



Mid- to Late Holocene organic-walled dinoflagellate cysts from the northern Argentine shelf

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ABSTRACT

A Mid- to Late Holocene dinocyst record from the northern inner shelf of Argentina is described. It is analyzed with respect to the distribution of modern dinocysts, other Holocene records from the Buenos Aires province and the biogeographic distribution of planktonic dinocysts and their motile equivalents. Between ca. 5360 and 3300 ¹⁴C yr BP the low diversity and abundance of the cyst assemblages can be related to a restricted littoral subtidal environments. After ca. 3300 ¹⁴C yr BP a major change is characterized by an increase in dinocyst abundance, indicating a normal inner neritic environment. The dominance of *Operculodinium centrocarpum* at some levels suggests some influence of continental shelf waters whereas the higher abundances of dinocysts from heterotrophic taxa e.g. *Protoperdinium stellatum*, *Votadinium calvum*, *V. spinosum* in other levels reflects a more inshore-coastal water influence with increased nutrient availability. Both assemblages are consistent with the present day transitional coastal-neritic conditions, suggesting that they were established after ca. 3300 ¹⁴C yr. These inferences supplement those based on other proxies, reflecting sea-level decrease and the coastal geomorphological evolution post ca. 5360 ¹⁴C yr BP.

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1. Introduction

The northern Argentine inner shelf, the de la Plata River and adjacent littoral-coastal zones of the Buenos Aires province were affected by a sea-level transgression that began after the Last Glacial Maximum (LGM), around 18,000 ¹⁴C yr BP. This fact is evidenced by several sedimentary environments that developed during the eustatic event (Violante and Parker, 2004). Sea-level curves for the Buenos Aires province show an increasing sea-level following the LGM, reaching a highstand between ca. 6500 and 6000 ¹⁴C yr BP before a regressive trend to the present position (Isla and Espinosa, 1998; Cavallotto et al., 1999; Guilderson et al., 2000; Cavallotto et al., 2004) (Fig. 1A). Recently, Holocene negative oscillations have been proposed for the Bahía Blanca estuary and correlated with those from Brazil coastal sections (Gómez et al., 2005).

Palynological analyses have allowed the reconstruction of Holocene vegetation and environmental conditions in relation to these sea-level fluctuations for the coastal sector of the Buenos Aires province between 35° and 40° S (e.g. Borel and Gómez, 2006; Stutz et al., 2006; Vilanova et al., 2006a,b). Records of Holocene organic-walled dinoflagellate cysts (dinocysts) are scarce, even when including the

entire Argentine coast and continental shelf. However, the dinocyst studies have documented estuarine and marginal marine environments related to higher sea-levels from the Beagle Channel, southern Tierra del Fuego (Borromei and Quattrocchio, 2007) (Fig. 1B). In addition, Holocene environments and marine influence at the Bahía Blanca estuary in the Buenos Aires province, inferred by dinocyst assemblages, have been published (Grill and Quattrocchio, 1996; Gómez et al., 2005; Borel and Gómez, 2006; Borel et al., 2006) (Fig. 1C).

The modern dinocyst records from surface sediments along the coast are also scarce. A pioneer dinocyst record, between 500 and 5000 m depth, was obtained offshore the de la Plata River as part of a NW–SE transect (36°–39° S; 53°–51° W) (Wall et al., 1977). Another record comes from the Patagonian shelf (42°–47° S), where the distribution of *Alexandrium excavatum* resting cyst was determined (Orozco and Carreto, 1989). Two other records are available from the inner shelf; one of them was taken across a tidal channel at the Bahía Blanca estuary following the bathymetry from the base of the channel to the tidal flats between 0 and 5 m depth (Grill and Guerstein, 1995); the other was obtained from a fixed station at 48 m depth, and sampled through a seasonal cycle (Akselman, 1999) (Fig. 1).

The aim of this study is to present the first Mid- to Late Holocene dinocyst record from a sedimentary core retrieved from the northern inner shelf of Argentina. The results are interpreted bearing in mind the distribution of modern dinocysts in surface sediments, various Holocene records from the Buenos Aires province, and the

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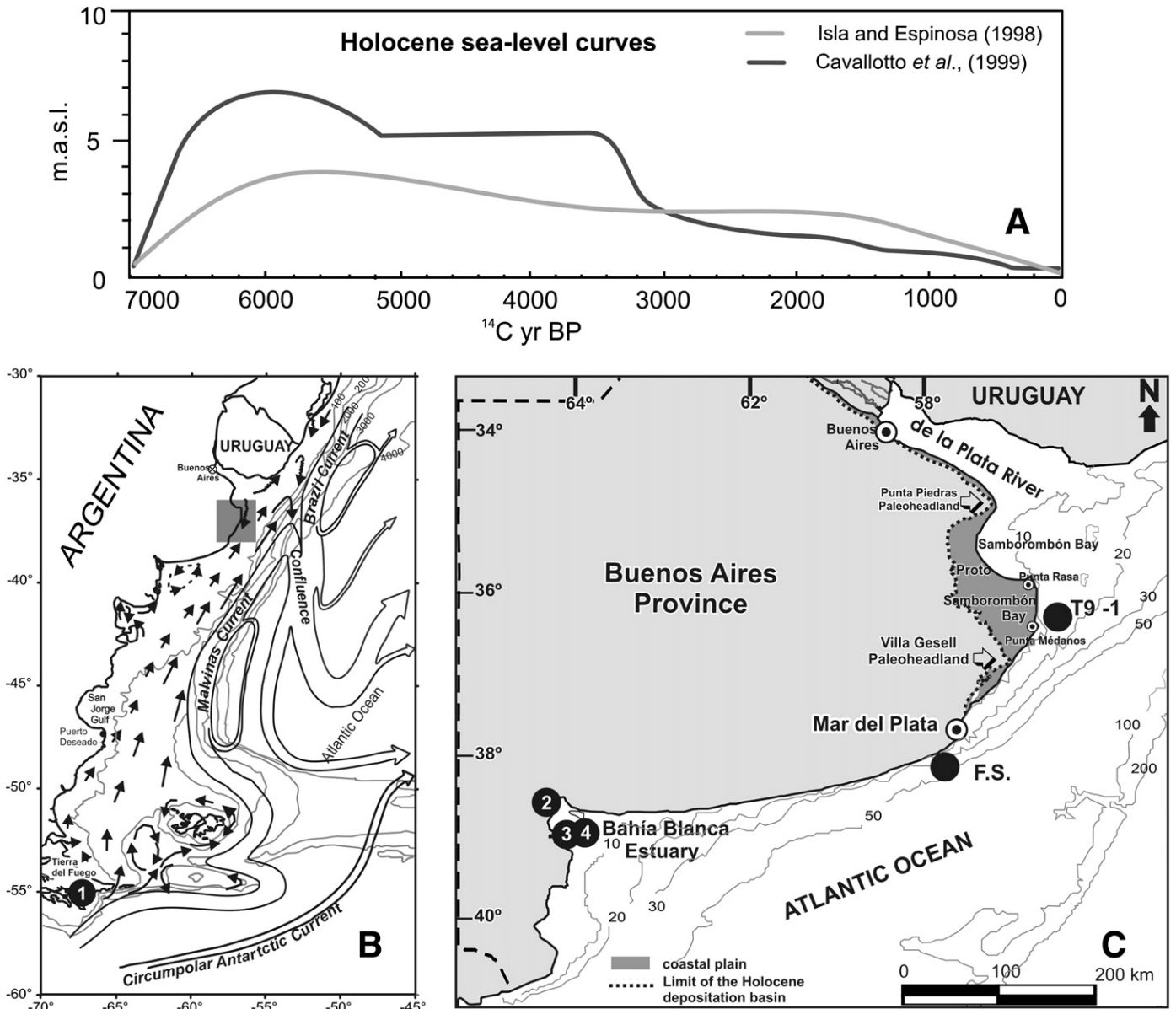


