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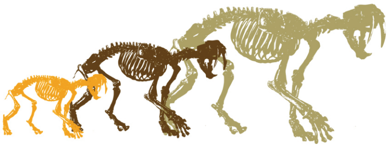

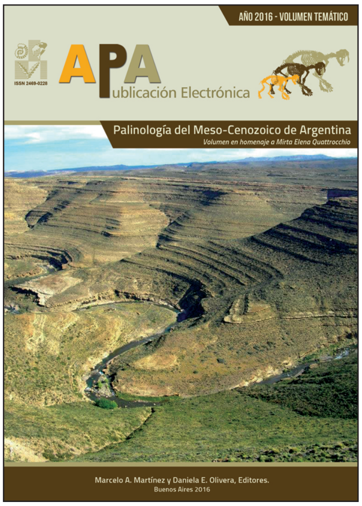

EARLY CRETACEOUS DINOFLAGELLATE CYSTS FROM THE NEUQUÉN AND AUSTRAL BASINS: A REVIEWAPPROACH

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EARLY CRETACEOUS DINOFLAGELLATE CYSTS FROM THE NEUQUÉN AND AUSTRAL BASINS: A REVIEW

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Abstract. The present work documents and gathers the most relevant records of the organic-walled dinoflagellate cysts from different sites of the Neuquén and Austral Basins. Most of these records have contributed to the palaeoenvironmental, biostratigraphical and palaeobiogeographical interpretations of the different stratigraphical units in both basins. The dinoflagellate cysts assemblages come from the Springhill, Upper Río Mayer, Piedra Clavada, Kachaike and “Margas Verdes” Formation of the Austral Basin, and from the upper part of the Vaca Muerta and the Agrio Formations of the Neuquén Basin, several of these stratigraphical units conform the main petroleum systems in both basins.

Key words. Cretaceous. Marine palynomorphs. Sedimentary basins. Argentina.

Resumen. QUISTES DE DINOFLAGELADOS DEL CRETÁCICO TEMPRANO DE LAS CUENCAS NEUQUINA Y AUSTRAL: UNA REVISIÓN. Se documentaron y recopilaron los registros más relevantes de los quistes de dinoflagelados de pared orgánica provenientes del Cretácico Inferior de las cuencas Neuquina y Austral en diferentes localidades de estudio. La mayoría de estos registros han contribuido a las interpretaciones paleoambientales, bioestratigráficas y paleobiogeográficas de diferentes sucesiones sedimentarias marinas en ambas cuencas. Las asociaciones de quistes de dinoflagelados provienen de las Formaciones Springhill, Río Mayer Superior, Piedra Clavada, Kachaike y “Margas Verdes” de la Cuenca Austral, y de la parte superior de las Formaciones Vaca Muerta y Agrio de la Cuenca Neuquina, varias de estas unidades estratigráficas conforman los principales sistemas petroleros de ambas cuencas.

Palabras clave. Cretácico. Palinomorfos marinos. Cuencas sedimentarias. Argentina.

ORGANIC-WALLED marine dinoflagellate cysts have offered valuable bioestratigraphic information for the Lower Cretaceous Basins from the Boreal (*e.g.,* Prössl, 1990; Williams *et al.*, 1990; Harding, 1990; Nør-Hansen, 1993) and Mediterranean Realms (*e.g.,* Leereveld, 1997a,b; Torricelli, 2000), as well as in the Southern Hemisphere in Australia (Helby *et al.,* 1987; Oosting *et al.*, 2006) and Antartica (Riding and Crame 2002). In southernmost South America, dinoflagellate cysts have contributed to elucidate biostratigraphic and palaeobiogeographic aspects in the Austral Basin (*e.g.,* Palamarczuk *et al.*, 2000a,b; Guler *et al.*, 2003; Guler and Archangelsky, 2006) and the Neuquén Basin (*e.g.,* Peralta, 1997; Volkheimer, 2010; Guler *et al.*, 2013), the two most important oil-producing basins from Argentina and Chile.

The Austral Basin is limited by the Southern Patagonian Andes to the west and by the Deseado Massif to the east (Biddle *et al.*, 1986; Robbiano *et al.*, 1996). It includes about 8000-m-thick deposits ranging from the Late Jurassic to the Cenozoic (*e.g.*, Schwarz *et al.*, 2011). During the Early Cretaceous, a regionally extended succession, mostly composed of marine fine sediments, was deposited in a sagging phase (Biddle *et al.*, 1986; Robbiano *et al.*, 1996). The Springhill Formation and its equivalents (lower Río Mayer and the subsurface “Lower *Inoceramus*” Formations) represent the oldest sedimentary rocks of the Austral Basin, which were deposited mostly during Berriasian–Barremian times. They represent a long-term (>25 My) transgressive cycle likely controlled by low-frequency sea-level fluctuations in a back arc setting (*e.g.*, Biddle *et al.*, 1986; Robbiano *et al.*, 1996; Arbe and Fernández Bell Fano, 2002), commonly developed as the infill of extensive topographic depressions (Schwartz *et al.*, 2011). The Aptian to Albian upper part of the Río Mayer

Formation, the equivalent Kachaike Formation and the subsurface deep marine “Margas Verdes” unit, were accumulated at the end of this thermal subsidence phase.

The Neuquén Basin is located in central-western Argentina between 32°–40° South Latitudes and covers part of the Mendoza, Neuquén, Río Negro and La Pampa provinces. The infill of the Basin comprises more than 7000 m of marine and continental sedimentary rocks, ranging in age from the Late Triassic to the Paleocene (Legarreta and Gulisano, 1989; Legarreta and Uliana, 1991). It is a major Mesozoic to Neogene depocenter, and one of the few Southern Hemisphere basins having an excellent marine record from latest Jurassic to mid Early Cretaceous (early Barremian) times. During that interval, the area formed a back-arc basin linked to the Pacific Ocean on its western margin through a volcanic island arc (Legarreta and Uliana, 1991). It is limited by cratonic areas to the northeast (Sierra Pintada System) and southeast (North Patagonian Massif). During the Early Cretaceous, the basin formed large marine embayments linked to episodes of relative sea level rise (Legarreta and Gulisano, 1989). The marine sedimentary rocks accumulated during the Early Cretaceous (Berriasian–early Barremian) are represented by the Vaca Muerta and Agrio formations of the Mendoza Group (Groeber, 1946). The thick and laterally continuous exposures, and the abundant fossil record of these deposits, make the Neuquén Basin an excellent site for stratigraphic, palaeontological and geochemical studies.

The aim of this work is to review and summarize the most relevant biostratigraphical and palaeobiogeographical

