

Sedimentology and palynology of the Calafate Formation (Maastrichtian), Austral Basin, Southern Patagonia, Argentina

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Abstract

The Calafate Formation crops out in south-western Santa Cruz Province, Argentina, and displays a stacking of asymmetrical coarsening–fining–upward cycles. These cycles are interpreted as the product of short-lived transgressive–regressive events in which the coarsening upward part represents sedimentary aggradation with a stable or decreasing sea level. Sedimentological and palynological analyses indicate nearshore marine conditions. Even though the existence of an estuary or incised valley cannot be determined, this is the most probable palaeogeographic model. Based on dinoflagellate cysts, the base of the section is considered to be not older than Maastrichtian. The presence of the oyster *Ambigostrea clarae* (Ihering) occurring together with the dinoflagellate cyst species *Manumiella druggii* (Stover) Bujak and Davies and *Eisenackia circumtabulata* Drugg in the middle part of the section indicates an age no older than late Maastrichtian. According to sedimentological data, deposits representing the Cretaceous–Palaeogene transition would have been eroded, which is confirmed by the presence of *Grapnelispora loncochensis* Papú. This megaspore is a consistent component of the Maastrichtian assemblages from Patagonia.

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1. Introduction

The Austral or Magallanes Basin includes the portion of the Patagonian and Fuegian Andes from 45 to 54°S. The northern margin is coincident with the maximum extent of marine sedimentation during the Mesozoic (Riccardi, 1988; Ramos and Aguirre-Urreta, 1994). The basin boundaries are the Northern Patagonian Andes to the north, the Deseado Massif to the east and the magmatic arc to the west. The origin of the basin is

linked to extensional episodes occurring during the separation of South America and Africa. This separation was also associated with the effusion of siliceous volcanic rocks during the Middle–Late Jurassic and the resulting rocks constitute the basin basement.

Ramos and Aguirre-Urreta (1994) pointed out that the Mesozoic development of this basin could be divided into two marine cycles, the first extending from the Late Jurassic to Early Cretaceous and the second occurring during the Late Cretaceous, the latter being restricted to the southernmost part of the basin.

The sedimentary infilling is represented first by the sandstones of the Springhill Formation and the Hauterivian–Barremian black shales in the Río Mayer

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Formation. During the Albian–Cenomanian a thick sedimentary sequence was deposited. This was associated with intense uplift in the western and southern areas of the basin. From the latest Campanian onwards until the end of the Palaeogene in northwestern areas there was a progradation of the depositional systems infilling the basin, most originating in shallow water. Malumián and Caramés (1997) stated that two main marine episodes characterize the Palaeogene. The first occurred during the Danian and the second, with several anthracogenic cycles, during the middle Eocene. According to Macellari et al. (1989), Manassero et al. (1990), and Manassero and Merodio (1992), the Late Cretaceous–Palaeogene sequence was deposited in a foreland basin and is almost entirely composed of sediments derived from an andesitic magmatic arc.

In the Lago Argentino area Macellari et al. (1989) recorded three Late Cretaceous depositional sequences. The youngest of these is composed of rocks referred to the Calafate Formation. This formation progressively overlies older strata in a northward direction. It was dated as Maastrichtian–Palaeocene by Nullo et al. (1981) and Macellari et al. (1989). However, Malumián and Caramés (1997, p. 198) suggested that in the area of Lago Argentino the Palaeocene was either missing or poorly developed. This was confirmed by Marensi et al. (2002), who recognized that, in the locality of Cerro Calafate (south of Lago Argentino), the Eocene Man Aike Formation unconformably overlies the Late Cretaceous Calafate Formation. Thus, if the Cretaceous/Palaeogene boundary deposits were ever represented there, they have since been entirely eroded. This unconformity was recorded by Riggi (1979) in subsurface deposits of the eastern part of the basin.

The present paper provides the sedimentological and biostratigraphical results of an analysis of the Calafate Formation at Estancia 25 de Mayo (Fig. 1), south of Lago Argentino ($50^{\circ} 23' \text{ LS}$; $72^{\circ} 12' \text{ LW}$). The nearshore marine deposits of which the formation is composed contain both marine (dinoflagellate cysts, prasinophycean algae, acritarchs) and nonmarine (pollen, spores, Zygnematacean and Chlorococcalean algae) components, as well as other fossil groups, which are useful for independent age and palaeoenvironmental interpretations.

2. Methods

A stratigraphic section was measured at Estancia 25 de Mayo using a Leica vector IV laser range-finder. The geometry of the beds, ranks of the bounding surfaces, lithology, texture, sedimentary structures and fossil content of the rocks were recorded. Samples were collected from fine-grained lithologies whenever possible

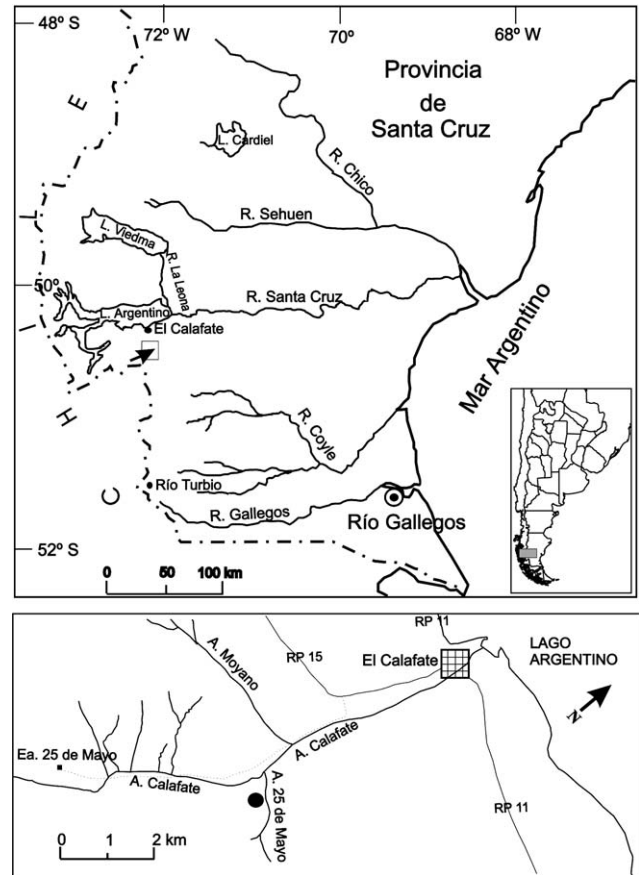


Fig. 1. Location map.

because the predominantly coarse-grained deposits are not suitable for palynological studies.