Fig. 1. A- Holocene sea-level curves for Buenos Aires province. B- Circulation scheme on the Argentine Continental Shelf (modified from Piola and Rivas, 1997). Broken arrows indicate continental discharge of Magellan Strait, de la Plata River and Lagoa dos Patos (Brazil) and dotted arrows indicate regions where flux direction and intensity are more uncertain. C- Buenos Aires province map with location of T9-1 core and fixed station (FS). Shade pattern represents coastal plains with infilling Holocene sediments (modified from Violante et al., 2001; Vilanova et al., 2006b). Circled numbers correspond to sites with fossil dinocyst record: 1- Borromei and Quattrocchio (2007). 2- Grill and Quattrocchio (1996). 3- Borel and Gómez (2006). 4- Gómez et al. (2005).

biogeographic distribution of dinocysts and their respective motile stages. The main objective is to infer palaeoenvironmental change through the Mid- to Late Holocene with reference to other proxies.

2. Environmental settings

2.1. Circulation

The oceanographic regimes of the northern Argentine shelf (Fig. 1B) are derived from advected waters of subantarctic origin, local sources of continental run-off and a locally generated salinity maximum (Lucas et al., 2005). Generally, subantarctic waters flow close to the shore up to 47° S from where they move to the central continental shelf as far as the de la Plata River area, thence along the shelf break, with the Malvinas Current to where they encounter the south-flowing Brazil Current in a highly energetic confluence where the two flows turn offshore (Piola and Rivas, 1997) (Fig. 1B).

Waters across the northern Argentine shelf undergo a seasonal oscillation in distribution and extension that implies a spring-summer reversal of the characteristic north-north-eastward flow within the coastal zone (Lucas et al., 2005). The de la Plata River has a weak seasonal signal in discharge volume with a pattern in the distribution of estuarine waters over the shelf coupling the seasonally varying wind fields (Guerrero et al., 1997; Lucas et al., 2005). In the summer months, prevailing onshore winds force the low salinity signal of de la Plata River plume to flow south and east along the coast as far 37° S. In autumn and winter, a net balance between onshore and offshore winds forces the estuarine waters to the northeast, flowing along the Uruguayan coast (Lucas et al., 2005).

2.2. Temperature and salinity

Temperature over the shelf is controlled by sea-air heat exchange coupled with bathymetry (Lucas et al., 2005). Sea surface temperature

(SST) displays a seasonal cycle typical of temperate areas. North of 38° S, SST reaches a maximum of 23 °C in early March and a minimum of 8.5 °C in early August (Lucas et al., 2005). No differences were detected between surface and bottom temperature annual cycles in the estuarine region of the de la Plata River (Guerrero et al., 1997). Surface horizontal temperature distribution for the summer period shows a weak thermal gradient (21–19 °C), which marks the boundary between the estuarine zone and the continental shelf regime towards the south. The winter temperature field does not reveal a boundary between estuarine and continental shelf waters and values range from 10° to 12 °C, show the horizontal homogeneity at the surface and at depth (Guerrero et al., 1997).

Sea surface salinity (SSS) serves to delineate two different water masses over the northern inner shelf between 35° and 38° S, one with a minimum in salinity of between 0 and 33.0 formed by the discharge of the de la Plata River and the other, continental shelf waters, with salinities between 33.5 and 33.7 from the central area of the shelf (Lucas et al., 2005). During the summer, waters from the de la Plata River may reach the study area (Fig. 1B, C) with the 25 isohaline in close proximity, whereas during the winter, the continental shelf waters influence the study area due to their northeastward displacement with the 30 isohaline close by.

2.3. Productivity

In the outer estuarine region of de la Plata River high chl *a* concentrations, up to 15.5 mg m⁻³, were recorded; this contrast with relatively low concentration, 0.1–0.2 µg l⁻¹, over the continental shelf (Carreto et al., in press). In the coastal system at 38° S, the annual phytoplankton growth cycle is characterized by a main peak in spring and a secondary one in autumn, with 2–4 mg m⁻³ and 1–2 mg m⁻³ chlorophyll *a* concentrations, respectively (Carreto et al., 1995). A midshelf front extends as a narrow strip from 38° to 42° S, with chlorophyll *a* values higher than 4 mg m⁻³ corresponding to the spring midshelf bloom (Romero et al., 2006).

2.4. Shelf geomorphological features

The inner shelf extends south of the de la Plata River mouth, characterized by a very gentle surface with a slope <0.06%, with an outer limit reaches at around 70 m depth (Violante and Parker, 2004). From the shore to the 30 m isobath at 36° S, aligned sand deposits or shoals characterize the sea floor (Parker et al., 1997; Violante and Parker, 2004).

3. Materials and methods

Samples for palynological analysis were obtained from a 499 cm long T9-1 piston core, which was taken from the inner continental shelf (36° 45' S; 56° 37' W) at 13 m depth and 4 km offshore (Fig. 1C), during the Goyena Sobral-1/77 cruise (Parker and Violante, 1982). The core consist of silty clay, coarse sand and silty sand with some shells, and intercalated mud. Two AMS radiocarbon dates of 5360 and 3287 ¹⁴C yr BP, performed on shells of *Mactra isabelleana*, were selected for chronological control (Vilanova et al., 2006b). The shells come from levels with abundant and entire valves without evidence of re-working (Table 1).