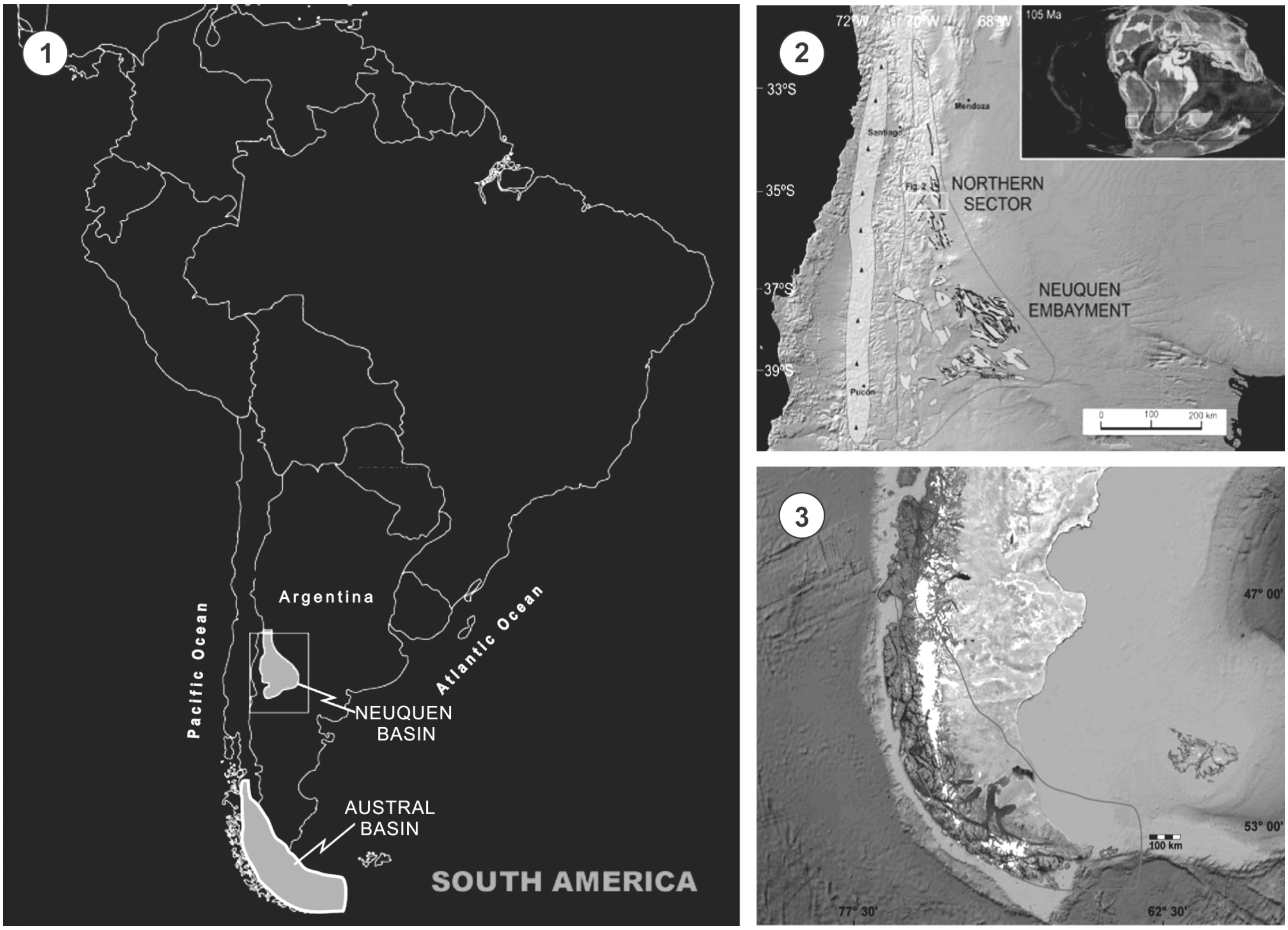


Figure 1. 1, Location map of the Neuquén and Austral Basins in the southernmost part of South America. **2,** Location of the Neuquén Basin in the central-west Argentina. **3,** Location of the Austral Basin in the southern tip of Argentina.

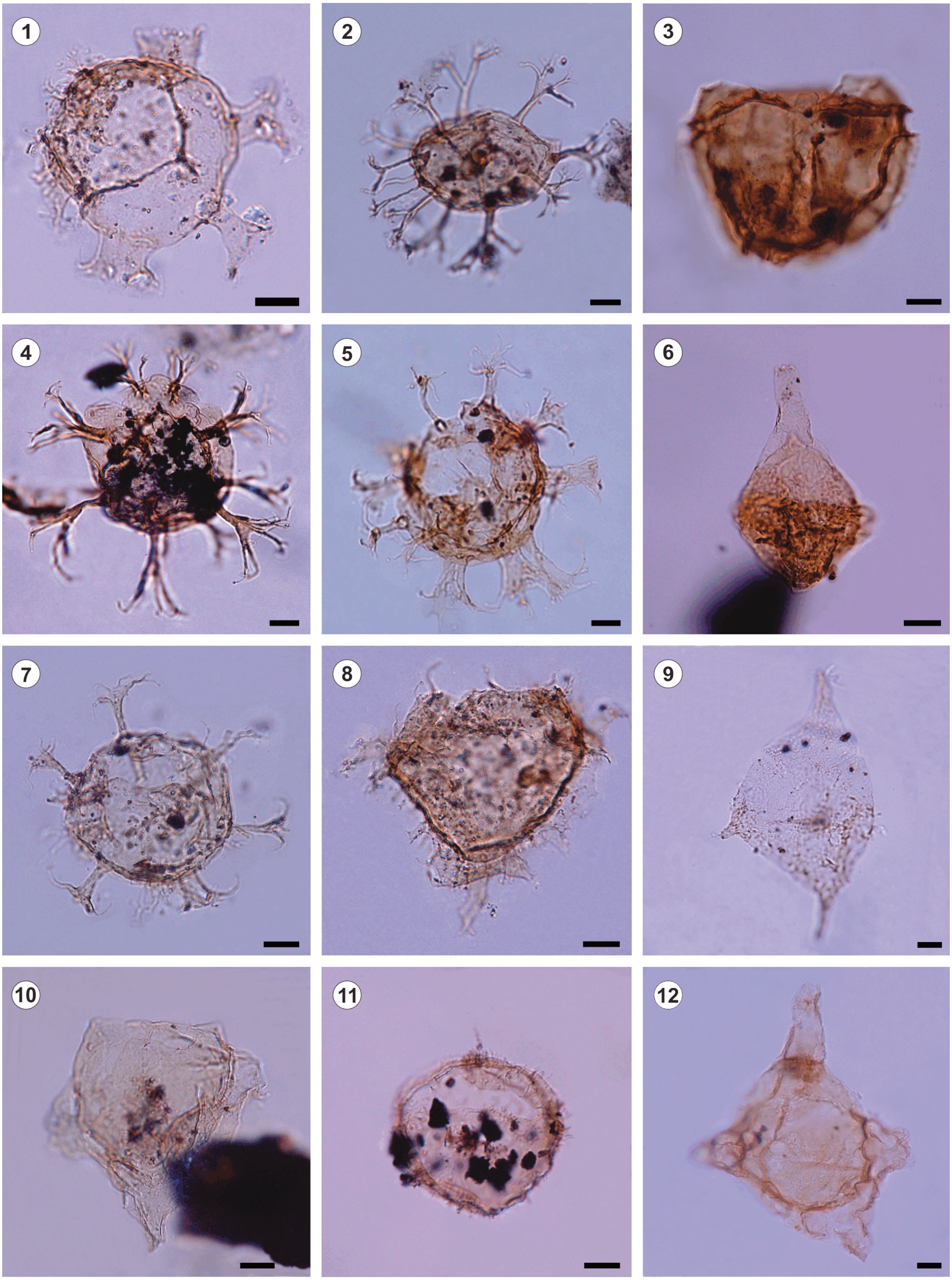
data based on dinoflagellate cysts published to date from Early Cretaceous sedimentary succesions of the Austral and Neuquén basins. Most of the stratigraphical units herein presented include several economically-important hydrocarbon source and reservoir rocks (Uliana and Legarreta, 1993).

SIGNIFICANT EARLY CRETACEOUS DINOFLAGELLATE CYSTS RECORD FROM THE SOUTHERNMOST PART OF SOUTH AMERICA

Neuquén Basin

Palynological studies on Cretaceous deposits of the Neuquén Basin, focused on dinoflagellate cysts, began in the 80's. The oldest records come from the black shales of the Vaca Muerta Formation of early Tithonian–early Valanginian age (Legarreta and Uliana, 1991; Legarreta *et al*., 1993). Quattrocchio and Volkheimer (1985) documented late Berriasian dinoflagellate cysts in the Mallín Quemado locality, Neuquén province. These authors recognized 12 dinoflagellate cyst taxa including *Gonyaulacysta* sp. A, cf. *Rhaetogonyaulax* sp., *Pareodinia* cf. *P. ceratophora* Deflandre 1947 *emend*. Gocht 1970, *Acanthaulax* sp., *Leptodinium ambiguum* (Deflandre 1939) Helenes 1984, *Ctenidodinium tenellum* Deflandre 1939, *Hystrichosphaerina neuquina* Quattrocchio and Volkheimer 1983 *emend*. Quattrocchio and Sarjeant 1992, *Systematophora* sp. A, *Prolixosphaeridium* sp., *Sentusidinium* sp. A, *Lithodinia* sp. A., and the new species *Cribroperidinium reticulatum* Quattrocchio and Volkheimer 1985. Afterwards, Quattrocchio and Volkheimer (1990) added *Pareodinia ceratophora* var. *pachyceras* (Sarjeant 1959) Lentin and Williams 1973, *Sentusidinium villersense* (Sarjeant 1968) Sarjeant and Stover 1978, and *Systematophora penicillata* (Ehrenberg 1843) Sarjeant 1980 to the previous taxonomic list of the Mallín Quemado locality, and considered *Hystrichosphaerina neuquina* and *Cribroperidinium reticulatum* as endemic species of the Neuquén Basin.

