	Picún Leufú Fm.	F. Nogueira Gr.	Limay Fm. -----	
		Vaca Muerta Fm.		Ortiz Fm.	
UPPER JURASSIC	TITHONIAN	Qda. del Sapo Fm.	Pichi P. Leufú Fm. -----		
	KIMMERIDGIAN	<i>Araucanic unconformity</i>		~153 Ma	

and Quattrocchio *et al.* (2006) established regional correlations based on well sections in northeastern Tierra del Fuego.

MATERIALS AND METHODS

The assemblages of dinoflagellate cysts were obtained by the author from grey siltstones and claystones from the lower part (Pilmatué Member) of the section of the Agrio Formation at Estancia Santa Elena locality (Neuquén Province). The preparation of the samples was carried out at the Palynology Laboratory of the Department of Geological Sciences of the University of Saskatchewan at Saskatoon, Canada. The slides are stored in the Paleopalynology Collection of the Department of Paleontology of IANIGLA/CCT-CONICET under the numbers MPLP 9039, 9040/A3 and 9041/A4 (MPLP: Mendoza-Paleopalintoteca-Laboratorio-Paleopalintología). The coordinates indicated in the text correspond to the microscope Leitz Dialux 20 of the Paleopalynology Unit of IANIGLA. Those coordinates preceded by the letters SAS correspond to the Zeiss Photomikroskop of the Department of Geology of the University of Sas-

katchewan at Saskatoon. The photomicrographs were obtained using Kodak T-MAX Film. The SEM micrographs have been obtained using a Philips SEM at the University of Saskatchewan.

SYSTEMATICS

A complete taxonomic list is given as an appendix at the end of the text. In this section, the description of new species of the genera *Oligosphaeridium* and *Muderongia* and taxonomic considerations on a species of the genus *Muderongia* are presented.

Kingdom PROTOCTISTA
 Division DINOFLAGELLATA (Bütschli, 1885)
 Fensome *et al.*, 1993
 Class DINOPHYCEAE Pascher, 1914
 Subclass PERIDINIPHYCIDAE Fensome *et al.*,
 1993
 Order GONYAULACALES Taylor, 1980
 Suborder GONYAULACINEAE (Autonym)
 Family GONYAULACACEAE Lindemann, 1928
 Subfamily LEPTODINIOIDEAE Fensome *et al.*,
 1993

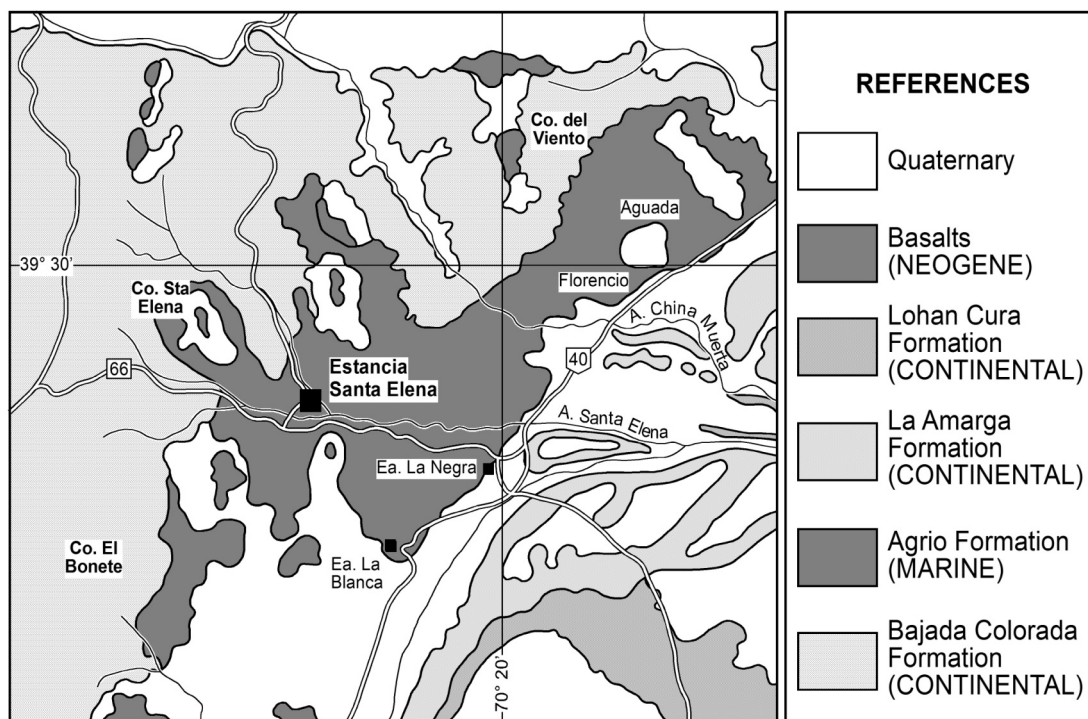


Fig. 2. Geology of the study area. Adapted from Leanza & Hugo (1997). For age of Mesozoic formations see Table 1. / *Geología del área de estudio. Adaptado de Leanza & Hugo (1997). Para las edades de las formaciones mesozoicas ver Tabla 1.*

Genus *Oligosphaeridium* Davey & Williams,
1966 emend. Davey, 1982

Type: *Xanthidium tubiferum* var. *complex*
White, 1842, pl. 4, fig. 11

Oligosphaeridium quattrocchioae Volkheimer,
sp. nov.
(Figs. 5.H-M; 6.A-B, F-H)

Diagnosis. *Oligosphaeridium quattrocchioae* is differentiated essentially from other species of the genus by the distal complexity of the fenestrate processes; an Endo/Proc ratio of 2.9 (Relation between endocyst diameter and length of processes) and the fact that the antapical process is not especially large. Length of processes around one third of equatorial diameter.

Description. Skolochorate cysts of medium size, having a spherical to subspherical central body with eighteen hollow, tubiform processes and one (or two) slender, solid processes. Processes intratabular corresponding to the formula 4', 6'', 6''',

1p, 1''', 1-2s. Processes formed from periphragm only. Tubiform processes infundibular and broadening distally, aculeate to broadly cauliflorate and exhibiting perforations of variable number, size, shape and location. Apical processes markedly more slender. One sulcal process constantly present; when a second sulcal process is present, it is very slender, unbranched and flexuous. Length of processes around one-third of equatorial diameter of central body. Surface of phragma without conspicuous ornament. Archaeopyle apical (type A); operculum free.

Derivation of name. In honour of the distinguished Argentinian palynologist Dr. Mirta Quattrocchio.

Holotype. Prep. MPLP 9041 A4/2H:15.3/95.4 (MPLP: Mendoza-Paleopalintoteca-Laboratorio-Paleopalintología) (fig. 6.B).

Paratype. Prep. MPLP 9041 A4/14C:26.2/94.9 (fig. 6.H).

Lodgement. Stored in the Unidad Paleopalintología del IANIGLA (Instituto Argentino de Nivología, Glaciología y Ciencias Ambientales), CCT-CONICET-Mendoza. The coordinates indi-