Palynomorphs were obtained from 15–30 g samples using a modified standard technique (Faegri and Iversen, 1989). (NaPO₃)₆ was

Table 1
Radiocarbon dates of T9-1 core

Depth (cm)	¹⁴ C yr BP	Lab. no.	δ C ¹³	Material
45–51	3287 ± 39	AA51338	+1.9	<i>Mactra isabelleana</i>
434–439	5360 ± 40	Beta -162050	+2.0	<i>Mactra isabelleana</i>

Table 2
Raw counts and concentration of dinocyst taxa from T9-1 core

Core depth (cm) / Taxa	Brigantidinium simplex	Echimidinium sp.	Lejeuncysta sp.	Protoperidinium stellatum	Quinquecuspis concreta	cf. Selenopemphix quanta	Votadinium cabvum	Votadinium spinosum	Protoperidinium spp.	Polykrikos kofoidii	cf. Gymnodinium catenatum	Operculodinium centrocarpum	Spiniferites spp.	Total
0–10	Raw counts 24	-	6	28	5	-	5	3	14	-	15	79	11	190
	Cyst/g 84.17	-	21.04	98.20	17.54	-	17.54	10.52	49.1	-	52.61	277.06	38.58	666.36
10–16	Raw counts 14	-	3	16	3	-	4	4	21	-	45	146	16	272
	Cyst/g 26.46	-	5.67	30.24	5.67	-	7.56	7.56	39.69	-	85.05	275.95	30.24	514.09
16–34	Raw counts 11	-	2	-	3	5	-	3	7	9	-	478	15	521
	Cyst/g 16.23	-	2.95	-	4.42	3.38	-	4.42	10.32	13.27	-	705.05	17.70	791.01
34–40	Raw counts 2	-	-	3	2	-	1	-	14	5	-	233	9	272
	Cyst/g 2.52	-	-	3.79	2.52	-	1.26	-	17.67	6.31	-	294.1	11.36	343.32
40–440	Raw counts -	-	-	-	-	-	-	-	-	-	-	0–38 ^a	0–14 ^a	1–46 ^a
	Cyst/g -	-	-	-	-	-	-	-	-	-	-	0–103.4 ^a	0–32.3 ^a	0.8–125.2 ^a

- absent
(a) minimum and maximum values.

used instead of KOH, acetolysis was not performed in order to prevent the decay and loss of sensitive organic-walled dinoflagellate cysts, and $ZnCl_2$ was used to separate the organic fraction in silty clays samples, checking the residues to be sure that no material was lost in the separation; this procedure follows Riding and Kyffin-Hughes (2004). The palynomorph concentrations were calculated following the addition of 3 *Lycopodium* spore tablets, each tablet containing $10,679 \pm 953$, before the physical–chemical treatment (Stockmarr, 1971). The residues were stained with Safranin O, and the dinocysts were identified and systematically counted using a Nikon Eclipse 600 transmitted light microscope at 600 \times and 1000 \times magnification. Digital photographs were taken with a Nikon Coolpix 950 digital camera and identification follows the work of Head (1996), Rochon et al. (1999), and Marret and Zonneveld (2003). The biological affinity of the cysts follows Akselman (1987), Head (1996), and Rochon et al. (1999).

Modern dinocyst data from the inner shelf area adjacent to the coast of Buenos Aires province serves as a comparison with the fossil record. These data were recovered from a fixed station (FS) at 38° 28' S–57° 41' W (Fig. 1B) at 48 m depth, and were collected with a Piccard dredge from May-1994 to July-1995 (Akselman, 1999). The FS is located within the transition zone between coastal and shelf systems, seasonally separated by a coastal front. During the sampling, SST varied from 9 °C in winter to 20 °C in late summer, during the greatest development of the seasonal thermocline (Carreto et al., 1998). SSS varied from 33.5 to 34.1; for most of the period, salinity was >33.7, except in spring, when values were 33.5–33.7.

4. Results

At least, thirteen dinocyst taxa, including cyst from both autotrophic and heterotrophic species have been identified from the T9-1 core (Table 2, Plate 1). Some comments and descriptions of the taxa and their geographic distributions on the Argentine shelf, as well as their general ecology are provided in Table 3.

The highest dinocyst diversity and abundance was observed in the upper 40 cm of the core (Table 2, Fig. 2). *Operculodinium centrocarpum* was the dominant taxon in all sediment samples, with the highest concentration (705 cyst/g), maximum raw count (478 dinocysts) and highest relative percentage (55%) in coarse sand levels between 16 and 40 cm core-depth (Table 2, Fig. 2). Protoperidiniacean cysts (e.g. *Brigantedinium simplex*, *Votadinium calvum*, *V. spinosum*, *Protoperidinium stellatum*), and cf. *Gymodinium catenatum* reached the highest concentrations in silty clay levels between 0 and 16 cm, where they provide nearly half of the total dinocyst concentration and raw counts (Table 2).

Total concentration of dinocysts, acritarchs and pollen was also the highest in this upper part of the core, with a maximum value near 8000 palynomorphs/g at the top (Fig. 2). Peaks of high concentration as well as some variation could indicate episodic sedimentation. Some dinocysts from above 16 cm contained cell contents, preventing the recognition of paratabulation or archeopyle formation.

In the FS modern record *Alexandrium tamarense* and *Operculodinium centrocarpum* were the most important species in both their frequencies and concentrations. They were accompanied by *Votadi-*

nium calvum, *Polykrikos schwartzii*, *Selenopemphix quanta*, *Spiniferites mirabilis*, *Spiniferites* spp., and *Protoperidinium stellatum* (Fig. 3). The total concentration graph has two peaks, corresponding to a spring and late summer bloom (Akselman, 1999).

5. Discussion

The dinocyst record between ca. 5360 and 3300 ¹⁴C yr BP shows low dinocyst diversity, characterized by *Operculodinium centrocarpum* and *Spiniferites* spp., in low abundance. A major change occurs after ca. 3300 ¹⁴C yr BP with an increase in concentration and relative abundance of *O. centrocarpum* and the appearance of cysts of heterotrophic dinoflagellates. This change is further followed by an increase in diversity and abundance of the cysts of heterotrophic dinoflagellates (Table 2, Fig. 2).

The T9-1 dinocyst record between ca. 5360 to 3300 ¹⁴C yr BP is different from the FS modern one described herein (Fig. 3), but is similar to some modern assemblages from the Bahía Blanca estuary where low dinocyst diversity and abundance were related to the absence of motile forms because of turbulent conditions, restrictive marine environments and dinocyst wall fragility (Grill and Guerin, 1995). In addition, it is similar to some Holocene assemblages from the Bahía Blanca estuary. In the outer estuary, the similar assemblages were related to shallow waters that inhibited dinoflagellate growth and to an increasing energy (Gómez et al., 2005), whereas in the inner estuary, the similar records were related to water turbidity and variable energy (Borel and Gómez, 2006). However, counts from the T9-1 core were so low as to preclude further speculation.