Dinoflagellate cyst assemblages from the late Valanginian–early Hauterivian Pilmatué Member of the Agrio Formation were documented for the first time by Quattrocchio and Volkheimer (1990) at the Pichaihue Abajo, Bajada Vieja and Cerro Mesa localities. More detailed studies of the Pilmatué Member were carried out by Peralta (1997) at the Cerro Mesa and Cerro Negro of Covunco sections (Neuquén province) where they recorded about 42 taxa. With the exception of the gymnodinialean genus *Dinogymnium* Evitt *et al.* 1967 *emend*. Lentin and Vozzhennikova 1990, the species identified belong to the Order Gonyaulacales, chorate and proximochorate cysts (*e.g., Achomosphaera neptuni* (Eisenack 1958) Davey and Williams 1966a, *A. ramulifera* (Deflandre 1937) Evitt 1963, *Kleithriasphaeridium fasciatum* (Davey and Williams 1966b) Davey 1974, *K. simpliscispinum* (Davey and Williams 1966b) Davey 1974, *Oligosphaeridium complex* (White 1842) Davey and Williams 1966b, *Spiniferities ramosus* (Ehrenberg 1838) Mantell 1854, *Surculosphaeridium longifurcatum* (Firtion 1952) Davey *et al*. 1966, *Systematophora rosenfeldii* Volkheimer and Sarjeant 1993, *Tanyosphaeridum variecalamum* (Davey and Williams 1966b); proximate cysts (*e.g.*, *Batiacasphaera asperata* Backhouse 1987, *Cassiculosphaeridia magna* Davey 1974 *emend*. Harding 1990, *Cribroperidinium orthoceras* (Eisenack 1958) Davey 1969 *emend*. Sarjeant 1985, *C. muderongense* (Cookson and Eisenack 1958) Davey 1969, among the most frequent) and cavate cysts with the common presence of *Dingodinium cerviculum* Cookson and Eisenack 1958 *emend*. Khowaja-Ateequzzaman *et al.* 1990 (Peralta, 1997). The relative abundance data of these three morphological groups of cysts contributed to characterize the marine palaeoenvironments which oscillates from external neritic to neritic and coastal environments through the section (Peralta and Volkheimer 1997, 2000). In 2010, Volkheimer described a late Valanginian–early Hauterivian dinoflagellate cyst assemblage from Santa Elena locality, and recognized 30 morphotypes with the definition of two new endemic species for the Member: *Oligosphaeridium quattrocchiae* Volkheimer 2010 and *Muderongia sarjeantii* Volkheimer 2010. Recently, Paolillo *et al*. (2015) identified at the Bajada del Agrio locality, 41 species belonging to the Order Gonyaulacales. Assemblages are dominated by *Cribroperidinium* spp., *Hystrichodinium pulchrum* Deflandre 1935, *Circulodinium distinctum* (Deflandre and Cookson 1955) Jansonius 1986 and *Florentinia* spp. Additionally, three biostratigraphically significant events were identified for the Lower Cretaceous of the Neuquén Basin, that consist of the oldest (first) and/or the youngest (last) occurrence of a particular species, herein referred as “First appearance datums” or FADs and “Last appearance datum” or LADs, respectively. These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events are the FAD of *Callaiosphaeridium asymmetricum* (Deflandre and Courteville 1939) Davey and Williams 1966b *emend*. Clarke and Verdier 1967, the FAD and the LAD of *Cymososphaeridium validum* Davey 1982. The FAD of *Callaiosphaeridium asymmetricum* was recorded at the base of the *Holcoptychites neuquensis* Subzone of the *H. neuquensis* Zone of Aguirre Urreta and Rawson (1997), assigned to the earliest Hauterivian. The FAD of *Cymososphaeridium validum* was identified at the uppermost part of the *Hoplitocrioceras gentilii* Subzone of the *H. gentilii* Zone of Aguirre Urreta and Rawson (1997), dated as late early Hauterivian, and the LAD of this species was recorded at the lower part of the *Crioceratites diamantensis* Zone of Aguirre Urreta and Rawson (1997), of a late Hauterivian age.

The first study on dinoflagellate cysts from the Agua de la Mula Member was carried out at the Agua de la Mula and Bajada del Agrio sections by Hernández *et al*. (2005) and Ottone *et al*. (2008). The gonyaulacalean *Circulodinium distinctum*, *Cribroperidinium orthoceras*, *Cribroperidinium spp., Exochosphaeridium bifidum* (Clarke and Verdier 1967) Clarke *et al*. 1968, *Florentinia mantellii* (Davey and Williams 1966b) Davey and Verdier 1973, *Florentinia* spp., *Kiokansium unituberculatum* (Tasch in Tasch *et al.* 1964) Stover and Evitt 1978, *Hystrichodinium pulchrum* and *Oligosphaeridium complex* are the dominant taxa in these assemblages and particularly, ceratiacean morphotypes such as *Phoberocysta neocomica* (Gocht 1957) Millioud 1969 *emend*. Helby 1987, *Muderongia staurota* Sarjeant 1966 *emend*. Monteil 1991b, *M. pariata* Duxbury 1983 *emend*. Monteil 1991b and other closely related forms are well represented. Besides the presence of the endemic *Oligosphaeridium quattrocchioae*, most of the species recovered are cosmopolitan such as *Circulodinium distinctum*, *Cribroperidinium* spp., *Exochosphaeridium* spp., *Kiokansium unituberculatum*, *Dingodinium cerviculum* and *Oligosphaeridium complex*, which are present in almost all the assemblages throughout the Agua de la Mula Member. Ceratiacean cysts are represented by *Phoberocysta neocomica, Pseudoceratium pelliferum* Gocht 1957 *emend*. Dörhöfer and Davies 1980 and several morphotypes of the genus *Muderongia* Cookson and Eisenack 1958, mainly *M.* cf. *M. staurota*, *M. pariata*, *M tomaszowensis* Alberti 1961 *emend*. Riding *et al*. 2001, *M*. cf. *M. siciliana* Torricelli 1997, and *M. tetracantha* (Gocht 1957) Alberti 1961 *emend.* Monteil 1991b (Hernández *et al*., 2005; Ottone *et al*., 2008; Guler *et al*., 2013; Paolillo, personal observation). Ottone and Pérez Loinaze (2002) erected a new species *Muderongia brachialis* from the Agua de la Mula Member at Paraje El Rincón (Río Agrio). It is a biostratigraphycally useful taxon within the Neuquén Basin, since its occurrence is restricted to the *Spitidiscus ricardii* and *Crioceratites schlagintweiti* ammonite Zones, which spans the latest early Hauterivian to the base of the late Hauterivian.

Table 1 contains the dinoflagellate cyst species identified in the Neuquén Basin and referenced according to the Fensome and Williams Index; Fensome and Williams (2004).

Austral Basin

Early Cretaceous dinoflagellate cyst assemblages recorded in the marine deposits of the Austral Basin, mainly come from the offshore subsurface sequences, whereas studies in continental areas of Patagonia are scarce. Based on dinoflagellate cysts and ammonites, Pöthe de Baldis and Ramos (1983, 1988) analized Aptian dinoflagellate cysts from the west of Santa Cruz Province, and Ottone and

Figure 2. Early Cretaceous dinoflagellate cysts from the Pilmatué and Agua de la Mula Members of the Agrio Formation, Neuquén Basin. **1,** ***Callaiosphaeridium asymmetricum*** (Deflandre and Courteville) Davey and Williams *emend*. Clarke and Verdier, apical view, low focus BA 4218 35/118,5. **2,** ***Cymososphaeridium validum*** Davey, lateral view, intermediate focus BA 4229 46,5/100. **3,** ***Meiourogonyaulax stoveri*** Millioud, ventral view, high focus BA AG3d 50/103. **4,** ***Surculosphaeridium longifurcatum*** (Firtion) Davey *et al*., dorsal view, low focus BA 4229 37,5/109. **5,** ***Oligosphaeridium quattrocchioae*** Volkheimer, apical view, high focus BA AG3d 29/108,5. **6,** ***Dingodinium cerviculum*** Cookson and Eisenack *emend*. Mehrota and Sarjeant, general view BA AG5b 51/104. **7,** ***Oligosphaeridium complex*** (White) Davey and Williams, oblique apical view, low focus BA 4227 47/108,5. **8,** ***Phoberocysta neocomica*** (Gocht) Helby, dorsal view, low focus BA 4227 54/116,5. **9,** ***Pseudoceratium pelliferum*** Gocht *emend.* Dörhöfer and Davies, ventral view, cross section BA 4211 19/110,5. **10,** ***Muderongia pariata*** Duxbury *emend.* Monteil, dorsal view, low focus BA AG10b 35/120. **11,** ***Nexosispinum*** sp. dorsal view, high focus BA AG21a 37,5/117. **12,** ***Muderongia*** **cf.** ***M. tomaszowensis*** Alberti *emend.* Monteil, ventral view high focus BA 4227 20,5/121,5. Scale bar= 10µm.