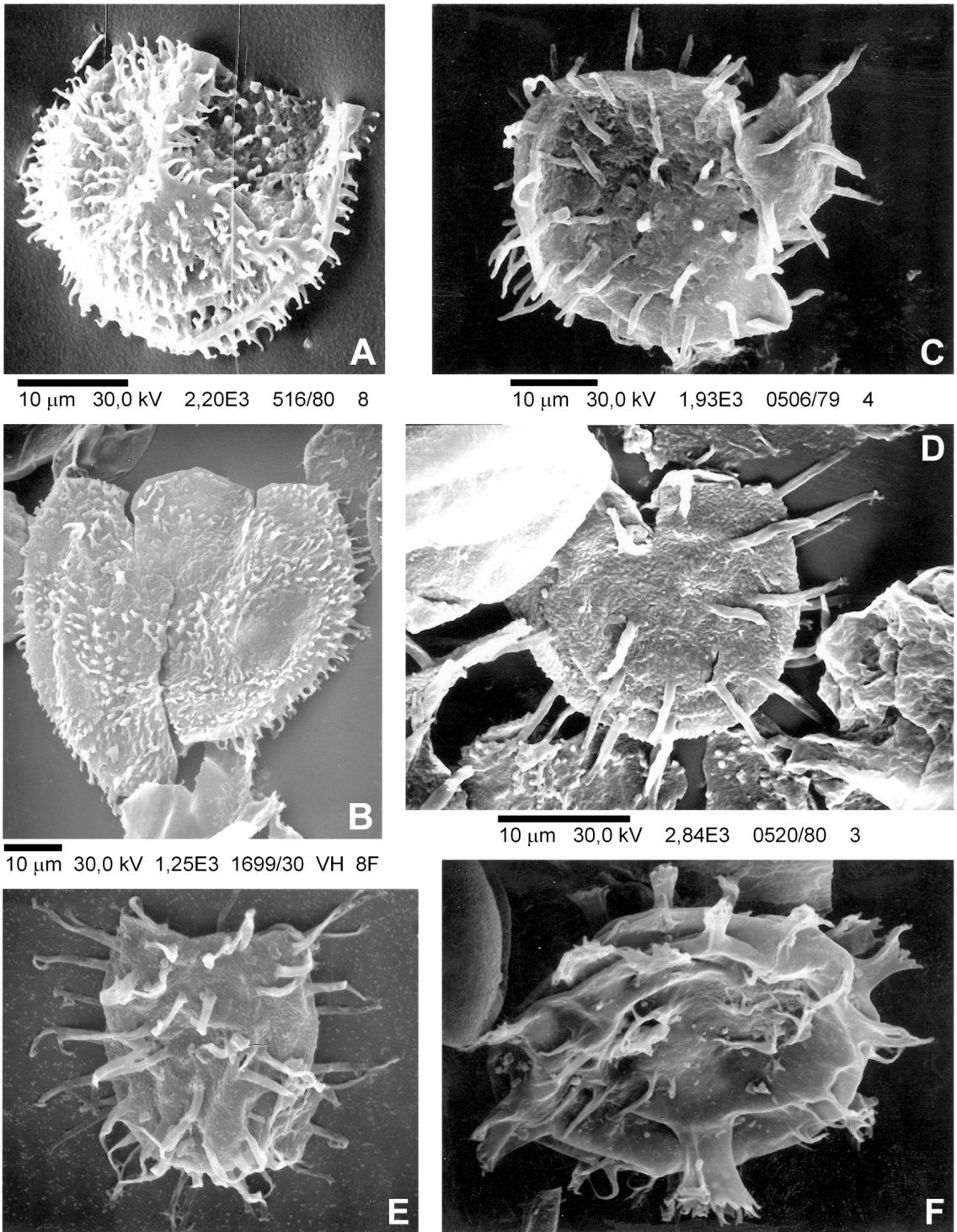


Fig. 3. All figures with SEM, from sample 9041. **A-B.** *Circulodinium distinctum* (Deflandre & Cookson, 1955) Janso-
nius, 1986. **C.** *Dapsilidinium chems* (Below, 1982) Lentin & Williams, 1985. **D.** *Dapsilidinium* cf. *duma* (Below, 1982)
Lentin & Williams, 1985. **E.** *Systematophora silybum* Davey, 1979a. **F.** *Florentinia* cf. *interrupta* Duxbury, 1980. /
Todas las figuras al MEB, de la muestra MPLP 9041.

cated correspond to the microscope Leitz Dialux 20 located at IANIGLA.

Dimensions. Holotype: maximum diameter of body: 53 μm . Paratype: maximum diameter of body: 58 μm . Range of maximum diameter of body: 44 (55) 66 μm (55 specimens measured). Length of processes 13-25 μm .

Horizon and locality. Lower Member (=Pilmatué Member) of the Agrio Formation, 23m above the lower limit of the Formation. Estancia Santa Elena, provincial road No.66, Neuquén province, Argentina.

Stratigraphic range. Lower Member (Pilmatué Member) of the Agrio Formation (Upper Valanginian to Lower Hauterivian).

Supplementary observations. The second sulcal process is exceptionally slender and may readily escape observation. It is not constantly present; it is visible on the specimen illustrated in figure 6.2, but lacking from the specimen sketched (fig. 6.1). No indication of an anterior sulcal process was seen in any specimen. The phragma surface is laevigate to finely granulate in all specimens seen. The apical processes are more slender than those on the loisthocyst, but have comparably complex terminations. Their proportionate length could not be measured.

The degree of complexity of the process tips is highly variable. In vertical view they may appear like a ragged-edged platform with an irregular scatter of perforation of variable size; in lateral view, they are seen to be secate to cauliflorate. Two processes on the loisthocyst, l'' (Iu) and lp (X), are markedly smaller than the others; the antapical process is of a size comparable to those of the pre- and postcingular paraplates.

For comparison with other skolochorate genera of dinoflagellate cysts see figure 3. Comparison with *Oligosphaeridium pulcherrimum* (Deflandre and Cookson) Davey & Williams, 1966 is close. Both species have fenestrations in the distal portions of the processes, but they differ in the Endo/Proc ratio, which is 1.9 in *O. pulcherrimum*, but 2.9 in *O. quattrocchioae*. The Endo/Proc ratio of *O. patulum* Riding and Thomas is 1.9, similar to

O. pulcherrimum, but it presents non fenestrate processes.

O. quattrocchioae finds also a close comparison with *Oligosphaeridium byersense* Duane, 1997, from the Early Cretaceous (Valanginian) of the Antarctic Peninsula, which is similar in Endo/Proc ratio (2.5 vs. 2.9). However it does not have fenestrate processes and the processes of that species are larger, buccinate rather than infundibular and of even greater distal complexity, adjacent processes being sometimes linked by trabeculae. Other species, such as *Oligosphaeridium complex* (White) Davey and Williams, have processes proportionately larger and, though of variable complexity, showing no close matches with *Oligosphaeridium quattrocchioae*. *Oligosphaeridium complex* subsp. *brevispinum* Jain, 1975 (p.182, pl. 1, figure 4) has short processes, but these are proportionately much thicker than in *O. quattrocchioae*, giving a totally different, heavier appearance to the subspecies mentioned.

Nevertheless, the size of processes is not reliable for differentiating chorate species, as process size is not only determined by genetics and therefore might not be a good characteristic to differentiate species in one genus. As an example, size of processes in *Lingulodinium polyhedrum* changes when salinity of sea water does. In normal salinity sea water this species forms normal cysts with normally long processes. But, when the cysts develop in less than normal salinity, the processes are shorter (Helenes, verbal communication).

