# ORGANIC-WALLED MICROPLANKTON IN THE JAGUEL FORMATION (UPPER MAASTRICHTIAN-DANIAN), NEUQUEN PROVINCE, ARGENTINA: IMPLICATIONS FOR THE THE CRETACEOUS/PALEOGENE BOUNDARY EVENT

by

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**THE CITY UNIVERSITY OF NEW YORK**

# Abstract

# ORGANIC-WALLED MICROPLANKTON IN THE JAGUEL FORMATION (UPPER MAASTRICHTIAN-DANIAN), NEUQUEN PROVINCE, ARGENTINA: IMPLICATIONS FOR THE CRETACEOUS/PALEOGENE BOUNDARY EVENT

by

Susana Palamarczuk

Adviser: Prof. John A. Chamberlain Jr.

Fossil organic-walled microplankton, dinoflagellates primarily, from marine deposits of the Jaguel Formation at two locations, Lomas Coloradas and Bajada de Jaguel, Neuquén Province, Argentina, were analyzed for age assignment, paleoenvironmental interpretation and paleobiogeography of selected species.

The abundant and diverse dinoflagellate cyst assemblages show that the Jaguel Formation is of Late Maastrichtian/Danian age and contains the Cretaceous/Paleocene boundary. The precise location, at the Bajada de Jaguel section, of a biologic turnover that is interpreted to represent the Cretaceous/Paleogene boundary event occurs at the bottom of a 17cm water lain ash layer and is defined on the basis of the first occurrence of worldwide known Danian dinocyst biostratigraphic markers such as *Damassadinium californicum* and *Senoniasphaera inornata.* Detailed studies of the dinoflagellates recovered show that the group was more resistant than the calcareous microfossils to the Cretaceous/ Paleogene boundary event and did not suffer mass extinction. This is probably because they are represented in the fossil record only by the encysted stage. However, dinoflagellates did undergo a sharp turnover with extinction of some species and migration of others. Locally, the last occurrence of Maastrichtian autotrophic, the gonyaulacacean affinity group, appears to be severely affected by the K/Plg boundary event. With the exception of *Deflandrea galeata* and the *Isabelididnium- Manumiella* complex, the peridinialean affinity group, considered as heterotrophic, survived the event.

Within 1m interval below the boundary, the first occurrence, peak and disappearance of the *Isabelidinium* /*Manumiella* group was documented. This group evolved through the Upper Cretaceous at high latitudes and its presence is interpreted as indicating a short- term episode of regression and/or water cooling prior to the boundary.

Within the 2m interval above the boundary, an unusual peak of acritarchs, single celled and colonial algae and small peridiniod species bloom are interpreted as the response to environmental stress in the aftermath of the boundary event.

Comparisons with studies in sections from the Southern Hemisphere suggest that temperature and /or salinity barriers controlled the paleogeography of the assemblages. The assemblages from Tierra del Fuego and Antarctica are very similar to one another, but differ from those of middle latitude analyzed in this study.

**classification is an arbitrary scheme applied**
**to Nature's**
**continuum by the human mind for**
**philosophical**
**and practical purposes...**

# ACKNOWLEDGEMENTS

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I'd like to dedicate this dissertation to the memory of my parents. They can't share this accomplishment with me, but they are always present in my heart.

I am also grateful to my children, who were always ready to help, especially during difficult times, and to my grandchildren, for bringing happiness and joy to my life. Last but not least, to my dear husband Edward Divins, who contributed to the completion of this thesis with his support and (sometimes) infinite patience.

# TABLE OF CONTENTS

Page

Chapter 1

INTRODUCTION

Chapter 2

GEOLOGIC SETTING

Chapter 3

METHODS

Chapter 4

LOMAS COLORADAS SECTION

Chapter 5

BAJADA DE JAGUEL SECTION

Chapter 6

THE K/PLG BOUNDARY IN THE BAJADA DE JAGUEL SECTION

Chapter 7

PALEOBIOGEOGRAPHY OF SELECTED DINOFLAGELLATE CYST SPECIES

# LIST OF TABLES

## LIST OF ILLUSTRATIONS

# CHAPTER 1

## INTRODUCTION

### Scope of the study

Studies on dinoflagellate cysts are scarce for middle latitudes in the Southern Hemisphere. The objective of this research is to ameliorate this situation by analyzing the organic-walled microfossils, mainly dinoflagellate cysts, which were recovered from two sections, near 38°06′ S.Lat. and 68°23′ W.Long. that expose the Late Cretaceous/ Danian Jaguel Formation in Neuquén Province, Argentina (Fig. 1).

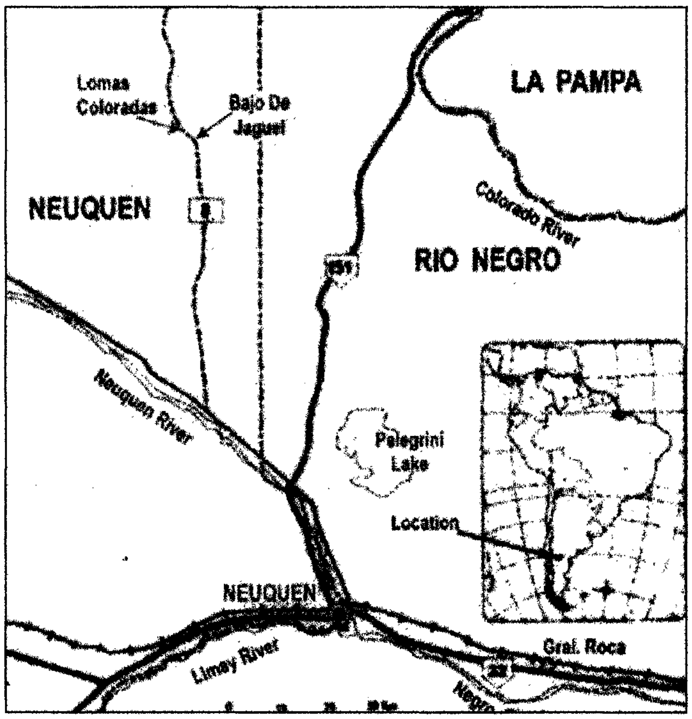

Figure 1: Location map

In particular, this study aims to:

- Document organic-walled microfossil assemblages in which most of their component species or morphotypes were not previously identified from Cretaceous/ Danian rocks in Argentina, or are new.
- Propose an informal, local biostratigraphic scheme based on assemblage intervals.
- Tentatively correlate the sections under study on the basis of their dinoflagellate content.
- Document the response of the organic-walled microplankton to the Cretaceous/ Paleogene boundary event.
- Establish a preliminary paleobiogeographic pattern of selected dinoflagellate cyst species for southern South America and Antarctica on the basis of personal observations and information obtained from the published literature.

## Dinoflagellates

Dinoflagellates are single-celled, planktonic organisms (protists) with a life cycle that comprises two stages: 1) a vegetative, motile stage, composed of the protoplasm enclosed in a cellulosic theca and propelled by two flagella. This stage is not preserved as fossil; and 2) a dormant, encysted stage, related to sexual reproduction, which has a cyst wall composed of complex organic matter similar to the sporopollenin that compose the pollen grains and spores. This encysted stage is preserved in the fossil record due to the resistance of the cyst wall to most sedimentary processes, with the exception of intense oxidation.

Dinoflagellates are important components of modern phytoplanktonic communities and are currently found in almost all types of aqueous environments. As fossils, they are widespread in Mesozoic-Cenozoic marine sedimentary rocks, and beginning in the Oligocene they occur as well in some deposits of non-marine origin. Modern dinoflagellates are well known as the producers of the so-called "red tides," that kill mollusks and fish.

Fig. 4 shows the life cycle of dinoflagellates. During the motile stage, these organisms live in the upper part of the water column (planktonic habitat). Some of them are autotrophic (primary producers, i.e., photosynthesizers, which use sun light as an energy source for synthesizing nutrients), while others are heterotrophic (consumers that obtain their food by the ingestion of other microscopic organisms, such as diatoms, or from nutrients that are in solution in the water).

The cysts that dinoflagellates produce, when environmental and climatic conditions are favorable, develop a new motile organism by the extrusion of the protoplasm through an opening of the cyst wall, and the construction of a new cellulosic theca. The empty cyst is eventually deposited on the substrate, and behaves as a sedimentary particle, normally in the fine sand/silt grain size range, and can be recovered from the sedimentary rocks using appropriate laboratory techniques

Studies on fossil dinoflagellate cysts are aided by analogy with the behavior and distribution in different environments of extant forms. Cyst morphology is genetically controlled, and reproduces some of the characteristics of the cellulosic cover of the motile stage (theca). This fact provides a basis for relating the two life stages (cyst and motile) within specific dinoflagellate clades. In the motile stage, the cellulosic theca is divided into tiny plates organized in tabulation patterns that are used by bilogists for the classification of the group. Three main regions can be recognized in the theca: apical, cingular and antapical. On the ventral surface, the area where both flagella arise, is the sulcus (Fig. 2).

In the encysted stage, the stage paleontologists deal with, the equivalent areas are named apical, paracingular and antapical and parasulcal respectively. The cysts do not show mechanical divisions of plates, but in some cases, plate patterns known as paratabulation, are reproduced on the cyst wall (see Fig. 3 for a schematic representation of a cyst and Plates 1 and 2 as examples of paraplates in the spiniferid group). In other cases, even though a pattern is not readily visible on the cyst wall, or not reproduced at all, the opening through which the protoplasm exits the cyst normally has a regular shape and a position that corresponds to the shape of a plate. This opening is called the archeopyle and is very useful in classifying fossil cysts and relating them to the

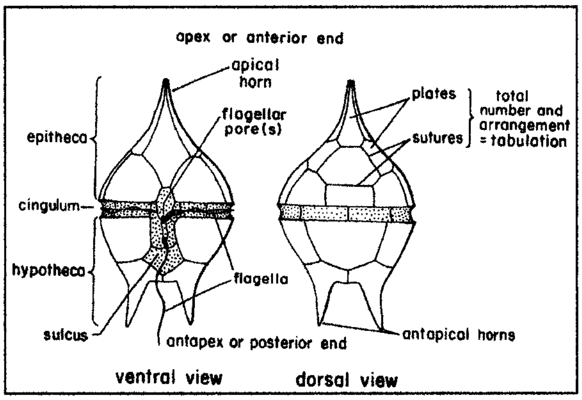

Figure 2: Schematic representation of a dinoflagellate theca (motile stage).

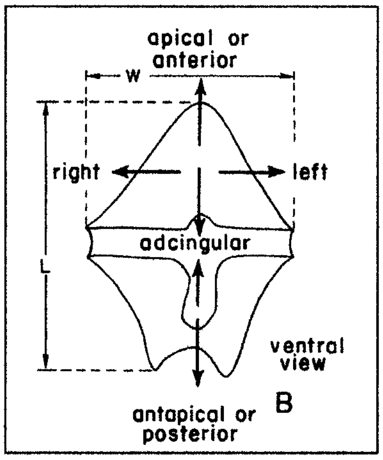

Figure 3: Schematic representation of the different regions of a dinoflagellate cyst.

motile stage. The position of this opening, according to its location on the cyst, can be precingular, i. e., adjacent to the paracingulum, apical, when it includes paraplates of this series, or intercalary, comprising paraplates between the apical and the paracingular row. Most of the specimens illustrated in plates 1 to 22 show and archeopyle.

Dinoflagellate cysts have a fossil record in sedimentary rocks extending from the end of the Triassic period to the present, although geochemically, they have been traced back to much older deposits. Many species are important biostratigraphic and environmental markers and allow accurate correlation and interpretation of ancient sedimentary environments. No fresh water dinoflagellate cysts have been clearly recognized before the first description by Traverse (1955), of peridiniacean forms from Oligocene deposits in Vermont, so that the presence of

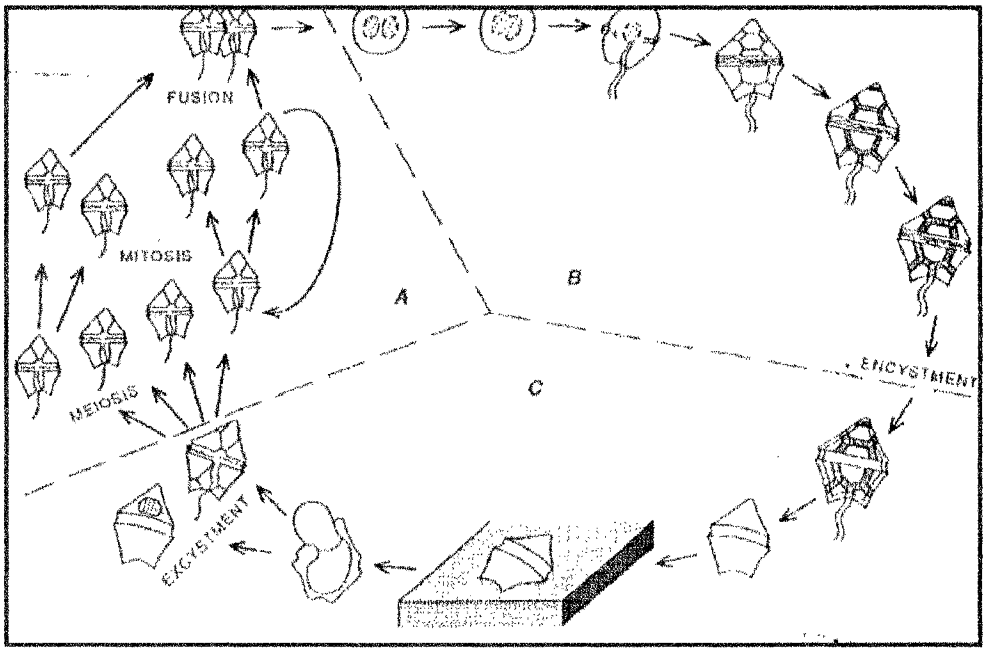

FIGURE 4: Dinoflagellates life cycle and the deposition of cysts as sedimentary particles.
A- Asexual (fission) and sexual reproduction of dinoflagellates in the motile stage. B- Construction of a new theca as a planozygote. C- Formation of a cysts inside the theca, deposition of the cyst and re- initiation of the cycle. (modified from Evitt, 1985).

dinoflagellates in older sedimentary rocks is usually considered as an indicator of marine conditions of deposition. However, several studies assign pre-Oligocene dinoflagellate assemblages to fresh water environments based on different arguments, such as low diversity, very fine cyst wall, and association with fresh water fossils (Batten, 1985; Backhouse, 1988; and Batten and Lister, 1988 a, b; Mao and Yu, 1990; among others). However, for sediments of Maastrichtian and Danian age, all dinoflagellates are viewed as marine.

## Maastrichtian-Danian Dinoflagellates in Argentina

Dinoflagellates, together with other groups of planktonic organisms of algal affinities, were extremely abundant during Maastrichtian-Danian time. Dinoflagellates dating from the 10 million years between 74 and 64 my before present have been recovered from sections all over the world (Heisecke, 1970;Benson, 1976; Hansen, 1979; Ioannides, 1986; Firth, 1987; Askin, 1988; Brinkhuis and Zachariasse, 1988; Elliot et al, 1994; Yepes, 2001; Slimani, 2001; Sarkis et al, 2002 among many other contributions).

Second order sea-level fluctuations, documented in palynological studies (Habib and Miller, 1989; Firth, 1987; Habib et al., 1992; Schioler and Wilson, 1993) occurred throughout the relatively high global sea-level which is associated with the Late Cretaceous/Danian. In the area of southern South America considered in this study, Maastrichtian-Danian deposition was the result of an Atlantic transgression related to one such sea level rise (Uliana, 1979, Uliana and Biddle, 1988). At its maximum extent, this transgression reached the west of the present Argentine territory (Uliana and Biddle, 1988). Abundant and well preserved assemblages of dinoflagellate cysts and other organic–walled microfossils were recovered from sediments of the Jaguel Formation which is one of the units deposited in the Neuquén Basin during this transgressive episode. These microfossils are the subject of this research.

The Jaguel Formation was sampled at two localities: Lomas Coloradas and Bajada de Jaguel. Microfossils extracted from sediment samples were identified and used to interpret the biostratigraphy and paleoecology of the area during the Maastrichtian-Danian interval, as well as to propose a preliminary paleobiogeographic reconstruction for dinoflagellate selected species in southern South America and Antarctica. A detailed analysis of the response of organic-walled microfossils to the Cretaceous/Paleogene boundary event, identified in the Bajada de Jaguel section by a marked turnover of the assemblages and confirmed by the analysis of calcareous microfossils and radiometric dating (Palamarczuk et al., 2002), was also carried out.

# CHAPTER 2

## GEOLOGIC SETTING

### Introduction

The Jaguel Formation, focus of this study, represents an episode of deposition of marine sediments in the Neuquén Basin during a transgression of the Atlantic Ocean that extended into the western part of the present Argentine territory during the Maastrichtian-Danian time interval (Fig. 5). The Neuquén basin is a sedimentary basin located in south-central western Argentina. It developed as a funnel- shaped, relatively confined setting, in the provinces of Neuquén and Mendoza (Fig. 6). It is limited by the cratonic areas Sierra Pintada massif to the northeast and Nord Patagonian massif to the south.

Three major sedimentary supercycles were recognized in the basin by Groeber (1946, 1953): "Jurásico" (Jurassic) with deposits from late Triassic to Late Jurassic; "Andico", from Late Jurassic to Early Cretaceous and "Riográndico", from Late Cretaceous to Paleocene. The northeastern and southern margins of the basin approximately coincide with the original depositional limits of the Jurassic and Cretaceous marine rocks (Barrio, 1990) while the present western flank is represented by the fold and thrust belt of the Andean Cordillera (Fig. 6).

The early development of the basin, that is, the Jurassic and Andico, were extensively studied by many authors (Digregorio and Uliana, 1980; Mitchum and Uliana, 1985, among others). The part of the Neuquén basin that represents and eastward extension of the Chilean-Argentine Andean Mesozoic basin is known as the Neuquén

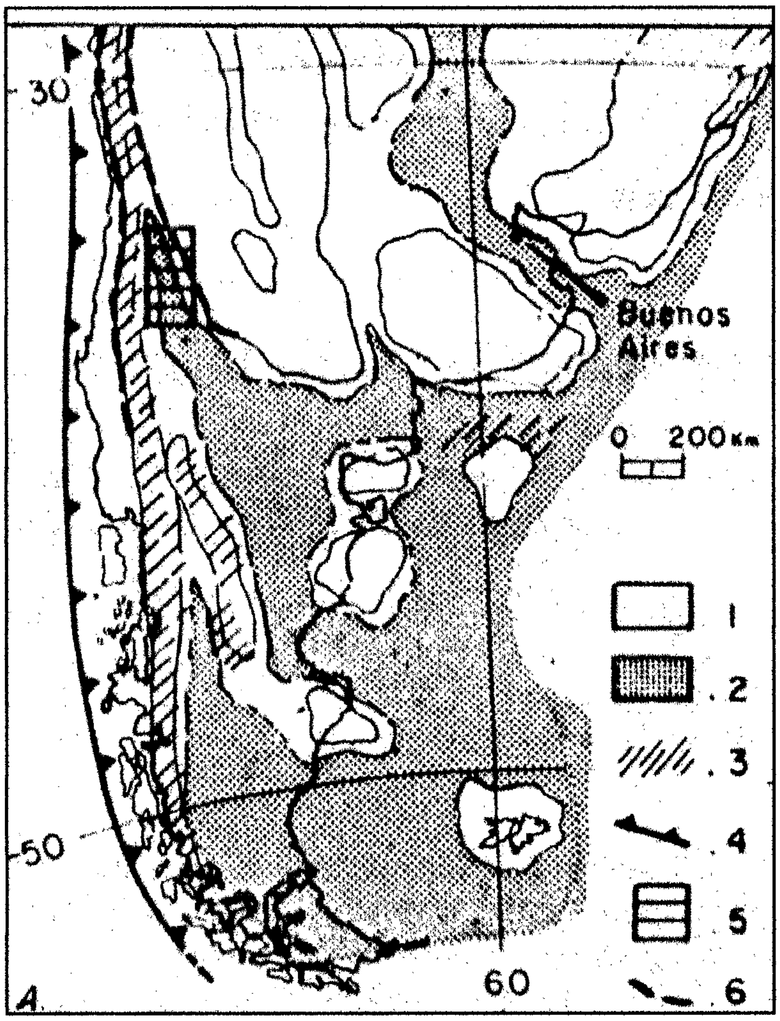

FIGURE 5: Paleogeographic reconstruction of the transgression that covered the present Argentine territory during the Maastrichtian and Danian (after Uliana and Biddle, 1988). References: 1- Emerged areas. 2- Submerged areas. 3- Igneous activity. 4- Arch-trench system. 5- General location of the area considered in this study. 6- Approximate limits of the Neuquén Basin during the Maastrichtian-Danian time interval

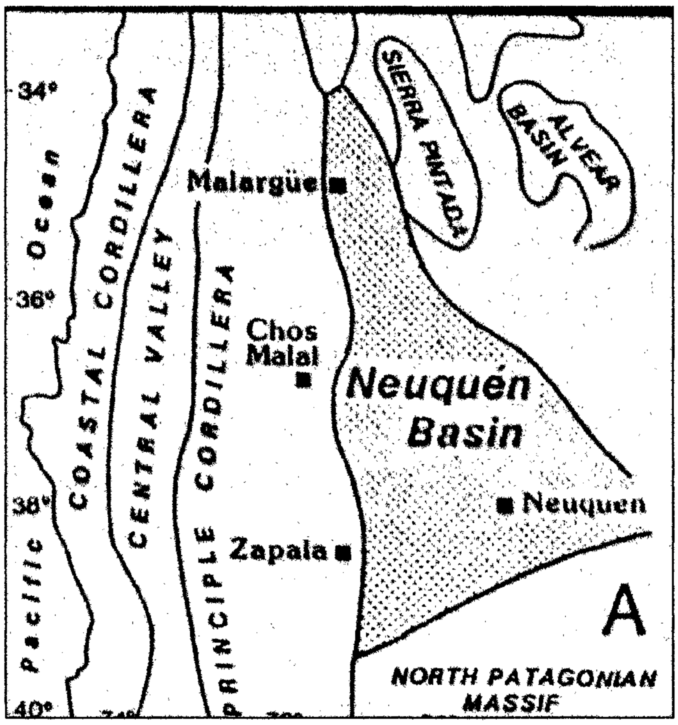

FIGURE 6: Schematic representation of the Neuquén Basin (modified from Barrio, 1990)

embayment (Bracaccini, 1964; Digregorio and Uliana, 1980).

This study focuses on one of the units that represent the transgressive episode within the "Riográndico", the youngest of these three Mesozoic/early Cenozoic supercycles. During the late Cretaceous, the tectonic evolution of the Neuquén Basin changed abruptly after the Mirano orogenic phase that took place in the Cenomanian. This was a compressional event that resulted in the uplifting of the western part of the basin. Molassic sedimentation derived from the uplifted area (Ramos, 1981; Malumián et al, 1983; Digregorio et al., 1984). This episode represents the initiation of the

"Riográndico" supercycle and is bounded at the bottom by a regional unconformity and overlying the Rayoso Formation.

The "Riográndico" was divided into "Neuqueniano" and "Malalhueyano" by Groeber (1946). The "Neuqueniano", deposited from the Mid Cenomanian to the ?Early Campanian, comprises continental fluvial deposits while transitional to marine Malalhueyano, which is considered to be Upper Campanian / Maastrichtian to Paleocene, represents the first Atlantic transgressive- regressive event into the basin. Uliana (1979), formally defined the "Neuqueniano" and "Malalhueyano" as Neuquén and Malargue Groups respectively. Evolving views on the lithostratigraphy of their rocks are shown in Fig. 7. (Windhausen, 1914, 1922; Wichmann, 1924, 1928; Bertels, 1968, 1980; Uliana, 1979).

## Sedimentology and Depositional Environment of the Malargue Group.

The Malargue Group comprises the following Formations from bottom to top: Allen, Jaguel, Roca, and El Carrizo. The lower beds of the Group are separated from the underlying top Formation of the Neuquén Group by a stratigraphic discontinuity (Uliana and Dellapé, 1981).

Allen Formation: The Allen Formation was divided into three parts by Uliana and Dellapé (1981), on the basis of the lithologic characteristics.

Lower interval: the base of the interval is composed of conglomeradic sandstones and conglomerates, grading toward the top to light gray, medium to coarse grained sandstones, partly friable and partly cemented by carbonates.