Thus, the poor dinocyst assemblages between ca. 5360 to 3300 ¹⁴C yr BP suggest that the depositional and hydrographical conditions were different from those of today in the Buenos Aires inner shelf area and may indicate a littoral subtidal restrictive environment that inhibited dinoflagellate productivity. Lithological changes indicate that different depositional rates occurred, implying variations in the influence of littoral currents with different energy (Fig. 2). According to Violante and Parker (2004), after ca. 5000 ¹⁴C yr BP, shoreline position and orientation were different from those at present and the action of marine and littoral currents prevailed, the latter induced by tides and waves in the inner shelf. Between ca. 5360 to 3300 ¹⁴C yr BP coastal progradation occurred in de la Plata River and adjacent inner shelf while sea-level was stable (Cavallotto et al., 2004) (Fig. 1A). Spit barriers attached to Villa Gesell Palaeoheadland concentrated the dynamic process and northeastward drift dominated (Violante et al., 2001) (Fig. 1B). Pollen records suggest halophytic–psammophytic communities on tidal plains related to the prograding littoral barriers (Vilanova et al., 2006b). Mud levels were almost completely barren of dinocysts, pollen (Vilanova et al., 2006b) and foraminifers (Laprida et al., 2007) (Table 4). *Operculodinium centrocarpum* and *Spiniferites* spp., two cysts which are moderately sensitive to aerobic decay (Zonneveld et al., 1997, 2001) show similar variations in concentration and peaks corresponding to those of pollen (Vilanova et al., 2006b) suggesting that episodic sedimentation rather than post-depositional degradation/selective preservation could affect their accumulation in sediments.

Plate 1.

- A. *Brigantedinium simplex* UNMdP T9-1 01 EF W39/3: dorsal view, visible archeopyle, high focus.
 B. *Echinidinium* sp. UNMdP T9-1 03 EF: W41/4: high focus.
 C, D. *Lejeunecysta* spp. UNMdP T9-1 01 EF V16/4: C- ventral view, high focus. D- dorsal view, high focus on epicyst with visible archeopyle.
 E, F. *Protoperidinium stellatum* UNMdP T9-1 01 EF T56/3: E- high focus. F- high focus with a Dispositive Interference Contrast (DIC).
 G, H. *Quinquecuspis concreta*: UNMdP T9-1 02 EF T24/4: G- epicyst, high focus on apical horn. H- hypocyst, high focus on antapical horns.
 I. cf. *Selenopemphix quanta*: UNMdP T9-1 03 EF S35/4: high focus.
 J. *Votadinium calvum*: UNMdP T9-1 02 EF N48/4: dorsal view, high focus on epicyst with visible archeopyle.
 K. *Votadinium spinosum*. UNMdP T9-1 01 EF G43/2: dorsal view, high focus, visible archeopyle and spines.
 L. *Polykrikos kofoidii* UNMdP T9-1 03 EF P34/4: mid focus, archeopyle faintly seen. Bar scale = 10 μ m.

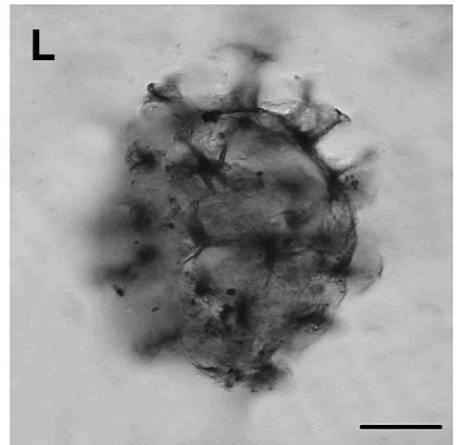
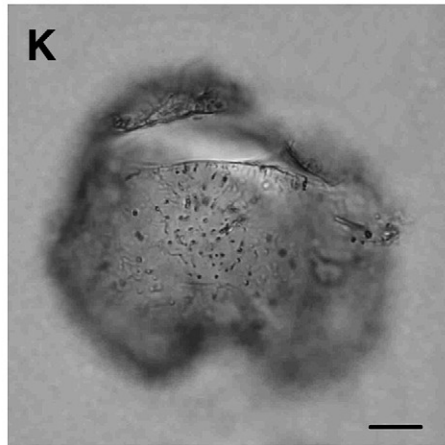
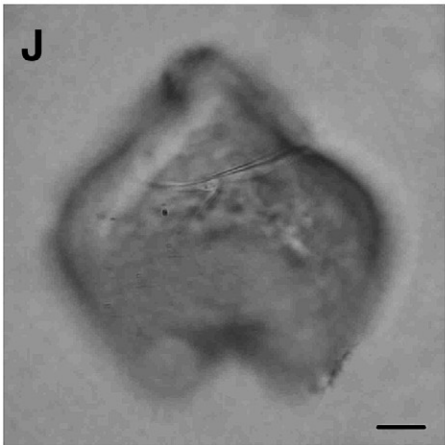
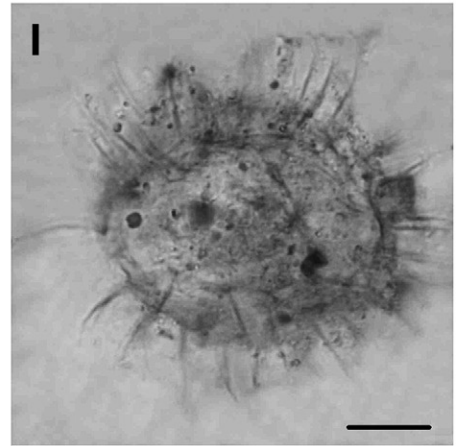
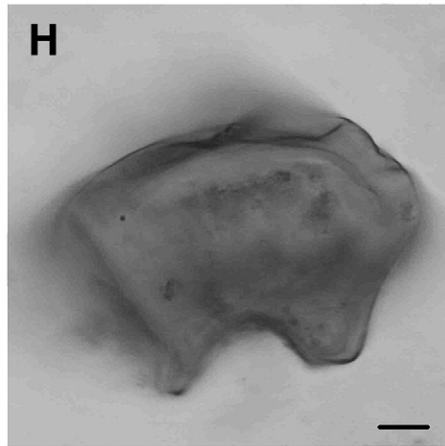
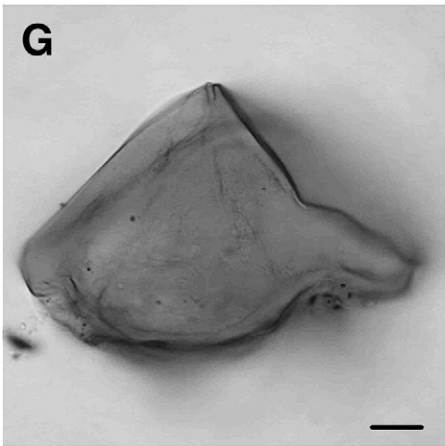
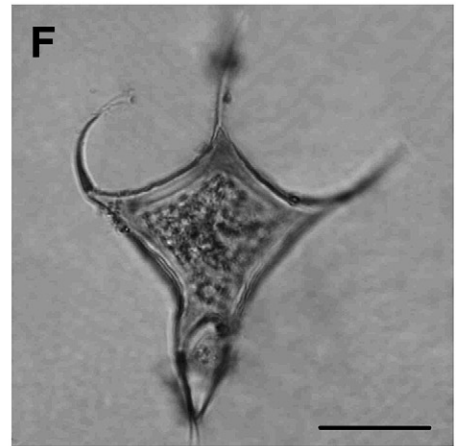
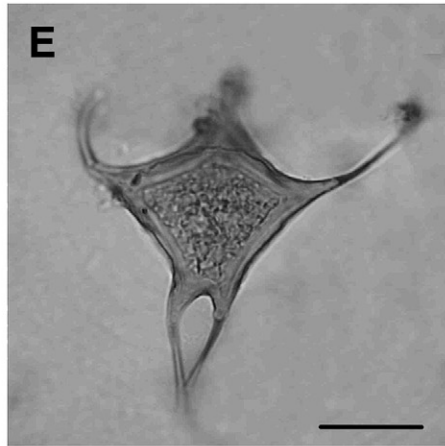
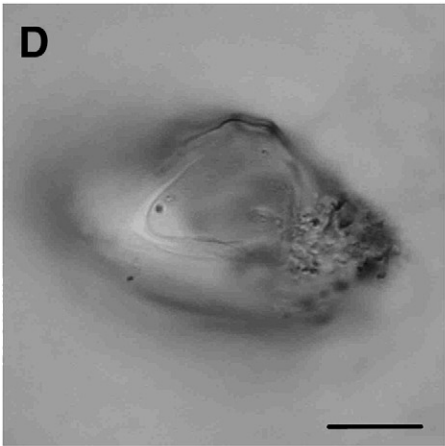
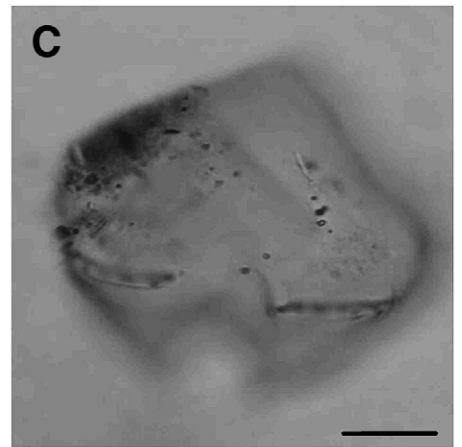
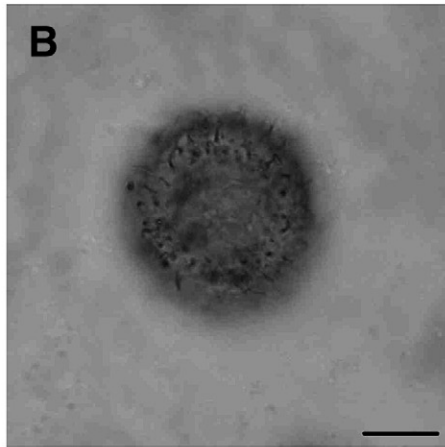
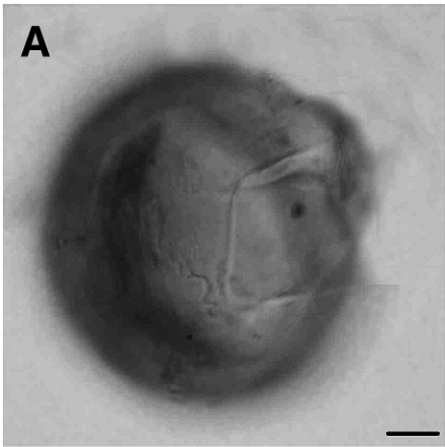