Table 1 – List of the dinoflagellate cyst taxa identified from the Early Cretaceous assemblages of the Neuquén and Austral Basins.

Taxa	*Neuquén Basin*	*Austral Basin*
Acanthaulax sp.	*x*	
Achomosphaera neptuni *(Eisenack 1958) Davey and Williams 1966a*	*x*	
A. ramulifera *(Deflandre 1937) Evitt 1963*	*x*	
Batiacasphaera asperata *Backhouse 1987*	*x*	
Callaiosphaeridium asymmetricum *(Deflandre and Courteville 1939) Davey and Williams 1966b* emend. *Clarke and Verdier 1967*	*x*	
Canninginopsis denticulata *Cookson and Eisenack 1962*		*x*
Cassiculosphaeridia magna *Davey 1974* emend. *Harding 1990*	*x*	*x*
Chichaouadinium boydii *(Morgan 1975) Bujak and Davies 1983*		*x*
Circulodinium distinctum (*Deflandre and Cookson 1955) Jansonius 1986*	*x*	*x*
Cometodinium *cf.* **C. comatum** *Srivastava 1984* emend. *Monteil 1991a*		*x*
Cribroperidinium confossum *(Duxbury 1977) Helenes 1984*		*x*
C. muderongense *(Cookson and Eisenack 1958) Davey 1969*	*x*	
C. orthoceras *(Eisenack 1958) Davey 1969* emend. *Sarjeant 1985*	*x*	
C. reticulatum *Quattrocchio and Volkheimer 1985*	*x*	
Ctenidodinium tenellum *Deflandre 1939*		*x*
Cyclonephelium vannophorum *Davey 1969*		*x*
Cymososphaeridium validum *Davey 1982*	*x*	
Dingodinium cerviculum *Cookson and Eisenack 1958* emend. *Kowaja-Ateequzzaman* et al. *1990*	*x*	*x*
Dinogymnium *Evitt* et al. *1967* emend. *Lentin and Vozzhennikova 1990*	*x*	
Dinopterygium tuberculatum *(Eisenack and Cookson 1960) Stover and Evitt 1978*		*x*
Exochosphaeridium bifidum *(Clarke and Verdier 1967) Clarke* et al. *1968*	*x*	
Florentinia mantellii *(Davey and Williams 1966b) Davey and Verdier 1973*	*x*	
Gonyaulacysta *sp. A.*	*x*	
Hapsocysta peridictya *(Eisenack and Cookson 1960) Davey 1979* emend. *Davey 1979*		*x*
Herendeenia postprojecta *Stover and Helby 1987*		*x*
Hystrichodinium pulchrum *Deflandre 1935*	*x*	
Hystrichosphaerina neuquina *Quattrocchio and Volkheimer 1983* emend. *Quattrocchio and Sarjeant 1992*	*x*	
Kaiwaradinium scrutillinum *Backhouse 1987*		*x*
Kiokansium unituberculatum *(Tasch in Tasch* et al. *1964) Stover and Evitt 1978*	*x*	
Kleithriasphaeridium fasciatum *(Davey and Williams 1966b) Davey* 1974	*x*	*x*
K. simpliscispinum *(Davey and Williams 1966b) Davey 1974*	*x*	
Leptodinium ambiguum *(Deflandre 1939) Helenes 1984 (as Millioudodinium ambiguum*)	*x*	

TABLE 1 – Continuation.

Taxa	*Neuquén Basin*	*Austral Basin*
Lithodinia *sp. A*	*x*	
Litosphaeridium arundum *(Eisenack and Cookson 1960) Davey 1979* emend. *Lucas-Clark 1984*		*x*
Muderongia brachialis *Ottone and Pérez Loinaze 2002*	*x*	
M. pariata *Duxbury 1983* emend. *Monteil 1991b*	*x*	
M. sarjeantii *Volkheimer 2010*	*x*	
M. staurota *Sarjeant 1966* emend. *Monteil 1991b*	*x*	
M. *cf.* **M. staurota** *Sarjeant 1966* emend. *Monteil 1991b*	*x*	
M. tetracantha *(Gocht 1957) Alberti 1961* emend. *Monteil 1991b*	*x*	*x*
M. tomaszowensis *Alberti 1961* emend. *Riding* et al. *2001*	*x*	
M. *cf.* **M. siciliana** *Torricelli 1997*	*x*	
Nematosphaeropsis densiradiata *(Cookson and Eisenack 1962b) Stover and Evitt 1978*		*x*
Odontochitina operculata *(Wetzel 1933) Deflandre and Cookson 1955*		*x*
Oligosphaeridium complex *(White 1842) Davey and Williams 1966b*	*x*	*x*
O. quattrocchiae *Volkheimer 2010*	*x*	
O. pulcherrimum *(Deflandre and Cookson 1955) Davey and Williams 1966b*		*x*
Ovoidinium cinctum *(Cookson and Eisenack 1958) Davey 1970*		*x*
Pareodinia *cf.* **P.ceratophora** *Deflandre 1947* emend. *Gotch 1970*	*x*	
Pareodinia ceratophora var. pachyceras *(Sarjeant 1959) Lentin and Williams 1973*	*x*	
Phoberocysta neocomica *(Gocht 1957) Millioud 1969* emend. *Helby 1987*	*x*	*x*
Prolixosphaeridum conulum *Davey 1969*		*x*
P. parvispinum *(Deflandre 1937) Davey* et al. *1969*		*x*
Prolixosphaeridium *sp.*	*x*	
Pseudoceratium pelliferum *Gocht 1957* emend. *Dörhöfer and Davies 1980*	*x*	
Senoniasphaera tabulata *Helby 1987*		*x*
Sentusidinium villersense *(Sarjeant 1968) Sarjeant and Stover 1978*	*x*	
Sentusidinium *sp. A*	*x*	
Spiniferities ramosus *(Ehrenberg 1838) Mantell 1854*	*x*	
Surculosphaeridium longifurcatum *(Firtion 1952) Davey* et al. *1966*	*x*	
Systematophora penicillata *(Ehrenberg 1843b) Sarjeant 1980*	*x*	
Systematophora rosenfeldii *Volkheimer and Sarjeant 1993*	*x*	
Systematophora *sp. A*	*x*	
Tanyosphaeridum variecalamum *(Davey and Williams 1966b)*	*x*	

References correspond to the Fensome and Williams Index; Fensome and Williams (2004).