<table>
<tr><th colspan="2">WINDHAUSEN<br>1914-1922</th><th>WICHMANN<br>1924-1928</th><th colspan="2">BERTELS<br>1968-1980</th><th colspan="3">ULIANA<br>1978</th></tr>
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<tr><td rowspan="4">Malargüe Group</td><td colspan="2">El Carrizo Fm</td></tr>
<tr><td rowspan="3">Rocanense</td><td>Upper</td><td>Allen Fm</td><td colspan="2">Roca Fm</td><td colspan="2">Roca Fm</td></tr>
<tr><td rowspan="2">Lower<br>"Jagüel Beds"</td><td>"Upper Senonian"</td><td rowspan="2">Jagüel Fm</td><td>"Upper Member"</td><td colspan="2">Jagüel Fm</td></tr>
<tr><td>"Lacustre Senonian"</td><td>"Lower Member"</td><td colspan="2">Allen Fm</td></tr>
<tr><td colspan="2" rowspan="2">Pehuenches</td><td rowspan="2">"Strata<br>with<br>Dinosaurs"</td><td colspan="2" rowspan="2">Neuquén Group</td><td rowspan="2">Neuquén Group</td><td rowspan="2">ío Colorado Fm</td><td>Anacleto Member</td></tr>
<tr><td>Bajo de la Carpa Member</td></tr>
</table>

FIGURE 7: Lithostratigraphic units of the Riográndico Supercycle in the Neuquén Basin according to the different authors who worked in the area

Middle interval: composed mostly of clay with veins of Gypsum.

Upper interval: Gypsum is the most abundant component with the occasional presence of limestones and claystones. The Allen Formation is interpreted as a transition between the continental Neuquén Group and the marine deposits characteristic of the overlying Jaguel Formation (Uliana, 1979).

Jaguel Formation: The Jaguel Formation is a monotonous pelitic unit composed of mudstones and claystones, with abundant gypsum toward the top. This unit is exposed on the eastern margin of the topographically low area known as the "Bajo de Añelo" where the sections considered in this study are located. In this region, the Jaguel Fm. commonly forms low hills of yellow to green color. Products of weathering of the clay material cover the exposures and make observations difficult. At the base of the Fm., the lithologic change from the uppermost gypsum of the Allen Formation represents the concordant lower boundary. The upper boundary of the Jaguel Fm. was placed at the base of the limestones that characterize the Roca Formation. The outcrop belt of the Jaguel Fm. approximately coincides with that of the Allen Formation. Fossils occurring in the Jaguel Fm. are pelecipod shells, ostracods, foraminifers, cocoliths, and palynomorphs, (Wichman, 1924; Bertels, 1969; Palamarczuk, 1997, 2001; Papú and Prámparo, 2000; Palamarczuk and Habib, 2001; Palamarczuk et al., 2002; Concheyro and Náñez, 2002 among others). Taken together, all these fossils indicate a marine depositional environment varying from nearshore to neritic and from inner to outer shelf

Roca Formation: The Roca Formation is considered as having been deposited during a regressive episode (Ulliana and Dellapé, 1981) and shows a varied lithology of mostly limestones, with abundant mollusc shells (coquina). Several sections studied show that this Formation has a constant thickness and similar lithologic characteristics over long distances. It has also been divided in three intervals (Ulliana and Dellapé, 1981). The lower interval composed of limestones of organic origin and is dominated by abundant mollusc shell fragments with a fine grained clastic matrix which grades from olive green to gray claystones. The middle interval is mostly composed of different types of limestones. The upper part is mostly composed of gypsum.

El Carrizo Formation: The uppermost unit of the Malargue Group, El Carrizo Formation, was probably deposited mostly in a lacustrine environment and toward the top, the structures and lithology are characteristic of a fluvial environment. The bottom of the Formation shows fine grained sediments, claystones and mudstones grading toward the top to sandstones and red mudstones. Fresh water microfossils were identified in this unit (Musacchio and Moroni, 1983)

## Geology of the Jaguel Formation

Windhausen (1912), was the first author to use the name "Capas de Jaguel" (Jaguel layers) in a much broader sense for the stratigraphic interval that was subsequently subdivided by Uliana and Dellapé (1981) into two Groups: Neuquén and Malargue. Wichman, (1924, 1927) subdivided the Jaguel layers into two units: "Senoniano lacustre" or "Inferior" (lacustrine or lower Senonian) and "Senoniano Superior" or Jaguel (Upper Senonian) (Fig. 7). Feruglio, (1949); Leanza, (1964); Camacho, (1967) and Andreis et al., (1974) followed this usage by restricting the term Jaguel to the upper, marine interval of the "Senoniano" (Senonian). Within the original Jaguel layers, Uliana and Dellapé (1981), recognized two Formations: the Allen and the Jaguel Formations. The latter was defined by these authors as the stratigraphic interval that extends from the uppermost evaporitic layer of the Allen Formation to the base of the coquina that marks the bottom of the Roca Formation. Defined in this way, the Jaguel Formation is composed of a monotonous sequence of light brown-yellowish to dark green mudstones and siltstones. In her definition of the Jaguel Formation, Bertels (1968) had restricted the name to the

Maastrichtian part of the pelitic sequence based on the change of the calcareous microfossils. The definition proposed by Uliana and Dellapé (1981) is currently accepted.

In the Neuquén region, exposures of reduced topographic expression in the form of low, rounded hills are characteristic of the geometry of the Jaguel Formation. No outcrops were found where this unit is completely exposed. The best exposures were found in the Lomas Coloradas area where the base of the unit could be sampled, and in the Bajada de Jaguel area, where the upper part of the unit is exposed and proved to contain the Cretaceous/Paleogene Boundary.The history of the successive investigations and discoveries by the pioneers who worked in the area can be found in Feruglio (1949-1950), and Weber (1964). Further contributions on the regional geology, stratigraphy, sedimentology, and micropaleontology of the area are given in Bertels (1968, 1969, 1974, 1975); Andreis et al. (1974); Uliana and Dellapé (1981); Barrio (1988); Legarreta et al., (1989) and Concheyro et al. (2002).

# CHAPTER 3

# METHODS

Sediment samples from the two Jaguel sections were collected for the purpose of extracting dinoflagellate cysts and other organic-walled microfossils. The sections were shown to the author by E. Musacchio, who also helped in the initial stages of the field work. The field and laboratory procedures used here, as well as the analytic procedures, are based on standard palynological methods.

## Sediment Sample Collection in the Field

Ten samples were taken from Lomas Coloradas section at levels where access was possible. The sampling intervals are shown in Table 1, Appendix 2 and are further described and illustrated in Chapter 4 (Fig. 8).

Samples were taken after digging at each level in order to get access to the outcrop after removing soil, loose debris, and all unwanted material. Clean implements were used in collecting each sample. The amount of sediment collected was approximately 150grams and the samples, labeled LC35 to LC26, were immediately sealed in plastic bags to avoid contamination with pollen grains of extant vegetation or other unwanted organic components, including particles from other sampled levels.

From the Bajada de Jaguel section, located 10 km to the south of Lomas Coloradas, nine samples (BJ12-BJ 4) were initially collected from the upper two thirds of the exposed interval (Table II, Appendix 2). As at Lomas Coloradas, soil and float was removed before sampling. The volume of sediment collected per sample was also about 150 grams. The lower third of the exposure at Bajada de Jaguel is covered by the products of weathering of the mostly pelitic, clay rich sediments. This part of the section was difficult to access, and was not sampled.

After the first laboratory treatment of this set of nine Jaguel samples, and a preliminary study of them under the microscope, it became apparent that a sharp compositional change in organic-walled microfossil assemblages occurred in the interval between the horizons from which samples BJ8 and BJ7 were taken. Better characterizing this assemblage turnover required a more detailed sampling of this BJ8-BJ7 interval.

To meet this encompassing BJ8-BJ7 fresh rock interval, a trench was excavated from the top to the bottom of a 6 meter interval to reveal pristine rock, and a further 17 samples were collected at intervals shown in Table III, Appendix 2. The position of these samples, labeled M1-M17 is shown in the illustrations of chapter 6 (Fig.17).

Study of this second suite of more closely spaced samples revealed that the change in assemblages was concentrated between samples M9 and M8. Thus, a third round of sample collection was conducted in which a 1m of the section was sampled at still closer intervals (see Chapter 6, Fig. 26 and Table IV, Appendix 2). In this third, detailed collection effort, each sample was divided into portions to provide material for additional sedimentological and micropaleontological analysis, and for radiometric dating of the assemblage turnover. This sampling procedure thus results in a threefold series of nested samples which provides a basis for pinpointing the time of occurrence, compositional changes, and the rate of diversity change of this turnover in dinoflagellate assemblages, which marks the upper part of the Jaguel Formation.

## Laboratory Work

Sample Preparation: The samples were processed in the Palynology laboratory of the ex Centro de Investigaciones en Recursos Geológicos. (CIRGEO), CONICET, Argentina, following standard palynological preparation techniques. Thus, the preparation methods used in this study consisted of the following steps:

- Treatment of approximately 25grams of sediment with 30% diluted hydrochloric acid to dissolve the carbonates. The material comprising this 25 gram separate was randomly chosen from the 150 gram samples collected at the outcrop.
- Treatment of the residue with 70% diluted hydrofluoric acid to dissolve the silicates.
- Washing of the residue several times with warm, diluted, (30%) hydrochloric acid to remove products formed during the previous treatment.
- Use of physical processes, including several brief periods of settlement and/or heavy liquid separation, to remove unwanted materials (organic and inorganic respectively). The heavy liquid used was zinc bromide (specific gravity 2.0).
- Sieving of the organic matter residue through 25 μm mesh

  The +25 μm fraction, where most dinoflagellate cysts concentrate, was used for this study.
- Staining of the organic residue was necessary in some cases because the organic walled microfossils were to light due to oxydation and required this procedure to facilitate the microscopic analysis. Safranin and Bismarck Brown usually used to stain palynomorphs were tried, with the latter showing the better results.
- Preparation of slides as strew mounts in glycerin-jelly mixed with formol for a longer preservation following the technique proposed in Cárdenas and Gamerro, (1980).

Slide Mounts: Different number of slides were mounted for each sample (Appendix 3) depending on the amount of organic matter recovered. Generally, samples with high volumes of organic matter required a larger number of slides to insure that microfossils were optimally mounted for efficient study. This same procedure was followed for the 17 samples that were collected from the Bajada de Jaguel section in the second step of sampling previously described (Samples M1 to M17).

The third set of 15 samples, covering the detailed sampling done on the approximately 1m interval in still more detail (sample BJ 21 to BJ35), were sent for processing to Palytech Ltd, a Palynology laboratory located in the United Kingdom. The amount sent for processing was 10gram of sediment. The total organic matter obtained following the standard palynological techniques was mounted to allow absolute counts of organic –walled microfossils per gram of sediment. In this processing, both the +25 and 10-25 µm fractions of organic matter were mounted. However, only the +25µm fraction was used for this study because this is the size range in which virtually all dinoflagellates occur. The 10-25µm, where most of the angiosperm pollen grains concentrate, are under study by a colleague in Argentina, preliminary results of which were presented in Barreda et al. (2004).

## Analytical procedures

A total of 139 slides were mounted for the whole study. All samples yielded abundant and well to very well preserved organic-walled microfossils. The slides were scanned under the microscope and the different morphotypes identified when possible to the species level. Specimens of species not previously described in the literature were photographed to document their presence.

Counts of organic-walled microfossil species were made for each sample to determine species richness, i.e, number of species or morphotypes per sample, and relative abundance, i.e., percentage in which each species is represented. The number of specimens tallied in each slide was 300, as is usual in palynological studies (Benson, 1976; May, 1980; Hultberg, 1986, among many other authors). Tallying 300 specimens per slide has been demonstrated statistically to include most of the species present in the microfossil assemblage from which the sample is drawn (Shaw, 1964). This is because the probability of finding a specimen of a new species decreases asymptotically as the number of specimens examined approaches 300. However, Marheinecke (1992), in his study on the Hamoor-Flora, Maastrichtian from Germany, stated that counts of 500 specimens or more should be done. He argued that for a rich assemblage with many species and only a few specimens of each, a count of 300 would not be large enough to accurately represent the actual number of species present. He concluded that the higher the number of taxa, the greater the number of specimens that should be counted. In view of Marheinecke's concerns, the present study uses specimens counts of 500 or more specimens as a basis for evaluating relative abundances of the different palynological forms. However, the results do not show important differences with the 300 specimen count method, i.e. very few new species were encountered when tallying above 300.

In order to minimize any possible bias introduced in placing the residue, counts of specimens on two different slides for each stratigraphic level were made. This provides a means of minimizing uncertainty about the representativeness of single slides.

Abundance categories used by different authors vary in the percentages selected to represent specific ranges. In this study the following descriptive categories for relative abundance of species were used:

Present: 1% or less

Sparse: Between 2% and 5%

Common: Between 5% and 15%

Abundant: Between 15% and 30%

Very abundant: More than 30%

These, or slightly different percentage intervals, are commonly used in palynological studies to represent relative abundance of species.

### Slide Repository

Temporarily, the slides, under the catalog number 1 to 107, will be located in the Paleontology collections of Brooklyn College, Department of Geology. The coordinates of the illustrated specimens given in this work are based on a Leitz Ortholux 963806 microscope.

### Photography

Photography was done using a variety of cameras, including manual and automatic cameras. The films used were Agfapan 25 and Kodak Technical Pan 100.

### Scanning Electronic Microscope Techniques

Pictures under the Scanning Electronic Microscope (SEM) were taken at the Institute of Neurobiology, CONICET, Buenos Aires, Argentina with the invaluable technical assistance of Mr. H. Cioccio. SEM work was also done in the "Centro Atómico de Bariloche", Balseiro Institute, in the Province of Río Negro, Argentina, where also technical assistance was provided.

The method followed for the study of specimens under the SEM consisted of picking them from the liquid residue with a micro- pipette and mounting them on a small piece of photographic film, developed but not exposed. The adhesive of the pellicle on the film was enough to keep them stuck without sinking. This technique was suggested by H. Gocht, Institut fur Palaeontologie, Unversitat Tubingen, Germany.

The material was covered by a thin layer of gold and then observed and photographed under the SEM.

# CHAPTER 4

# LOMAS COLORADAS SECTION

## Introduction

At the Lomas Coloradas section, the Jaguel Formation conformably overlies the uppermost gypsum of the Allen Formation. The sedimentological and stratigraphical description of this outcrop by Uliana (1979) was used as the basis for the sampling.

The samples for the palynological analysis were taken at levels where access was possible, and referred to Uliana's stratigraphic column, following the sampling procedures outlined in the "Methods" chapter of this thesis. Ten samples labeled LC35 to LC 26 from bottom to top were taken at irregular intervals in this approximately 90m outcrop of the Jaguel Formation. (Fig 8 and Appendix 2, Table I)

The lower part of the Formation was more densely sampled than the upper part at this location. Towards the top, the outcrop is partially covered, so that unaltered, pristine rock is difficult to access, thus precluding sample collection.

## Description of the Assemblages and Biostratigraphy

All the samples taken from the Jaguel Formation at Lomas Coloradas yielded abundant and well preserved palynomorphs, especially dinoflagellate cysts, and subordinate, other organic-walled microfossils of marine origin. The chart in Fig. 9 shows the stratigraphic distribution and relative abundance of species recovered from the samples in this interval.

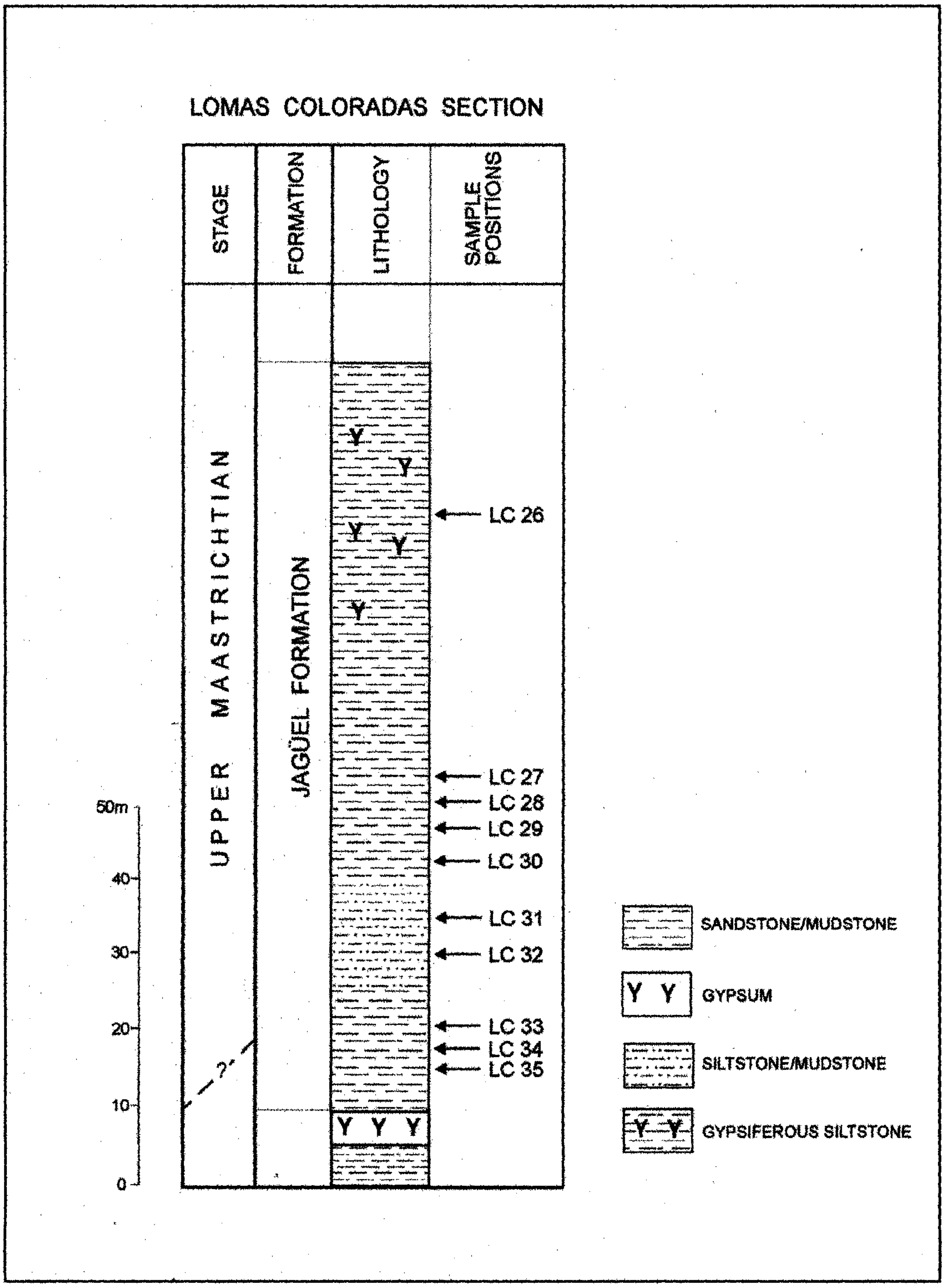

FIGURE 8: Lomas Coloradas Section. Stratigraphic column showing position of samples

The age assignment of the bottom of this exposure of the Jaguel Fm is not precise. The low species richness of the assemblages, reflecting marine transitional deposition, precludes from an accurate dating. The presence of *Glaphyrocysta retiintexta* and *Palaeocystodinium golzowense*, the latter in a very low relative abundance, suggests a probable Early/Late Maastrichtian age for the lowermost 10m of the Formation. The most abundant group recovered from this interval is *Glaphyrocysta* spp., with subordinate number of a highly variable population of peridiniod affinity cysts assigned to *Vozzhennikovia* sp., (see Plate 18). In sample LC34, *Pterospermella australiensis* is abundant

Species richness increases from sample LC33, as shown in Figs. 9 and 10, indicating neritic conditions. First occurrence of many species in these rocks was registered. Some of these newly appearing species are restricted to a short stratigraphic interval while others extend throughout the section and are also found in the Bajada de Jaguel section up to the uppermost limits of the Maastrichtian stage (Fig.10). First occurrences from samples LC33 are: *Areoligera senonensis*, *Trithyrodinium* sp., peridiniod cyst Gen et sp. indet.3, *Kleithriasphaeridium* sp. *Coronifera oceanica*, *Cordosphaeridium* cf. *exilimurum*, *Turbiosphaera filosa*, *Phelodinium magnificum*, *Exochosphaeridium* cf. *bifidum* and *Dinogymnium acuminatum.* Even though the composition of the basal 10m and the assemblages recovered from samples LC33 differ in abundance and species richness, there are no biostratigraphic markers that indicate a difference in time of deposition. Therefore, they are considered to represent the same assemblage interval.

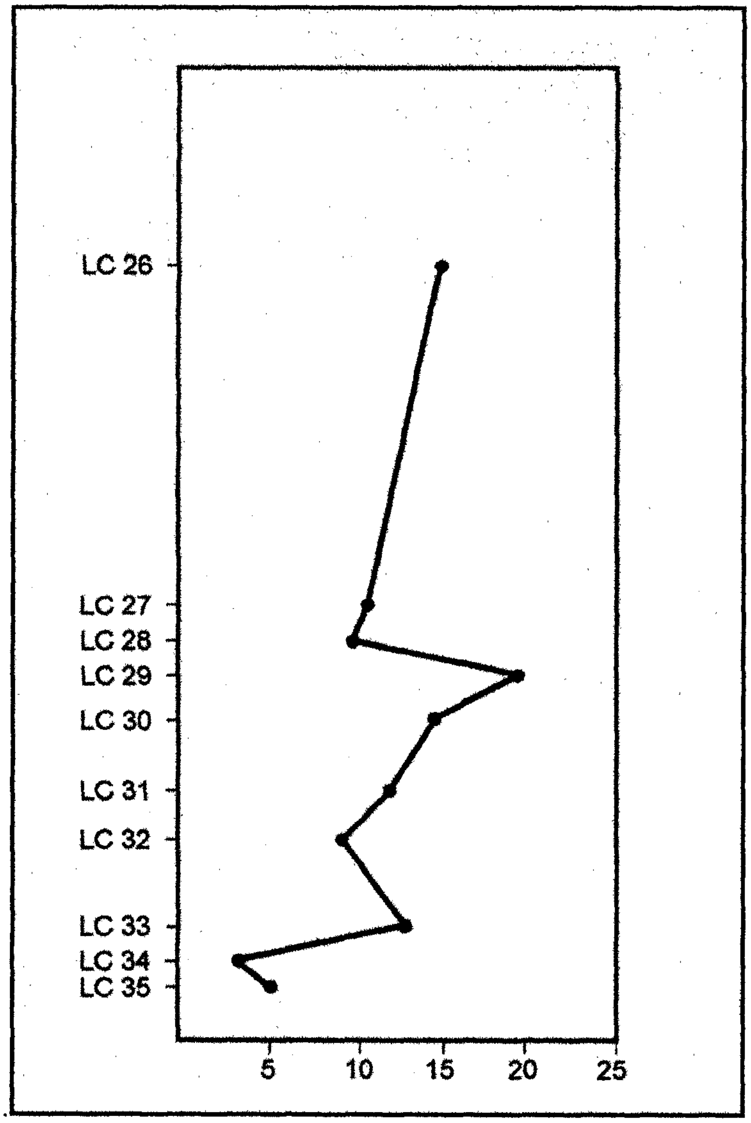

FIGURE 9: Graph showing species richness throughout the sampled interval at Lomas Coloradas section

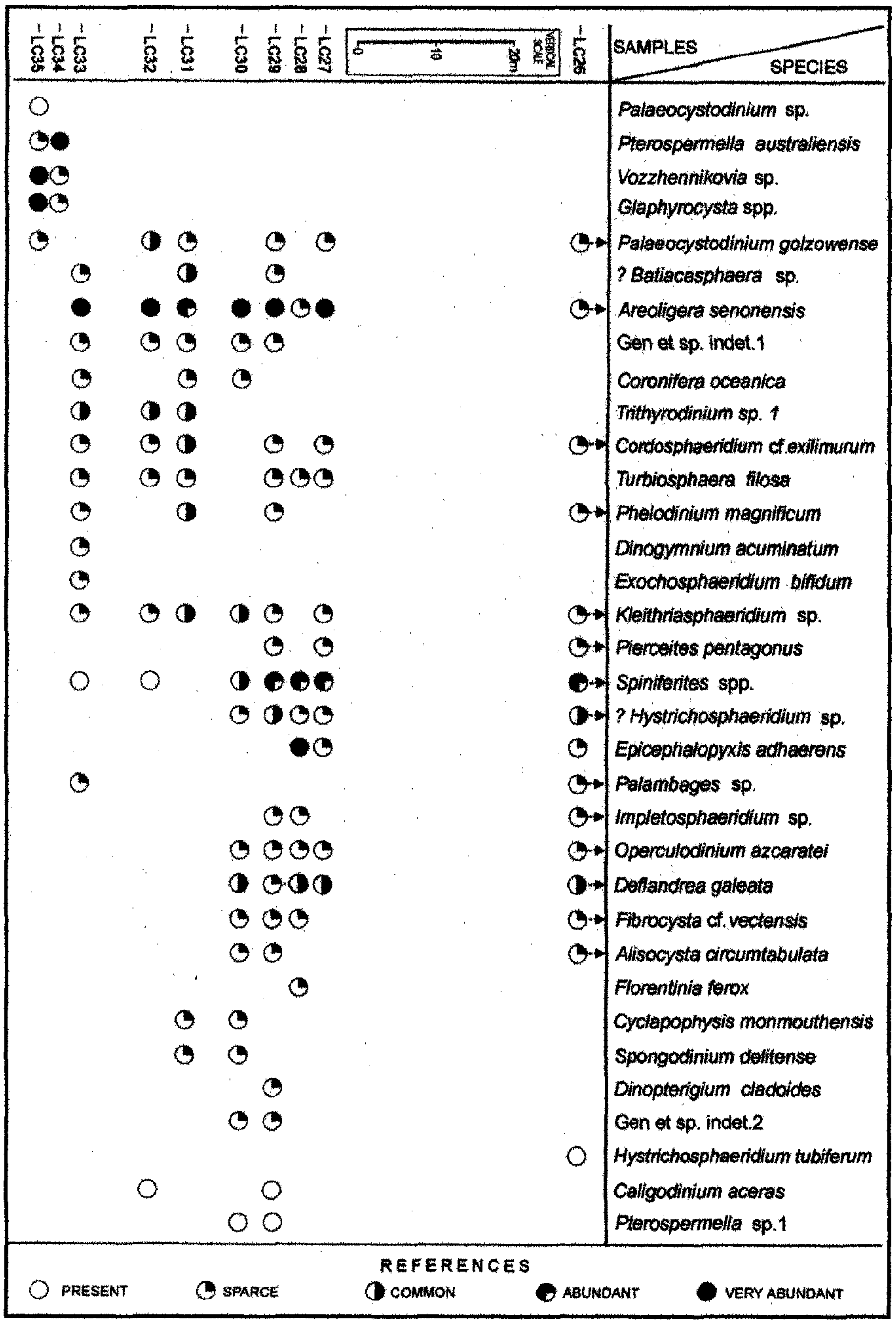

FIGURE 10: Stratigraphic distribution and relative abundance of species in Lomas Coloradas section. Arrows indicate species that have been recovered from younger sediments in the area.