Table 3
Comments, distribution on Argentine shelf and ecology of modern cysts taxa (from plankton and sediment samples) and corresponding motile stage recorded from T9-1 core

Taxa	Motile affinity	Comments, description	Distribution on Argentine shelf	Ecology
<i>Brigantedinium simplex</i> Plate IA	<i>Protoperidinium conicoides</i>	Some cysts with cell contents.	Cyst: in sediments from FS ^a , in plankton from Mar del Plata harbour and Puerto Deseado inlet ^b Motile stage: slope and shelf cold-waters offshore Buenos Aires province and Tierra del Fuego ^c . In 5.5–11.4 °C and 33.48–33.47 psu ^c	Often associated with up-welling or nutrient availability. Coastal to oceanic, within a broad range of temperature, salinity and nutrient concentrations ^d
<i>Echinidinium</i> sp. Plate IB	Unknown	Small spheroidal brown cysts 20–25 µm in diameter, with granulate wall, and randomly distributed solid spines with acuminate ends.	No previous records	Mesotrophic/eutrophic waters some of them related to up-welling ^{e,f,g}
<i>Lejeunecysta</i> spp. Plate IC, D	Unknown,? <i>Protoperidinium leonis</i>	50–55 µm in length, symmetrical antapical horns with solid acuminate tips.	No previous records	Nearshore up-welling areas ^h
<i>Protoperidinium stellatum</i>	<i>Protoperidinium stellatum</i>	Archeopyle not observed. Central body length 30–50 µm and processes 10–20 µm	Cysts: in sediments from FS ^a , sediments and plankton from Mar del Plata harbour in 21.5 °C and 33.54 psu ⁱ . Plankton from San Jorge Gulf 6.8–10.94 °C and 33.43–33.50 psu ^b Motile stage: neritic and coastal zone from 38° 55' to 47° 45' S ^b . In plankton from de la Plata River, at –2 m depth and 22.1 °C ^k .	Inner neritic temperate ^j . Temperate to tropical regions, brackish–fully marine, well-mixed upper water column ^e
Theca based name Plate IE, F				
<i>Quinquecuspis concreta</i> Plate IG, H	<i>Protoperidinium leonis</i> <i>P. obtusum</i> ^b	Brown cyst, faint longitudinal lineation, central body length 60–75 µm.	Motile stage-cyst pair: plankton from San Jorge Gulf, 6.58°–11.35 °C, and salinity 33.26–33.75 psu ^b . Motile stage: Argentine and Uruguayan shelves and adjacent oceanic region ^c and Samborombón Bay ^l Cysts: in sediments from FS ^a .	Inner–outer neritic, cool temperate to tropical ^j
<i>Selenopemphix quanta</i> Plate II	<i>Protoperidinium conicum</i>	Light brown wall. Processes 10–12 µm in cingular margins, 40–60 µm width.		Inner–outer neritic, mesotrophic to eutrophic environments ^{e,j}
<i>Votadinium calvum</i> Plate IJ	<i>Protoperidinium oblongum</i>	Strongly rounded peridinioid. Smooth wall. Archeopyle extending over the apex, conspicuous sulcal depression. Length 50–65 µm.	Living cysts: in sediments from FS ^a and Mar del Plata coastal waters with temperature of 8.2–20.0 °C. Planktonic germinated cysts: San Jorge Gulf ^b . Motile stage: Argentine Sea, 36° 11'–to 40° 34' S ^b . Cyst: in sediments from FS ^a , sediments from Mar del Plata harbour and plankton of Buenos Aires province ^b .	Inner neritic / nearshore estuarine environments ^{e,j}
<i>Votadinium spinosum</i> Plate IK	<i>Protoperidinium claudicans</i>	50–66 µm long, conspicuous archeopyle and numerous short spines, 3–4 µm, somewhat larger on antapical horns.	Motile stage and cyst: San Jorge Gulf, more frequently in spring, 6.6–20.0 °C and 33.58 psu ^b . Motile stage and cyst: Mar del Plata harbour ^f	Temperate subtropical, inner neritic, fully marine and oligotrophic/mesotrophic environments ^{e,j}
<i>Polykrikos kofoidii</i> Theca base name Plate I.L	<i>Polykrikos kofoidii</i>	Archeopyle hardly seen. Fan-shaped processes 55*35 µm.	<i>Polykrikos schwartzii</i> cyst: in sediments from FS ^a , Mar del Plata harbour ⁱ and Patagonian shelf ^m and motile stage in plankton from FS ^r and Mar del Plata harbour ^r <i>Polykrikos</i> sp.: motile stage in the coast of Uruguay ⁿ Cyst: in sediments from FS ^a .	SW Atlantic 30°–40° S. Not found <11.8 °C. Abundant in 25–29.1 °C and 31.6–36.6 psu. Coastal (shelf) fully marine, oligotrophic/eutrophic environments ^e .
cf. <i>Gymnodinium catenatum</i> Theca base name	<i>Gymnodinium catenatum</i>	Chasmic aperture, fine reticulate brown wall, 30 to 35 µm in diameter.	Motile stage: <i>G. catenatum</i> in Mar del Plata harbour ^r plankton of Buenos Aires province ^q de la Plata River, Uruguay coast ⁿ	Coastal in temperate regions, estuaries and marine habitats.
<i>Operculodinium centrocarpum</i>	<i>Protoceratium reticulatum</i> (= <i>Gonyaulax grindleyi</i>)	Central spherical body with 40–60 µm in diameter. Processes >3 µm covered by small detritus particles.	Cyst: in sediments from FS ^a Bahía Blanca estuary ^o and northern Argentine shelf ^p Motile stage: SW Atlantic, 37° 53' S to 47° 45' S, 5.9–13.48 °C and 33.57–34.38 psu. Austral Patagonia ^c .	Oceanic–estuarine ^j . High relative abundances in cold/temperate, nutrient-enriched surface waters ^e .
<i>Spiniferites</i> spp.	<i>Gonyaulax</i> spp.	No paratabulation determination.	Cysts: in sediments of FS ^a , Mar del Plata harbour ^d and Bahía Blanca Estuary ^o .	