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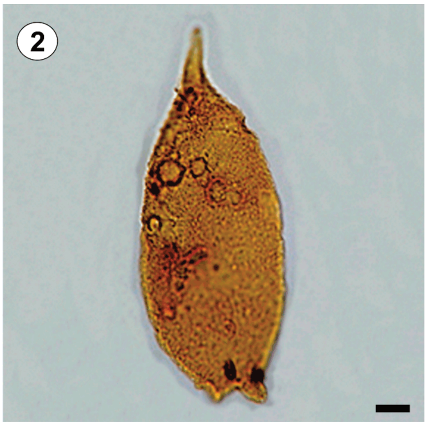
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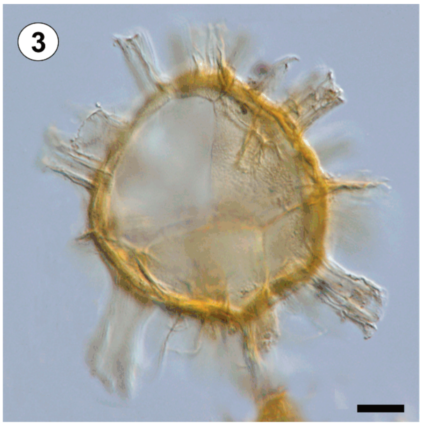
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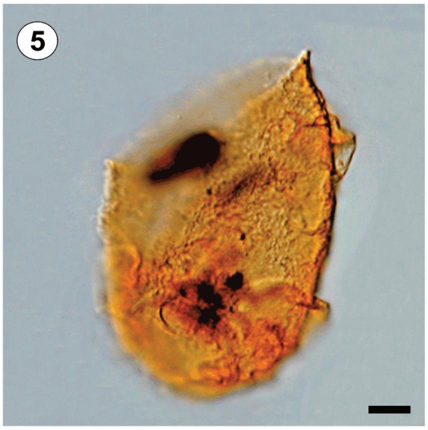
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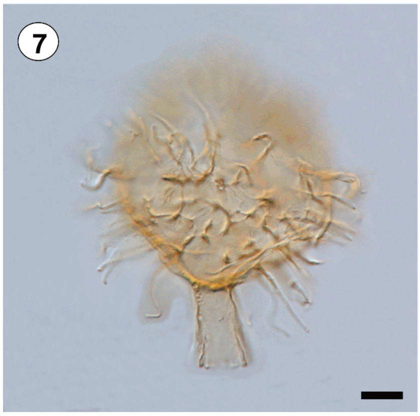
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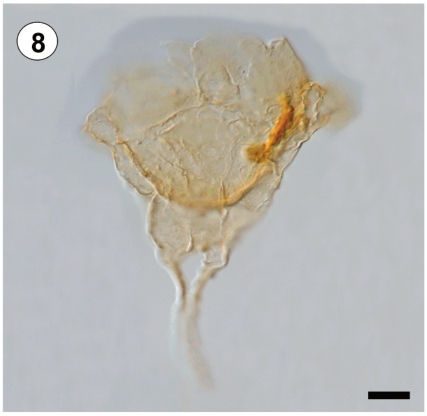
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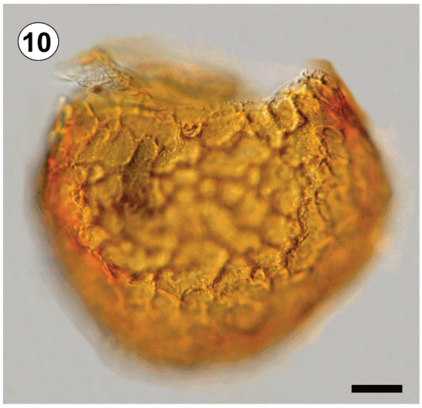
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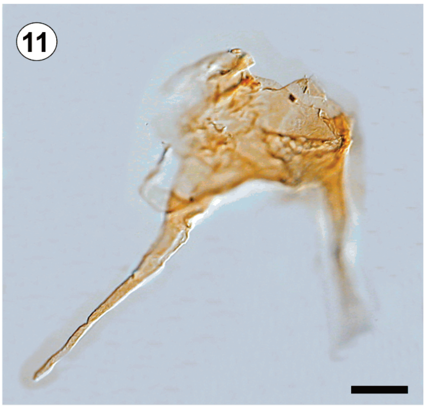
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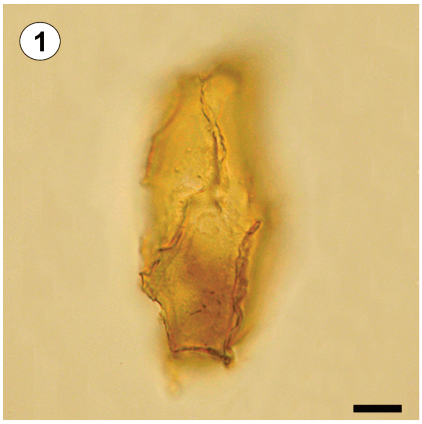
Aguirre Urreta (2000) suggested a probable late early Hauterivian–early Barremian age for the Springhill Formation, at southwestern Santa Cruz Province. Cornú (1986) described the palynoflora from wells sections offshore eastern Tierra del Fuego province and indicates four informal dinoflagellate cyst zones for the upper marine interval of the Springhill and the Lower *Inoceramus* formations. Also, Palamarczuk *et al.* (2000a,b) recognized a late Valanginian–Hauterivian lower marine interval in well sections offshore eastern Santa Cruz.

Offshore northeastern Tierra del Fuego province, Quattrocchio *et al.* (2006) correlated deposits of the Springhill Formation with the *Interulobites-Foraminisporis* Assemblage Zone (upper Valanginian–upper Hauterivian) of Archangelsky *et al.* (1984), defined for the Austral Patagonia, and with the upper Valanginian–lower Aptian *Cyclusphaera psilata-Classopollis* Zone of Volkheimer (1980), for the Neuquén Basin. They recorded a dinoflagellate cyst-dominated palynomorph assemblage composed by *Circulodinium distinctum, Cometodinium* cf. *C. comatum* Srivastava 1984 *emend.* Monteil 1991a, *Cribroperidinium confossum* (Duxbury 1977) Helenes 1984, *Cyclonephelium vannophorum* Davey 1969 and *Oligosphaeridium complex,* suggesting transitional to offshore marine conditions, and other assemblage characterized by *Aptea* spp. and prasinophyceaen algae (*Tasmanites* Newton 1875 and *Pterospermella* Eisenack 1972) indicating brackish-water environments.

Well preserved and moderately diverse dinoflagellate cyst assemblages were recovered from the Springhill Formation in eight wells located offshore southeastern Argentina (Guler *et al.*, 2003; Guler *et al.,* 2015). A sequence of eight age-diagnostic bioevents characterizes the easternmost Early Cretaceous deposits of the Austral Basin. These are, in ascending order: the LAD of *Senoniasphaera tabulata* Helby 1987*,* the LAD of *Kleithriasphaeridium fasciatum*, the FAD of *Prolixosphaeridium parvispinum* (Deflandre 1937) Davey *et al.* 1969*,* the LAD of *Phoberocysta neocomica*, the FAD of *Herendeenia postprojecta* Stover and Helby 1987*,* the FAD of *Odontochitina operculata* (Wetzel 1933) Deflandre and Cookson 1955, the LAD of *Cassiculosphaeridia magna* and the LAD of *Kaiwaradinium scrutillinum* Backhouse 1987. These bioevents constrain the age of the subsurface sections to the late Barremian. Furthermore, it was recognized the upper part of the *Muderongia testudinaria* and the *Muderongia australis* Zones of Helby *et al.* (1987), extending both zones to the beginning of the late Barremian and the early Aptian (Oosting *et al.,* 2006), respectively. Palaeopeoperidiniod cysts-dominated assemblages of cf. *Ovoidinium* sp. were recorded consistently at the top of most of the sequences (Guler *et al.,* 2003, 2015), which presumable represent endemic taxa for the southeastern Atlantic Ocean. An acme of *Ovoidinium cinctum* (Cookson and Eisenack 1958) Davey 1970 mark the *O.* (as *Ascodinium*) *cinctum* Subzone (Helby *et al.*, 1987, 2004) when it is present at the uppermost part of the *M. australis* Zone. Oosting *et al.* (2006) document the consistent presence of *O. cinctum* and recognize the Subzone in the *M. australis* and *O. operculata* Zones, boundary in the earliest Aptian. The late Barremian age proposed for the Springhill Formation is in accordance with the strong diachronism of the unit, being the youngest deposits at the east and north of the basin; the wells are located in front of the southernmost tip of Santa Cruz province, and these