The difference in species richness is interpreted as the result of increasingly marine conditions under which the sediments were deposited as the Atlantic marine transgression advanced toward the west.

The first occurrence of *Deflandrea galeata* is registered in the sample LC30. The species persists to the top of the upper Maastrichtian and is well known from many locations in both the northern and southern hemispheres as a marker for the beginning of the late Maastrichtian (Moshkovitz and Habib, 1993; Schioler and Wilson, 1993, Slimani, 2001 among others). Other species that first appear in samples LC 30 are: *Operculodinium azcaratei*, *Fibrocysta* cf. *vectensis* and ?*Hystrichosphaeridium* sp. Species restricted to samples LC30 and LC29 are: *Spongodinium* cf. *delitiense* and *Dinopterigium cladoides*. Other species illustrated for this part of the section are: *Cordosphaeridium exilimurum*, Gen. et sp. Indet. 1, cf. *Epicephalopyxis adhaerens*, *Cymatiosphaera* sp. and *Pterospermella* sp.

The proposed age assignment for the bottom of the sampled interval is based on the presence of the *Glaphyrocysta* spp., probably including *G. retiintexta*, and *Palaeocystodinium golzowense*, is, as was already pointed out, Early/Late Maastrichtian. The dominance of the *Glaphyrocysta* group was observed also in other locations (Habib and Miller, 1989, Brinkhuis and Zachariasse, 1988, among other authors). Habib and Miller (1989) documented the dominance of *Glaphyrocysta retiintexta,* together with *Areoligera medusetiformis,* in late Maastrichtian samples from the Dorchester well, South Carolina. *P golzowense*, first described for the Oligocene of Europe by Alberti (1961), shows for the Southern Hemisphere a stratigraphic distribution that extends from the Late Maastrichtian to the Mid-Late Paleocene and is the basis for the *P. golzowense* zone proposed by Wilson (1988) for New Zealand. Towards the top of the sampled interval, the assemblages are clearly Late Maastrichtian.

The uppermost part of the section could not be sampled but presumably will be younger still but whether the Cretaceous /Paleogene boundary is present here is unclear because it was not identified in the palynological study, and the change of color that is characteristic for the boundary in the area was not observed. However, the presence of the species *Cyclapophysis monmouthensis*, *Alisocysta circumtabulata* and *Pierceites pentagonus*, normally present in deposits close to the K/Plg boundary, were recovered from this section in the uppermost levels analyzed. This leaves open the possibility that the boundary might be present at the very top of the section. Further studies are required to confirm or rule out this possibility.

## Paleoenvironmental Interpretation

The observed differences in species richness reflect the fluctuating environmental conditions in which the palynomorphs accumulated, and is indicative of transitional – shoreline environments in the lowermost 10m, and open marine conditions in the higher parts of the section. Species richness, that is, the count of species per level as explained in chapter "Methods", or diversity indexes when richness is combined with relative abundance, are the most usual parameters in Palynology for paleoenvironmentnal interpretations in the marine environment.

The basal 10m interval represents deposition at the initiation of the transgressive episode in the Neuquén Basin area. The assemblages show low species richness and are composed of an abundant and highly variable population tentatively assigned to *Glaphyrocysta retiintexta*, although it might represent more than one species considering the highly variable morphology of the group and the difficulty of the assignment at the specific level. The low species richness, together with the dominance of the *Glaphyrocysta* group can be considered characteristic of a transitional environment, either close to the shoreline or deposited from waters of reduced salinity compared to that of normal marine conditions. The high relative abundance of *Glaphyrocysta* and *Areoligera* complexes was analyzed in the dinoflagellate cyst literature both in biostratographic as well as in paleoecological interpretations.

Brinkhuis and Zachariasse (1988), characterized sedimentary environments on the basis of different dinocysts groups: the *Cyclonephelium* group, that includes the genus *Glaphyrocysta*, with no modern equivalents, is considered to have flourished in transitional to near shore marine environments. They based their conclusions on the paleoenvironmental interpretation of the group in the K/Plg section at El Haria, Northwest Tunisia, on published information by Lienjarern et al.(1980), who suggested that species of *Glaphyrocysta* were abundant in estuarine waters. Further analyses by Brinkhuis (1994) and by Powell et al., (1995), considered that the *Areoligera* group indicates coastal sediments deposition. *Pterospermella* species, abundant in sample LC34, are usually confined to oceanic areas but abundance of this group in modern sediments has also been related to low salinity of the water (Guy-Ohlson, 1996).

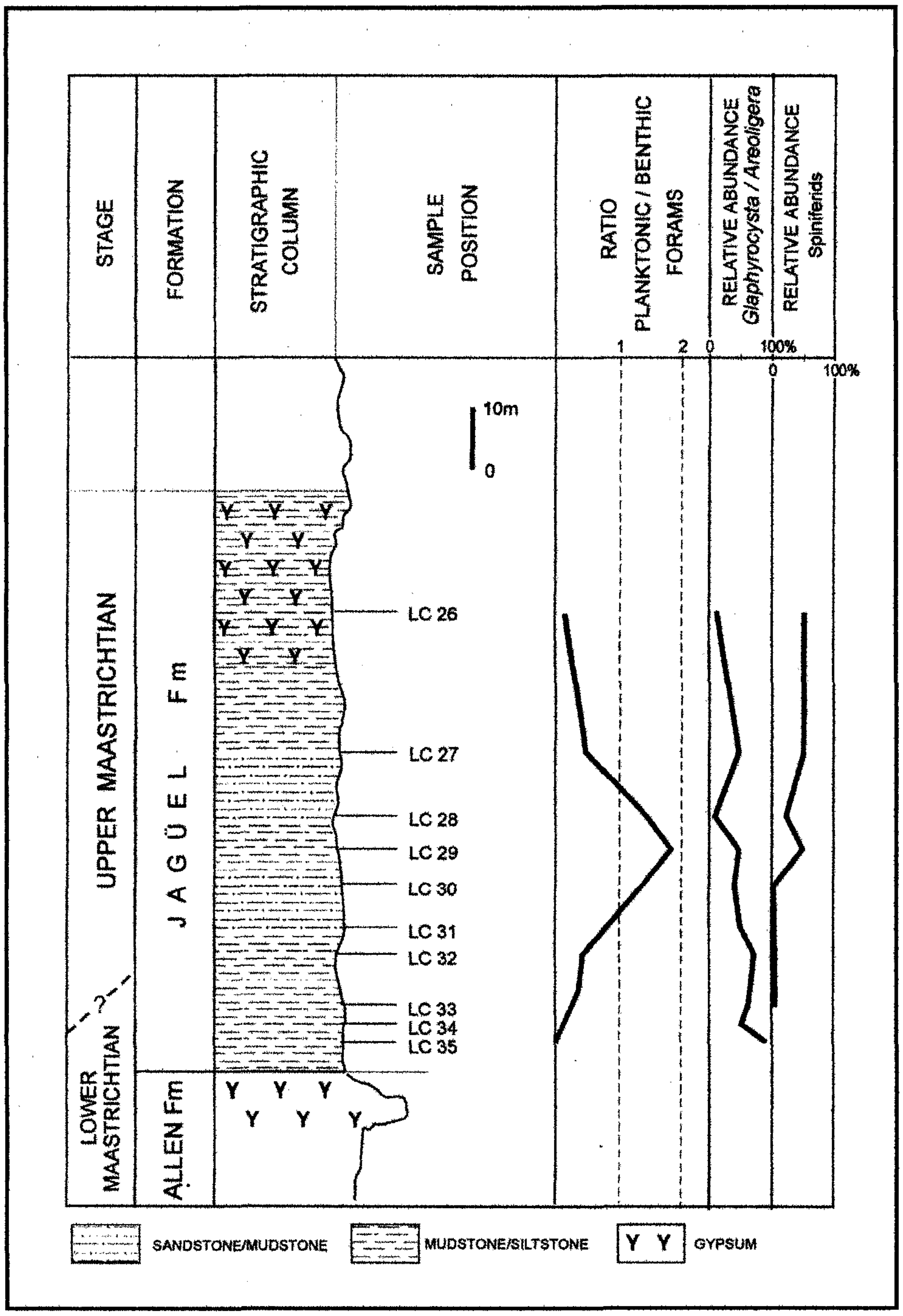

FIGURE 11: Ratio planktonic/benthic foraminifers and relative abundance of the dinoflagellate cyst groups *Glaphyrocysta/Areoligera* and spiniferids in Lomas Coloradas Section

The composition of the assemblages from the upper part of the section, (Sample LC 33 to LC26), shows characteristics of a depositional environment fluctuating from inner to outer shelf on the basis of the species richness, that peaks in samples LC 30 and LC 29. The ratio of planktonic/benthic foraminifers (Fig.11) supports this interpretation. Samples LC 30 and LC 29 represent the maximum flooding surface showing extremely abundant, well preserved and species-rich assemblages and a maximun planktonic/benthic foraminifers ratio.

Two important groups in paleoenvironmental interpretations, considered here as species complexes due the high variability and the difficulty of an objective assignment at the species level, are the *Glaphyrocysta/Areoligera* and the spiniferids. The relative abundance of both groups is shown in Fig. 11. The *Glaphyrocysta/Areoligera* complex is considered as a single group because of their similar morphology in some respects, and the views that they represent a particular depositional environment as discussed above. This is the criteron followed in the present study. However, more recent observations, point to a different interpretation of the depositional environment for these two genera. The abundance of *Glaphyrocysta* complex occurs in transitional to near shore marine environments, while *Areoligera* spp. are present abundantly in the samples that represent the maximum flooding surface. This difference between the two groups as probably representative of different environments was also observed by Firth (pers. comm., 2003). Additional observations are needed in order to clearly discern whether these two groups should be considered together or separately in the interpretation of ancient depositional environments.

According to the observations made in this section, the *Spiniferites* group is at the lower levels, subordinate in relative abundance to either *Glaphyrocysta* or *Areoligera.* A reversal of this tendency is observed toward the top of the section, and is interpreted in this study as biostratigraphic, rather than a the result of a local response to environmental conditions, due to the fact that the same tendency was observed in other localities throughout the upper Maastrichtian, regardless of depositional conditions, as it is explained below.

*Spiniferites* and allied genera were analyzed in paleonvironmental interpretations with controversial results by different authors. Increase in dominance of *Spiniferites* spp. and related genera through the Upper Maastrichtian was observed in cores and outcrops samples from Denmark and Sweden (Hulterg and Malgrem, 1986). They interpret the higher abundance of the group in sections of Swedish and Danish basins as the result of deposition in a shallow marine environment. Downie et al. (1971), found in assemblages from the Paleocene of England that the *Spiniferites* association (considered in a broader sense and including *Spiniferites* spp., *Achomosphaera* spp., *Hystrichosphaeridium* spp. and *Cordosphaeridium* spp.) and the *Areoligera* spp. and *Cyclonephelium* spp. association were representative of open marine conditions. Schioler et al., (1996), however, indicate in their study of the type Maastrichtian of the Netherlands, that representatives of the *Spiniferites* group dominate the association in the lower and middle part of the analyzed interval and reached high relative abundance in some levels of the upper part, but in relatively low diversity. In samples from the upper part of the succession, *Areoligera* and *Hystrichosphaeridium* groups showed high relative abundance. They relate their observations in the Maastrichtian type section to the distribution of modern *Spiniferites* that according to studies by Wall et al. (1977) and Head and Wrenn (1992) among other authors, occupies outer neritic waters.

In the Lomas Coloradas section, the *Glaphyrocysta* group is dominant in the transitional to nearshore environment characterized by very low species richness. In the Maastrichtian of the Creighton section from South Dakota this was also the case (Palamarczuk et al, 2003). The *Areoligera* group in the Lomas Coloradas section is dominant in the samples with high species richness. The *Spiniferites* group tends to increase diversity and relative abundance toward the upper levels of the Maastrichtian interval.

# CHAPTER 5

## BAJADA DE JAGUEL SECTION

### Introduction

At the Bajada de Jaguel section, located 10km to the south of the Lomas Coloradas section, approximately 35m of the Jaguel Formation are exposed (Fig.12).

The unit at this location is characterized by a homogeneous, monotonous pelitic sequence, showing colors that vary from light brown-grayish in the lower two thirds to dark green in the upper third. The change in color is sharp and more noticeable when the section is observed from a distance, as in Fig.12. This change in color from light to dark could be the result of decrease in oxygen in the environment, as interpreted from the better preservation of the organic-walled microfossils, which are destroyed in oxygen rich environments and by the occurrence of lamination in this part of the section, which is a primary sedimentary structure often associated with low-oxygen, non-bioturbated conditions.

Over much of the exposure studied, fresh sedimentary rock is hidden beneath a significant cover of weathered material. This situation made sampling of the section difficult. The procedure for clearing surface debris and sampling the underlying pristine rock is explained in the "Methods" chapter. The initial sampling at this site covered the total thickness of the exposed interval of the Jaguel Formation. Samples were taken at

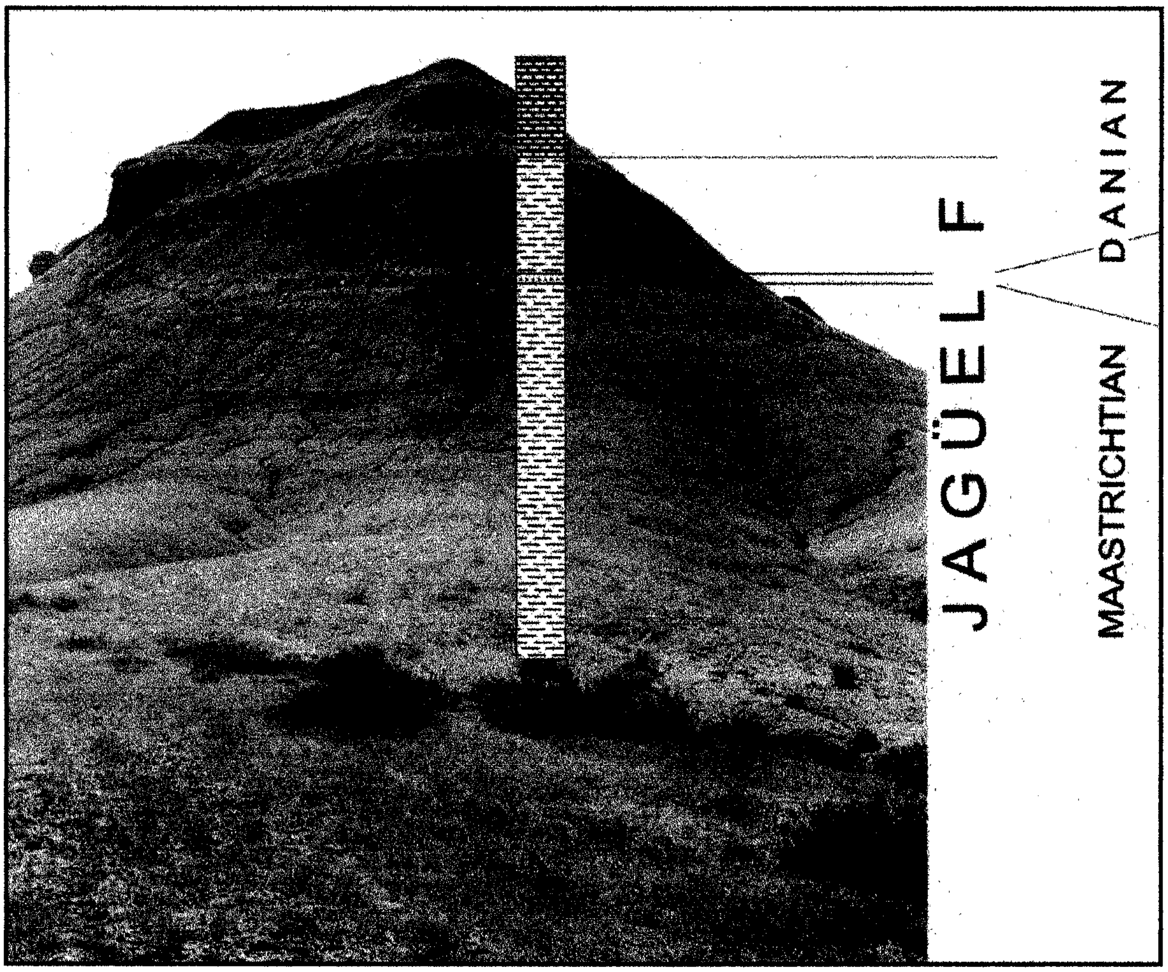

FIGURE 12: Exposure of the Jaguel Fm. at the Bajada de Jaguel section

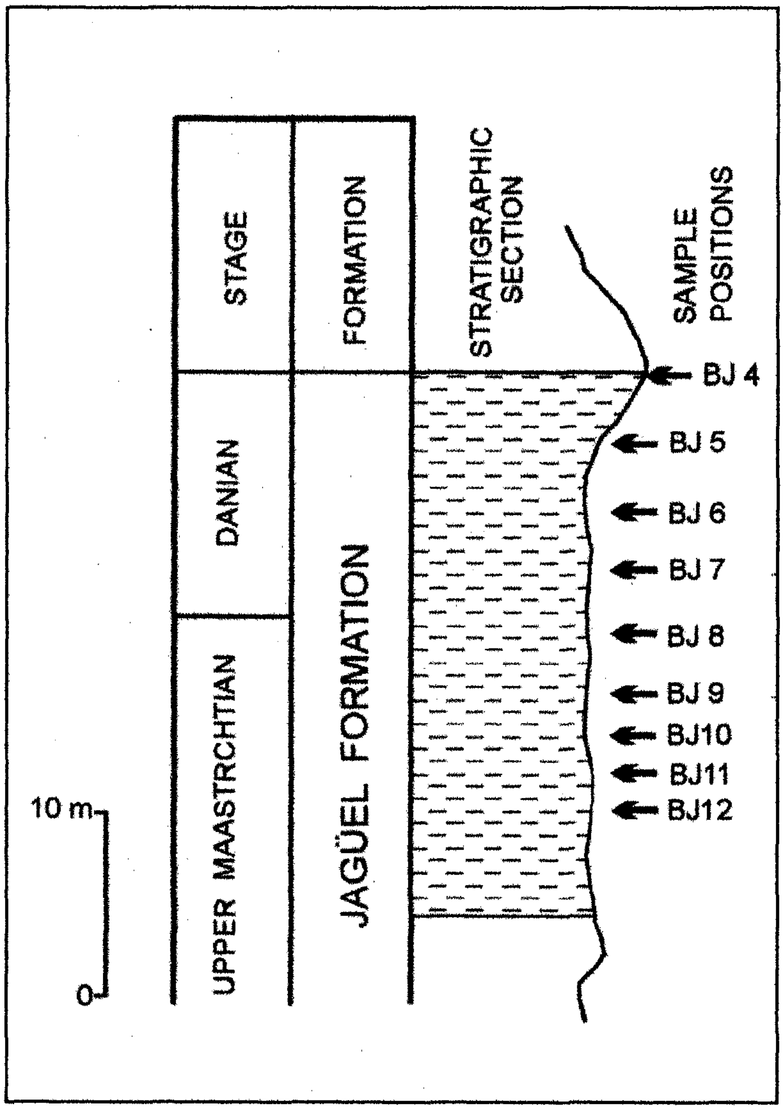

FIGURE 13: Stratigraphic column showing sample positions

stratigraphic intervals typically used in palynologic studies The position of samples and sampling intervals are given in Fig 13 and Table II, Appendix 2.

All the samples processed for organic-walled microfossils yielded very rich and well to very well preserved assemblages of marine organic- walled microplankton, with terrestrial palynomorphs in subordinate number. The palynostratigraphic analysis, combined with the previously described results obtained from Lomas Coloradas, makes possible the tentative correlation of the two sections, and provides a basis for a preliminary scheme of zonation for the Jaguel Formation.

## Description of the Assemblages: I- Lower part of the exposure:

The samples taken from the lower two thirds of the Bajada de Jaguel section and processed for palynology, following the techniques previously described, yielded assemblages similar to those recovered from the uppermost levels of Lomas Coloradas. Notable among the mutually occurring species in the upper part of Lomas Coloradas and the lower levels of Bajada de Jaguel are, among others: *Deflandrea galeta*, *Coronifera oceanica*, *Florentinia ferox*, *Turbiosphaera filosa*, *Fibrocysta* cf. *vectensis*, *Cyclapophysis monmouthensis*, "*Cordosphaeridium lemniscatum*", *Kleithriasphaeridium* sp., ?*Hystrichosphaeridium* sp., *Impletosphaeridium* sp. and *Pierceites pentagonus*. Fresh- water fern masullae of *Azolla* sp. and *Azollopsis* sp., the fresh water colonial alga *Botryoccocus* sp and the "megaspore" *Grapnelispora* evans*ii* (see Plate 24), carried into the marine basin from bodies of water in the surrounding areas, are also present in the assemblages. The distribution of selected marine species in a detailed 6m interval of the section is given in chapter 6, Fig.18.

Even though the *Spiniferites* and *Areoligera* groups show relatively high abundance with repect to the rest of the species, the same dominance of the *Spiniferites* group with respect to the *Areoligera* group occurs for both the upper Lomas Coloradas and the lower part of the Bajada de Jaguel section. The fact that there is a strong common component in the assemblages of these two horizons suggests that they are time-equivalent and correlatable. A tentative correlation on the basis of the dinoflagellate cyst content as a result of this analysis is depicted in Fig.15.

Important biostratigraphic markers identified from the sampled interval at Bajada de Jaguel are the species: *Deflandrea galeata*, *Cyclapophysis monmouthensis*, *Pierceites pentagonus* and *Alisocysta circumtabulata.* All of these species indicate an uppermost Maastrichtian age for sample BJ8 and the interval lying stratigrapahically below it.