Twenty samples were processed for palynomorphs, nine of which proved to be palynologically barren. Chemical processing included hydrofluoric and hydrochloric acid treatment. The residues were stained using Bismarck C and mounted in glycerine jelly.

Light microscopic examination was undertaken using a Nikon Eclipse 600 microscope (serial n° 772751) at the Departamento de Geología, Universidad Nacional del Sur. Microscope co-ordinates are from the vernier scale of the microscope. Specimens were photographed using a Nikon Coolpix 950 camera. England Finder (EF) references are provided in the corresponding figure explanations. The figured specimens are housed in the Palynological Collection, Departamento de Geología, Universidad Nacional del Sur, Bahía Blanca, Argentina. The geological time scale corresponds to Gradstein et al. (1995).

3. Sedimentology and palaeoenvironment

The Calafate Formation is bounded by unconformities and therefore at Estancia 25 de Mayo variable

thicknesses have been recorded. In the section sampled we measured a 240-m-thick column. This is dominated by sandstones with occasional beds of conglomerates and very few mudstones (Fig. 2). The exposures show at least four sandy–conglomeratic beds, each 10–30 m thick, that form vertical cliffs. These intervals are separated by 30–50-m-thick intervals of finer-grained brownish sediments that are less steeply inclined, thus leading to good soil development and poor exposures.

These fine-grained intervals constitute facies association 1, while the coarse-grained comprise facies associations 2 and 3. Facies association 1 partly includes facies W of Arbe and Hechem (1984, p. 149), which have been interpreted as “inter- to sub-tidal deposits under an estuarine regime”. Facies associations 2 and 3 are partially coincident with facies X of Arbe and Hechem (1984, p. 149) and interpreted as “sub-tidal wave deposits under an estuarine regime and sub-tidal

channel deposits in sequences of progradational estuarine bars”.

Facies association 1: tidal flats (5–50 m thick)

Description. This facies association includes the finest-grained lithofacies of the entire unit, which yielded the palynologically productive samples. They are fine- to very fine-grained, occasionally muddy sandstones with wavy lamination, flaser bedding, undulitic and, to a lesser degree, lenticular bedding, containing isolated molluscs. They include small lenses (up to 4 m wide and 30 cm thick) of coarser, massive, trough cross-bedded sandstones with fragments of invertebrates. Occasionally dark, massive or rarely laminated mudstones occur that contain plant debris or small fragments of wood.

Interpretation. The fine grain size and sedimentary structures, indicating relatively low energy and periodically fluctuating current strengths, suggest sedimentation on a sandy or muddy-sandy tidal flat (De Raaf and Boersma, 1971). These flats generally occupy the deepest (sub-tidal) parts of shelves that are subject to tidal influence. In the section examined this is further supported by the absence of structures that might suggest at least periodic emergence. The intercalated lenses within the fine-grained sediments represent (according to their lithology and sedimentary structures) periodic events of higher energy, and are possibly storm deposits.

Facies association 2: sub-tidal main channels (4–11 m thick)

Description. The lithofacies of this association form fining-upward sequences (Fig. 3C). The geometry of these beds is lenticular with moderate to high erosive bases, but they form tabular to sigmoidal sets that are laterally continuous for several hundred metres. They show more or less flat tops and relatively low erosional bases.

At the base of these sets there are 1–5-m-thick conglomerates, massive or with medium scale trough or tabular cross-stratification in sets about 50–80 cm thick. The conglomerates are clast-supported, the matrix is sandy and clasts (maximum size 18 cm) are predominantly of volcanic rocks, although abundant angular sandy and silty intraclasts and rounded quartz, chert, metamorphic rock fragments, oysters and wood can also be found. Overlying the conglomerates are up to 2 m of coarse to medium-grained sandstones with medium scale (sets of 50–80 cm) tabular cross-bedding and lateral accretion surfaces. These deposits grade upward into medium- to fine-grained sandstones with medium scale (sets of 20–30 cm) trough cross-bedding, strongly wedge shaped and with millimeter-thick mud drapes.

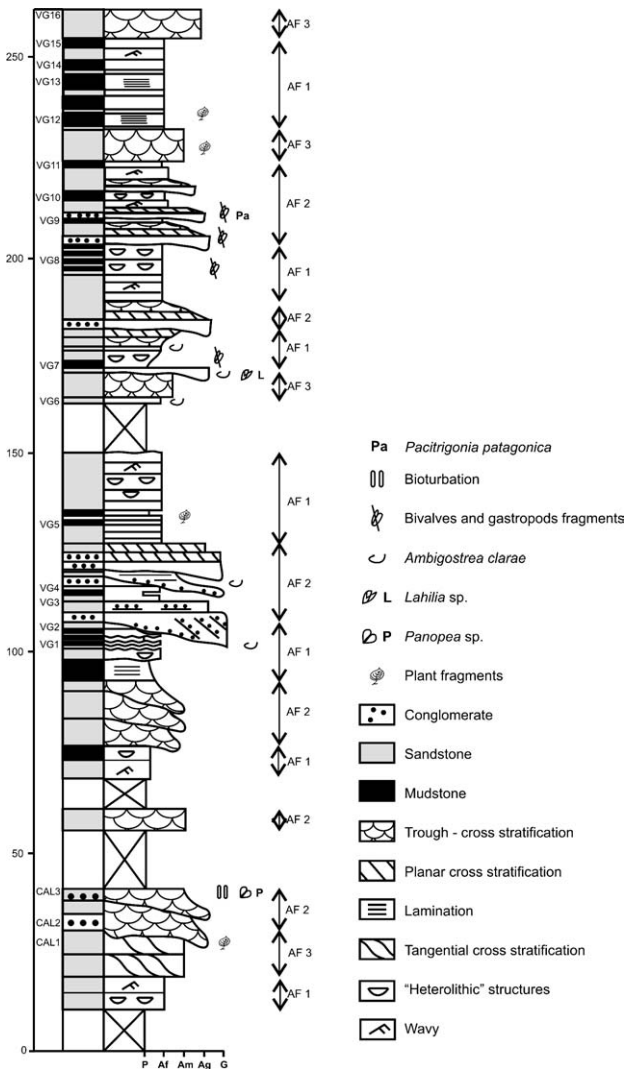


Fig. 2. Stratigraphic section of the Calafate Formation at the Estancia 25 de Mayo.