Suborder CERATIINEAE Fensome *et al.*, 1993

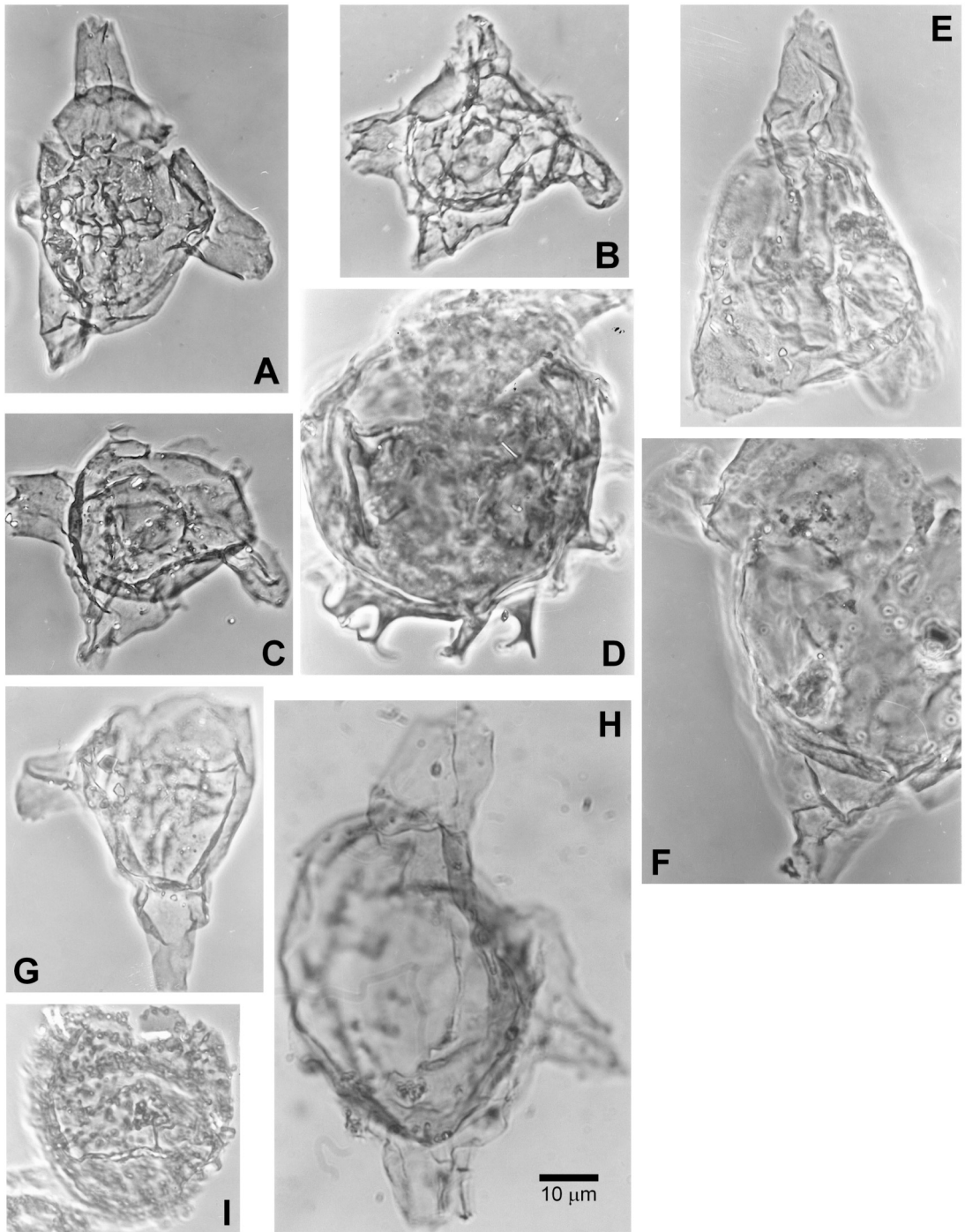
Family CERATIACEAE Lindemann, 1928

Genus *Muderongia* Cookson & Eisenack, 1958
emend. Monteil, 1991b

Type Species. *Muderongia mcwhaei* Cookson & Eisenack, 1958, pl. 6, fig. 2

Muderongia siciliana Torricelli, 1997
(Figs. 4, A-C)

Fig. 4. **A, B, C, D, F** with phase contrast; **E, G, H, I** with interference contrast. **A, B, C.** *Muderongia siciliana* Torricelli, 1997 (magnification: x 550). **A.** Prep. MPLP 9041. A4/1C: SAS 104.0/13.5. **B.** Prep. MPLP 9041. A4/1C: SAS 105.2/13.4. **C.** Prep. MPLP 9041. A4/1C: SAS 101.0/13.5. **D.** *Achomosphaera* sp. A of Norwick & Burger, 1976 (magnification: x 1000). Prep. MPLP 9041. A4/2H: SAS 99.0/13.0. **E-H.** *Muderongia sarjeantii* n. sp. (magnification: 5-7: x 1000). **E.** Prep. MPLP 9041/A4/4C: 32.5/104.4. **F.** Prep. MPLP 9041:A4/4C: SAS 96.4/16.3. **G.** Prep. MPLP 9041. A4/4C: SAS 91.0/23.6 **H.** Prep. MPLP 9041. A4/2H: 15.1/93.0. **I.** *Sentusidinium cuculliformis* Davies, 1983. (magnification: x 1000). Prep. MPLP 9040: A3/10C: SAS 99.3/20.0. *Las figuras A, B, C, D, F se obtuvieron con dispositivo de contraste de fases. Las figuras E, G, H, I con dispositivo de contraste de interferencia. Aumentos: figuras A-C x 550, figuras H-I x 1000.*



Remarks. The Argentinian specimens correspond in all essential features with those from Sicily. However, it should be noted that the operculum is by no means always free, often

showing ventral attachment. The age of the Sicilian specimens (early Hauterivian) is very close to that of the Argentinian ones (latest Valanginian to earliest Hauterivian).

Muderongia sarjeantii Volkheimer, sp. nov.
(Figs. 4, E-H)

Diagnosis: A species of *Muderongia* in which all three horns are of comparable dimensions, very broad-based, tapering gently to blunt, rather ragged-looking tips and having a length between two-fifths and three-fifths of the length of the central body. Cingulum marked by faint lines and a slight central depression. Paratabulation not otherwise directly indicated. Endoblast almost spheroidal, but bulging into the base of the right lateral horn. Endophragm finely to coarsely granular; periphragm levigate or very finely granulate.

Description. Large cysts, ceratoid, cornucavate, with three prominent horns, apical, antapical and right lateral. The horns are broad-based, tapering gently to a blunt and irregular open tip. The apical horn is polar in position, its length less than that of the central body. The antapical horn may be polar in position or may be positioned slightly or markedly to the left of the antapical pole; its length is less than that of the central body. The right lateral horn is post-cingular in position; it may be shorter than the other horns or may approach them in length. It may be straight or recurved and may exhibit a cingular notch.

Endoblast spheroidal to ellipsoidal in ambitus or bulging into the base of the right lateral horn. It may exhibit some dorsoventral flattening or may be rotund. Periblast may exhibit few low ridges bounding the cingulum, which may be shallowly concave. Alternatively, the cingulum may not be directly indicated. Sulcus and paratabulation marked by faint lines or not at all. Endophragm and periphragm laevigate or finely granulate or punctate.

Archaeopyle apical (type tA). Archaeopyle suture rounded to weakly angular; sulcal notch,

when discernible, offset slightly to the left. Operculum free or attached.

Derivation of name. In honour of Dr. William Antony Swithin Sarjeant, distinguished palynologist and great author of science fiction.

Lodgement. Stored in the Unidad Paleopalínología del IANIGLA (Instituto Argentino de Nivología, Glaciología y Ciencias Ambientales), CCT-CONICET-Mendoza. The coordinates indicated correspond to the microscope Leitz Dialux 20 located at IANIGLA.

Holotype. Prep. 9041 A4/4C;32.5/104.4 MPLP (Mendoza-Paleopalínoteca-Laboratorio-Paleopalínología).

Total length: 72 μm ; endoblast 40x46 μm . (fig. 4.E).

Paratype. Prep. 9041 A4/2H:15.1/93.1 MPLP.

Total length: 74 μm ; endoblast 35x48 μm (fig. 4.H).

Observations. The wide, blunt and distally open horns are marking the difference from *M. siciliana* and other earlier described species of *Muderongia*.

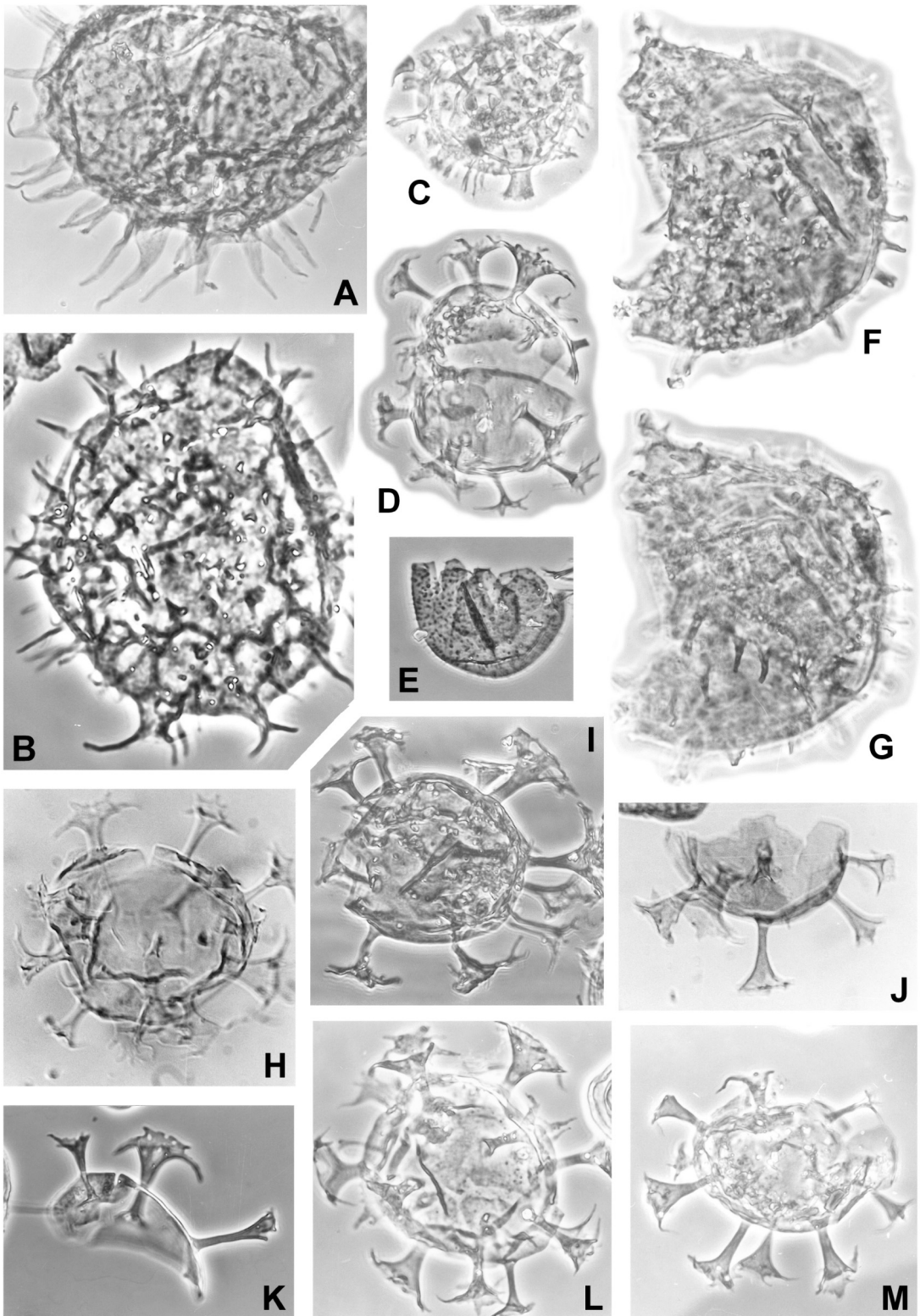
Dimensions. Range of maximum total length: 69-101 μm (6 specimens measured). Specimen illustrated in figure 5.8: total length 74 μm ; endoblast 35x48 μm