## Description of the Assemblages: II- Upper part of the exposure

Between samples BJ8 and BJ7 a very sharp change in the composition of the assemblages was observed (Fig.14). The species recovered from sample BJ8, as discussed immediately above, are consistent with the composition of the assemblages throughout the uppermost Lomas Coloradas section and with the other samples from the lower levels at Bajada de Jaguel. In contrast, samples BJ7 shows a rich assemblage of different composition, including: *Trithyrodinium evittii*, *Cerodinium leptodermun*, *Phelodinium*

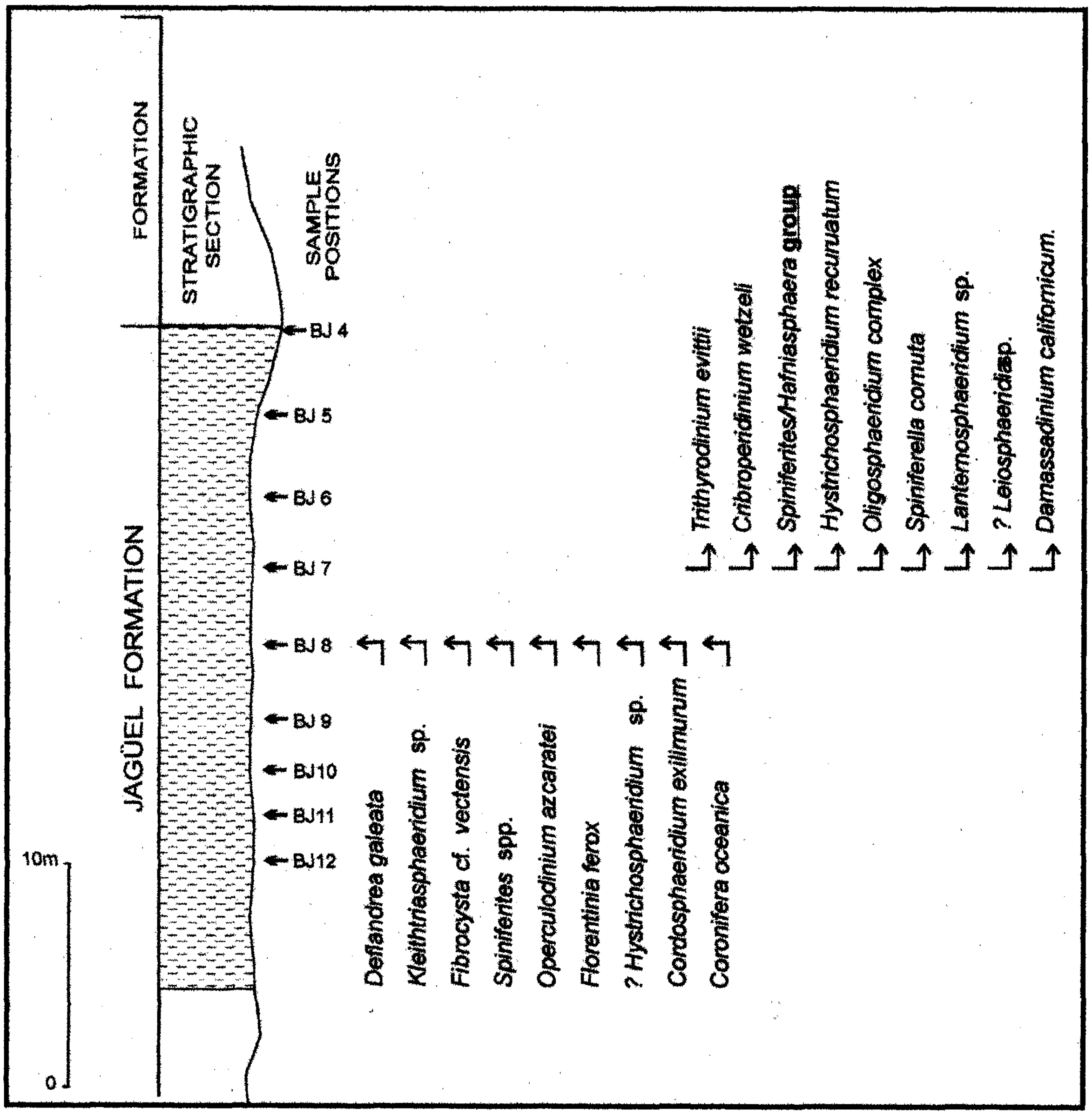

FIGURE 14: Stratigraphic distribution of selected species at Bajada de Jaguel section showing a sharp turnover of assemblages between samples BJ8 and BJ7

*magnificum*; species showing transitional morphotypes between *Senoniasphaera inornata* and *Glaphyrocysta* sp. and an abundance of spiniferids with vesicular wall and others with an apical structuture (*Hafniasphaera* sp., *Spiniferites* sp, *Spiniferella cornuta* subsp. *laevimura*). However, no *Areoligera* species and *Spiniferites* morphotypes recovered in the lower part of the section were found in this sample.

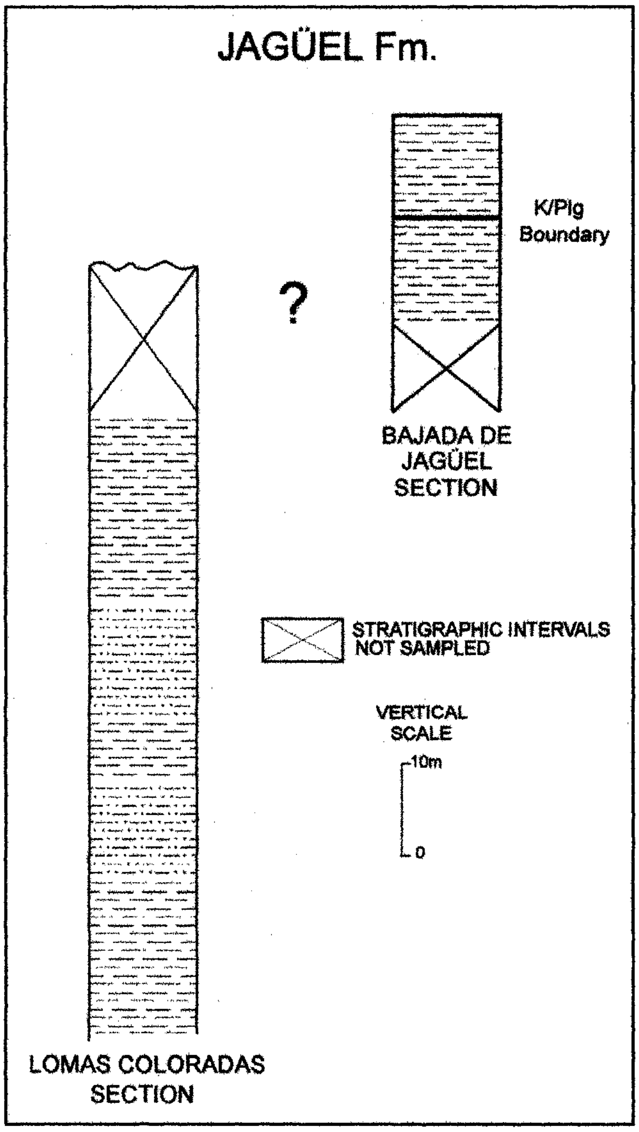

FIGURE 15: Tentative correlation of Lomas Coloradas and Bajada de Jaguel exposures of the Jaguel Fm on the basis of the dinoflagellate cyst content

The age of sample BJ7 appears to be Lower Danian because present within the dinoflagellate assemblage in this sample are well known Lower Danian marker species, including: *Damassadinium californicum*, *Senoniasphaera inornata*, *Hafniasphaera septata* and *Trithyrodinium evitii* as it is recorded in the Southern Hemisphere. *Damassadinium californicum* and *Senoniasphaera inornata* have been cited from different K/Plg sections at which also calcareous microfossils were used to calibrate the information. (Hansen, 1977; Habib, 1989; Habib and Miller, 1989; Habib et al., 1992; Slimani, 2001). *Trithyrodinium evittii*, first described by Drugg (1967) for the Danian of California, was documented earlier in the Maastrichtian in other locations in the Northern Hemisphere (Marheinecke, 1992; Palamarczuk et al, 2003), but it was found to mark the initiation of the Danian in New Zealand and Antarctica (Wilson, 1988; Wilson and Moore, 1988; Askin, 1988; Elliot et al., 1994). Toward the top of the section, as indicated by samples lying above BJ7, the first appearance of *Hystrichokolpoma bulbosa, Diphyes colligerum*, *Lanternosphaeridium* sp.1 and the acmé of *Cerodinium leptodermun* were documented. These species indicate a Danian age ( Morgenroth, 1968; Quattrocchio and Sarjeant, 1996) but it is not clear at the present whether they are restricted to the Lower Danian or they can reach the Upper Danian.

Other species recovered in this part of the section, though in low relative abundance, include: *Cyclapophysis monmouthensis*, *Cribroperidinium wetzelii*, cf. *Carpatella cornuta*, *Deflandrea* sp. cf. *D. pentaradiata*, *Hystrichosphaeridium recurvatum*, *Hystrichosphaeridium tubiferum*, *"Cordosphaeridium", lemniscatum*, *Operculodinium centrocarpum*, *Spiniferella cornuta* subsp. *laevimura*, *Palaeocystodinium* spp., *Cordosphaeridium inodes*, *C. inodes* subsp. *longipes*, *Cannosphaeropsis* cf. *utinensis, Glaphyrocyasta* sp. 1, *G.* sp. 2 and *G.* sp. 3. and Gen. et sp. indet. 2.

## Correlation and Zonation of Late Cretaceous sediments of theNeuquen Basin

A tentative correlation between the Lomas Coloradas and Bajada de Jaguel sections on the basis of the dinoflagellate cysts content is shown in Fig15. This interpretation reflects considerations of dinoflagellate age and occurrence as discussed above. On the basis of first appearances of selected species from the two sections of the Jaguel Formation analyzed in this study, four informal dinoflagellate assemblage zones are proposed (Fig. 16). These informal zones are designated as assemblage interval I, II, III and IV from bottom to top.

Assemblage interval I is characterized by a high abundance of *Glaphyrocysta* spp., at the bottom and presence of *Palaeocystodinium golzowense, Trithyrodinium* sp., *Dinogymnium acuminatum, Kleithriasphaeridium* sp.and *Coronifera oceanica.*

The first occurrence of *Deflandrea galeata* marks the initiation of assemblage interval II. At the top of this zone markers of the times close to the K/Plg, such as *Cyclapophysis. monmouthensis* and *Pierceites pentagonus* were recovered.

Assemblage interval III is characterized by the first appearance of the *?Lanternosphaeridium* complex, along with few specimens of *Damassadinium californicum*, the transitional morphotypes of the complex *Senoniasphaera inornata/Glaphyrocysta* spp., and very variable populations of vesicular- walled spiniferids. *Hystrichokolpoma bulbosa*, *Lanternosphaeridium* sp. 1, *Diphyes colligerum* and the acme of *C. leptodermun* characterize assemblage interval IV.

In a broad sense, the zones can be considered as Interval zones according to the North American Code of Stratigraphic Nomenclature (NACSN, 1983), although they are not formally named and described. According to both, the International Stratigraphic Guide (ISG) Salvador (1994), and the NACSN, biostratigraphic units can be formal or informal. Units. Formal units are named and described in accordance with the Guide or Code, whereas informal units are named and described without precise connotation and without being part of an organized system of terminology. The scheme proposed here follows the latter criterion. The division of the Jaguel Formation into four assemblage intervals cannot be formally defined because it is based on only two closely spaced localities and therefore, is of local value only. The proposed informal zonation has to be tested in a more regional context in order to decide whether the zones discussed here can be formally established as interval zones following the rules of the Stratigraphic Code.

## Implications for interpreting the cause of the end-Cretaceous catastrophic event

In previous studies of the Bajada de Jaguel exposure, a similar pattern of turnover in assemblage composition was found for calcareous microfossils (Bertels, 1968, 1969, 1970 and 1978), who identified the presence of both Maastrichtian and Danian marker species of calcareous microfossils. The mentioned author initially interpreted this turnover in composition as a hiatus that represented most of the Upper Maastrichtian basing her interpretation on comparisons with calcareous microfossil zones proposed in the Northern Hemisphere. She compared the Jaguel calcareous microfossil assemblages especially with the European zones and found that the Upper Maastrichtian marker species were missing in the calcareous microfossil data from Bajada de Jaguel.

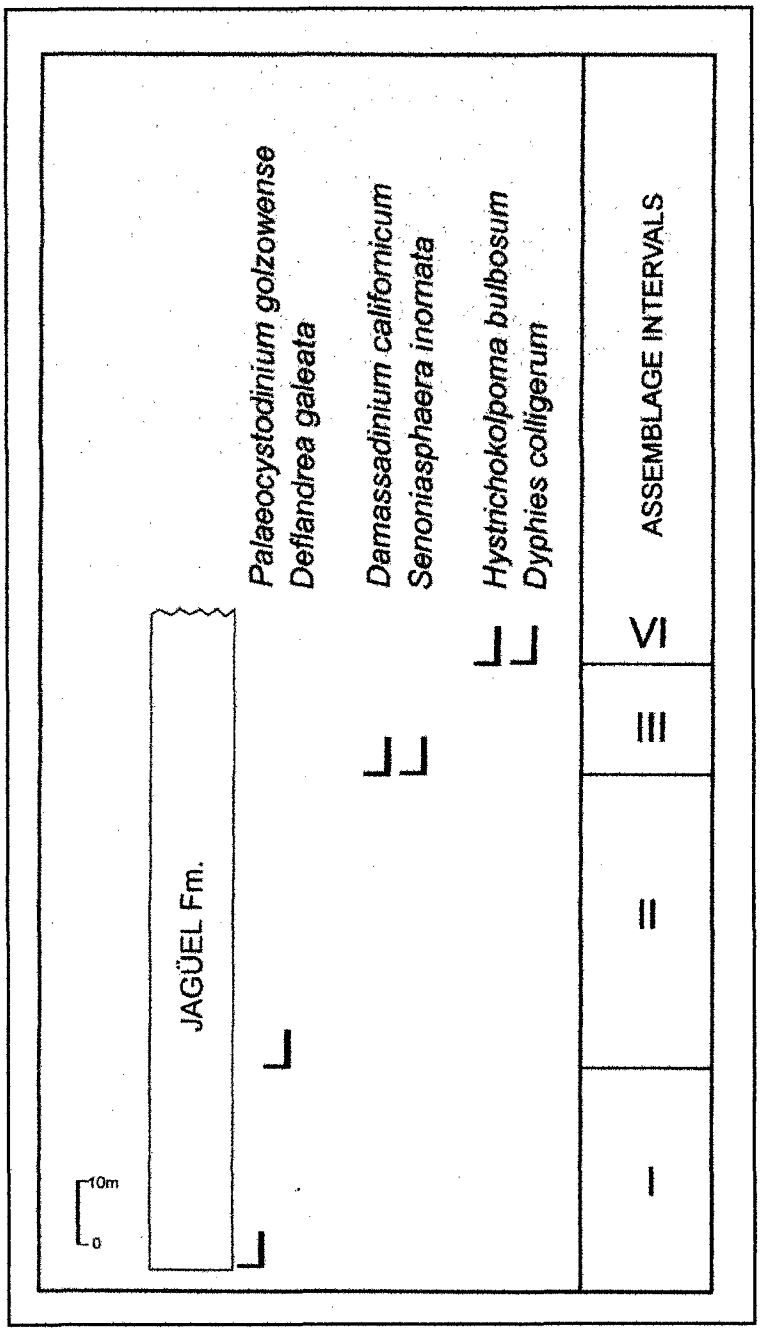

FIGURE 16: Dinoflagellate cyst assemblage intervals on the basis of first occurences of selected species in the Jaguel Formation

Therefore,the Bajada de Jaguel section was assigned by Bertels to the Middle Maastrichtian / Danian time interval. Further work in the Neuquén area utilized this age assignment as a basis for interpreting the geology of the Neuquén Basin (Andreis et al., 1973; Uliana, 1979; Uliana and Dellapé, 1981; Barrio, 1990).

More recently, the assumption of the presence in the Jaguel Formation of a hiatus comprising the Upper Maastrichtian was revised by both, palynologists and calcareous microfossils specialists. (Palamarczuk, 1997; Papú et al., 2000; Concheyro et al, 2002), as it became apparent that one or more catastrophic events marked the end of the Cretaceous, such as the impact of a large extraterrestrial object (e.g., Alvarez et al., 1980) or the fast outpouring of an enormous volume of basaltic lava in the Deccan Traps in India (Officer and Drake, 1985).

It is clear that the rocks preserved at Bajada de Jaguel encompass the K/Plg boundary. The palynological record they contain may thus provide insight on the nature and timing of the events that mark this unique episode in the history of life, and its role in the evolution of microplankton. A focus of the present work was to make detailed samplings of the stratigraphic interval between BJ7 and BJ 8. The goal was to provide data from which to base a better understanding of the short term environmental changes that might have taken place as a consequence of end-Cretaceous events and their role in causing the palynological turnover occurring in the interval between samples BJ8 and BJ7. This issue will be addressed in chapter 6 of this thesis

# CHAPTER 6

## THE CRETACEOUS/PALEOGENE BOUNDARY IN THE BAJADA DE JAGUEL SECTION

### Introduction: The "Sandy Layer"

As a result of the analysis explained in chapter 5, a second set of samples was collected in order to study in detail the sudden change of the dinoflagellate cyst assemblages observed between samples BJ8 and BJ7 (Fig. 14) at the Bajada de Jaguel section. An interval of approximately 6 vertical meters, which contained the horizons from which these two samples were taken, was closely sampled after excavating a trench that allowed access to the fresh rock as explained in the Methods chapter. As noted in Fig. 17, samples were collected and processed for palynological analysis. All of these samples yielded abundant to very abundant dinoflagellate cyst and other organic-walled microplankton assemblages which were relatively well to well preserved.

When closely observed, the pelitic sedimentary rocks that are characteristic of the Jaguel Formation showed an interbedded, 17cm thick layer composed of coarser grained, sandy, unconsolidated sediments, here termed the "Sandy Layer," that had not been detected in previous studies and was not noticeable in the general field observation of the section. Above and below this layer, there is a marked difference in color of the pelitic sediments as well as a change in the sedimentary structures. The beds below the Sandy Layer are light brown to yellowish and are massive whereas the beds above are dark green to grayish and show lamination. The bottom of the Sandy Layer is slightly undulating, while the top is horizontal. The position of this layer coincides with the sharp change in color that can be observed from the distance at the section as shown in chapter 5 (Fig.12). This layer was found to be of volcanic origin.

## Organic-Walled Microplankton across the K/Plg. Boundary – Previous Studies

Only previous studies on dinoflagellate cysts having ranges that extend across the K/Plg boundary are considered here. Papers dealing with only Maastrichtian or Danian assemblages stratigraphically more distant from the boundary are not discussed in this chapter because the focus here is on the response of the organic-walled group of organisms to the K/Plg boundary event. Although studies on dinoflagellate cysts across the K/Plg boundary have been conducted on a global scale, the bulk of available data derive from sections located in the Northern Hemisphere.

Studies on European sections: Hansen (1977, 1979), and Kjellstrom and Hansen (1980) analyzed sections from Denmark and Southern Scandinavia. They proposed for the area containing the Danian stratotype a zonation based on dinoflagellates cysts.

They divided the Upper Maastrichtian interval *Palynodinium grallator* Zone into three subzones: *Tanyosphaeridium magdalium*, *Talassiphora pelagica* and *Chiropteridium inornatum* (now *Senoniasphaera inornata*)/*Palynodinium grallator*, and the Danian *Danea mutabilis* (now *Dammasadinium californicum*) Zone into two subzones: *Ch. inornatum*

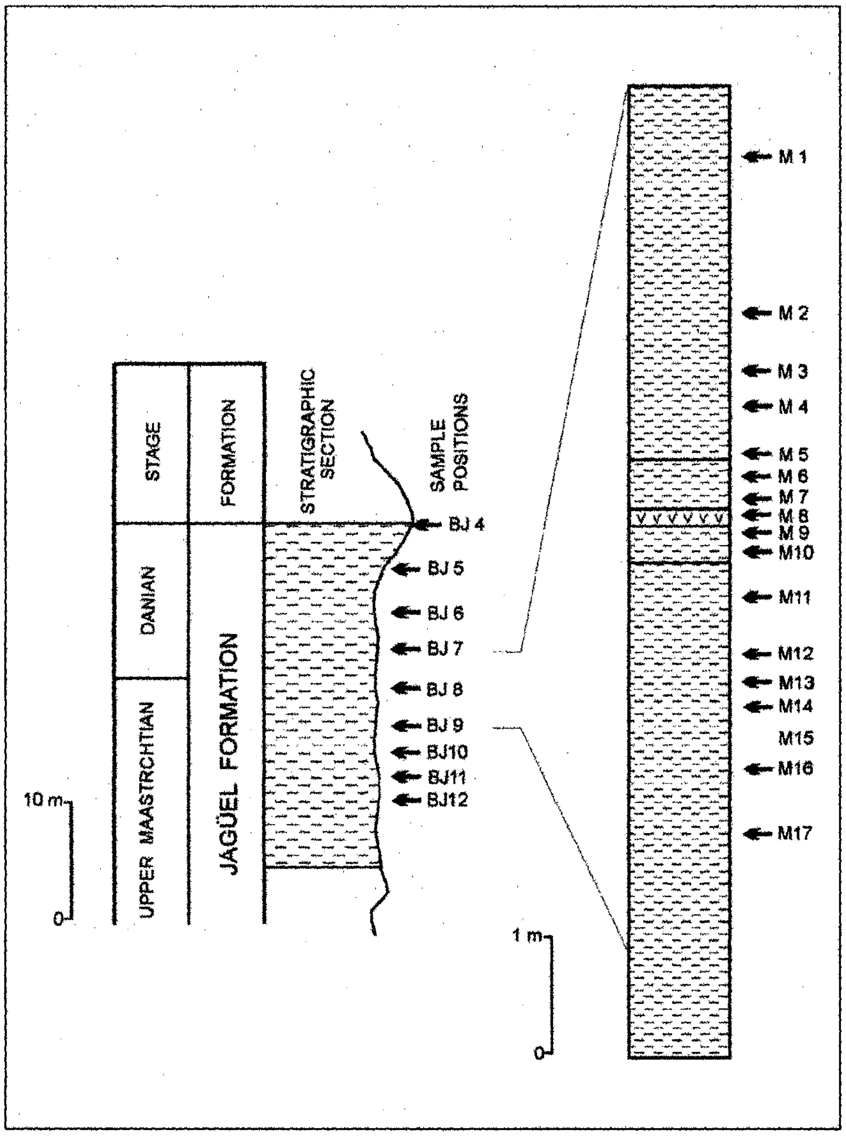

FIGURE 17: Stratigraphic column of the Bajada de Jaguel section showing position of samples BJ12-BJ4 explained in chapter 5 and position of samples M17-M1 at the second, detailed stage of analysis

and *Hafniasphaera criptovesiculata*. The *Ch. inornatum* Subzone was divided into three Zonules: *Carpatella cornuta, Xenicodinium rugulatum* and *Xenicodinium lubricum*. The uppermost Subzone, that is, the *H. criptovesiculata,* remained undivided. The contribution of these authors is mostly biostratigraphic. They interpreted the different composition of dinoflagellate cyst assemblages across the boundary in terms of environmental changes. However, it should be noted that these investigations were carried out before the hypotheses of catastrophic impact and/or volcanism were proposed as a cause of mass extinction at the K/Plg boundary.

De Coninck and Smit (1982) analyzed the dinoflagellate cyst content in samples from the Barranco del Gredero section in Spain containing the K/Plg boundary. They characterized the samples as Upper Maastrichtian and Danian on the basis of biostratigraphic markers such as *Palynodinium grallator* and *Senoniasphaera inornata* respectively and concluded that "the marine organic-walled microfossils do not show a terminal Cretaceous mass extinction compatible with the one observed in planktonic foraminifera". They related the changes of the assemblages to the aftermath of the impact of a large meteorite that could have affected the intensity of sunlight, or a comet that could have created a "heat flash" as suggested by Emiliani (1980) and Hsu, (1980).

Brinkhuis and Schioler (1996), conducted investigations on a section containing the boundary located in Limburg, SE Netherland. They recovered stratigraphically diagnostic dinoflagellate cysts that allowed them to characterize the section as relatively complete and deposited in marginal marine, inner neritic environmental conditions with nearby landmasses providing important terrestrial input. They did not observe a dramatic change throughout the succession, but they point out the high relative abundance of *Spiniferites* as indicative of open marine influence.