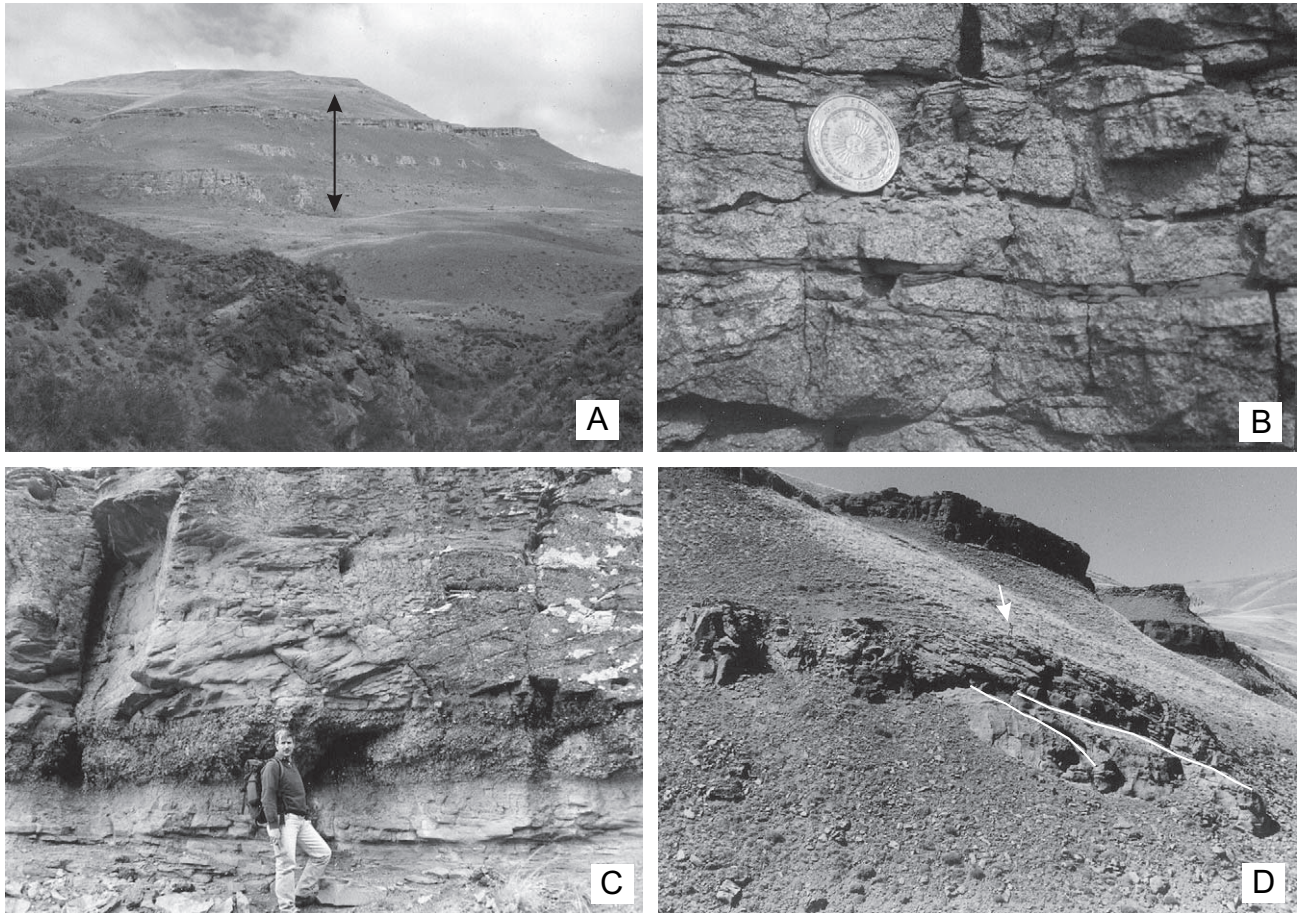


Fig. 3. Field photographs. A, outcrops of the Calafate Formation (arrowed) in the area studied. Note the alternation of more resistant, well-exposed beds with covered intervals. B, fine-grained rippled sandstones and mud-drapes (flaser bedding) typical of facies association 1. C, fining-upward channel fill of Facies Association 2. D, large-scale sand-waves in Facies Association 3. Note person for scale and reactivation surfaces.

Finally, there are fine- to very fine-grained sandstones, occasionally with intercalated mudstone laminae with wavy or flaser lamination.

Interpretation. The lenticular geometry of the beds, the erosional bases, and the decreasing energy arrangement suggested by the grain size as well as by the sedimentary structures indicate that these deposits represent channel infillings. The lateral pinch-out together with mud drapes, flaser and wavy lamination suggest tidal currents (De Raaf and Boersma, 1971). The large lateral extension of the amalgamated sets, the presence of lateral accretion surfaces, and the geometry of the individual beds suggest that these intervals represent the lateral migration of main tidal channels, forming a complex channel-belt system. Sandy dunes and sand-waves migrated along the deepest parts of these channels, while in areas of weaker currents small ripples migrated on sandy tidal flats. The presence of abundant sandy and silty intraclasts suggests that individual channels were flanked by finer-grained sediments, possibly tidal flats similar to those represented by

facies association 1, which were eroded as the channels migrated laterally.

Facies association 3: sandy tidal waves (8–20 m thick)

Description. This facies association comprises complex sandstone bodies showing a hierarchical juxtaposition of different bedforms. They are composed of medium to coarse-grained sandstones with dispersed granules and fine gravel in some localized horizons and large-scale planar-tabular or trough cross-stratification (sets of up to 4 m). These sets are bounded by flat or wavy surfaces that may or may not be demarcated by silty material (reactivation surfaces of De Mowbray and Visser, 1984). Internally they show a stacking of co-sets of medium scale (20–50 cm) trough cross-bedding. In the simpler bodies there is a strong fining-upward trend within each set, as well as to the lee face, and also a mud layer over the lee face (mud drape).

Interpretation. The size of the bed forms, the sedimentary structures and the complex arrangement,

together with the predominantly sandy grain size and tidal action evidence such as reactivation surfaces and mud drapes, suggest that this facies association represents large tidal sand-waves.