Stratigraphic range. Lower Member of the Agrio Formation (upper Valanginian to lower Hauterivian).

REGIONAL COMPARISON

The assemblage of the Lower Member of the Agrio Formation at Santa Elena is compared with other Early Cretaceous assemblages of dinoflagellate cysts from the southern hemisphere and related gondwanic areas. In order to avoid unnecessary extension of the list of References, for cita-

Fig. 5. All figures with phase contrast. **A.** *Hystrichodinium pulchrum* Deflandre 1935. (magnification: x 1000) Prep. MPLP 1940/A3/10C:30.3/96.4 . **B.** *Achomosphaera neptuni* (Eisenack, 1958a) Davey & Williams, 1966. (magnification: x1000). Prep. MPLP 9040. A3/10C: SAS 100.0/21.8. **C.** *Florentinia cf. interrupta* Duxbury, 1980 (magnification: x 550). Prep. MPLP 9041/A4/11C. SAS 98.3/19.4. **D.** *Heterosphaeridium? galiciae*, Masure, 1988 (magnification x 550). Prep. MPLP 9041. A4/5C. SAS 92.0/16.5 . **E.** *Pilosidinium filiatum* (Davies, 1983) Courtinat, 1989 (magnification: x 550). Prep. MPLP 9041. A4/5C. SAS 96.2/16.5. **F, G.** *Occisucysta tentoria* Duxbury, 1977 (magnification: x 1000). Prep. MPLP 90.41 A4/2H: SAS 100.3/13.8. **H-M.** *Oligosphaeridium quattrocchioae* Volkheimer, sp. nov. (magnification: x 550). **H.** Prep. MPLP 9041. A4/4C. SAS 101.9/23.0. **I.** Prep. MPLP 9041. A4/5C. SAS 95.8/17.2. **J.** Prep. MPLP 9041. SAS 94.3/12.5. **K.** Prep. MPLP 9041. A4/5C. SAS 91.1/18.2.. **L.** Prep. MPLP 9041.A4/4C.: SAS 97.0/21.5. *Todas las figuras se obtuvieron con dispositivo de contraste de fases. Aumentos: figuras A, B, F, G, x 1000, figuras C, D, E, H-M, x 550.*



tions of papers older than 2004, on dinoflagellate cyst taxonomy, please see the list of references in Fensome & Williams (2004).

Early Cretaceous pre-Aptian assemblages of dinoflagellate cysts have been recorded from central western Argentina (Quattrocchio & Volkheimer, 1985, 1990; Peralta 1996, 1997, 2000; Aguirre-Urreta *et al.*, 1999); Patagonia (Ottone & Aguirre-Urreta, 2000); the South Atlantic Malvinas Plateau (Harris, 1976; Bair, 1984); the Indian Ocean: Mozambique Ridge east of Durban (cit. Harris, 1976); the continental shelf of South Africa (Davey, 1971); the Livingston and Snow Islands of the Antarctic Peninsula (Duane 1996); Australia (Edgell, 1964; Evans, 1966; Wiseman, 1979, 1980; Burger, 1980, 1982; Backhouse, 1987; Helby, *et al.*, 1987); DSDP Sites 280-284, Leg 29, off Southeastern Australia and western New Zealand (Haskell & Wilson, 1975).

Central western Argentina

Early Cretaceous dinoflagellate cysts up to 1990 were reviewed by Quattrocchio & Volkheimer (1990). In the southern part of the Neuquén Basin, they described a Berriasian assemblage, characterized by *Systematophora penicillata* (Ehrenberg, 1843) Sarjeant, 1980, *Sentusidinium villersense* (Sarjeant, 1968) Sarjeant & Stover, 1978, and *Prolixosphaeridium* sp., which also occur in Boreal associations, and an Hauterivian assemblage with *Achomosphaera* cf. *ramulifera* (Deflandre, 1937) Evitt, 1963, *Cribrerodinium orthoceras* (Eisenack, 1958) Davey, 1969, *Gonyaulacysta* sp., *Hystrichosphaeridium* sp., *Hystrichosphaerina neuquina* Quattrocchio and Volkheimer emend. Quattrocchio & Sarjeant, 1992, *Meiourogonyalax* sp., *Oligosphaeridium complex* (White, 1842) Davey & Williams, 1966, *Pseudoceratium* cf. *gochtii* Neale & Sarjeant, 1962, *Scriniodinium* sp. A, *Sentusidinium villersense* (Sarjeant, 1968) Sarjeant & Stover, 1978, *Spiniferites* cf. *ramosus* (Ehrenberg 1838) Loeblich & Loeblich, 1966, and *Systematophora penicillata* (Ehrenberg, 1843) Sarjeant, 1980.