Brinkhuis, in Herngreen (1998), presented results of a survey of dinoflagellate cysts preserved in Cretaceous/Tertiary strata in the Curfs Quarry, also located in the Netherlands. They recovered stratigraphically diagnostic dinoflagellate cyst species of Upper Maastrichtian and Danian age deposited in a neritic environment and correlated the differences in relative abundance of groups or morphotype complexes to the sea-level cycles proposed by Haq et al (1988) and Hardenbol (1994). In their study, the initiation of the Danian is characterized by the first occurrences of *Senoniasphaera inornata* and *Lanternosphaeridium reinhardtii*, and coincides with a sharp increase in bryophyte spores.

Kuhn and Kirsch (1992), in their analysis of a Cretaceous/ Tertiary section from Austria, recovered important biostratigraphic markers calibrated with planktonic foraminifers. In this work, the initiation of the Danian is marked by the first occurrence of *Damassadinium californicum* (as *Danea californica*). They also concluded that the dinoflagellate cyst populations did not suffer mass extinction at the boundary. They observed only a change in the relative abundance of certain taxa. The *Areoligera* complex is dominant in both, the Maastrichtian and Paleocene assemblages, with the *Spiniferites* group subordinate in percentage.

Slimani (2001), analyzed dinoflagellate assemblages of the Campanian to Danian from Belgium and The Netherlands. The species that mark the initiation of the Danian in these sections are: *Damassadinium californicum* and *Carpatella cornuta.*

## Studies in North America

Benson (1976) presented the first study of dinoflagellates across the K/Plg boundary in the USA. He studied the organic-walled microplankton recovered from the Maastrichtian Monmouth Fm. and the Paleocene Brightseat Fm. of the Atlantic Coastal Plain in Maryland. He interpreted the sudden change of assemblages in the area as the result of a paraconformable relationship between the Cretaceous and Paleocene strata. Therefore, no conclusions were drawn about a possible event at the boundary due to incompleteness of the section.

Firth (1987) analyzed the dinoflagellate biostratigraphy of the Maastrichtian to Danian interval in the Albany core, Georgia. Several species were found to be biostratigraphically useful to characterize the interval. The presence of *Cyclapophysis monmouthensis*, a genus and species created by Benson (1976), along with *Manumiella seelandica* were used to recognize the upper part of the upper Maastrichtian. *Palynodinium grallator* was also restricted to the upper part of the upper Maastrichtian. The Cretaceous/ Tertiary boundary did not show a large turnover in dinoflagellate taxa. Rather, the changes in relative abundance of several species indicate, according to the author, environmental changes across the boundary interval.

Habib and Miller (1989), Habib et al. (1992), Moshkovitz and Habib (1993), and Habib et al. (1996) analyzed the Cretaceous-Tertiary boundary in Alabama and Georgia from a multidisciplinary standpoint integrating information from dinoflagellate cysts, foraminifers and nannoplankton. They observed a turnover in the assemblages of these microfossils, and attributed this change to a variety of factors, including sea-level fluctuation and the consequences of the impact of a meteorite at the K/Plg boundary. Some important biostratigraphic markers were identified in the dinoflagellate cyst assemblages. *Palynodinium grallator* for the uppermost Maastricthtian and *Senoniasphaera inornata*, followed by *Damassadinium californicum*, *Carpatella cornuta* and *Xenicodinium lubricum* for the planktonic foraminifer Zones P0, P α and P1a respectively. A peak in the abundance of acritarchs of the genus *Micrhystridium* was documented in the interval immediately above the boundary

## High latitude assemblages in the Northern Hemisphere

Nor- Hansen and Dam (1997), reported the palynological results of the analysis of a section in Nuussuaq, Greenland. *Palynodinium grallator* was found in the Maastrichtian as well as *Cyclapophysis monmouthensis* (identified in this paper as *Disphaerogena carposphaeropsis*). However, the stratigraphic range of these dinoflagellates did not reach upward to the boundary, while *Manumiella* spp. was restricted to a very short interval below the boundary. *Senoniasphaera inornata* and *Trithyrodinium evittii* (identified as *T. fragile*) was taken by Nor-Hansen as marking the beginning of the Danian. These changes across the boundary were interpreted as a result of a regression below the boundary and a transgression in the early Danian.

Ioaniddes (1986) conducted a study on dinoflagellate cysts from Upper Cretaceous-Lower Tertiary sections on Bylot and Devon Islands, in the Canadian Arctic Archipelago. The analysis is systematic and biostratigraphic and includes species characteristic of the boundary but a detailed analysis of the boundary event is not given.

## South America

Relatively few studies on dinoflagellate occurrences across the K/Plg boundary have been carried out in sections from South America.

### Low latitude sections

Yepes, (2001), reports on two equatorial sections located in Colombia and Venezuela. He recovered stratigraphic markers such as *Cyclapophysis monmouthensis* (as *Disphaerogena carposphaeropsis*), *Manumiella seelandica* in the uppermost Maastrichtian and *Damassadinium californicum* and *Senoniasphaera inornata* in the lowermost Danian.

Sarkis et al. (2002) analyzed the dinoflagellate assemblages from Pedreira Poty, Northeastern Brazil. *Cyclapophysis monmouthensis* (identified as *Disphaerogena carposphaeropsis*) with a first occurrence in the uppermost Maastrichtian and *Damassadinium californicum* occurring in the lowermost Danian, are the most important biostratigraphic markers recovered from this section. The authors found that while most of the species were present both above and below the boundary and apparently not greatly influenced by it, the abundances of twelve species were altered by the K/Plg boundary event, mostly of the *Dinogymnium* group.

### High latitute sections in the Southern Hemisphere

### Southern Chile

Troncoso and Doubinger (1978) reported results of dinocysts analysis from the El Ganso Well, Magallanes Province, Chile. The sampling intervals were not sufficient to analyze the boundary in detail, but change in the assemblages allowed the authors to tentatively locate the approximate stratigraphic position of the boundary.

### Antarctica

Askin (1988), Elliot et al. (1994) and Askin and Jacobson (1996), analyzed sections from Seymour Island, Antarctica. These authors related the changes observed in the organic-walled assemblages to a shallowing trend and changes in water chemistry due to volcanic activity. They did not find a sharp change in dinoflagellate composition but rather a transition across the K/Plg boundary.

### New Zealand and Australia

Papers by Wilson (1987), Wilson et al. (1988), and Strong et al. (1995), reported dinoflagellate assemblages from sections in New Zealand. In Strong et al., (1995), Wilson characterizes the uppermost Maastrichtian by the presence of *Manumiella druggii* and the initiation of the Danian by *Trithyrodinium evittii*.

Helby et al. (1987) briefly report on dinoflagellates across the boundary in their proposed zonation for the Mesozoic of Australia that also includes the Early Paleocene. However, this paper does not give an interpretation of the changes observed to occur at the boundary. Their goal was mostly biostratigraphic.

### Studies in African sections

Studies on dinoflagellate cysts assemblages across the boundary in the type section of the Cretaceous/Paleogene boundary were carried out by Brinkhuis and Zachariasse

(1988). They presented a high resolution integrated biostratigraphy based on planktonic foraminifers and dinoflagellate cysts. They found that the level of mass extinction of the calcareous microfossils coincided with the first occurrence of *Damassadinium califonicum* (as *Danea californica*). According to this study, dinoflagellate cysts do not show an accelerated rate of extinction at the boundary. However, on the basis of the ratio terrestrial/marine palynomorphs, they observed important compositional changes that reflect a rapid sea-fall during the uppermost Maastrichtian which culminates, according to these authors, at the level of the K/Plg boundary. They interpret the compositional change of the dinoflagellate assemblages at the boundary as the result of sea-level changes.

Herbig and Fechner (1994), documented palynomorphs from a Cretaceous/ Tertiary section in Morocco. They recovered poorly preserved dinoflagellate assemblages in the scope of a more comprehensive geologic analysis. Abundance of *Areoligera* spp. was also recorded in this section. No interpretation about the response of the dinoflagellate cysts to the Cretaceous/ Paleogene boundary event is given in this contribution. Studies by Smit and Brinkhuis (1996) and Brinkhuis et al. (1998) summarized information about the K/Plg boundary including the response of dinoflagellate cysts to the event.

## Studies on dinoflagellates across the K/Plg boundary in sections from Argentina

Besides the preliminary studies presented by Palamarczuk (1997), Palamarczuk and Habib (2001) and Palamarczuk et al. (2002), Papú et al. (1997), reported on

Palynology in samples from the exposure of the Jaguel Formation at the Opaso section, Neuquén Province, but no detailed study on the boundary was provided.

## Description of the organic-walled microfossil assemblages in the 6m detailed sampling interval of the Bajada de Jaguel section

The 17 samples analyzed at this second stage of the study (Fig 17) yielded well to very well preserved dinoflagellate and other organic-walled microfossils assemblages. The stratigraphic distribution and relative abundance of species or groups of species identified in this 6m interval are depicted in Fig.18.

### Pre-"Sandy Layer" Assemblages:

Assemblages recovered from the samples below the Sandy Layer are similar in composition to the assemblages contained in samples BJ12 to BJ8 (Fig. 14), described previously in the first stage of sampling (Chapter 5). Dinoflagellate species recovered from this interval , that is, samples M17 though M9, comprise among others: *Deflandrea galeata, Coronifera oceanica, Kleithriasphaeridium* sp., *Cyclapophysis monmouthensis, "Cordosphaeridium " lemniscatum, Turbiosphaera filosa, Pierceites pentagonus, Fibrocysta* cf. *vectensis, Spiniferites* spp. and subordinate *Areoligera* spp., together with fresh to brackish water fern masullae of microspores of the genera *Azolla* and *Azollopsis* and the spore species *Grapnelispora evansii,* carried into the marine basin from the surrounding areas. Restricted to the 1 meter interval below this layer, the first occurrence, peak and disappearance of *Isabelidinium* complex is registered, with some specimens resembling the genus *Manumiella,* whose morphology is explained below in the chapter on Systematic (Chapter 8).

## Sandy Layer and Post-Sandy Layer Assemblages:

Samples M7 through M 1 above the boundary layer yielded very rich organic-walled assemblages, increasing in number of species toward the top of the interval. First appearance of a very variable population of ?*Lanternosphaeridium* sp, resembling *L. reinherdtii* Moshkovits and Habib (1993) was documented, along with *Cribroperidinium wetzelii*, *Trithyrodinium evittii*, *Hafniasphaera* spp, *Spiniferella cornuta* and other spiniferids with vesicular cyst wall. Blooms of *Senegalinium obscurum*, the acritarchs *Mychystridium* spp., presence of single celled algae of uncertain affinity (?*Leiosphaeridia* sp.) and cysts of colonial algae of the genus *Palambage* spp., with first occurrence of *Palambages* form B of Manum and Cookson, characterize the assemblages recovered from samples M7 through M1.

The appearance of the species *Oligosphaeridium complex* in this interval deserves especial consideration. The genus *Oligosphaeridium* is one of the most frequent components of the palynological assemblages throughout the Cretaceous, but was not registered in the Maastrichtian in the locations where this stage has been studied in Antarctica and Tierra del Fuego. It first reappears in both locations as well as in the Bajada de Jaguel section in the lowermost Danian (Palamarczuk et al., 1984, Olivero et al. 2003).

*Cyclapophysis monmouthensis*, "*Cordosphaeridium* " *lemniscatum*, *Turbiosphaera filosa*, *Trigonopyxidia ginella*, *Alisocysta circumtabulata*, *Tanyosphaeridium xanthiopyxides*, *Pierceites pentagonus* and *Palaeocystodinium* spp. were recovered from the intervals above and below the Sandy Layer.

Throughout the interval, that is, below, in and above the Sandy Layer, Lower Cretaceous (?Hauterivian/Barremian) palynomorphs, mostly of terrestrial origin, with a few marine specimens of the dinoflagellate genus *Cribroperidinium*, were recovered in fluctuating number and clearly decreasing in abundance immediately below the boundary. The most common species recovered was the gymnosperm pollen *Cyclusphaera psilata*, probably due to the resistant nature of its wall. The source of these palynomorphs is considered to be the uplifted area that is located to the west of the basin margin from which the sediments were derived, and they can be easily recognized because recycled palynomorphs usually show darker color or poorer preservation compared to the local assemblages.

## Proposed hypotheses to explain mass extinction and geochemical changes across the K/Plg boundary

The K/Plg was a crucial time in the history of the Earth in general, and of life in particular. It is well known that a mass extinction occurred in both, the marine and terrestrial realm. The best-known group of animals that became extinct at that time are the dinosaurs. However, other groups of organisms also suffered important losses, especially marine calcareous planktonic microfossils. Other microplanktonic organisms such as diatoms and dinoflagellate cysts seem to have been less affected.

Even though most species extinctions in the fossil record occur outside the major extinction event, mass extinction events have profound biological consequences because they dramatically change diversity and disrupt background selection regimes (Jablonski, 1986).

The important changes that took place in the Earth's biota during a very short period of time that mark the separation between the Mesozoic and the Cenozoic eras are considered a mass extinction and several hypotheses have been proposed to explain it:

1) The mass extinction was produced by the fall of a large asteroid that collided with the Earth. (Alvarez et al., 1980; Alvarez et al, 1984; Olsson and Liu, 1993; Olsson et al, 1997, among many other contributions on the subject). The aftermath of the impact created a disruption of the ecosystem due to the dust produced and then suspended in the atmosphere for a period of time after the fall. These atmospheric conditions, known as impact winter, affected life in all environments. The discovery of a thin clay layer, enriched in the element iridium, which coincides with the level of mass extinction, has been used as argument to support this hypothesis. Iridium is an element that is very rare in the crust of the Earth and its enrichment in a sedimentary section is taken as evidence of extraterrestrial origin of the layer. The presence of shocked quartz and tektites in some sections containing the boundary was also used as a evidence supporting this hypothesis. In the early 90's, a crater structure was found in Chicxulub, Yucatan Peninsula of Mexico,that was considered to be the impact area (Hildebrand et al. 1991, Pope et al, 1991).

   The impact of a large asteroid of approx. 10 km in diameter was predicted to result in major global environmental disasters suggested by the crater in Yucatan, and would have caused mass extinction involving both, marine and non marine organisms (Rampino et al., 1996).
2) The mass extinction was produced by increased volcanic activity. The gases that were ejected during the eruption were the cause of the ecosystem disruption.

To support this hypothesis, the Deccan Traps, a huge body of basalt that covers extended areas of west India, and that is considered to be Upper Cretaceous-Lower Danian in age, is used as the basis for this argument. Supporters of this hypothesis (Alexander, 1981; Officer and Drake, 1987; Courtillot and Cisowski, 1987; Courtillot, 1999) –consider the *iridium* enrichment to be of volcanic origin.

Mc Lean (1977, 1991), postulated that 65 million years ago, at the K/Plg boundary time, the earth experienced a major perturbation of the carbon cycle that unified the K/Plg geobiological record, including the mass extinctions. He related this effects to the Deccan Trap eruptions.

3) The mass extinction was caused by sudden changes in sea-level. The sea-level fluctuations that are documented for the Maastrichtian and beginning of the Danian could have affected the ecosystem and could have produced mass extinction in some groups of organisms (Brinkhuis and Zachariasse, 1988, Hultberg and Malgren, 1986; Firth, 1993).
4) The mass extinction was caused by changes in climatic conditions. This view was developed through the analysis of oxygen isotopes measured on shells of calcareous organisms. (Pardo et al., 1999).

Some authors have denied the idea of the occurrence of mass extinction at the K/Plg boundary (Zinsmeister and Feldmann, 1993). According to these authors, there was no mass extinction and the event has to be interpreted as a transition.

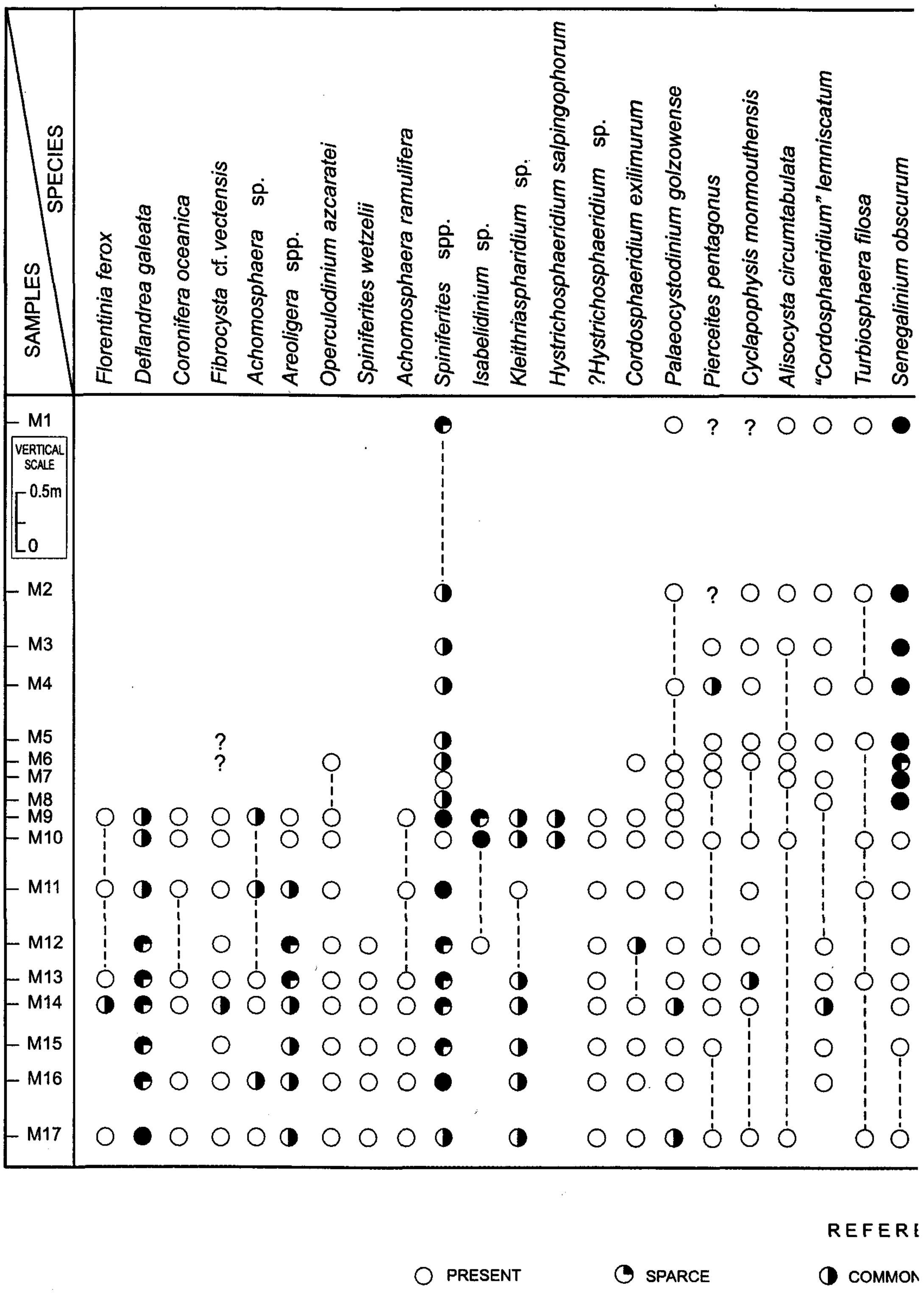

FIGURE 18: Stratigraphic distribution and relative abundance of species and groups of species in the approximately 6m interval sampled in the Bajada de Jaguel Formation containing the K/Plg boundary. Dotted lines connect intervals where species were not recovered

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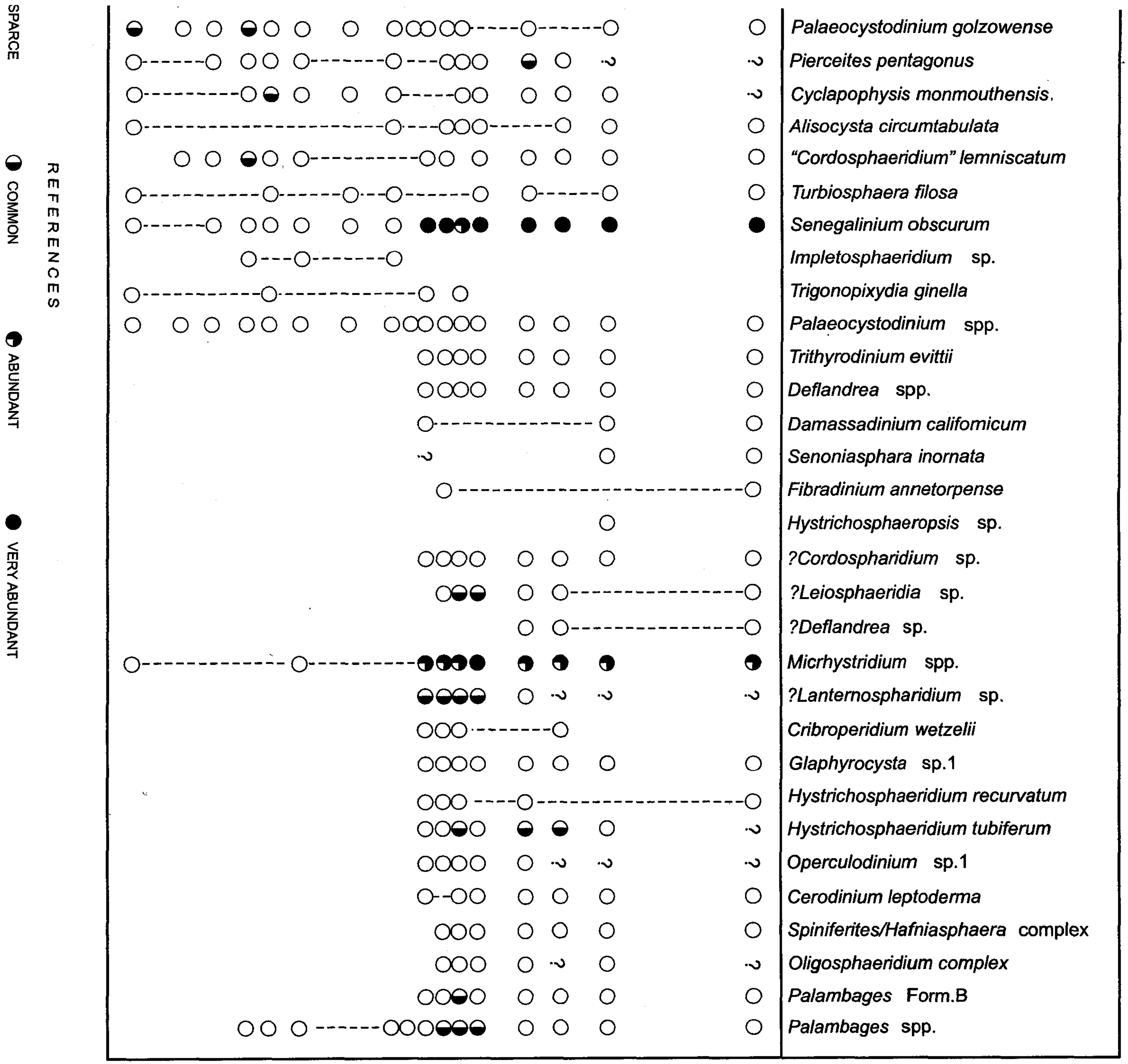


## Analysis of the K/Plg Boundary at Bajada de Jaguel

It is clear from the stratigraphic distribution and relative abundance data plotted in Fig. 18 that sample M8, taken from the "Sandy Layer" in this interval represents the stratigraphic level at which the most significant turnover in the dinoflagellate assemblages occurs. The Sandy Layer is also the horizon at which *Damassadinium californicum* and morphotypes related to *Senoniasphaera inornata,* all of which are worldwide marker species for the early Danian, first appear in the Bajada de Jaguel record. In terms of dinoflagellates, therefore, it would appear that the Cretaceous/Paleogene boundary is defined by the Sandy Layer. This interpretation is consistent with planktonic foraminifers (Palamarczuk et al., 2002). which show a similar change at this same stratigraphic level, as it was shown in a more detailed analysis explained below in this chapter.

## Significance of selected dinoflagellates and other organic- walled microfossils in the interpretation of the K/Plg boundary at the Bajada de Jaguel section

### *Isabelidinium/Manumiella* group:

This group, of peridiniod affinity, first appears in the section 1m below the boundary and reaches in sample M10 more than 50% of the total composition of dinoflagellate species. The same rapid increase in abundance and short stratigraphic distribution of this group has been identified in other sections in the Northern and Southern Hemispheres (Firth, 1987; Askin, 1988; Elliot et al., 1994; Wilson, 1987, 1988; Nohr-Hansen and Dam, 1997). The most common species recorded by these authors , and the one most similar morphologically to *Isabelidinium/Manumiella* from the Bajada de Jaguel section, is *Manumiella seelandica*, which has a geologic range restricted to a very short stratigraphic interval of the uppermost Maastrichtian.