Figure 3. Barremian dinoflagellate cysts from the Springhill Formation, offshore Austral Basin. **1,** ***Dingodinium cerviculum*** Cookson and Eisenack, right lateral view, cross section, BA PB Pal 6301 100.5/44.5 EF J30/4. **2,** ***Batioladinium micropodum*** (Eisenack and Cookson) Brideaux, ventral view, low focus, BA PB Pal 6306 39/106 EF W30. **3,** ***Kleithriaspheridinium fasciatum*** (Davey *et al.*) Davey, oblique ventral view, low focus, BA Pb Pal 6312 24/113 EF M24/3. **4,** ***Muderongia australis*** Helby, dorsal view/low focus, BA Pb Pal 6306 31/99 EFZ31/4. **5,** ***Aprobolocysta* sp. cf. *A. alata*** Backhouse, left lateral view, intermediate, BA PB Pal 6307 29.5/105 EF V29/2. **6,** ***Herendeenia postprojecta*** Stover and Helby, oblique ventral view, cross section, BA PB Pal 6301 23.5/112.5 EF N23. **7,** ***Coronifera oceanica*** Cookson and Eisenack, ventral view, high focus, BA PB Pal 6301 33.5/113 EF N35/1. **8,** ***Muderongia imparilis*** (Duxbury) Bint, dorsal view, high focus, BA PB Pal 6306 47/104 EF W47/4. **9, cf. *Ovoidinium* sp.,** dorsal view, intermediate focus, BA PB Pal 6301 48107.5 EF H48/2. **10,** ***Cassiculosphaeridia magna*** Davey, dorsal view, intermediate focus, BA PB Pal 6312 46.5/117 EF H47/3. **11,** ***Odontochitina operculata*** (Wetzel) Deflandre and Cookson, dorsal view, low focus, 6306 48.9/112 W27. **12,** ***Apteodinium granulatum*** (Eisenack) Lucas-Clark BA Pb Pal ventral view, low focus, BA PB Pal 6306 43/104.5 EF V43/4. Scale bar= 10µm.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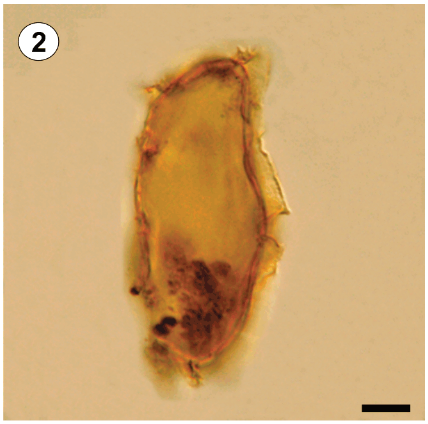
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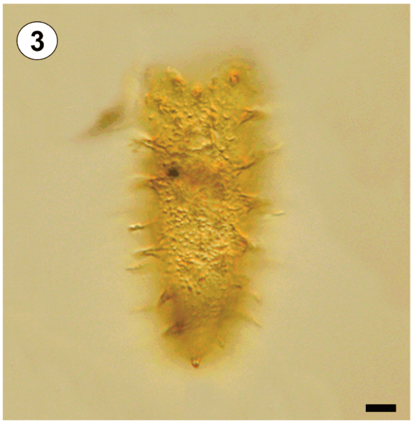
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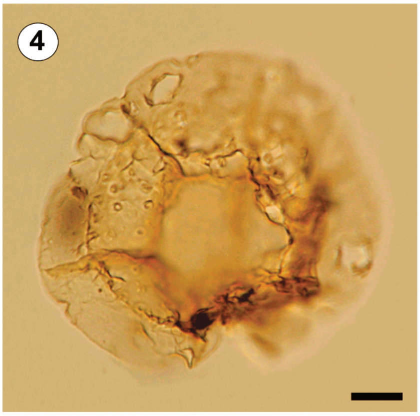
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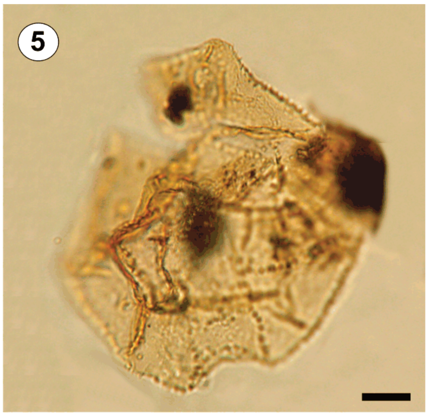
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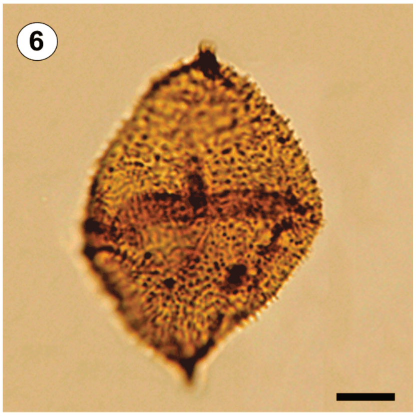
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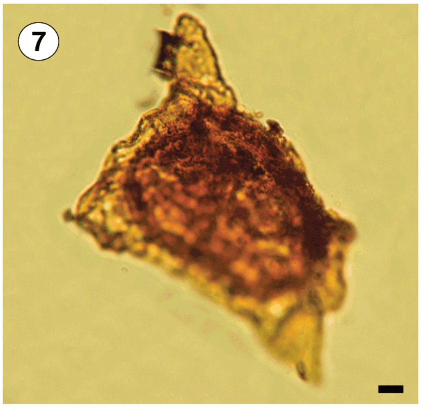
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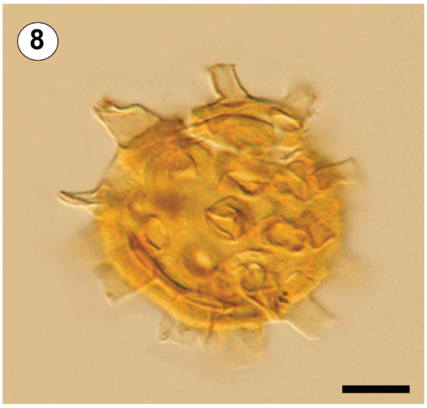
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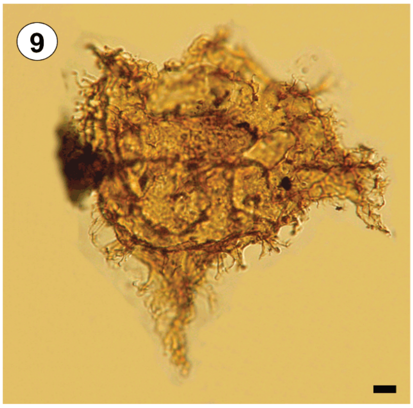
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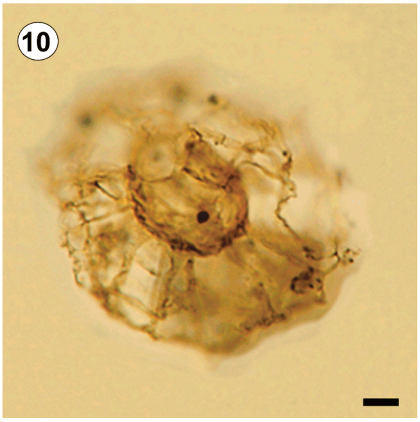
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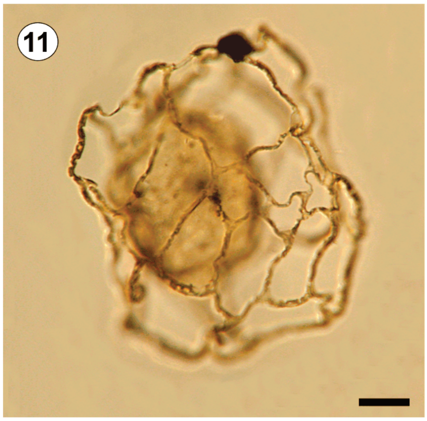
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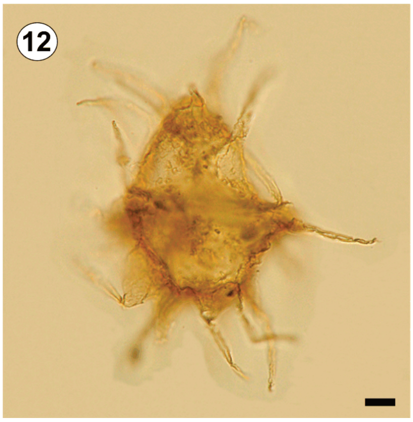
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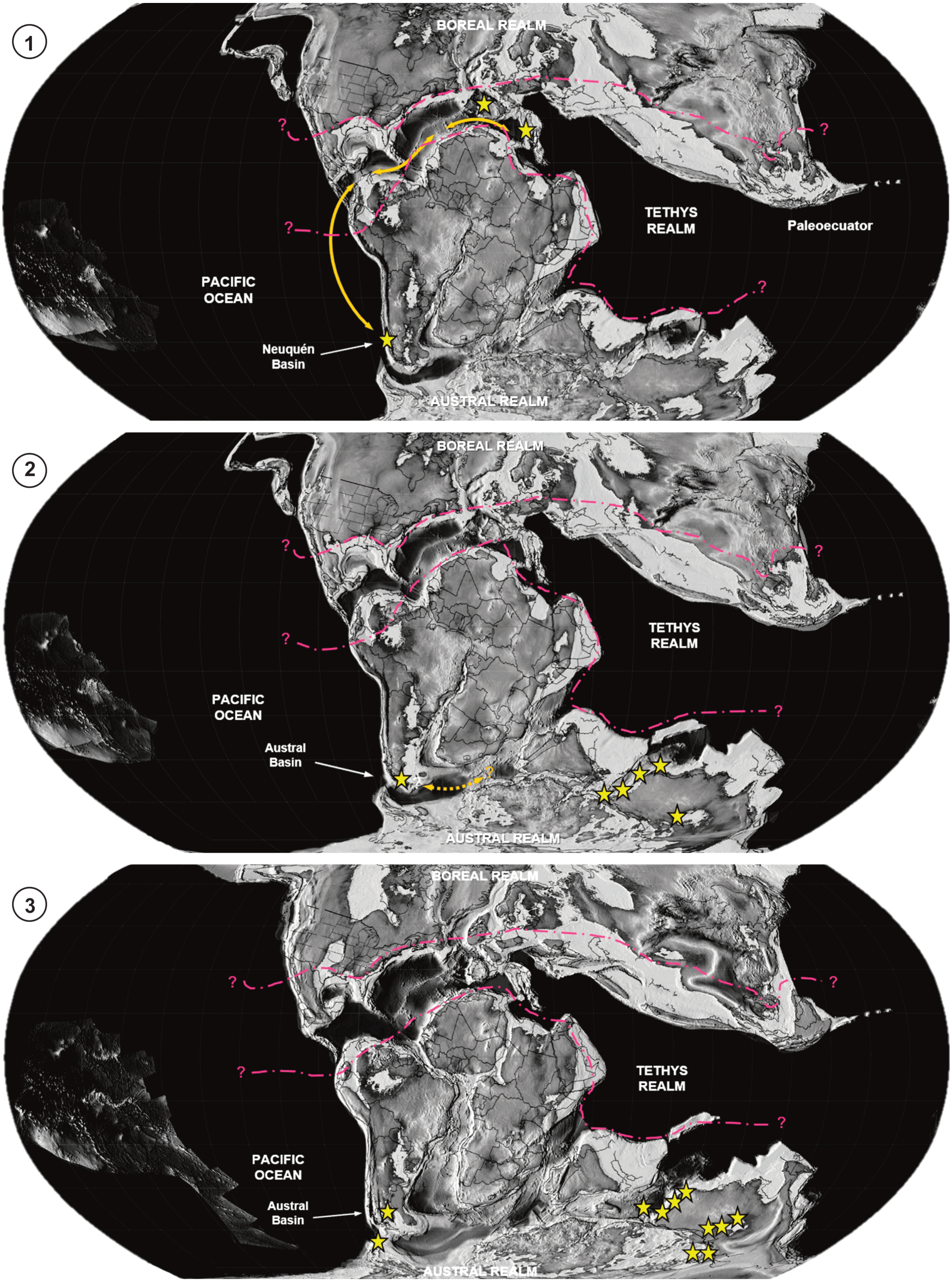
sequences accumulated in the eastern margin of the basin.