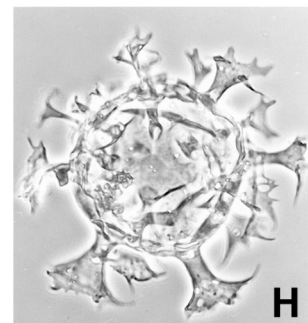
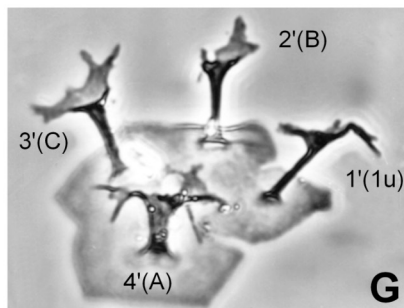
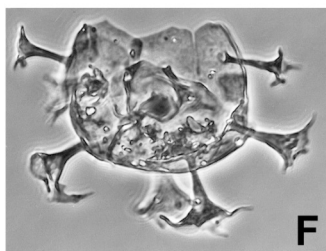
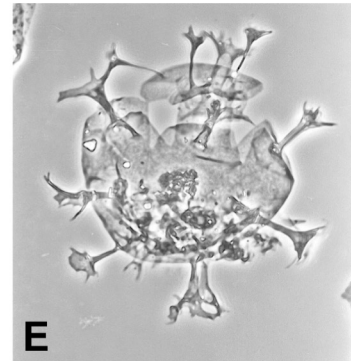
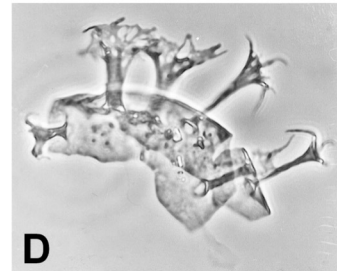
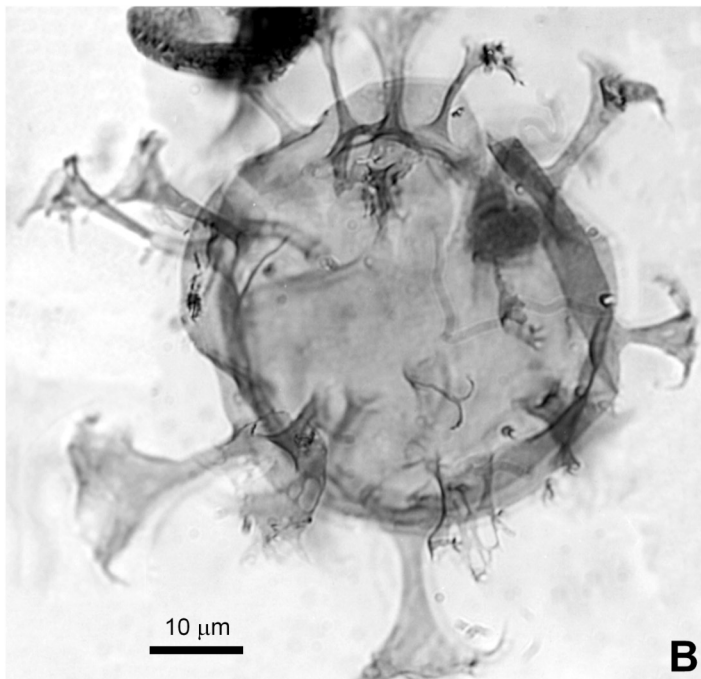
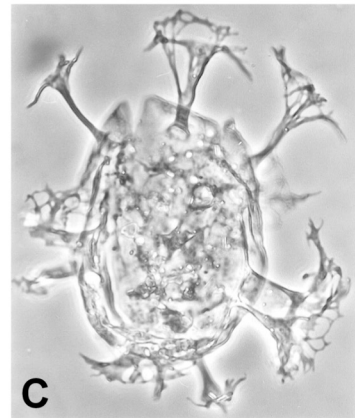
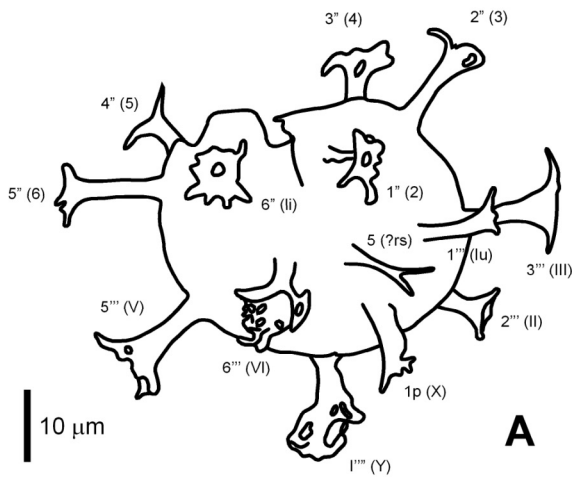
A major contribution to the palynostratigraphic knowledge of the Early Cretaceous of the

Neuquén Basin was the doctoral thesis of Peralta (1997) on the dinoflagellate cysts of Cerro Negro and Cerro Mesa de Covunco. She described and/or illustrated 43 species of dinoflagellate cysts from the Lower Member of the Agrío Formation. The dominant species reported in that paper are *Cribrerodinium orthoceras* (Eisenack) Davey, 1969, *Dingodinium cerviculum* Cookson & Eisenack, 1958 and *Achomosphaera ramulifera*. Other frequent species are *Batiacasphaera asperata* Backhouse, 1987, *Cleistosphaeridium australe* Burger, 1980, *Epelidosphaeridia pentagona* Morgan, 1980, *Millioudodinium aichmetes* Sarjeant, 1966, *Oligosphaeridium complex* (White) Davey & Williams, 1966, *Sentusidinium* sp., *Spiniferites ramosus* (Ehrenberg) Mantell, 1854, and *Systematophora rosenfeldii* Volkheimer & Sarjeant, 1993. As stratigraphic indicators for the interval Valanginian–Barremian she considers the following species: *Cassiculosphaeridia magna* Davey, 1974, *Cribrerodinium muderogense* (Cookson and Eisenack) Davey, 1969, *Dinogymnium acuminatum* Evitt *et al.*, 1967, *Oligosphaeridium nannum* Davey, 1974, *Millioudodinium aichmetes* (Sarjeant) Stover & Evitt, 1978, *Pseudoceratium gochtii* Pocock, 1962, *Systematophora rosenfeldii* Volkheimer & Sarjeant, 1993, and *Callaiosphaeridium asymmetricum* (Deflandre and Courteville) Davey & Williams, 1966. In accordance, an early Hauterivian age of the assemblage of dinoflagellate cysts is indicated by the association with guide ammonites: *Acanthodiscus vaceki* (Neumayer and Uhlig), which corresponds to the *Lyticoceras pseudoregale* Zone (Leanza, 1981).

Patagonia

The late Valanginian to Hauterivian and Barremian Springhill Formation of southern Patagonia contains, in addition to an abundant (and prevailing) terrestrial microflora, an assemblage of dinoflagellate cysts surprisingly similar to that of the Agrío Formation of the Neuquén Basin. Based on this similarity, Ottone & Aguirre-Urreta (2000) postulated the presence of a marine corridor between the Austral Basin (Patagonia) and the Neuquén Basin, at least during

Fig. 6. **A-B.** *Oligosphaeridium quattrocchioae* Volkheimer, sp. nov. **A.** Sketch. **B.** Holotype. Observe the slender sulcal process and the adhering operculum. Prep. MPLP 9041. A4/2H:15.3/95.4. **C-D.** *Stiphrosphaeridium dictyophorum* (Cookson & Eisenack) Davey 1982. **C.** Prep. MPLP 9041. A4/5C. SAS 96.3/23.0 **D.** Prep. MPLP 9041. A4/5C. SAS 92.6/18.8. **E.** *Stiphrosphaeridium* sp. Prep. MPLP 9041.A4/5C. SAS 93.7/16.2. **F-H.** *Oligosphaeridium quattrocchioae* Volkheimer, sp. nov.(all magnifications x 550; less the operculum on Fig. 6..**G:** x 1000). **F.** Prep. MPLP 9040. A3/10C. SAS 102.0/10.0. **H.** Prep. MPLP 9041. A4/14C: 26.2/94.9. **A.** Dibujo. **B.** Holotipo. Obsérvese el delgado proceso sulcal y el opérculo adherido. Aumentos x 550, con excepción del opérculo de la figura **6G:** x 1000.



the Hauterivian and early Barremian. They cite (and partly illustrate) an assemblage composed by *Apteodinium* sp., *Biorbifera* (?) sp., *Circulodinium distinctum* Deflandre and Cookson, *Cribroperi-*

dinium muderongense (Cookson and Eisenack) Davey, *Exochosphaeridium* ? sp., *Gonyaulacysta* sp., *Hystrichosphaeridium* sp. cf. *H. tubiferum* (Ehrenberg) Deflandre, *Muderongia australis*

Table 2. Stratigraphic position and lithology of the palynologic samples studied. Agrio Formation, Estancia Santa Elena, Neuquén province, Argentina. / Posición estratigráfica y litología de las muestras palinológicas estudiadas. Formación Agrio, Estancia Santa Elena, provincia de Neuquén, Argentina.

# of sample	stratigraphic distance above the upper limit of Bajada Colorada Fm.	lithology	preservation	# Paleopalyn. Laboratory IANIGLA
020382/9	35 m	siltstone, gray	fair	9043
020382/8	29 m	siltstone, gray	fair	9042
020382/7	23 m	siltstone, gray-brown	well	9041/A4
020382/6	19 m	siltstone, gray-brown	well	9040/A3
020382/5	15 m	claystone gray	well	9039

Table 3. Comparison of *Oligosphaeridium quattrocchioae* with similar species. / Comparación de *Oligosphaeridium quattrocchioae* con especies similares.

Taxon	Endocyst / Processes	Shape of processes
<i>O. pulcherrimum</i>	(58/30 = 1.9)	Multifurcate, only distal fenestration
<i>O. quattrocchioae</i>	(55/19 = 2.9)	Multifurcate, fenestration all over
<i>O. byersense</i>	(56/22 = 2.5)	Multifurcate, non fenestrate
<i>O. patulum</i>	(58/30 = 1.9)	Spiny, non fenestrate
<i>Stiphr. anthophorum</i>	(70/50 = 1.4)	Non furcated, distal trabeculae, fenestrate

Helby emend. Monteil, *Muderongia crucis* Neale and Sarjeant emend. Monteil, *Muderongia staurota* Sarjeant emend. Monteil, *Oligosphaeridium complex* (White) Davey and Williams, *Prolixosphaeridium* sp., *Systematophora rosenfeldii* Volkheimer and Sarjeant.