FS=fixed station

(a) Akselman (1999)

(b) Akselman (1987)

(c) Balech (1988)

(d) Rochon et al. (1999)

(e) Marret and Zonneveld (2003)

(f) Zonneveld (1997)

(g) Targarona et al. (1999)

(h) Radi and de Vernal (2004)

(i) Capitanio and Martínez Peck (1988)

(j) Mudie and Harland (1996)

(k) Kogan and Akselman (2001)

(l) Gómez et al. (2004)

(m) Orozco and Carreto (1989)

(n) Méndez et al. (1997)

(o) Grill and Guerin (1995)

(p) Wall et al. (1977)

(q) Akselman et al. (1998)

(r) Unpublished results from Akselman R.

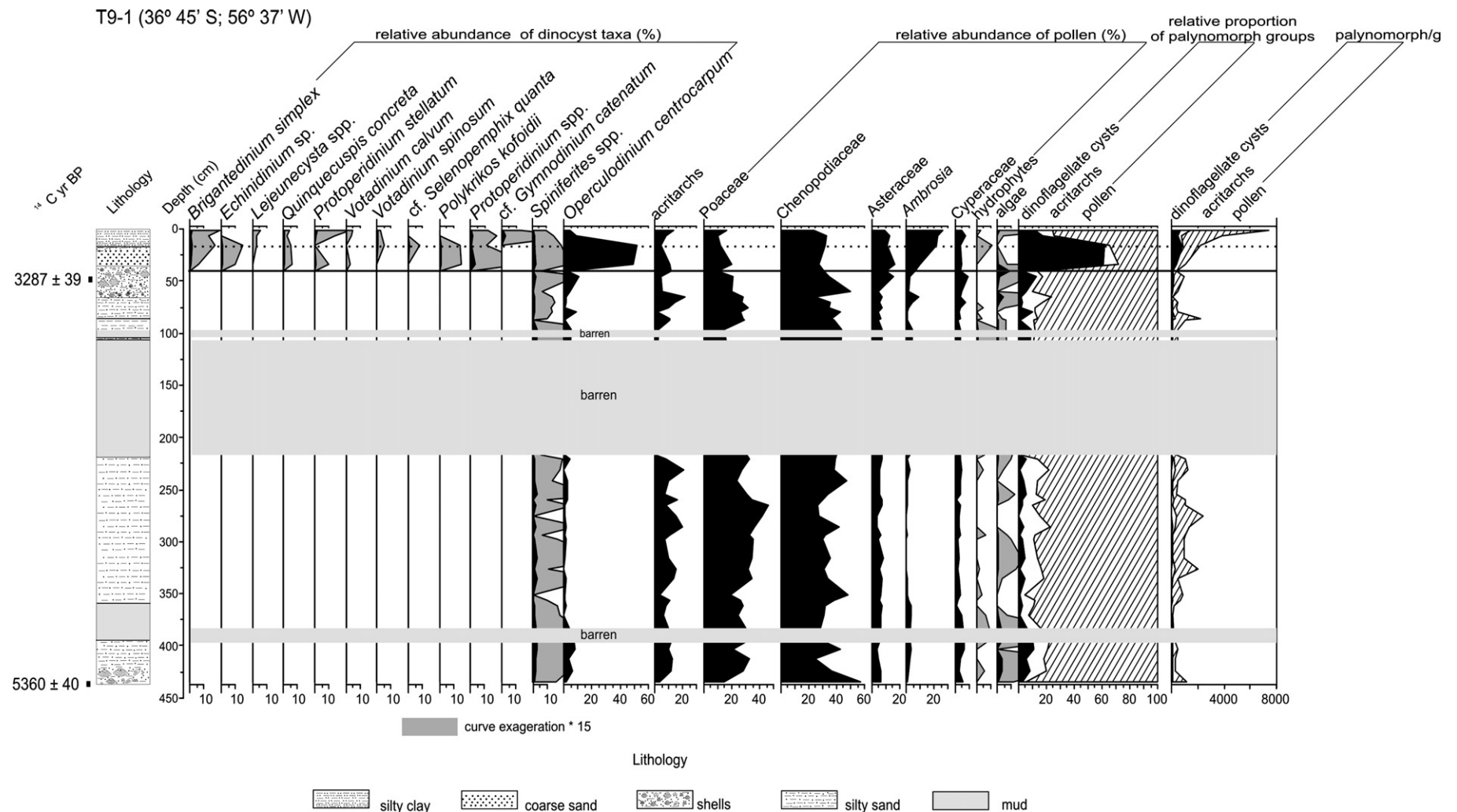


Fig. 2. Diagram of relative abundances of dinocyst taxa and pollen, and relative proportions and concentration of the palynomorph groups from T9-1 core (percentages were calculated on a total palynomorph sum). Hydrophytes represent *Alternanthera* sp. and *Ranunculus* sp. herbs; and algae represent *Pediastrum* sp. and *Botryococcus* sp. Lithology is modified from [Parker and Violante \(1982\)](#).