Tidal sand-waves are large bottom forms made up mainly of sandy sediment (preferably less than 1% gravel) that originate on the bottom of shallow shelves (20–80 m deep) or at the mouth of open estuaries, under the action of strong tidal currents. These sandy bodies measure a few metres in height (1–20 m) and dozens to a few hundred metres in length, with crests oriented quasi-orthogonally to the direction of the strongest tidal current (Allen, 1980). Internally, these sandy-waves can show ever more complex structure as the asymmetry

index between the incoming and outgoing tidal currents decreases. Despite the fact that study of these forms is only preliminary, those observed in the Calafate Formation seem to belong to types IV, V and/or VI as described by Allen (1980).

In general, the sedimentary section of the Calafate Formation represents a stacking of asymmetrical coarsening–fining-upward cycles, in which the thicknesses of the coarsening upward intervals are far greater than those of the fining-upward hemicycles. The coarser sediments and erosional surfaces appear in facies associations 2 and 3, at the top of the coarsening upward cycles. This arrangement resembles type 1 of the

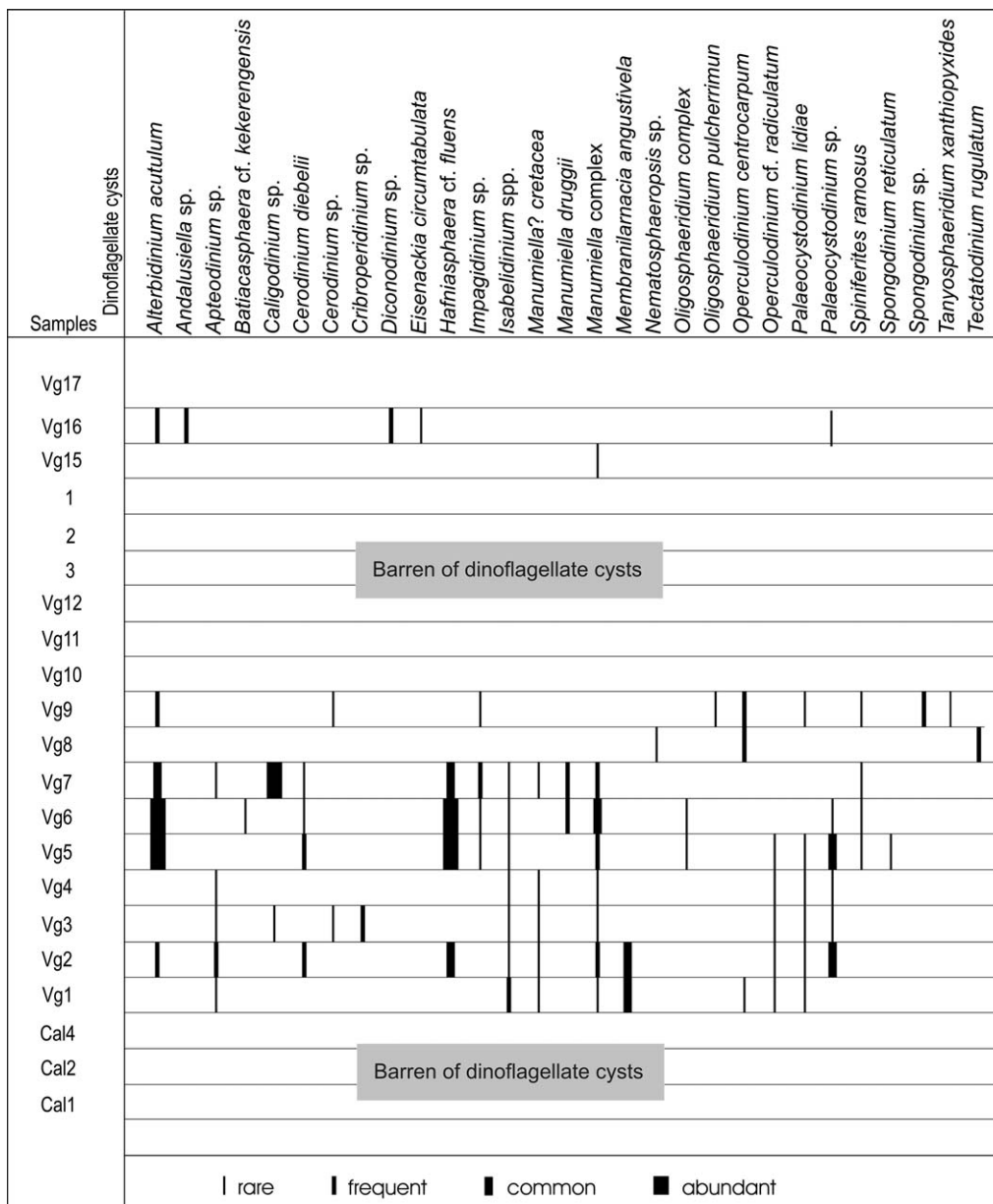
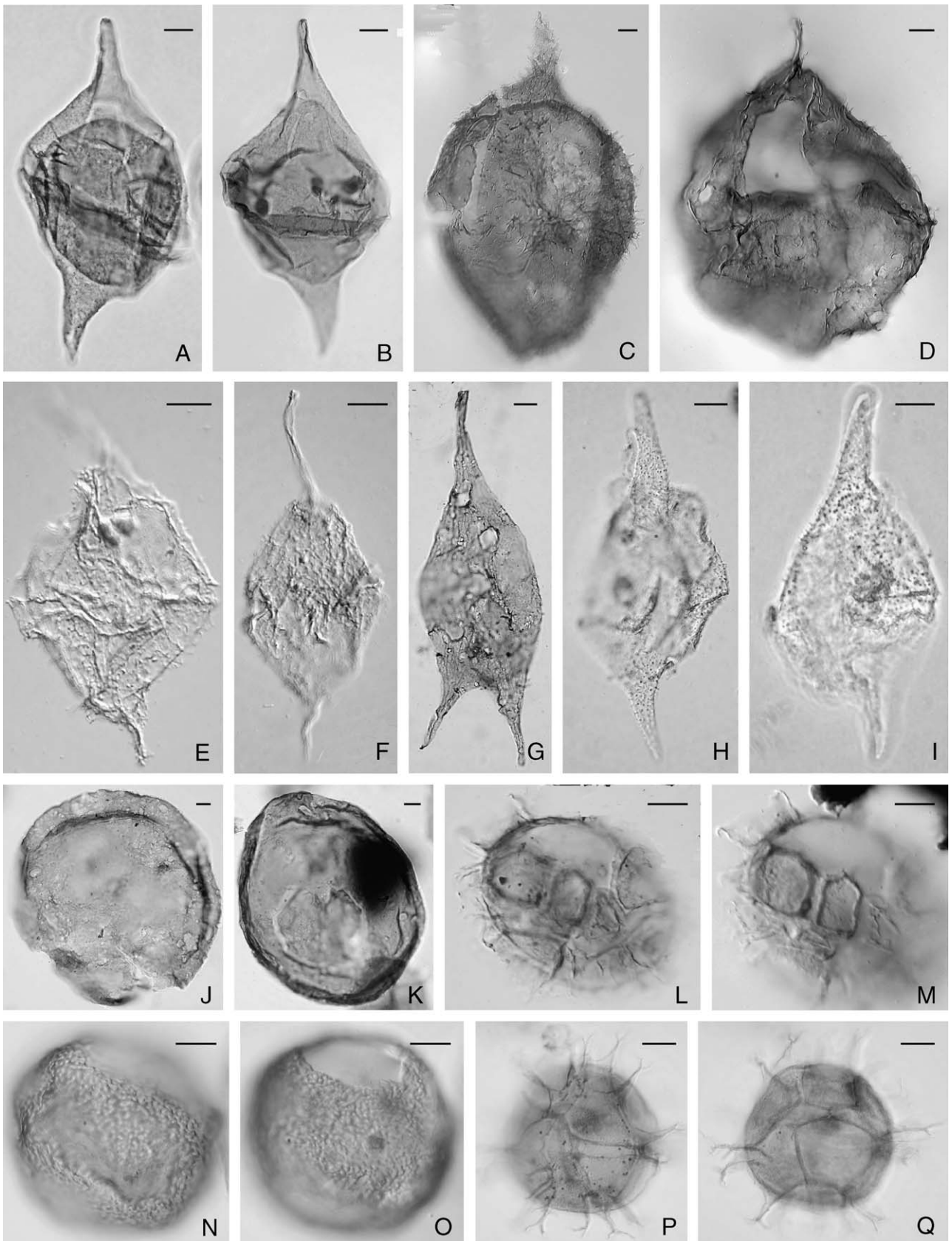