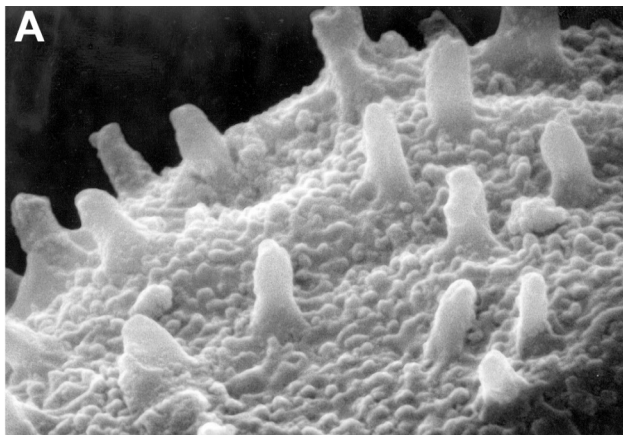
These data are derived from Estancia El Salitral locality and the combined evidence from the terrestrial microflora and the assemblage of dinoflagellate cysts indicates a Hauterivian to lower Barremian age (Ottone & Aguirre-Urreta, 2000).

Quattrocchio *et al.* (2006) studied well sections of northeastern Tierra del Fuego, Argentina. They established a correlation with the *Interulobites-Foraminiisporis* Assemblage Zone (Upper Valanginian–Upper Hauterivian) of Austral Patagonia and with

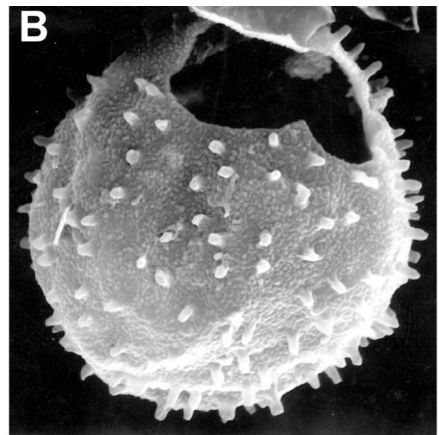
the Upper Valanginian–Lower Aptian *Cyclusphaera psilata*-*Classopollis* Zone of the Neuquén Basin.

South Atlantic Malvinas Plateau

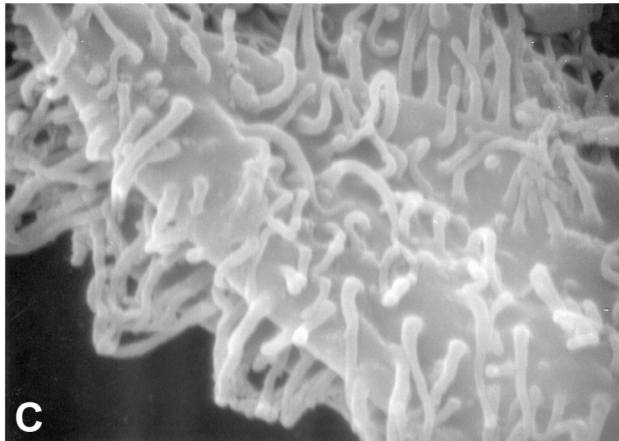
Harris (1976) studied cores from Deep Sea Drilling Sites 327, 328 and 330, situated on the Malvinas Plateau. He mentions a very strong southern hemisphere component, particularly in the marine elements, which show similarities with western Australia and the Indian Ocean. Common elements with the Agrio Formation are *Tenua hystrix* Eisenack, *Cribooperidinium orthoceras* (Eisenack) Davey, *Dingodinium cerviculum* Cookson and Eisenack, *Prolixosphaeridium* sp., *Spiniferites* sp. cf. *S. ramosus* (Ehrenberg) Mantell and *Chytroeisphaeridia* sp.



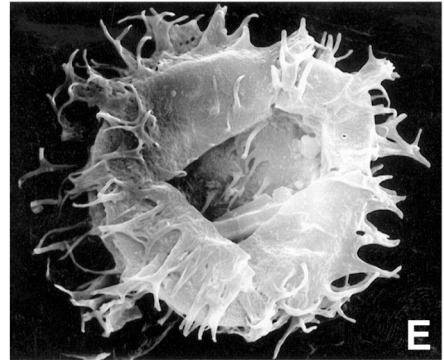
10 μm 30,0 kV 1,09E3 0981/93 3DL



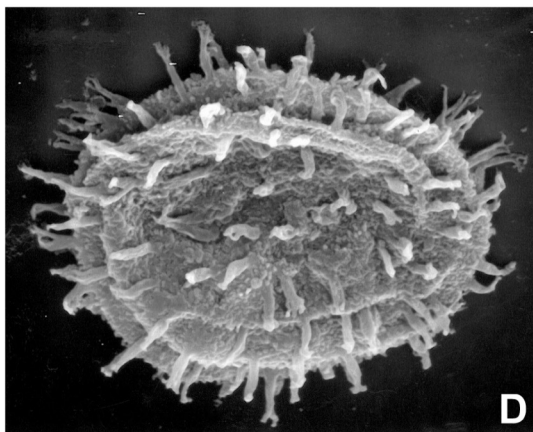
10 μm 30,0 kV 2,84E3 0980/93 3DL



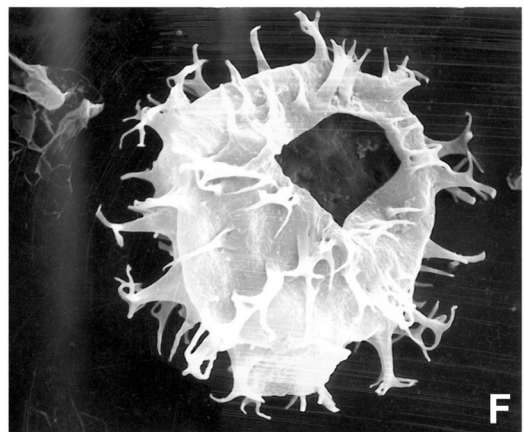
10 μm 30,0 kV 9,60E3 1715/31 VH 8F



10 μm 30,0 kV 1,05E3 1624/25 VH 8D



10 μm 30.0 kV 2.72E3 1965/30 VH 8F



10 μm 30.0 kV 1.05E3 1624/25 VH 8D

Fig. 7. All figures with SEM, from sample MPLP 9041 **A-B.** ?*Pervosphaeridium* sp. Figure 7A is a magnification of Fig. 7 B. **C-D.** *Protoellipsodinium* sp. **E.** *Spiniferites lenzii* Below, 1982. **F.** *Spiniferites* cf. *S. speetonensis* Duxbury, 1980. / Todas las figuras con MEB, de la muestra MPLP 9041. La figura 7A es una ampliación de la figura 7B.

Antarctic Peninsula: Livingston and Snow Islands

The Byers Group (Late Jurassic–Early Cretaceous) of Livingston and Snow islands, Antarctic Peninsula were deposited in a fore-arc setting and is comprised by the Late Jurassic Anchorage Formation, the Berriasian President Beaches Formation, the Valanginian Chester Cone Formation and overlying, non-differentiated non-marine strata. Duane (1996) emphasizes the strong affiliation of the Byers Group palynoflora to those from the Mesozoic of Australia and southern South America and the marked provincialism within the Valanginian marine microplankton content.

Australia

The assemblage of dinoflagellate cysts from the lowermost part of the Agrio Formation (Neuquén Basin) can be correlated with part of the Australian *Muderongia* Superzone and, within this superzone, with the *Phoberocysta burgeri* Interval Zone (Helby *et al.*, 1987), which extends from the oldest occurrence of *Phoberocysta burgeri* (at the base) and apparently the oldest occurrences of *Muderongia* spp. to the oldest occurrence of *Dinogonium cerviculum*. Significant forms within the Interval Zone mentioned are *Kaiwaradinium scrutillinum* Backhouse, *Systematophora areolata*, Klement, *Senoniasphaera tabulata* Backhouse and Helby and *Muderongia testudinaria* Burger. The suggested age is Late Valanginian to Early Hauterivian (Helby *et al.*, 1987). The Reference section is the Mullaloo-1 well, 821-861m, Leder-ville Formation.

PALEOBIOGEOGRAPHIC AND PALEOGEOGRAPHIC IMPLICATIONS OF THE ASSEMBLAGE OF DINOFLAGELLATE CYSTS OF THE AGRIO FORMATION AT SANTA ELENA LOCALITY

Of a total number of 27 morphotypes studied at the species level, 13 are from NW and W Europe, six from the Tethyan Realm, four from Australia and two from Canada.