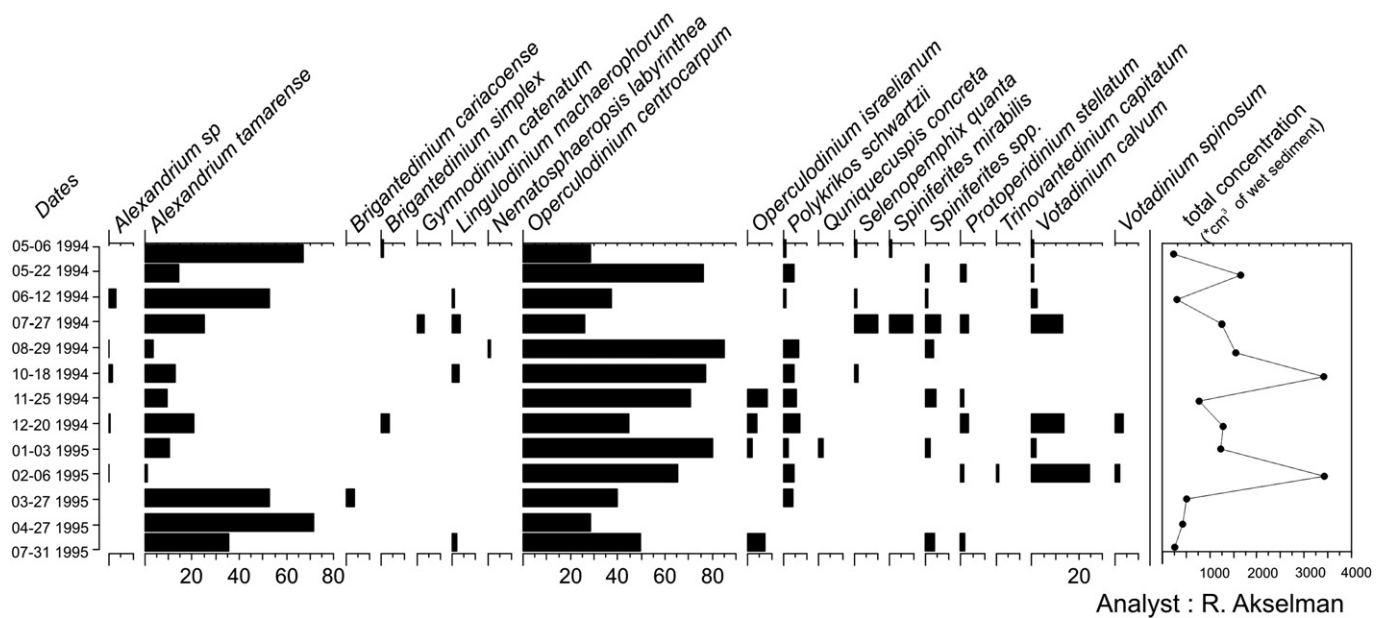


Fig. 3. Species composition, relative abundance seasonal distribution of modern cysts (living and excysted) and total concentration from the fixed station (FS).

The ca. 3300 ^{14}C yr BP major change is characterized by an increase in dinocyst diversity and abundance together with changes in the pollen spectra and lithology (Fig. 2). The dinocyst assemblage is similar to that of the FS modern record, except for some taxa. For example, *Lejeunecysta* sp. is only present in the fossil record and conversely *Alexandrium tamarense*, recorded in the FS, is absent in the fossil record (Fig. 3). The absence of *A. tamarense* may be due to either low/weak preservation of the thin outer wall (Head et al., 2006) or this species did not inhabit the area during the Late Holocene. The first appearance and toxic outbreak in recent time was recorded in the southern shelf in 1980 (Carreto et al., 1985). Similarly, it has been registered in modern assemblages from the Bahía Blanca estuary whereas it is absent in the fossil record of the estuary (Borel et al., 2006). The modern dinocyst taxa and their corresponding motile stages, represented in the T9-1 core by their cysts, derive from waters with a wide range of temperature, salinity and distribution in the southwestern Atlantic Ocean (Table 3). Foraminifers indicate an open marine high-energy nearshore environment with a gradual change towards estuarine conditions (Laprida et al., 2007) (Table 4). The inner

neritic conditions can be related to a landward displacement of shoreline that started after 5000 ^{14}C yr BP in relation to the modifications of littoral barriers (Violante et al., 2001) and to different depositional and hydrographic conditions.

The dominance of *Operculodinium centrocarpum* in coarse sand levels after ca. 3300 ^{14}C yr BP may result from an over-representation (Fig. 2). However, similar high percentages have been registered in the FS and in the transitional coastal oceanic assemblages from surface sediments retrieved offshore de la Plata River and in the slope-rise zone, showing an increasing trend between 500 and 5000 m depth (Wall et al., 1977). Based on its autotrophic character and modern distribution, it is possible that *O. centrocarpum* record is associated with low turbidity waters under some influence from continental shelf water masses. *Polykrikos kofoidii*, at the same levels, is consistent with a neritic shelf distribution. The occurrence of these taxa may suggest cooler but not cold water as it has not been found in regions where SST is below 11.8 °C (winter SST) (Table 3; Fig. 4A, C). This condition is also supported by *Echinidinium* sp., which has been related to warm environments (Marret and Zonneveld, 2003). Overall,

Table 4

Lithology and Mid- to Late Holocene palaeoenvironments inferred from dinocyst, pollen, and foraminifers from T9-1 core