Late Aptian, Albian and early Cenomanian dinoflagellate cyst assemblages were recorded at the uppermost Río Mayer Formation and the overlying Kachaike or the equivalent Piedra Clavada Formations outcrop sections, as well as from the deep marine shales of the "Margas Verdes" Formation in the subsurface deposits. The Kachaike Formation is a typical Albian unit in the southwest of Patagonia at the San Martin lake area, and the uppermost part of the Río Mayer Formation is well-known by its rich fossiliferous content, where marine invertebrates include ammonoids of the Aptian/Albian transition. The FADs of *Litosphaeridium arundum* (Eisenack and Cookson 1960) Davey 1979 *emend*. Lucas-Clark 1984 (Fig. 2.2), *Chichaouadinium boydii* (Morgan 1975) Bujak and Davies 1983, *Prolixosphaeridum conulum* Davey 1969 and *Dinopterygium tuberculatum* (Eisenack and Cookson 1960) Stover and Evitt 1978 and the LAD of *Muderongia tetracantha* constitute key biostratigraphic events and constrain the age of the Kachaike Formation and the coetaneous Piedra Clavada Formation in different sites of southwestern Patagonia (Baldoni *et al*., 2001; Guler and Archangelsky, 2006; Medina *et al.,* 2008). The underlying uppermost Río Mayer Formation is well-known by their rich fossiliferous content, it is a classical section in the Santa Cruz province where marine invertebrates include ammonoids of the Aptian/Albian transition, whereas the Piedra Clavada Formation is dated as early Albian based on ammonoids of the genus *Beudanticeras* (Medina *et al.,* 2008). The presence of *Dingodinium cerviculum* in these deposits represents the LAD for the species in the Austral Basin, and it is associated with Aptian/Albian transition ammonite fauna; in accordance with the range of the species in Australia which extends into the lowest *Muderongia tetracantha* Zone. It was recognized in these Albian units the Subzone b of *Endoceratium turneri* Zone and the coeval *Muderongia teracantha* Interval Zone of Morgan (1980) and Helby (1987), of early Albian age; the LAD of *Muderongia tetracantha* marks the top of these zones. Subsurface sections of the "Margas Verdes" Formation from the offshore Austral Basin exhibit a complete Albian dinoflagellate cyst event sequences (Palamarczuk *et al.,* 2000a; Guler, personal observation), mostly the last occurrences where the continuous and common occurrence of *Hapsocysta peridictya* (Eisenack and Cookson 1960) Davey 1979 *emend*. Davey 1979 is indicative of a minimum early Albian age. The *H. peridictya* stratigraphic range extends from the top of the Subzone a, to the top of the Subzone b of the *Pseudoceratium turneri* of Morgan (1980), assigned to the early Albian. In Australia, the last occurrences of *H. peridictya* and *M. tetracantha* are simultaneous (Morgan, 1980) and the absence of *M. tetracantha* is presumably due to the deep marine character of these assemblages. In general, in these Albian assemblages, it is common the presence of species of *Diconodinium* Eisenack and Cookson 1960 *emend.* Morgan 1977, *Odontochitina* (mostly *O. costata* Alberti 1961) and *Canninginopsis denticulata* Cookson and Eisenack 1962*.* In turn, those assemblages from deep marine settings are characterized by high proportions of *Impagidinium* Stover and Evitt 1978*, Pterodinium* Eisenack 1958 and chorate cysts like *Oligosphaeridium pulcherrimum* (Deflandre and Cookson 1955) Davey and Williams 1966b, *O. complex, Nematosphaeropsis densiradiata* (Cookson and Eisenack 1962b) Stover and Evitt 1968 and

Figure 4. Late Aptian–Albian dinoflagellate cysts from the Upper Río Mayer, Kachaike, Piedra Clavada and "Margas Verdes Formations, onshore Austral Basin. **1,** ***Carpodinium granulatum*** Cookson and Eisenack emend. Leffingwell and Morgan, ventral view, **1,** high focus. **2,** cross section PC 05 31/105 N45/4. **3,** ***Prolixosphaeridinium conulum*** Davey, ventral view, high focus, PC 05 T47 EF T47/4. **4,** ***Dinopterygium tuberculatum*** (Eisenack and Cookson) Stover and Evitt, antapical view, intermediate focus, MV 35/114 EF. **5,** ***Canninginopsis denticulata*** Cookson and Eisenack, dorsal view, low focus, MV 23,5/111 EF U53. **6,** ***Diconodinium multispinum*** (Deflandre and Cookson) Eisenack and Cookson, Oblique right lateral view, low focus, MV 31/105 N46/3. **7,** ***Endoceratium ludbrookiae*** Cookson and Eisenack *emend*. Morgan, ventral view, intermediate focus, MV 38/99 H38/2. **8,** ***Litosphaeridium arundum*** (Eisenack and Cookson) Davey *emend*. Lucas-Clarke, dorsal view, high focus, Kch 99 35/101 K41/4. **9,** ***Endoceratium turneri*** (Cookson and Eisenack) Stover and Evitt, dorsal view, low focus, MV 15/114 EF X48. **10,** ***Nematospheropsis densiradiata*** (Cookson and Eisenack) Stover and Evitt, general view, MV 38/110 S38. **11,** ***Hapsocysta peridictya*** Eisenack and Cookson *emend*. Davey, oblique ventral view, high focus, MV 27/108 R50. **12,** ***Hystrichodinium pulchrum*** Deflandre, left lateral view, high focus, PC 27/113 W50/3. Scale bar= 10µm.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Hapsocysta peridictya, which are typical oceanic taxa. At the upper part of the sequences it is recognized the middle Albian *C. denticulata*, the late Albian *E. ludbroockiae*, *X. asperatus* and the early Cenomanian *D. multispinum* Zones of Helby *et al.* (1987) and the equivalent subzones of the *E. turneri* and *E. ludbrookiae* Zones of Morgan (1980).