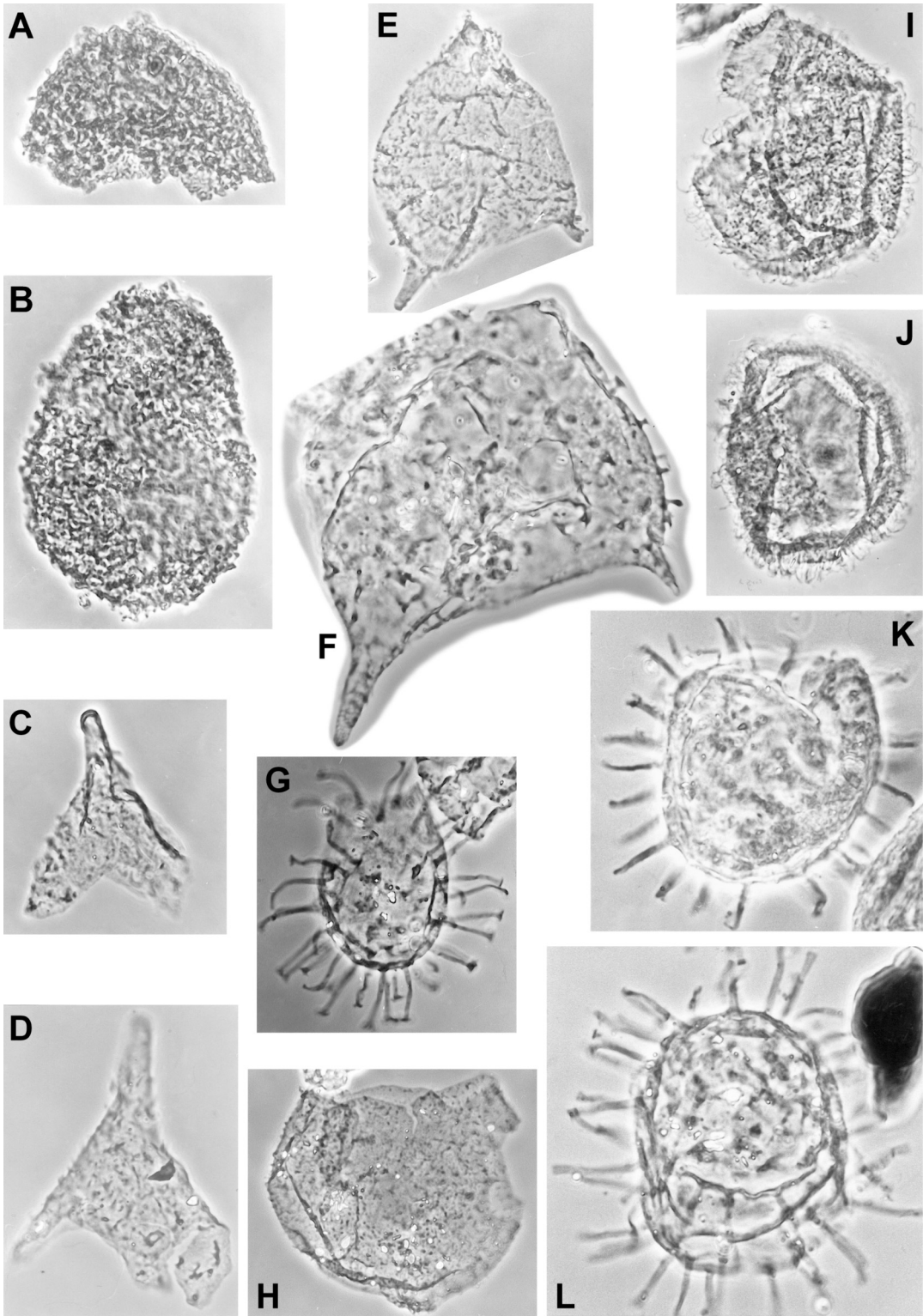
The cosmopolitan character of the assemblage of marine dinoflagellate cysts of the Agrio Formation at Estancia Santa Elena locality indicates for the late Valanginian and early Hauterivian an open marine connection between the Neuquén Basin, the Tethyan Realm and western/northwestern Europe. It also indicates a low gradient of paleotemperatures between paleoequator and poles.

Based on ammonite faunas, Aguirre-Urreta *et al.* (1999) established a correlation of the Agrio Formation with the column of the western Tethys, complemented by studies on palynomorphs and calcareous nannofossils. Their results show that an open marine connection, as above mentioned, continued through the Hauterivian and Barremian. In a later contribution, Aguirre-Urreta *et al.* (2008) show that early in the Cretaceous the ammonites are represented in the Neuquén Basin by six families (belonging to 20 genera/subgenera) of tethyan affinities and that paleotemperatures in the Neuquén Basin were similar to those in the Tethys.

STRATIGRAPHIC RANGE OF THE SPECIES OF DINOFLAGELLATE CYSTS PRESENT IN THE LOWERMOST SECTION OF THE AGRIO FORMATION AT ESTANCIA SANTA ELENA LOCALITY (TABLE 4)

Only two of the morphospecies present were originally described in Jurassic strata: *Prolixosphaeridium anasillum* Erkmen & Sarjeant, 1980 from the Late Callovian (Lamberti Zone) of Yorkshire and *Stiphrosphaeridium dictyophorum* (Cookson and Eisenack) Davey 1982 from the Late Jurassic of Australia. *Cometodinium habibii* Monteil, with a holotype from the Berriasian stratotype section in France and *Pilosidinium filiatum* (Davies) Courtinat, 1989 from the Upper Deer Bay Formation (Berriasian-Valanginian of Arctic Canada) have both a Late Jurassic to Valanginian distribution. The remaining 18 morphotypes are exclusively Cretaceous forms: 15 of them limited to the Early Cretaceous and three extending into the Late Cretaceous, as indicated

Fig. 8. All figures with phase contrast. **A-B.** *Protoellipsodinium* cf. *seghire* Below, 1981. **A.** Prep. MPLP 9040. A3/10C. SAS 107.5/18.2. **B.** Prep. 9040.A3/2H.SAS 100.0/3.4. **C-F.** *Pseudoceratium pelliferum* Gocht, 1957. **C.** Prep. MPLP 9041 A4/4C. SAS 91.1/11.2. **D.** Prep. MPLP 9041/A4/4C. SAS 97.5/16.8. **E.** Prep. MPLP 9040. A3/10C. SAS 100.1/19.0. **F.** Prep. MPLP 9041.A4/4C.SAS 96.9/16.0. **G.** *Tanyosphaeridium boletus* Davey, 1974. Prep. MPLP 9041/A4/4C. SAS 90.7/10.0. **H.** *Cyclonephelium* cf. *vannophorum* Davey, 1969. Prep. MPLP 9041. A4/5C. SAS 90.4/22.7. **I-J.** *Cometodinium* sp. cf. *C. habibii* Monteil, 1991a. **I.** MPLP 9041. A4/4C SAS 98.5/14.7. **J.** MPLP 9041. A4/4C. SAS 98.0/16.0. **K-L.** *Tanyosphaeridium isocalamum* (Deflandre & Cookson, 1955) Davey & Williams, 1969. **K.** MPLP 9041.A4/11C. SAS 95.7/20.0. **L.** MPLP 9041. A4/11C. SAS 97.0/220.0. Magnifications: **A-B, F-L:** x 1000, **C-E:** x 500. / Todas las figuras con contraste de fase. Aumentos: **A-B, F-L:** x 1000, **C-E:** x 500.