Although the Bajada de Jaguel form is clearly a member of this species complex, morphological variability among the Jaguel specimens suggests that it is preferable to consider them as representing *Isabelidinium* in a broad sense with some morphotypes resembling *Manumiella seelandica.* Specimens of this group have not been recovered from older sediments in the Jaguel Formation. However, the evolution of *Isabelidinium* and related genera can be traced through the Upper Cretaceous of Antarctica, (e.g., Askin, 1988; Palamarczuk, 1993) and they are common in the uppermost Cretaceous of Tierrra del Fuego (Olivero et al, 2002, 2003). The abrupt eruption of the group in the Neuquén basin can be interpreted in different ways as it is explained below, considering that they belong to the peridinealeans and therefore, the general conclusions about the environmental interpretations of the order applies to this species complex: the unusually high relative abundance and short temporal distribution and disappearance at the boundary level can either represent a regressive episode or the arrival to the basin of a mass of cooler water with increased amount of nutrients. According to some authors, (Brinkhuis and Zachariasse, 1988; Habib et al., 1996, among others) a global regression is inferred on the basis of dinoflagellate analysis, combined with observations of other parameters, shortly before the end of the Maastrichtian. The sudden appearance of the *Isabelidinium*/*Manumiella* complex in the Neuquén Basin may in some way relate to this apparently global event. This interpretation is based on studies by different authors cited below and on the analysis of several parameters conducted in this study, as species

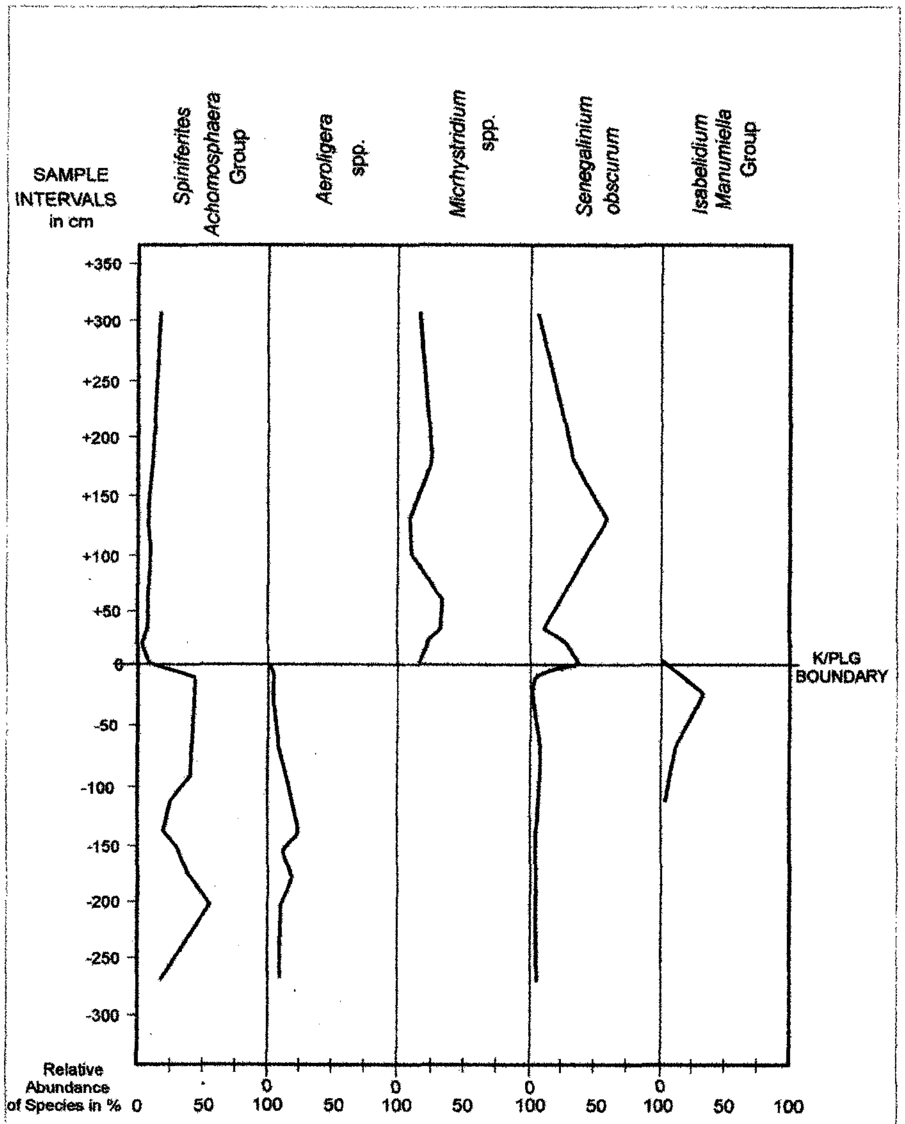


FIGURE 19: Relative abundance of species or groups of species considered of environmental significance throughout the 6m interval containing the K/Plg boundary in the Bajada de Jaguel section.

richness and number of gonyaulacoid/number of peridiniod cysts ratio, as shown in Figs.20 and 21 respectively. Estimates of species richness support this interpretation.

Paleoecological models in Palynology are based on the relative abundance of genera, species, species richness or morphotypes, which grouped into assemblages or associations, may indicate specific environmental conditions. Wall (1965) published a pioneering study of the paleoecological relationship of Mesozoic-Cenozoic microplankton. He based his conclusions on studies of acritarchs carried out in the Lias of England. The assemblages he analyzed showed a consistent relationship with cycles of sedimentation. Assemblages recovered from early stages of a transgression were uniform in composition, while open sea conditions resulted in greater variety of species. During the regressive stage, a reduction in diversity and abundance was registered.

In the Malm of Germany, Kunz, 1990, applied the gonyaulacacean ratio proposed by Harland (1973) and concluded that observations made by this author agreed with his results of his analysis of the sections from Germany, that is, the higher the index the ratio Gcysts/ P cysts, the greater the distance to shore.

Mao and Mohr (1992) used the same index to determine paleoenvironments in the Santonian/Maastrichtian, southern Indian Ocean. Brinhuis and Zachariasse, 1988, using dinoflagellate species or groups of species, divided the section at El Haria, NW Tunisia, into four intervals each one related to eustatic sea-level curves. The found that the regressive episode was characterized by abundance of spiniferids and the transgressive tendency was marked by the abundance of *Senegalinium*.

Many other studies on fossil dinoflagellate cysts, by analogy with the distribution of recent cysts in the ocean bottom, have made paleoenvironmental interpretation on the basis of dinoflagellate cysts distribution, considering the relationship of abundance and/or dominance of groups to sea-level fluctuations (Goodman, 1979, Bint, 1988; Davies and Norris, 1980; Prauss, 1989; Riding et al., 1991; Hultberg, 1986; Smelror and Leereveld, 1989, Brinkhuis and Biffi, 1993, among many others)

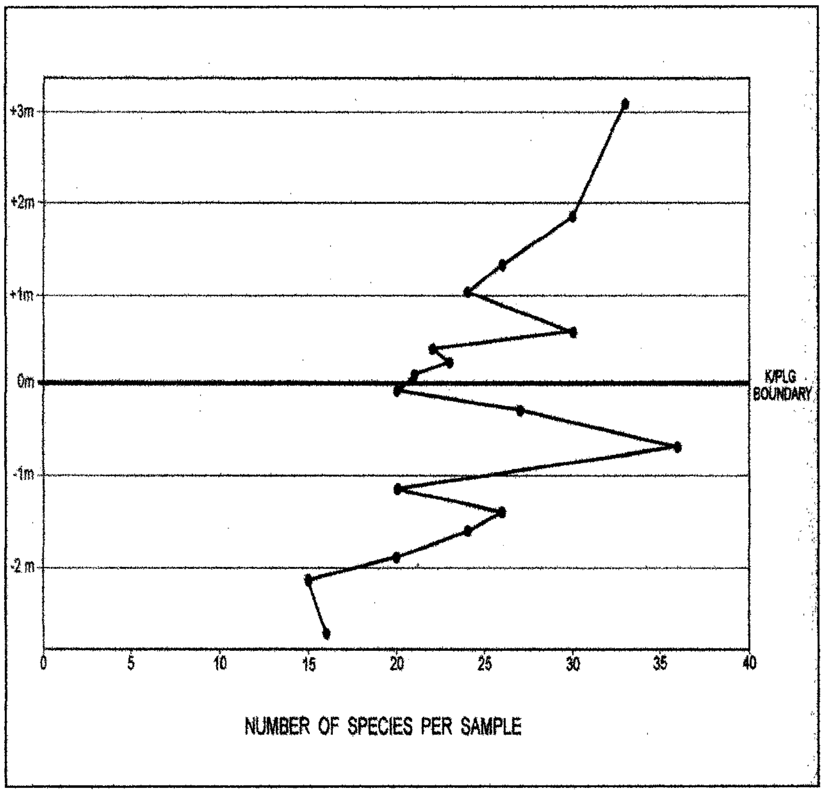


FIGURE 20: Graph showing number of species or groups of species per sample throughout the 6m interval showing fluctuating values but a clear decrease approximately 80cm below the boundary and a general tendency to a recovery immediately above the boundary.

At the Bajada de Jaguel interval under consideration, (Fig. 20), after reaching a maximum at aprox. 80cm below the boundary, a marked decrease in species richness is registered, that continues up to the boundary layer, suggesting a regressive tendency. As it was explained in the previous paragraph, this is one of the parameters that is used in Palynology to infer sea- level fluctuations in the geologic record. It should be noted that the number of species per sample is a parameter that is not purely objective because it is not always possible to clearly discern the morphotypes at the species level due to preservation, small size, or complicated morphology. Some of the morphotypes represent groups rather than individual species.

The analysis of the gonyaulacean/peridinialean relative abundance can also contribute to the understanding of the nature of the boundary event. The Gonyaulacacean ratio, that is, the number of gonyaulacacean species to peridinialean species proposed by Harland (1973), as explained above, can be used as an indicator of proximity to shore: the higher the ratio, the greater the distance from shore. Sample M10 is clearly dominated by the *Isabelidinium* complex, of peridinialean affinity, and could indicate a regressive tendency during the stratigraphic interval under consideration. Besides the *Isabelidinium*/ *Manumiella* group, considered independently because of its possible especial paleoenvironmental significance, *Deflandrea galeata* is the only abundant species of the peridinialean that has its last occurrence at the boundary. *Phelodinium* spp, *Cerodinium* spp, *Palaeocystodinium* spp. and *Pierceites pentagonus*, always in low relative abundance, were not affected by the boundary event.

In a well balanced marine assemblage, e.g., one in which interspecific and environmental conditions are in equilibrium, dinoflagellates cyst assemblages typically have the gonyaulacoids as dominant over the peridinioids (Brinkhuis and Zachariasse, 1988). It can be observed that below the boundary between samples M16 to M10 (Fig.21) this is the case, while within the approximately 1m interval below the boundary, from sample M9, this pattern reverses itself and continues for approximately 2m above the boundary.A normal relative abundance of both groups is observed again in Sample M2, when the balance seems to have been recovered. These differences in relative abundance of G/P cysts can be interpreted as a result of disruptions in the environmental conditions prior to and as a consequence of the K/Plg boundary event

Gonyaulacoid cysts are produced by autotrophic species; therefore, decrease in the amount of solar light can affect this group more severely than the peridinialean, more abundant in colder or rich in nutrient waters. In Fig.22, the selective response of the two main groups, peridinialean and gonyaulacacean to the boundary event in the Bajada de Jaguel section is shown. It can be observed that, with the exception of *D. galeata* and the short term lasting *Isabelidinium* sp, the peridinialean species survived the event. Among the G cysts, those with fibrous wall (e.g., *Cyclapophysis*, *Cordosphaeridium* and *Turbiosphaera* which are characterized by a fibrous periphragm. and a relatively large size are present above and below the boundary.

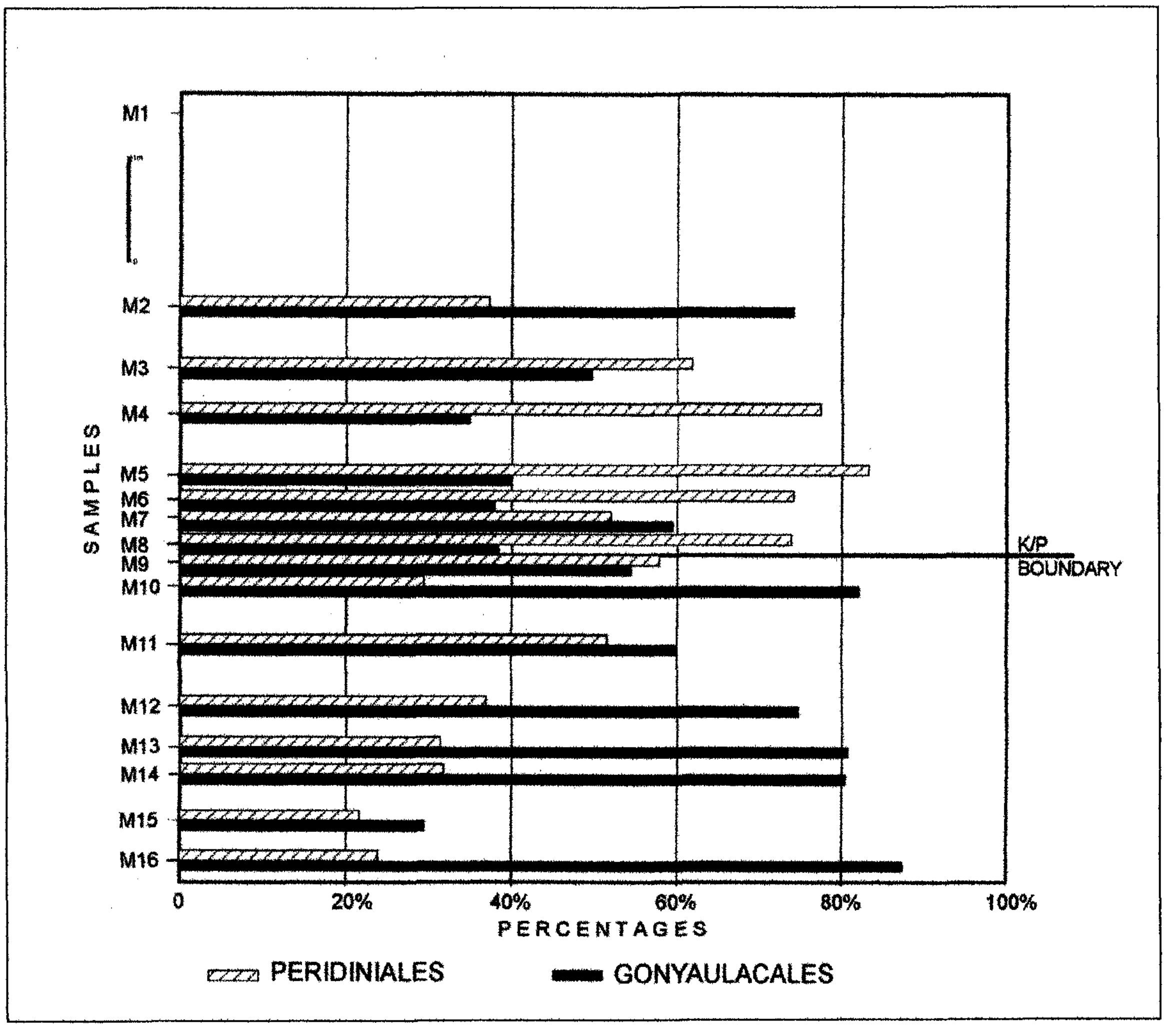


FIGURE 21: Relative abundance of P and G cysts. The bars indicate the percentage for each group recovered from each sample

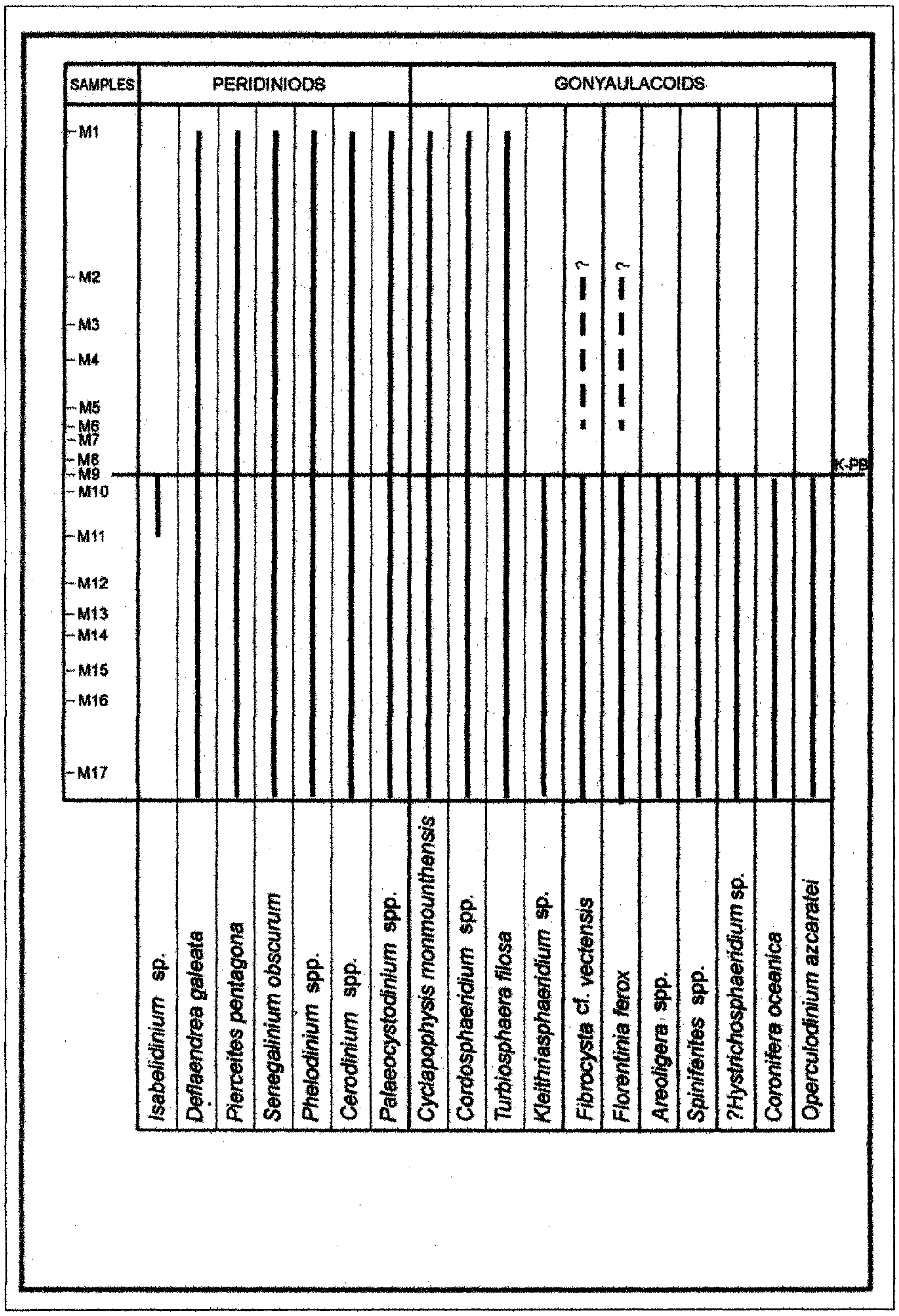


FIGURE 22: Selective response of the two main groups of dinoflagellate cysts to the K/Plg boundary event

### Relative abundance of peridiniod (P) average size/ small size, and gonyaulacoid (G) average size/ small size cysts:

Another parameter analyzed in this contribution is the relative abundance of average and small size dinoflagellates for both groups, the G and the P cysts. The results, shown in Figs. 23 and 24, point toward a period of stressed environment immediately above the Sandy Layer. It should be emphasized that this parameter deals with the size of the cysts themselves, and has nothing to do with population size, or assemblage diversity. Usually, under stressed environmental conditions, small species, which are generally considered to be opportunistic- capable of exploiting spasmodically occurring environments (Begon et al., 1990)- flourish and become more abundant than average size species. Fig. 23 shows the abundance of G cysts of average size relative to G cysts small size. Fig. 24 shows the relative abundance of P cysts of small size to P cysts average size. In Fig. 23, no clear pattern of size dominance in G cysts can be identified within the stratigraphic interval under consideration, whereas in Fig. 24, an increase of small peridiniod species can be observed immediately above the Sandy Layer, mostly *Senegalinium obscurum.* This species has been also abundantly recovered above the boundary in Antarctica and was considered as opportunistic (Elliot at al, 1994).

It can be inferred from the comparison of the relative abundance of both groups across the boundary that an environmental disruption if the ecosystem occurred after the K/Plg boundary event that produced an imbalance in the normal marine dinocyst populations, with an increase of heterotrophic opportunistic species.

*Areoligera* spp. /Spiniferids: As it was pointed out in Chapter 4, the general tendency toward a decrease in this ratio was observed during the Upper Maastrichtian. At the end of the Cretaceous, this ratio reaches a minimum. Spiniferids, morphologically diverse are dominant over *Areoligera* spp. Only a few specimens of the *Areoligera* group are still present in the uppermost Maastrichtian samples. The latter group has its last occurrence in the section in the sample immediately below the boundary (Sample M9). Elsewhere in the world, the group has representatives above the K/Plg boundary, (Kuhn and Kirsch, 1992 and other contributions on Paleocene and Eocene dinoflagellate cysts). Its disappearance from this section has to be interpreted as a response to local conditions that could have forced the group to migrate rather than to extinction.