Fig. 4. Stratigraphic distribution and abundances of dinoflagellate cyst species identified in this study.



shelf depositional styles suggested by Cant and Hein (1986). These kinds of sequences, which are the most common in the Cretaceous of the Western Interior of North America, are characterized by the superposition of coarsening and thickening upward cycles up to 40 m thick. These cycles are interpreted to be the product of short-lived transgressive-regressive events in which the coarsening upward part represents sedimentary aggradation with a stable or decreasing sea level.

At the same time, the tidal sand-waves interpreted from facies association 3 show features similar to those described by Brenner et al. (1985), who considered that these bedforms start developing during a regressive period, when the erosional power and transport capacity of tides and storms on the shelf are increased. Selection and winnowing of finer particles produce a deposit of sandy beds, which show a coarsening upward trend but also in the direction of the current transport. Flow models show that this trend is orthogonal to the axis of the sandy deposit. Most of the sand is transported as dunes oriented at a high angle to the crest of the macroform. These bedforms tend to develop highly hierarchical boundary surfaces and lateral accretion surfaces (master bedding-planes of Harris, 1988).

Arbe and Hechem (1984) were the first to interpret the Calafate Formation as representing an estuarine system with inter- and sub-tidal flats, sub-tidal channels and tidal sandy bars. Harris (1988) developed a sequential infilling model for an open estuary. He suggested that during transgression and initial flooding, tidal flats were developed along the margins, while sand-waves or sandy dunes formed along the central part of the estuary. The last stage of infilling involves the development of sand-waves that gradually migrated towards the open sea until they wholly occupy the mouth of the estuary.

Although the general characteristics of the sediments of the Calafate Formation suggest a sub-tidal environment, the geometry of the basin has not been yet recorded. Therefore, the existence of an estuarine or incised valley cannot be confirmed, even though this is the most likely palaeogeographic model.