Table 1 contains the dinoflagellate cyst species identified in the Austral Basin referenced according to the Fensome and Williams Index; Fensome and Williams (2004).

PALAEOGEOGRAPHIC AND PALAECOLOGIC IMPLICATIONS FOR THE AUSTRAL AND NEUQUÉN BASINS

In general terms, dinoflagellate cyst assemblages from the Pilmatué Member (Peralta, 1997; Volkheimer, 2010; Paolillo *et al*., 2015) and the Agua de la Mula Member (Guler *et al*., 2013) of the Agrio Formation, show similarity with the late Valanginian–late Hauterivian assemblages from the Tethyan Realms (*e.g.,* Leereveld 1997a,b; Torricelli 2000; 2001; 2006).

Otherwise, Early Cretaceous dinoflagellate cysts from the southernmost tip of South America, from offshore Austral Basin and southern Patagonia have strong Austral affinities. It is clear that the Australian palynological zonal schemes of Morgan (1980) and Helby (1987) are applicable to Early Cretaceous deposits of the Austral Basin (*e.g.,* Guler *et al*., 2003; Guler *et al*., 2015), providing evidence of palaeobiogeographical affinities with the western and central Australia, mainly during Barremian and Aptian times, when the youngest rocks of the Springhill Formation were accumulated (Fig. 5.2). Mid–Cretaceous assemblages from surface and subsurface deposits of the Austral Basin, including Kachaike, Piedra Clavada and Upper Río Mayer; "Margas Verdes" formations (Medina *et al*., 2008; Guler and Archangelsky, 2006; Guler, personal observation) compare well with those from well dated sequences of the James Ross Basin, exposed at the north eastern tip of Antarctic Peninsula (Riding and Crame, 2002), which contains one of the thickest and complete Cretaceous sedimentary sequences in the Southern Hemisphere. Also, these Albian–early Cenomanian assemblages are similar to those from Australia (*e.g.,* Morgan, 1980; Helby *et al*., 1987; Backhouse, 2006) and New Zealand (*e.g.,* Wilson, 1984), reflecting open marine connections among the southernmost part of South America, Antarctic Peninsula, Australia and New Zealand (Fig. 5.3).

Ceratiaceans evolved into a significant number of species through the Early Cretaceous worldwide and they proved to be biostratrigraphically useful in the Boreal and Tethyan Realms (Duxbury, 1977; Leereveld, 1997b; Monteil, 1992) as well as in the Austral region (Helby *et al*., 1987; Backhouse 1987). The presence of *Muderongia staurota*, *M. pariata*, *M.* cf. *M. siciliana,* and closely related *Muderongia* morphotypes recorded in the Hauterivian of the Neuquén Basin, denote similarity with the Northern Hemisphere. These species of *Muderongia* are conspicuous taxa in the Hauterivian Boreal and Tethyan cyst assemblages (*e.g.*, Duxbury, 1977; Leereveld, 1997b; Torricelli, 2000; 2001; 2006) and are absent in the high-latitude Southern Hemisphere basins. Also, typical austral *Muderongia* species among them *Muderongia australis* Helby 1987, *Muderongia testudinaria* Burger 1980 are index taxa for the Australian zonations (Helby *et al*., 1987; 2004; Backhouse, 1987) and they were not recorded neither in the Northern Hemisphere nor in the Neuquén Basin.

Furthermore, for the Early Cretaceous, assemblages composed by species of *Aprobolocysta* Duxbury 1977*, Ba-*

Figure 5. 1, Palaeobiogeographic affinities of the late Valanginian–?early Barremian dinoflagellate cysts of the Neuquén Basin. Palaeogeographic reconstruction of the Early Cretaceous showing the main marine connection between the Neuquén Basin and the Tethyan Realm, Western Europe (Leereveld, 1997; Torricelli, 2000; 2001; 2006). **2,** Palaeobiogeographic affinities of the Barremian dinoflagellate cyts of the Austral Basin with the intracratonic areas and marginal basins of Australia (*e.g.*, Helby *et al*., 1987). Presumable open marine seaways are unknown. **3,** Palaeobiogeographic affinities of the Albian dinoflagellate cyts of the onshore Austral Basin with central and the coastal western Australia (Morgan, 1980; Helby *et al*., 1987; Backhouse, 2006), New Zealand (Wilson 1984) and Peninsula Antarctica (Riding and Crame, 2002). Base maps by Scotese (2013, PALEOMAP).

tioladinium jaegeri, *B. micropodum*, *Carpodinium granulatum* Cookson y Eisenack 1962, *emend*. Leffingwell y Morgan 1977, *Cassiculosphaeridia magna*, *Dingodinium cerviculum* (large forms with relatively thick walls), among others, were associated with relatively cool waters (De Renéville and Raynaud, 1981; Habib and Drugg, 1987; Leereveld, 1995). Based on these criteria, the dinoflagellate cyst assemblages recorded in the Austral Basin characterized by the common presence of these taxa would reflect cool environments. Large thick-walled and coarse ornamented specimens of *Dingodiniun cerviculum* (Fig 3.1) are common in the Austral Basin assemblages, whereas thin-walled forms (Fig 2.6) were recorded in the Neuquén Basin and other Mediterranean assemblages related to relatively warm environments (Leereveld, 1995, Torricelli 2000, 2001, 2006; Oosting *et al*., 2006).

Thus, Early Cretaceous dinoflagellate cyst assemblages from southern South America, first from the north of Patagonia, have mediterranean affinities reflecting exchange of taxa between the Mediterranean Sea and the Southeastern Pacific Ocean, and then, with the Neuquén Basin (Fig. 5.1), despite the semi enclosed nature of the basin. The palaeooceanographical connection between the Neuquén Basin and the northwestern and Western Europe during the late Valanginian–late Hauterivian interval is supported by Early Cretaceous echinoids, ammonoids and bivalves, which also proved that water palaeotemperatures would have been properly high to allow immigration of equatorial faunal components (*e.g*., Aguirre Urreta *et al*., 2008). Instead, assemblages from the Austral Basin suggest oceanic connection between the southernmost tip of South America and other high-latitudes South Hemisphere sites in Australia, New Zealand and Peninsula Antarctica (Figs. 5.2, 3).

In addition to the global palaeogeography and the palaeooceanographic current context, these palaeobiogeographical affinities are closely related to the geodynamic evolution of the both two basins. During the Berriasian–early Barremian, the Neuquén Basin was connected to the Pacific Ocean (Uliana and Biddle, 1988) through a volcanic arc in the western margin, allowing the incoming of thermophilic taxa from the Tethyan region. On the other hand, the oldest sedimentary fill of the Austral basin (Berriasian–Barremian) deposited during the sag phase, represents a long-term (>25 My) transgressive cycle (Robbiano *et al.*, 1996) that is considered contemporary with the initial development of the basin and then, the opening of the Atlantic Ocean (Arbe, 2002). Despite the close palaeogeographical position of both basins, the dinoflagellates cyst assemblages of the Neuquén Basin do not reflect palaeobiogeographic affinities with neither the Austral Basin nor other Southern Hemisphere high latitudes sites, probably due to palaeotemperature differences and/or absence of marine connections.

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