The highly diversified spiniferid group that was present in the uppermost Maastrichtian samples, (examples of which can be observed in Plate 1, Figs 1-9) was also affected at the boundary. It was replaced above the boundary by new morphotypes mostly with vesicular cyst walls and development of apical structures, such as *Hafniasphaera* spp, *Spiniferella cornuta*, *Spiniferites* sp., (Plate 2, Figs. 1-9). Other plausible reasons for an increase of peridinialean abundance have been proposed. The increase in relative abundance of the group can indicate cooler waters, associated with an increase of available nutrients. (Mudie et al., 1990; Powell et al., 1990). This interpretation would be consistent with the general evolution of the group that took place at high latitudes and first appears in the Neuquén area shortly before the end of the Maastrichtian. It is not clear whether this unusual abundance of the peridiniod group

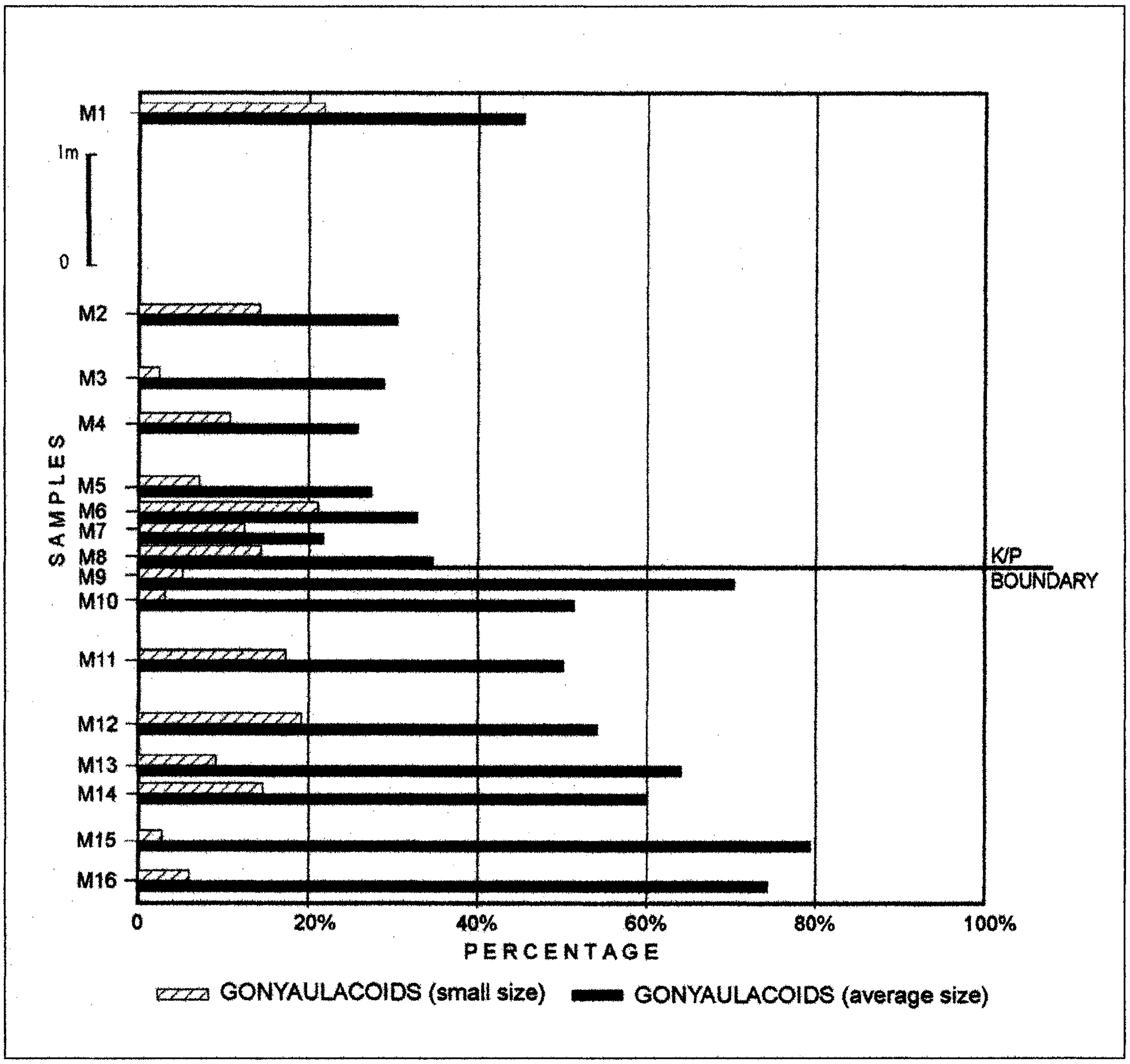


FIGURE 23: Relative abundance of G cysts average small size/G cysts average size

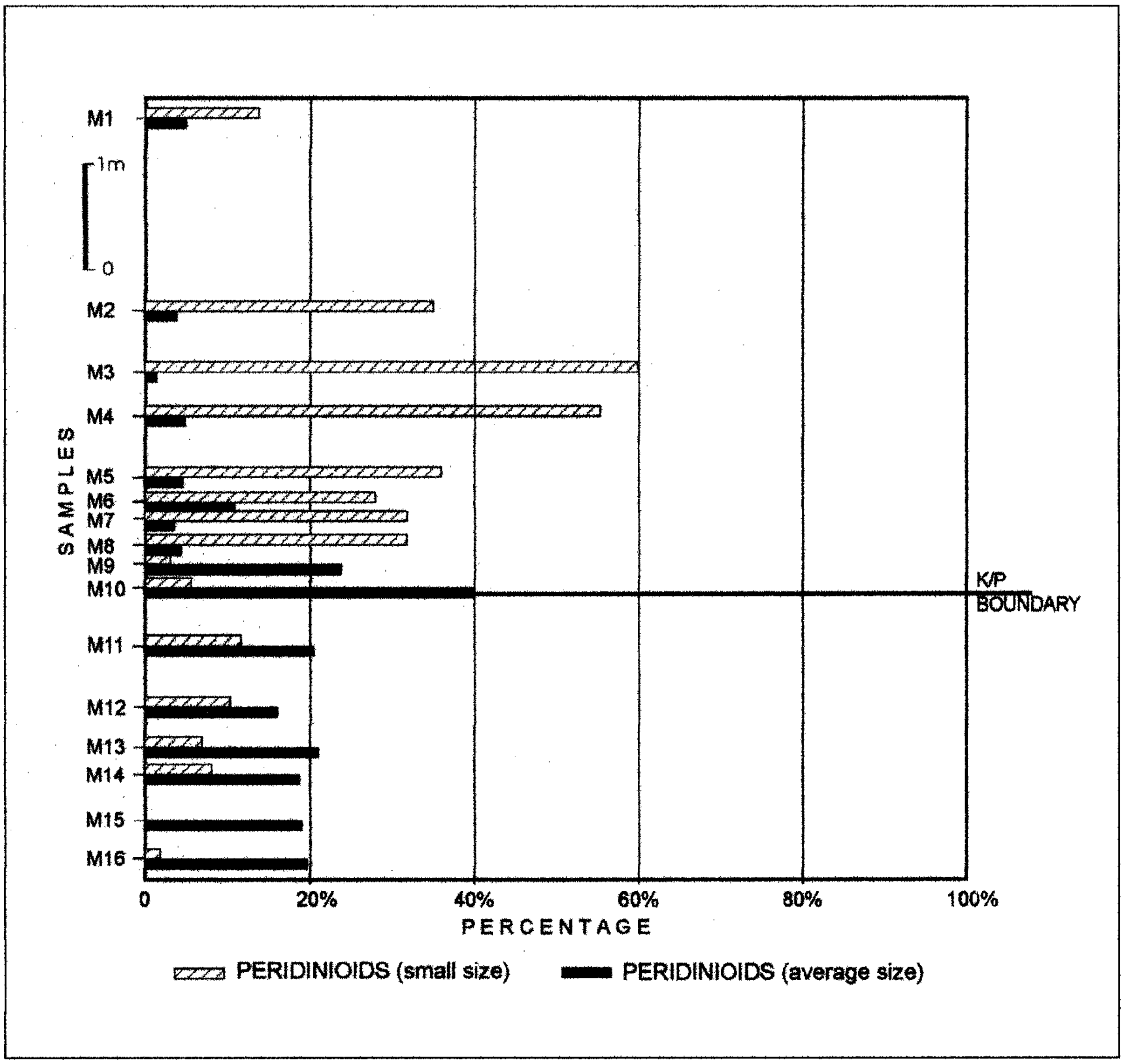


FIGURE 24: Relative abundance of P cysts average size/P cysts small size

should be related to the ingression into the basin of cooler waters due to changes in oceanic circulation patterns.

### Significance of other organic-walled organisms to interpret the K/Plg boundary in the Bajada de Jaguel section.

As it is shown in Fig. 25, not only dinoflagellate cysts were recovered from the samples analyzed in this study. Other components, such as colonial and single celled algae, and acritarchs, are present in variable relative abundance. Usually, the main organic –walled microfossils in a normal marine association are dinoflagellate cysts. That is the case in this section below the boundary layer. Above the layer, however, important percentages of other mentioned groups are documented and their significance discussed below.

Colonial cysts of *Palambages* spp. are common in the upper Cretaceous and Danian. In the Bajada de Jaguel section this group is represented below and above the boundary. Above the boundary, the group becomes abundant and mostly composed of *Palambages* Form B of Manum, that has its first local occurrence in the boundary layer. Acritarchs, although present, are not common components of Mesozoic and Cenozoic marine assemblages. Acritarchs of the genus *Michrystridium*, barely represented in the upper most Maastrichtian part of the section, flourished above the boundary. The same unusual abundance of specimens of the genus we found above the boundary in sections from Alabama (Habib, 1996). Firth (1993), in an analysis of sediments from the Nankai Trough, ODP Site 808, found an unusual concentration of acritarchs associated with an anoxic episode in the lower Maastrichtian.

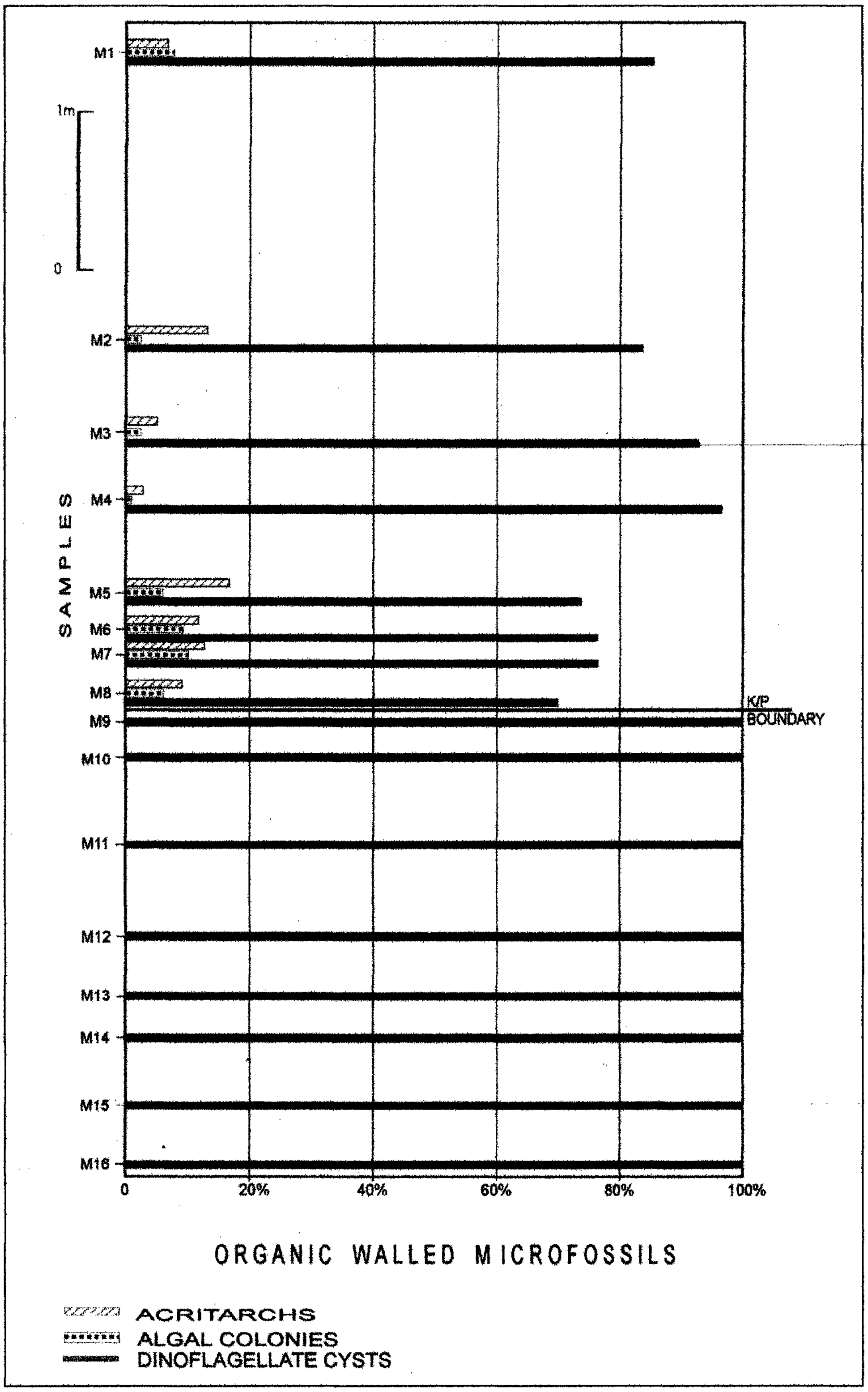


FIGURE 25: Relative abundance of different groups organic-walled microfossils

A population of relatively large cysts of uncertain affinity (Plate 21) first occurs at the boundary and is present in the initial stages of the Danian in the section. All these evidences point toward a disruption of the environmental conditions as inferred from the study of the organic-walled microfossils present in the layers immediately above the boundary during a period of time that lasted during the deposition of the initial 2m of sediments. As previously discussed, in the 1m interval below the boundary, the first occurrence, peak and disappearance of the *Isabelidinium* group shows evidence that there were changes in the environmental conditions prior to the boundary event related to factors that are difficult to decouple, such a regression, cooling of the waters, the influence of the local volcanic episode that produced the ash layer, the influence of the Deccan Traps on the global atmospheric conditions, or a combination of all those factors.

The deposition of the ash layer reflecting a volcanic event in the area, could have also had local consequences on the vegetation of the surrounding areas as concluded in Barreda et al., (2004) and on the marine basin, but the change of assemblages registered with the first occurrence of global markers for the Danian recovered from the bottom of the ash layer, together with the changes in relative abundance of microfossil groups other than dinoflagellate cysts, and the blooms of opportunistic species are evidences of a global event that can be related to the aftermath of an impact.

It was postulated that, after the impact in the marine realm the extinctions were concentrated in food chains that relied directly upon primary productivity by living photosynthetic organisms. (Sheenan and Fastovsky, 1992). This interpretation would be consistent with a temporary drop in solar transmission created by a dust cloud caused by the impact and that affected the entire planet, creating a photosynthesis shut down and a very short period of global cooling known as the impact winter. Relationship of these changes to the outpouring of the Deccan Traps are, at present, not clear, as it is not the probability that impacts can trigger volcanism.

## Additional studies across the boundary

A new, closer spaced sampling was conducted, covering approximately 1m interval of the section between samples M10 and M5 of the previous analyses. The position of these samples, labeled BJ21 to BJ35, and the relationship to the former stages of sampling are represented in Fig. 26. The purpose of this analysis was many fold and the preliminary results were presented in Palamarczuk, 2002.

### Detailed study of the "Sandy Layer"

As it was explained above, after excavating a trench of 6 vertical meter to sample in detail the interval between samples BJ8 and BJ7, a coarser grained, unconsolidated 17cm thick layer was detected, interbedded in the monotonous pelitic sequence characterstic of the Jaguel Fm (Figs. 27 and 28). This layer was not noticeable in the general field observation of the section. Three samples, BJ27, BJ 28 and BJ29, covering this 17cm layer were collected to perform palynological, sedimentological and petrographic analyses. As a result of the petrographic analysis of two thin sections of samples BJ27 and BJ 29, it could be observed that this layer is composed almost entirely of volcanic material, with fragments of shells, foraminifers and a few grains of quartz, that point to a water lain ash layer (See Figs. 29 and 30). The main mineralogical component of the granular fraction of the bed is the calcium rich plagioclase Labradorite,

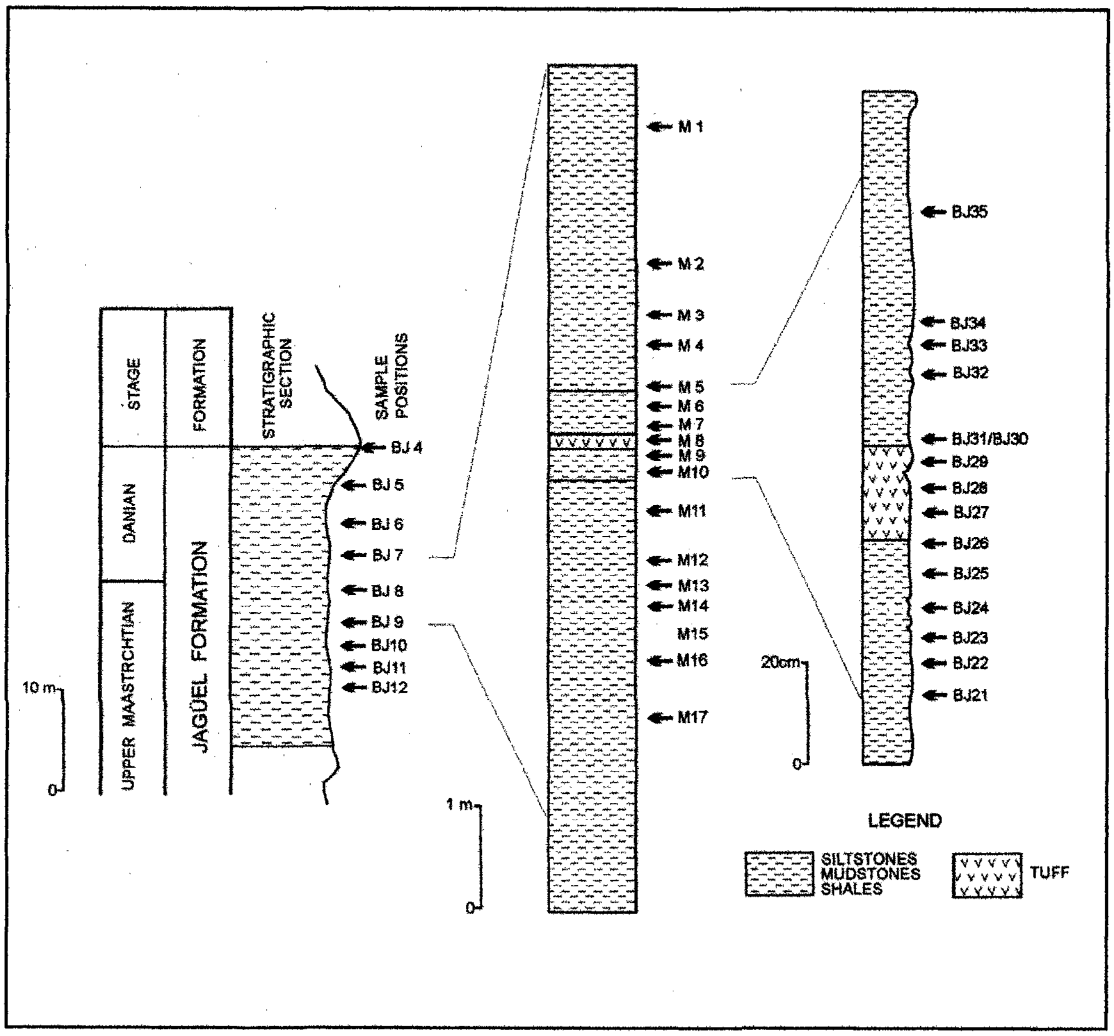
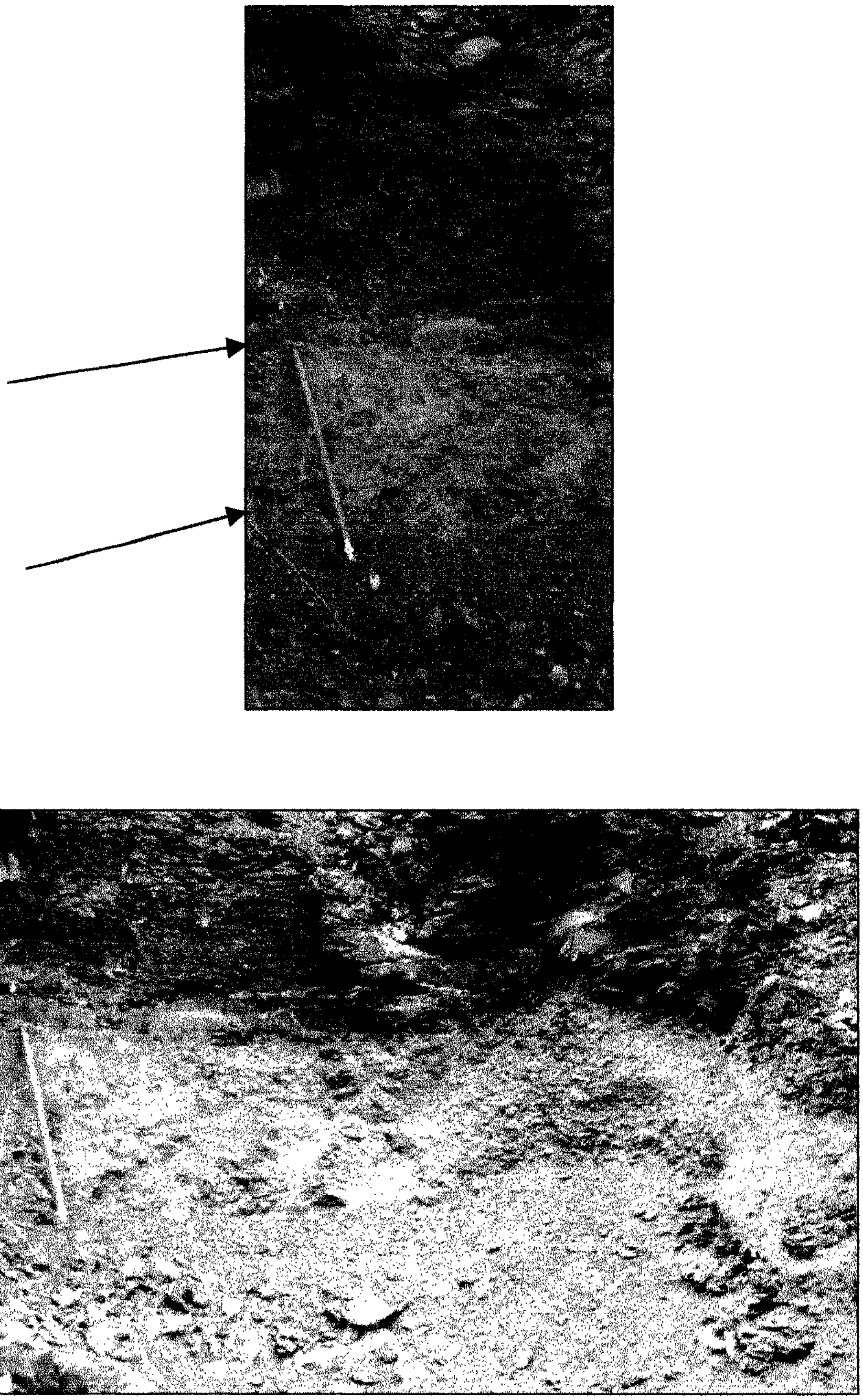


FIGURE 26: Stratigraphic column of the Bajada de Jaguel section showing three levels of sampling



FIGURES 27 and 28: Two views of the sandy layer after removal of the cover of weathered material. Arrows pointing to top and bottom of the layer present in euhedral and broken grains, unaltered and unweathered. Most of the altered matrix must originally have been glass.

The euhedral plagioclase grains were probably formed in a melt and ejected in composite fragments consisting of both, phenocrysts and melt/glass. The concentration of euhedral and broken labradorite grains suggest some removal of fine matrix byr winnowing, but very little rounding by abrasion. (Brock, pers. comm., 2003). These evidences point to the interpretation of this layer as a pyroclastic deposit in the marine basin, with probable origin in the active volcanic arc located to the west of the basin. (See Chapter 2, Fig. 5). This bed is, therefore, probably the result of a local volcanic event, since an ash layer has not been reported from any other Cretaceous/ Paleogene boundary section yet studied. Other sections studied in the world where the boundary was detected by a mass extinction of planktonic foraminifers and nannoplankton and/or a turnover of organic-walled microplankton show a clay layer with unusual enrichment of the element Iridium that has been associated with the impact of an extraterrestrial object.

### Grain size analysis of samples BJ21-BJ35

The samples were analyzed in the Sedimentology Section of the Geology Department of the University of Buenos Aires by R. Scasso. The results of the grain size analysis is presented in Fig. 31. It can be observed that for the samples below and above the "Sandy Layer" the distribution of frequencies concentratres on the silt/clay fraction, while the ash layer shows the curves clearly displaced toward the sand fraction.