4. Palynological results

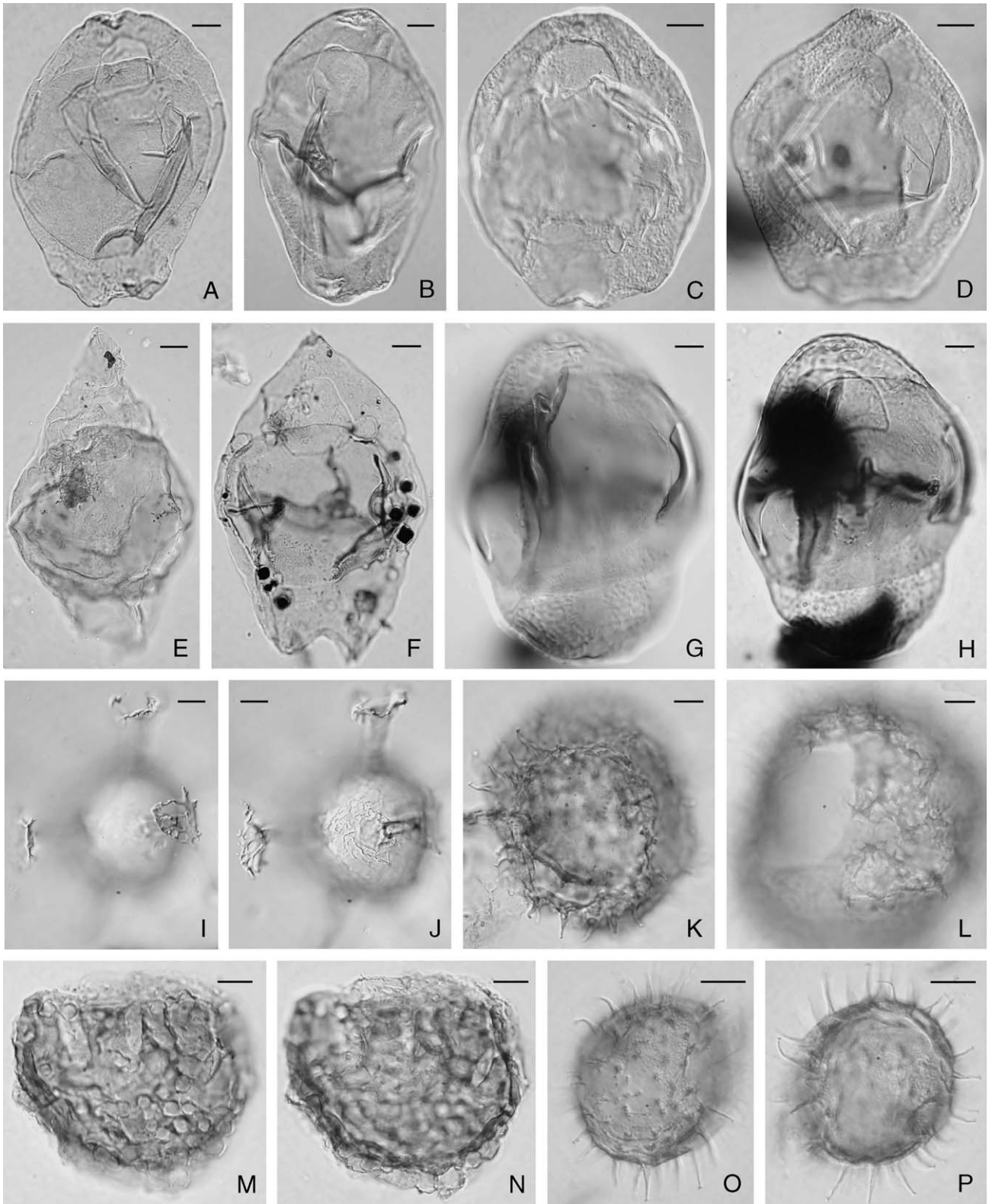
The dinocyst/sporomorph ratio and the abundance of certain dinoflagellate cyst species is variable throughout the section. Even when dinocysts outnumber sporomorphs, their diversity remains low (up to 12 species per sample). The terrestrial component is dominated by spores of pteridophytes and bryophytes, indicating the presence of continental water bodies (Salviniaceae) and wet conditions (Cyatheaceae, Osmundaceae, Gleicheniaceae, Lophosoriaceae, Sphagnaceae and Ricciaceae) in the adjacent source area. Gymnosperm and angiosperm pollen grains are subordinate. The consistent presence of continental components together with the low diversity of dinocysts suggests nearshore marine environments. The distribution and frequencies of all dinocyst species encountered in this section are shown in Fig. 4. Selected specimens are illustrated in Figs. 5–7.

4.1. Age and discussion

Our age assignment is mainly based on the known ranges of dinoflagellate species elsewhere, particularly in mid to high latitudes in the Southern Hemisphere (Brinkhuis et al., 2003; Williams et al., 2004). Our assemblages may also be compared with the Upper Cretaceous dinoflagellate zonation schemes for New Zealand (Wilson, 1984; Roncaglia et al., 1999), Australia (Helby et al., 1987) and the Antarctic Peninsula (Askin, 1988).

Askin (1988) defined a preliminary zonation of strata in the James Ross Basin, northeastern Antarctic Peninsula. In her zone 3 (p. 139) she indicated a continuous morphologic variation between the two end members of the *Manumiella* sp. 1 and “*Manumiella*” sp. 2 complex. The base of this zone is marked by the lowest occurrence of *Manumiella* sp. 1 of Askin (1988), and the age of the zone is Maastrichtian, probably late Maastrichtian. Similarly, a *Manumiella* complex characterizes assemblages from the bottom of the Austral Basin section, where some specimens compare well with *Manumiella* sp. 1 of Askin (1988), though “*Manumiella*” sp. 2 of Askin was not recorded. Based on this

Fig. 5. All specimens illustrated were recovered from the Calafate Formation at Estancia 25 de Mayo except A–D, which come from coeval deposits in the area studied. Digital images were taken using interference contrast, except A and I in phase contrast. A, B, *Alterbidinium acutum* (Wilson) Lentini and Williams emend. Khowaja-Ateequzaman et al. A, specimen in dorsal view, high focus; slide LA54, 41.5/105, M42/2; B, specimen in ventral view, low focus; slide LA54, 46.7/110, G47/2. C, D, *Apteodinium* sp. C, specimen in lateral view, high focus; slide LA38, 42.8/110, G43/1; D, specimen in dorsal view, high focus; slide LA38, 39.5/103, O40./2. E, F, *Andalusiella* sp. E, specimen in ventral view, high focus; slide Vg16-1, 46.5/95, W47/4; F, specimen in ventral view, high focus; slide Vg16-1, 46/111, I47,1. G, *Cerodinium diebelii* (Alberti) Lentini and Williams, specimen in ventral view, high focus; slide Vg5-2, 42.5/97.2, T43. H, I, *Diconodinium* sp. H, specimen in dorsal view, intermediate focus; slide Vg16-1, 22/108, H21/4; I, specimen in ventral view, high focus; slide 3431-1, 40.5/97, U41. J, K, *Caligodinium* sp. J, specimen in lateral view, high focus; slide Vg6-2, 25.5/101, Q25; K, specimen in apical view, low focus; slide Vg6-2, 28.5/102, O28/4. L, M, *Eisenackia circumtabulata* Drugg, specimen in ventral view, high and intermediate focus respectively; slide Vg16-2, 37.5/106.5, K38/3. N, O, *Batiacasphaera* cf. *kekerengensis* Schiøler and Wilson, specimen in lateral view; slide Vg6-1, 52.5/99.8, R53. P, Q, *Hafniasphaera* cf. *fluens* Hansen, specimen in ventral/left lateral view, in high and low focus respectively; slide Vg6-1, 37.1/95, W37.2.