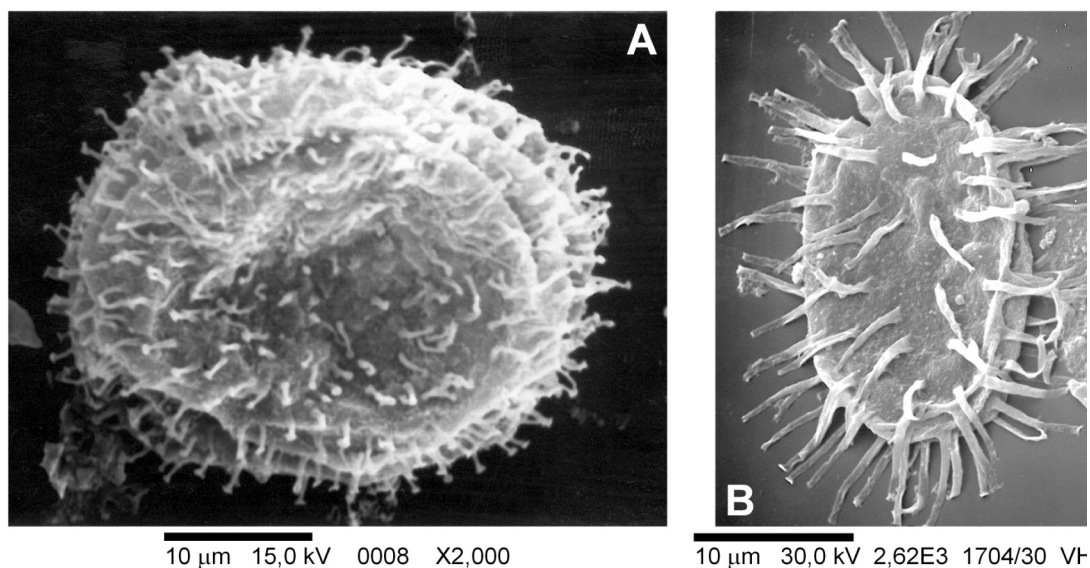


Fig. 9. All figures with SEM, from sample MPLP 9041. **A.** *Tenua* cf. *hystrix* Eisenack emend. Sarjeant, 1985. **B.** *Prolixosphaeridium* cf. *anasillum* Erkmén & Sarjeant, 1980. / Todas las figuras con MEB, de la muestra MPLP 9041

Table 4. Stratigraphic range of dinoflagellate cyst species present in the lowermost section of the Agrío Formation at Estancia Santa Elena locality. / Distribución estratigráfica de las especies de quistes de dinoflagelados presentes en la parte inferior de la Formación Agrío en la localidad Estancia Santa Elena.

Taxon	Obs.	Jurassic				Cretaceous							
		Mid	Late			Early					Late		
		Call	Oxf	Ki	Tit	Berr	Val	Hau	Barr	Apt		Alb	
<i>Prolixosphaeridium anasillum</i>	cf.	█	█	█	█	█	█	█					
<i>Pilosidinium filiatum</i>			█	█	█	█	█	█					
<i>Cometodinium habibii</i>	cf.				█	█	█	█	█	█	█	█	█
<i>Stiphrosphaeridium dictyophorum</i>					█	█	█	█					
<i>Sentusidinium cuculliformis</i>					█	█	█	█					
<i>Occisucysta tentoria</i>						█	█	█	█				
<i>Pseudoceratium pelliferum</i>						█	█	█	█				
<i>Oligosphaeridium quattrocchioae</i>						█	█	█	█				
<i>Muderongia sarjeantii</i>							█	█	█				
<i>Muderongia siciliana</i>							█	█	█				
<i>Dapsilidinium chems</i>							█	█	█	█			
<i>Spiniferites speetonensis</i>	cf.						█	█	█	█	█		
<i>Systematophora silybum</i>							█	█	█	█	█		
<i>Tanyosphaeridium boletus</i>							█	█	█	█	█		
<i>Tanyosphaeridium isocalamum</i>							█	█	█	█	█	█	
<i>Protoellipsodinium seghire</i>	cf.						█	█	█	█	█	█	█
<i>Spiniferites lenzii</i>							█	█	█	█	█	█	█
<i>Dapsilidinium duma</i>	cf.						█	█	█	█	█	█	█
<i>Florentinia? neptuni</i>							█	█	█	█	█	█	█
<i>Cyclonephelium vannophorum</i>	cf.						█	█	█	█	█	█	█
<i>Hystrichodinium pulchrum</i>							█	█	█	█	█	█	█
<i>Circulodinium distinctum</i>							█	█	█	█	█	█	█

on Table 4. The latter are *Cyclonephelium van-nophorum* Davey extending to the Cenomanian, *Hystriochodinium pulchrum* Deflandre and *Circulodinium distinctum* (Deflandre and Cookson) Jansonius, both with holotypes of Senonian age. The known distributions of the two endemic forms *Oligosphaeridium quattrocchioae* nov. sp. and *Muderongia sarjeantii* nov. sp. are limited to the late Valanginian and early Hauterivian strata of the study area.

CONCLUSIONS

1. In an assemblage of dinoflagellate cysts from the Pilmatué Member of the Early Cretaceous Agrio Formation (Neuquén Basin) 30 marine species are recognized.
2. The new species *Oligosphaeridium quattrocchioae* and *Muderongia sarjeantii* are endemic.
3. Comparison of the dinoflagellate cyst assemblage of the Pilmatué Member of the Agrio Formation at Santa Elena locality with other Early Cretaceous assemblages from the southern hemisphere, the Tethyan realm and northwestern Europe, shows the cosmopolitan character of most components of the assemblage here studied and indicates a low gradient of temperatures between the paleoequator and poles during Early Cretaceous times.

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The author thanks Dr. W. A. S. Sarjeant for advise during a stay in Saskatchewan and during his visit to Argentina in 2000. This work was originally planned as a joint publication with him, who unfortunately died on 8th of July, 2002. This

paper is written in memory of my good friend William Antony Swithin Sarjeant.

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APPENDIX

List of species

In this section a full list of the dinoflagellate cyst taxa studied from the Agrio Formation at Estancia Santa Elena locality is given. The classification follows that of Fensome *et al.* (1993). For citations of papers referred to in the list that follows, see Fensome & Williams (2004). Full citations of papers published since that work, or cited when taxonomic proposals are made, are presented in the "References". In cases of doubtful determination (? or cf.), a brief explanation is given after citation.

- Achomospaera* sp. A of Norvick & Burger, 1976 (fig. 4.D)
Circulodinium distinctum (Deflandre & Cookson, 1955) Jansonius, 1986 (figs. 3.A-B)
Cometodinium sp. cf. *C. habibii* Monteil 1991a (The cf. refers to the difficulty to observe the position of the archaeopyle) (figs. 8.J-L)
Cyclonephelium cf. *vannophorum* Davey, 1969 (Identification is based on only one specimen of fair preservation) (fig. 8.H)
Cymosphaeridium sp. 1 of Davey, 1982
Dapsilidinium chems (Below, 1982) Lentin & Williams, 1985 (fig. 3.C)
Dapsilidinium cf. *duma* (Below, 1982) Lentin & Williams, 1985. (Identification is based on only one specimen of fair preservation) (fig. 3.D)
Florentinia cf. *interrupta* Duxbury, 1980 (The cf. refers to the greater complexity of the processes, especially the antapical process, in our material) (figs. 3.F and 5.C)
Achomospaera neptuni (Eisenack, 1958a) Davey & Williams, 1966 (fig. 5.B)
Heterosphaeridium? galiciae, Masure, 1988 (Identification is based on only one specimen of fair preservation) (fig. 5.D)
Hystrichosphaeridium pulchrum Deflandre 1935 (fig. 5.A)
Muderongia siciliana Torricelli, 1997 (figures 4.A-C)
Muderongia sarjeantii Volkheimer, sp. nov. (figs. 4.E-H)
Occisucysta tentoria Duxbury, 1977 (figs. 5.F-G)
Oligosphaeridium quattrocchioae Volkheimer, sp. nov. (figs 5.H-M and 6.A-B, F-H)
? *Pervosphaeridium* sp. (Identification is based on only one specimen) (figs. 7.A-B)
Pilosidinium filiatum (Davies, 1983) Courtinat, 1989 (fig. 5.E)
Prolixosphaeridium cf. *anasillum* Erkmen & Sarjeant, 1980 (Identification is based on only one specimen) (fig. 9.B)
Protoellipsodinium cf. *seghire* Below, 1981 (Identification is based on only one specimen of fair preservation) (figs. 8.A-B)
Protoellipsodinium sp. (figs. 7.C-D)
Pseudoceratium pelliferum Gocht 1957 (figs. 8.C-F)
Sentusidinium cuculliformis Davies, 1983 (fig. 4.I)
Spiniferites lenzii Below, 1982 (fig. 7.E)
Spiniferites cf. *S. speetonensis* Duxbury, 1980 (Identification is based on only one specimen) (fig. 7.F)
Stiphrosphaeridium dictyophorum (Cookson & Eisenack) Davey 1982 (figs. 6.C-D)
Stiphrosphaeridium sp. (fig. 6.E)
Systematophora silybum Davey, 1979a (fig. 3.E)
Tanyosphaeridium boletus Davey, 1974 (fig. 8.G)
Tanyosphaeridium isocalamum (Deflandre & Cookson, 1955) Davey & Williams, 1969 (fig. 8.K-L)
Tenua cf. *hystrix* Eisenack emend. Sarjeant, 1985 (Identification is based on only one specimen of fair preservation) (fig. 9. A).