Palaeoenvironments					
^{14}C yr BP	Depth (cm)	Lithology (from Parker and Violante, 1982)	Dinocysts (this work)	Pollen (Vilanova et al., 2006b)	Foraminifers (Laprida et al., 2007)
3287±39	0-	Silty clay	Mesotrophic–eutrophic	Dunes with psammophytic vegetation	No data
	50-	Coarse sand with shells Silty sand with some shells	Oligotrophic–mesotrophic Littoral–subtidal with restrictive environmental conditions and or/ unfavourable depositional environment	Psammophytic/halophytic vegetation on tidal flat	Open marine–fluvio marine estuarine shelf
	100–150–200–250–300–350–400-	Mud	Barren	Barren	Extreme low number or complete absence
	450-	Silty sand	Littoral–subtidal under the action of marine and littoral currents, restrictive environmental conditions and/or unfavourable depositional environments	Psammophytic/halophytic communities on tidal flats related to littoral barrier	Normal marine to brackish shelf No data
	400-	Mud	Barren	Barren	Normal marine shelf low energy fluvio marine estuarine
5360±40	450-	Silty sand with some shells	Littoral–subtidal with restrictive environmental conditions and or/unfavourable depositional environment	Psammophytic/halophytic vegetation on tidal flat	Open marine shelf

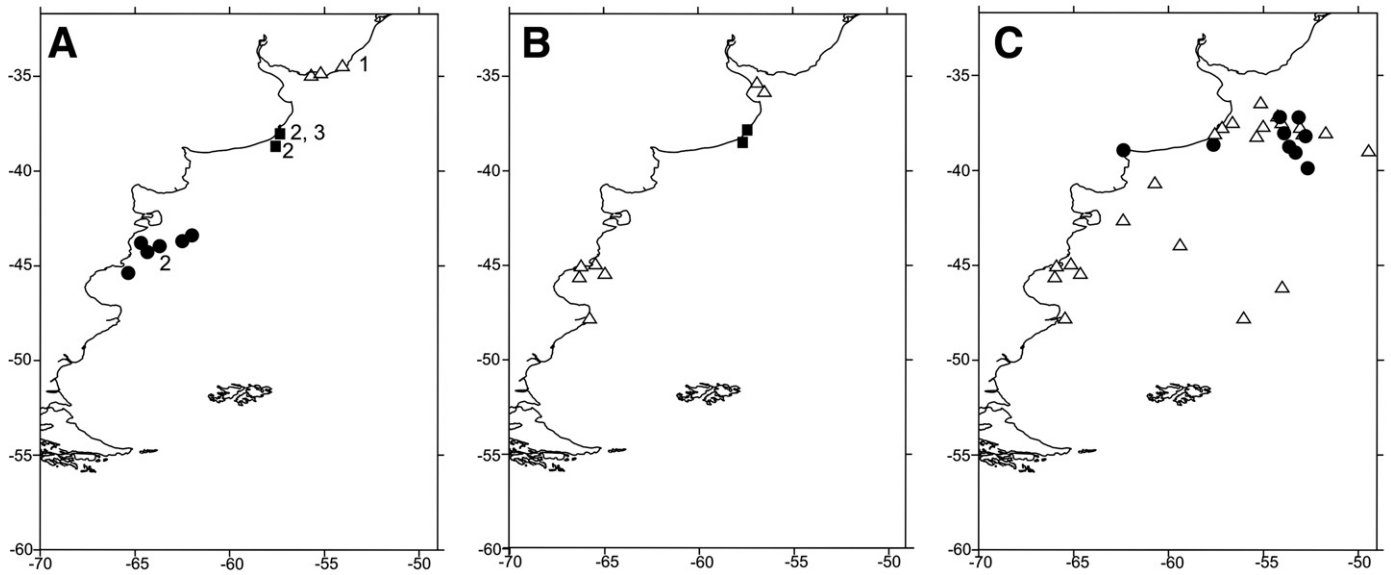


Fig. 4. Modern records on Argentine shelf and Uruguayan coast of *Polykrikos* sp.(1), *Polykrikos schwartzii* (2) and *Polykrikos kofoidii* (3) (A); *Protoperidinium stellatum* (B); and *Operculodinium centrocarpum* and *Gonyaulax grindleyi* (C). These records correspond to cysts from sediment samples (●), cysts from sediment samples and motile stage specimens from plankton samples (■), and motile stage specimens from plankton samples (△). References and detailed information are in Table 3.

the assemblage is consistent with mesotrophic and mesohaline–polyhaline waters, like those occurring at present in the area.

The increase in diversity of protoperidiniacean cysts in the silty clay levels above ca. 3300 ^{14}C yr BP suggests inshore–coastal water influence, since most of them occurred in the nearshore FS (Table 3, Fig. 3). The increase in pollen concentration also reflects the influence of littoral currents and coastal processes. The abundance of protoperidinioid cysts may be related to a higher cyst production and concentration in fine grain sediments. Although dinocysts advected away from their point of production cannot be disregarded, their higher diversity and abundance suggest mesotrophic–eutrophic waters with nutrient availability. This may be linked to a frontal system as occurs today. However, the concentration in *Protoperidinium* cysts is low (ca. 350 cysts/g of dry sediment, Table 2, Fig. 2) and cautions against too much speculation. Neither can be speculated about degradation/selective preservation since there is no information available about oxic processes due to oxygen in pore water or bottom sediments. Nevertheless, the increase in concentration and relative abundance of *Operculodinium centrocarpum* along with heterotrophic dinocyst records after ca. 3300 ^{14}C yr BP coincide with a change in lithology and pollen spectra, which suggest that they are related to environmental changes rather than post-depositional decay due to oxygen penetration into sediments.

The differences in diversity and abundance of heterotrophic dinocysts between the coarse sand and silty clay levels suggest a change in water masses features reflecting a complex oceanic regime. This change undoubtedly involves coastal, marine and fluvial influences associated with littoral–coastal currents, the plume of de la Plata River and the displacement of continental shelf waters as sea-level falls to its present position after ca. 3000 ^{14}C yr BP. According to Violante et al. (2001), a rapid and significant coastal progradation took place after ca. 3000 ^{14}C yr BP in the northern Buenos Aires province as sea-level fell due to a high fluvial sediment input from the de la Plata River deltaic system on the Samborombón Bay area (Fig. 1C). Consequently, a transitional coastal–neritic system with intermediate hydrographic composition between coastal and shelf waters was established.

6. Final remarks

The dinocyst record from the T9-1 core reflects changes in depositional environments and ecological conditions during the Mid- to Late Holocene. The inferences from the dinocysts record supple-

ment those based on other proxies, and in particular reflect different palaeoenvironments after ca. 5360 ^{14}C yr BP as to sea-level fall (Table 4). The FS modern record provides a good analogue.

Between ca. 5360 and 3300 ^{14}C yr BP low diversity and abundance may be related to littoral subtidal restrictive environments in relation to prograding barriers in the area providing unfavourable depositional conditions. After ca. 3300 ^{14}C yr BP the increase in dinocyst abundance indicates a change to inner neritic environments. The dominance of *Operculodinium centrocarpum* in the coarse sand levels suggests some influence of continental shelf waters whereas the higher abundances of heterotrophic dinocysts taxa in silty clay levels reflects a more inshore–coastal water influence. Both cases are consistent with the present transitional coastal–neritic location, suggesting it was established after ca. 3300 ^{14}C yr.

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