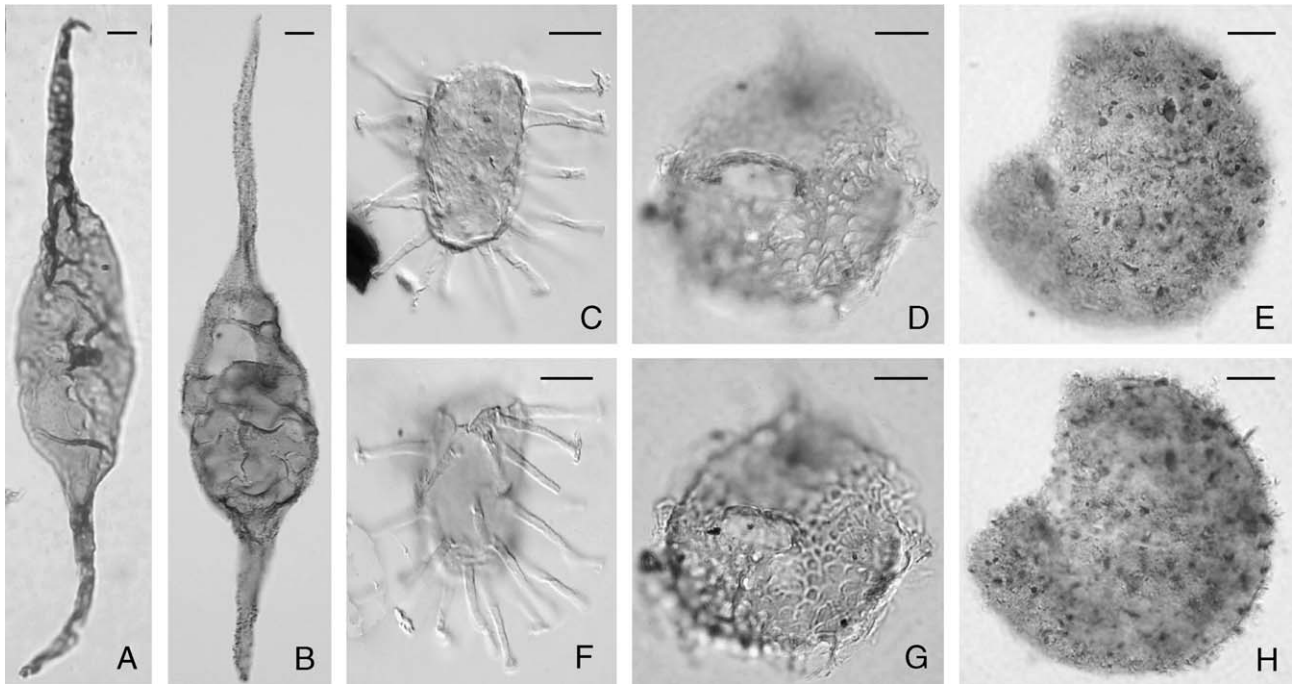


Fig. 7. All specimens illustrated come from the Calafate Formation at Estancia 25 de Mayo, except two which are from an equivalent section. A, *Palaeocystodinium lidiae* (Górka) Davey, specimen in ventral view, intermediate focus; slide Vg5-1, 46.5/99.8, R47/4. B, *Palaeocystodinium* sp., specimen in dorsal view, high focus; slide LA51, 34.5/94.5, W34/4. C, F, *Tanyosphaeridium xanthiopyxides* (Wetzel ex Deflandre) Stover and Evitt, specimen in ventral view, low and high focus respectively; slide Vg9, 44/118, J44/2. D, G, *Spongodinium reticulatum* Hultberg, specimen in ventral view, high and low focus respectively; slide Vg5-1, 45.5/92, Z46. E, H, *Tectatodinium rugulatum* (Hansen) McMinn, specimen in high and cross section respectively; slide Vg8, 22.5/105.5, L22.2.

comparison, we suggest an age no older than Maastrichtian (probably late Maastrichtian) for the lower part of the section.

Likewise, Askin (1988) defined a zone 4 on the basis of the presence of the *Manumiella druggii*-*M. seelandica* complex. The first occurrences of *Manumiella druggii* and *Exochosphaeridium bifidum* mark the base of this zone, whereas the highest occurrence of the complex indicates the top of this zone. She assigned zone 4 to the latest Maastrichtian. In our assemblages *Manumiella druggii* has its first occurrence in sample Vg6 (approximately 160 m from the bottom of the section).

Williams et al. (2004) have indicated that *M. druggii* (as *M. seelandica*) first appeared during the late Maastrichtian (67.5 Ma) at high latitudes of the Southern Hemisphere, whereas at mid latitudes it appeared at the beginning of the Maastrichtian

(71.29 Ma). Moreover, the oldest occurrence of *Manumiella druggii* marks the base of the upper Maastrichtian–basal Danian *Manumiella druggii* Interval Zone of Helby et al. (1987) in Australia. This dinocyst event coincides with the upper Haumurian *M. druggii* Range Zone of Wilson (1984) in New Zealand. Roncaglia et al. (1999) proposed a new zonation scheme for five sections from New Zealand, where they recognized the *M. druggii* Interval Zone of Helby et al. (1987), which they assigned to the early–late Maastrichtian. Based on the above information, a late Maastrichtian age is indicated for the middle part of the Calafate Formation at Estancia 25 de Mayo.

According to Williams et al. (2004), *Eisenackia* (as *Alisocysta*) *circumtabulata* appeared at 65 Ma in the Northern Hemisphere, whereas at high latitudes in the Southern Hemisphere it appeared at 68.5 Ma.

Fig. 6. All specimens illustrated come from the Calafate Formation at Estancia 25 de Mayo. All digital images were taken using interference contrast. A, *Manumiella* sp., specimen in dorsal view, high focus; slide Vg6-1, 21.5/102, P21/2. B, *Manumiella* sp., specimen in dorsal view, high focus; slide Vg6-1, 22/107, K22/1. C, D, *Manumiella druggii* (Stover) Bujak and Davies. C, specimen in dorsal view, high focus; slide Vg6-1, 28.5/102.2, O38/3; D, specimen in ventral view, low focus; slide Vg6-2, 50.2/106.5, K51/1. E, *Isabelidium* sp., specimen in ventral view, low focus; slide Vg2-1, 23.5/104.9, M23/2. F, *Manumiella* sp., specimen in dorsal view, high focus; slide Vg2-1, 23.5/104.2, M23/4. G, H, *Manumiella? cretacea* (Cookson) Bujak and Davies, specimen in ventral view, high and low focus respectively; slide Vg2-1, 52.5/93, Y53/4. I, J, *Oligosphaeridium pulcherrimum* (Deflandre and Cookson) Davey and Williams, specimen in ventral view, high and intermediate focus respectively; slide Vg9, 21.5/100, Q21/4. K, L, *Operculodinium* cf. *radiculatum* Smith. K, specimen in ventral view, high focus; slide Vg2-2, 49/99.5, R50/4; L, specimen in lateral view, high focus; slide Vg5-2, 37.5/105.5, L38/2. M, N, *Membranilarnacia angustivela* (Deflandre and Cookson) McMinn, specimen in dorsal view, high and low focus respectively; slide Vg1, 22.5/110, G22/2. O, P, *Operculodinium centrocarpum* (Deflandre and Cookson) Wall, specimen in ventral view, high and intermediate focus respectively; slide Vg9, 36.5/95, W37.3.

Eisenackia (as *Alisocysta*) *circumtabulata* was recorded from the uppermost part of zone 4 of Askin (1988) and in the upper part of the *Manumiella druggii* Interval Zone of Helby et al. (1987). Similarly, in our study *Eisenackia circumtabulata* first occurs in the uppermost part of the section.

Brinkhuis et al. (2003) described Maastrichtian dinocyst assemblages from Ocean Drilling Program Site 1172, southeastern Tasmania, where *Manumiella druggii* and *Eisenackia* (as *Alisocysta*) *circumtabulata* constitute important biostratigraphical markers. The Tasmanian assemblages are mainly composed by peridinioid cysts represented by species of *Manumiella*, *Alterbidinium*, *Diconodinium*, *Palaeocystodinium* and *Cerodinium*, which are also common to abundant in most of our assemblages.

In summary, the dinocyst assemblages indicate an age no older than Maastrichtian (possibly late Maastrichtian) for the base of the section, and the stratigraphical interval between Vg6 and Vg7 is interpreted as late Maastrichtian. The stratigraphical ranges of the few species recovered from the sample Vg16 extend into the Palaeogene. Thus, the dinocyst assemblages do not allow a restriction of the age of the top the section to the Maastrichtian. However, the absence of species that first appear within the Danian, prevents confirmation of a Danian age for the uppermost part of the section.

Precise age determinations cannot be inferred from the long-ranging spores and pollen encountered in our assemblages. Sample Vg2 yields *Azollopsis* (*Azollopsis*) *polyancyra*, which has previously been recorded by Stough (1968) from Late Cretaceous deposits in southern Chile. *Granelispora loncochensis*, which occurs in samples Vg7 and Vg16, and as fragments at other levels, is an important guide form for the Campanian–Maastrichtian of Argentina (Sepúlveda et al., 1989; Papú, 1990, 1993, 1997, 2002; Papú and Sepúlveda, 1995).

The oyster *Ambigostrea clarae* (Ihering) is present in several beds through the middle part of the section. It is an index species for the late Maastrichtian in northern Patagonia (Casadio, 1998). Likewise, the presence of specimens of the bivalve *Pacitrigonia patagonica* (Feruglio) towards the top of the section (Vg9) suggests a Late Cretaceous age for the Calafate Formation in this area. Both support our age determination based on the dinoflagellate cyst analysis.

Although abundant, the low diversity of species in our dinocyst assemblages impedes comparison with coeval assemblages from the other South American mid latitude basins of Neuquén, Colorado and Punta del Este. However, these three Atlantic basins yield similar dinocyst assemblages, allowing a strong correlation with the latest Maastrichtian (Daners and Guerstein, 2004; Daners et al., 2004). The weak affinity between dinoflagellate assemblages from the Austral

Basin and the mid latitude south-western Atlantic basins might be a result of the restricted marine conditions recognized in the Calafate Formation. However, we cannot dismiss the possibility of a latitudinal and/or oceanographic differentiation in the latest Maastrichtian, because evidence of latitudinal influence has been recognized in some fossil faunal groups (Feldmann et al., 1995, 1997; Casadio, 1998).

5. Conclusions

The Calafate Formation represents a stacking of asymmetrical coarsening–fining–upward cycles in which the thickness of the coarsening upward intervals are far greater than those of the fining-upward hemicycles. They are interpreted as the product of short-lived transgressive-regressive events in which the coarsening upward part represents sedimentary aggradation with a stable or lowering sea level.

Although the general characteristics of the sediments together with the low diversity of dinoflagellate cysts suggest a nearshore marine environment, the geometry of the basin that these deposits fill has not yet been determined. Therefore, the existence of an estuarine or incised valley cannot be proved, even though this is the most likely palaeogeographical interpretation.

Dinoflagellate cysts indicate an age no older than Maastrichtian (probably late Maastrichtian) for the base of the section and a late Maastrichtian age for the middle part. Based on sporomorph occurrences and field data we suggest an age no younger than Maastrichtian for the top of the section.

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Appendix

List of dinoflagellate cyst and sporomorph species cited in the text.

Dinoflagellate cysts

Alterbidinium acutum (Wilson, 1967) Lentin and Williams, 1985 emend. Khowaja-Ateequzaman et al., 1991
Batiacasphaera cf. *kekerengensis* Schiøler and Wilson, 1998
Cerodinium diebelii (Alberti, 1959) Lentin and Williams, 1987
Eisenackia circumtabulata Drugg, 1967
Exochosphaeridium bifidum (Clarke and Verdier, 1967) Clarke et al., 1968 emend. Davey, 1969
Hafniasphaera cf. *fluens* Hansen, 1977
Manumiella? *cretacea* (Cookson, 1956) Bujak and Davies, 1983

Manumiella druggii (Stover, 1974) Bujak and Davies, 1983
Membranilarnacia angustivela (Deflandre and Cookson, 1955) McMinn, 1988
Oligosphaeridium complex (White, 1842) Davey and Williams, 1966
Oligosphaeridium pulcherrimum (Deflandre and Cookson, 1955) Davey and Williams, 1966
Operculodinium centrocarpum (Deflandre and Cookson, 1955) Wall, 1967
Operculodinium cf. *radiculatum* Smith, 1992
Palaeocystodinium lidiae (Górka, 1963) Davey, 1969
Spiniferites ramosus (Ehrenberg, 1838) Mantell, 1854
Spongodinium reticulatum Hultberg, 1985
Tanyosphaeridium xanthiopyxides (Wetzel, 1933 ex Deflandre, 1937) Stover and Evitt, 1978
Tectatodinium rugulatum (Hansen, 1977) McMinn, 1988

Sporomorphs

Azollopsis (*Azollopsis*) *polyancyra* (Stough) Sweet and Hills, 1974
Granelispora loncochensis Papú, 1997