### Study of the foraminifers contained in the samples

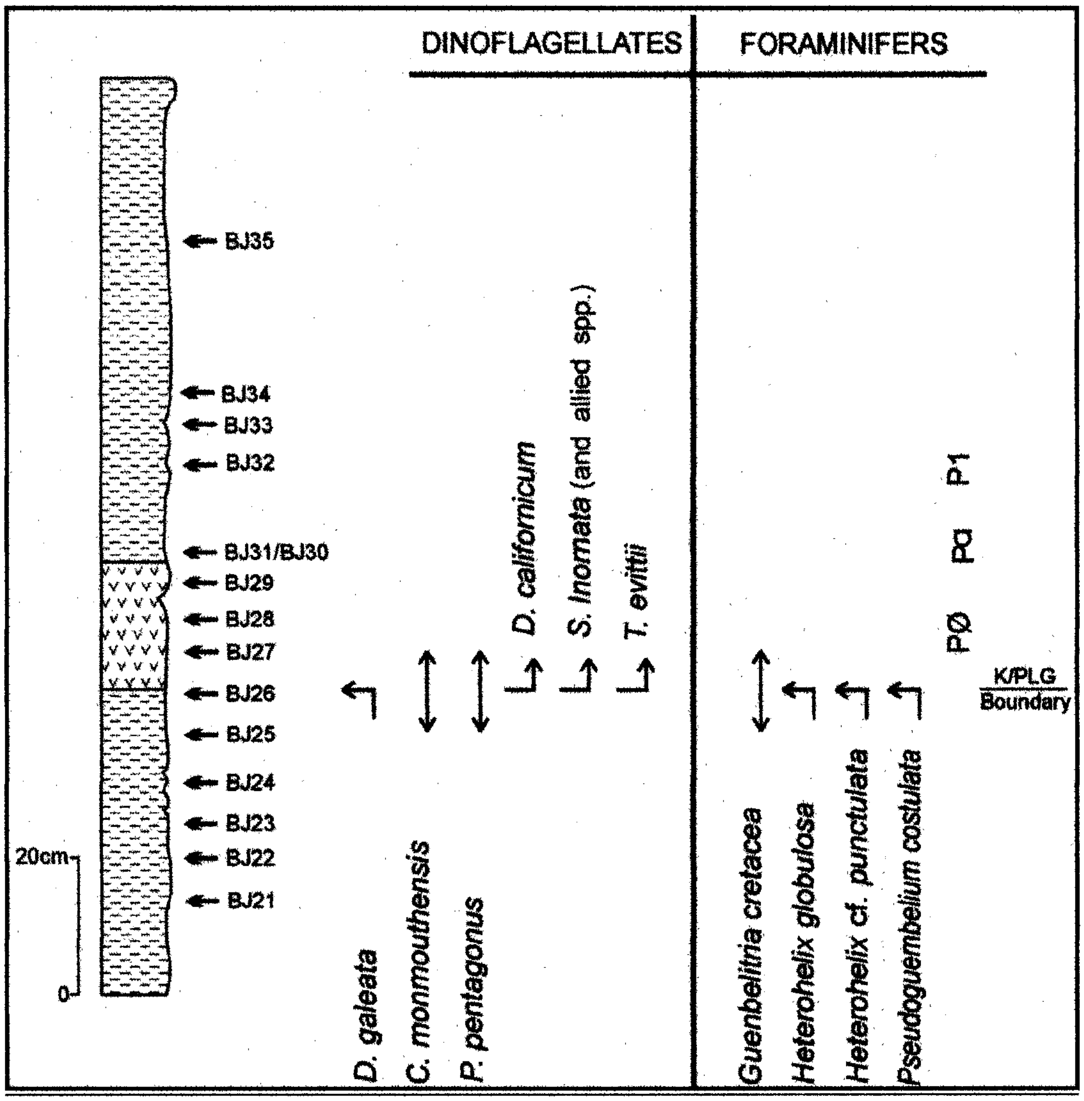


FIGURE 29: Calibration of the dinoflagellate markers with planktonic foraminifers

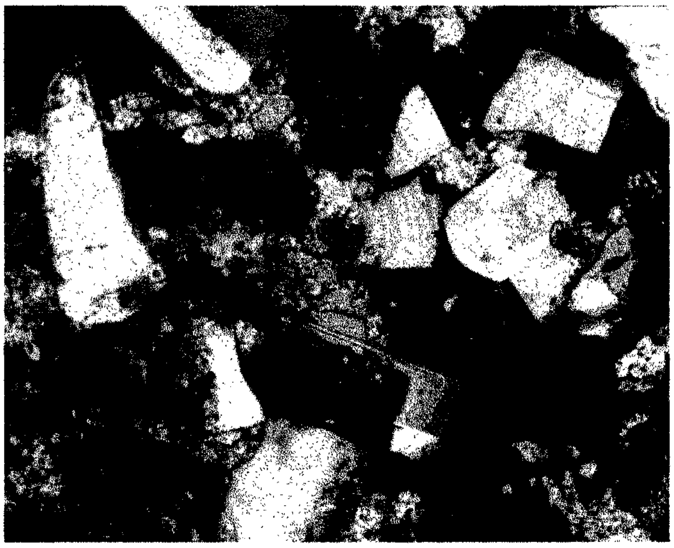


FIGURE 30: Thin section of the ash layer showing broken crystals

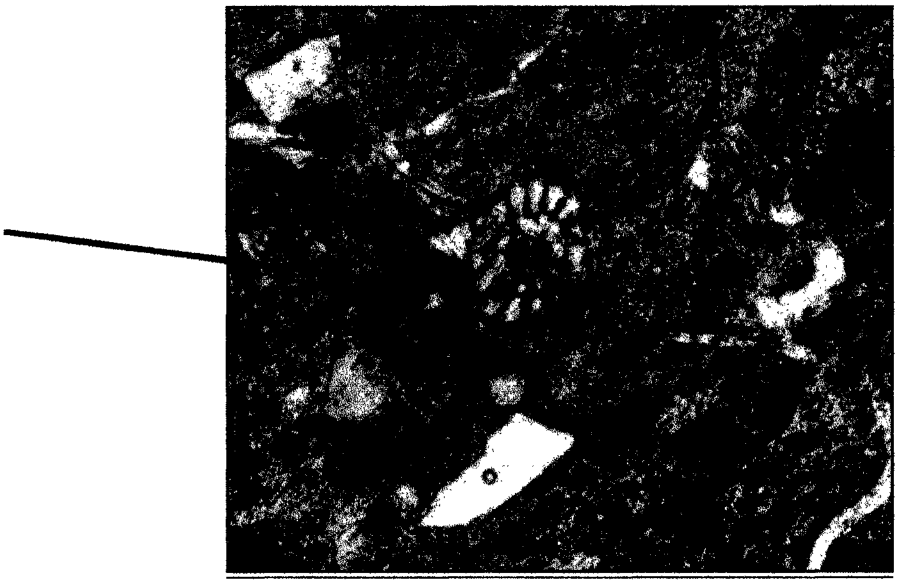


FIGURE 31: Thin section of the ash layer. Arrow pointing to a foraminifer test

In order to calibrate the biostratigraphic information and complement the paleoenvironmental interpretation obtained from the dinoflagellate cysts, the foraminifers contained in the same samples used for Palynology were studied (Palamarczuk et al., 2002). The biostratigraphic boundary was also placed, on the basis of the foraminifers, at the base of the ash layer as previously documented by means of the dinoflagellate cyst content. Danian planktonic foraminifer zones P0 in the ash layer, and zones Pα and P1 immediately above, were identified (Fig. 29). A paleodepth of approximately 50m was indicated by benthic foraminifers in both intervals, above and below the boundary.

## Comparisons of the results with zonations across the K/Plg boundary

The results obtained in this, still more detailed sampling, were compared with the zonations proposed by the different authors mentioned above from the Northern Hemisphere. Even though some important biostratigraphic markers were identified for both, the Maastrichtian and Danian, no strict coincidence was found with the schemes proposed in other latitudes, especially for the lack of uppermost Maastrichtian species *Chiropteridium inornatum* and *Talassiphora pelagica*. The genus *Chiropteridium* was not registered in the Southern Hemisphere. *Talassiphora pelagica* was documented in Eocene deposits of Tierra del Fuego, (pers. observ.) and Antarctica (Wrenn and Hart, 1988) but up to the present, it was never reported from the Maastrichtian in those areas. The lack of the uppermost Maastrichtian markers in the Bajada de Jaguel section could be the result of the restricted geographic distribution of the species in the case of *Ch. inornatum*, and a diachronous dispersion in the case of *T. pelagica*, but it can't be ruled out the presence of a very short hiatus, considering the slightly undulated lower contact

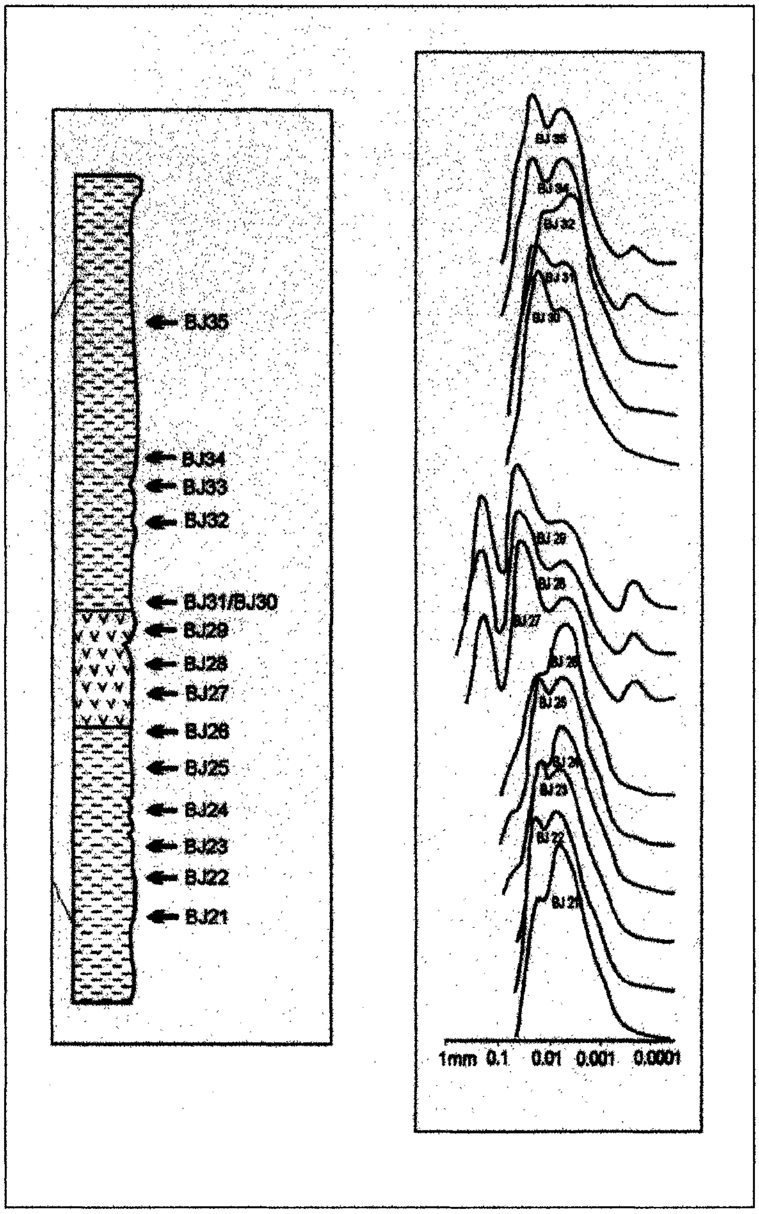


FIGURE 32: Grain size frequency distribution for each sediment sample collected for palynologic analysis. Notice the displacement of grain size toward the sand fraction in the three samples (BJ27, BJ28, BJ29) taken from the Sandy Layer identified here on the basis of dinoflagellate content as the K/Plg boundary.

between the upper Maastrichtian pelitic sedimentary rocks and the volcanic fragment rich boundary layer.

### Terrestrial Palynomorphs

Analysis of the pollen grain content in the samples were conducted in order to compare the response of the vegetation in the surrounding areas to the changes observed in the marine basin. Preliminary results of this analysis were communicated in Barreda et al. (2004). A demise of the angiosperm pollen grains was identified at the boundary and an increase in abundance of the pollen grains of *Classopollis* and a very variable population of a spore of uncertain affinity, mostly preserved in tetrades (Plate 24, Fig. 1). This abundance was observed to peak above the interval corresponding to this stage of sampling.(Fig. 30). The abundance of this spore is interpreted as having been produced by pioneering plant communities after the vegetational disruption created by the local volcanic event, or as a result of a global catastrophe.

### Number of marine specimens per gram of sample

Absolute counts of number of specimens of marine origin per gram of sample were performed. As it was explained in the chapter Methods, the same amount (10gr) was processed for each sample at this stage of the analysis, and the whole organic residue recovered, mounted for the palynological study. In this way, it was possible to relate the number of specimens obtained to the weight of sample processed. The results of these counts (Fig 31), show a tendency to a decrease in number of specimens from the sample located approx. 18 cm below the boundary layer, with a minimum at the top, and a subsequent recovery immediately above the layer. The decrease in absolute number of specimens per gram of sample close to and in the ash layer can be interpreted as a consequence of the regressive episode discussed below, combined with the faster rate of sedimentation of the water- lain ash layer, due to the greater abundance of coarser grained particles (sand fraction) in the layer. The decrease of both parameters, species richness and abundance of specimens per gram of sample shortly below the deposition of the Sandy Layer, seem to confirm the idea of a regressive episode, as it was globally documented for the upppermost Maastrichtian, prior to the boundary event.

The recovery of normal marine conditions is documented for both parameters in this interval of the Bajada de Jaguel section after the deposition of the initial 2m of the Danian. (See Figs.20 and 34).

It can be concluded that the bottom of the “Sandy Layer”, composed mostly of pyroclastic material, represents the biostratigraphic K/Plg boundary. There is no evidence in other sections studied yet, of a K/Plg boundary marked by an ash layer. Even though in this study the ash layer was interpreted as having local origin, the presence of the turnover of the assemblages of both, the organic-walled and the calcareous microplankton, is clearly related to a global event, probably the result of the Yucatan impact. Additionally, Palamarczuk et al., (2002), determined an age of the Sandy Layer of 65.97 +/-0.19 My on the basis of 40Ar/39Ar in Sanidine crystals from this horizon. This is within experimental error of the accepted age of the K/Plg boundary. A geochemical analysis to determine the presence of an Iridium enrichment in the Sandy Layer will shed light for the interpretation of this boundary layer in the Neuquén Basin.This is planned for future studies.

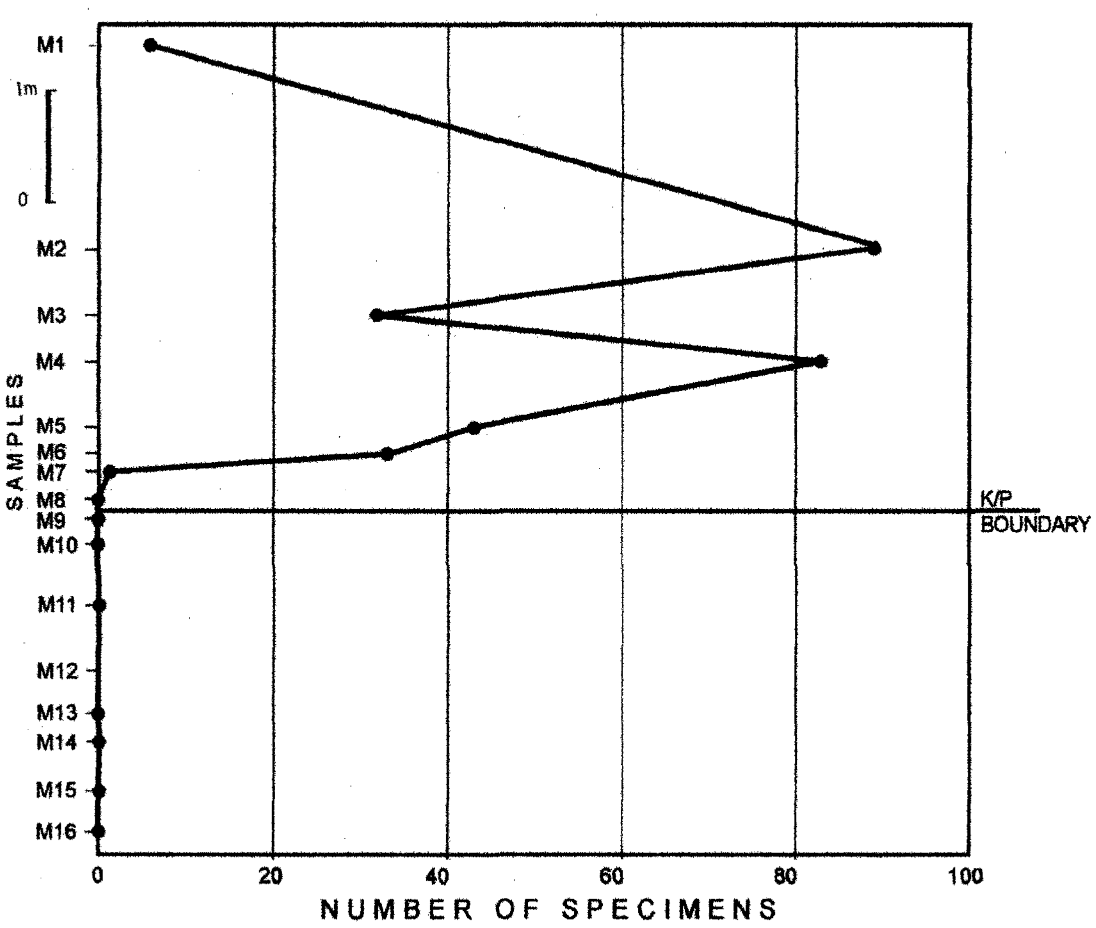


FIGURE 33: Number of spores of uncertain botanical affinity (single or in tetrades)

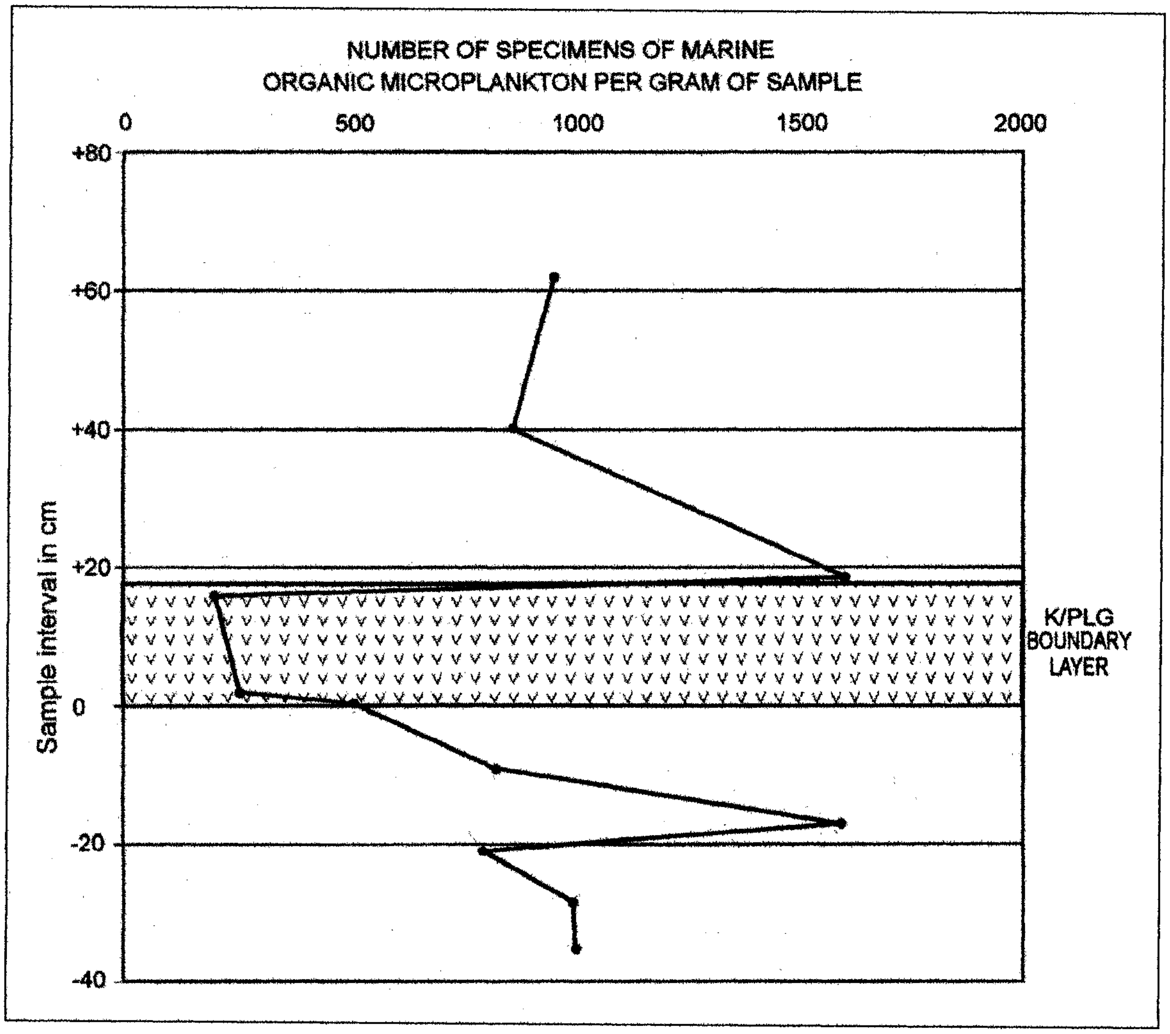


FIGURE 34: Number of organic-walled specimens of marine origin per gram of sample. The Sandy Layer containing the K/Plg boundary is shown by the pattern

# CHAPTER 7

## PALEOBIOGEOGRAPHY OF SELECTED DINOFLAGELLATE CYST SPECIES

### Introduction

The first step in the analysis of the paleobiogeography of organisms is to discern what general biogeographic patterns can be inferred for the time interval under study. This should be followed by an attempt to explain the causes of the observed patterns.

Since the plate tectonics theory became the accepted paradigm in geology, considerable interest in the paleobiogeography of a wide variety of fossil organisms has developed. This expansion in interest, which includes dinoflagellate paleobiogeography, has in part been spurred by the realization that plate movements, if known, can often help to explain fossil distributions that otherwise would not clearly be understood. Likewise, paleobiogeography can sometimes elucidate plate movements.

In order to achieve the goal of establishing a geographic distribution pattern for a group of organisms during a particular time interval much information has to be gathered. In the case of dinoflagellate cysts, only since the 1960's, when the knowledge of these microfossils started to expand, and with the advent of the theory plate tectonics, has the understanding of these microfossils become sufficiently robust to address paleobiogeographic issues. Since then, many sections have been studied in the Northern Hemisphere, but there is still a gap in knowledge about dinoflagellates, and their paleobiogeography, in the Southern Hemisphere, especially for South America.

This chapter summarizes the available information on paleobiogeography of dinoflagellate cysts and focuses on the palogeography of selected species or groups of species in southern South America and Antarctica during the Maastrichtian- Danian time interval. This treatment is based upon data obtained from personal observations and from the dinoflagellate literature.

**Important Biogeographic Parameters**

The main factors that influence the distribution of living organisms in the marine realm are:

Habitat: Planktonic organisms tend to be more cosmopolitan than benthic organisms, particularly those that inhabit the neritic zone.

Oceanic currents: The distribution of planktonic microorganisms, which have very limited ability to move independently, depends to a great extent on oceanic circulation patterns (Wall and Dale, 1970).

Climate: In the present time there is a strong diversity gradient in most groups between the poles and the tropics. (Fischer, 1960, Brown, 1988). With increasing latitude, diversity declines, usually reaching minimum values close to the poles. Sanders (1968) proposed the hypothesis that the key controlling factor, both for latitudinal and onshore-offshore diversity gradients was environmental stability rather than the temperature. It should be noted that at the present time, the importance of climate as a biogeographic parameter influencing the distribution of organisms is largely a result of the marked temperature gradient from the tropics to the poles. However, at times in the past when the poleward temperature gradient was more muted, the expansion and contraction of epicontinental seas played a very important role in controlling the degree of endemism. Contraction of the sea-level creates local basins with, to a certainn extent, independent biotas. This was the case in the Late Cretaceous. Thus, one might expect that factors controlling biogeographic distribution of dinoflagellate cysts during the portion of earth history under consideration here (Maastrichtian/Danian) are likely to differ from the modern situation to some degree.

Incidence of light: Light incidence diminishes away from the tropics. This factor affects especially the distribution of autotrophic Planktonic organisms, including autotrophic dinoflagellates.

Salinity: Organisms show different tolerance to salinity variation. Dinoflagellate cysts tend to be less diverse in transitional marine environments, such as estuaries, in which salinity commonly fluctuates. In such environments dinoflagellate cysts often show a pattern of monospecific dominance. This observation cannot be completely separated from the salinity of the environment. (Mc Minn, 1992; Hudson, 1990, among many other contributions)

Sea-level changes: Evidence of rise and fall of sea level are abundant in the stratigraphic record. Some cases of sea level change were regional in extent, while others were global as shown in the global coastal onlap curve (Haq et al, 1987)). In both cases, however, there are often significant consequences for the distribution of organisms (Hallam, 1992).Recent dinoflagellate distribution patterns show variation in composition and diversity for assemblages from inner neritic, outer neritic and oceanic. (Harland, 1983; Wrenn and Kokinos, 1986) Changes of sea level would be reflected in subsequent changes in the composition and diversity of the assemblages.

Nutrients: Waters rich in nutrients favor the abundance of certain organisms. In groups like dinoflagellates, which include both autotrophic and heterotrophic forms, upwelling currents rich in nutrients, favor unusual abundances of heterotrophic species. (Wall et al., 1977; Dale, B., 2002)

## Dinoflagellate Palebiogeography

The first comprehensive study of global distribution patterns of dinoflagellate cysts was produced by Lentin and Williams (1980) for Campanian peridinialean dinoflagellate cysts. These authors defined three assemblages that, according to their interpretation, reflect regional differences in environmental parameters rather than local paleoecologic control. These assemblages correspond roughly to Cretaceous latitudinal belts, and thus show a relationship to Cretaceous climatic zones. Lentin and Williams (1980) designated these three assemblages as: 1) the Malloy or tropical-subtropical suite; 2) the Williams, or warm-temperate suite; and 3) the McIntyre or boreal suite. The tropical/subtropical Malloy suite is characterized by the genera *Andalusiella*, *Cerodinium*, *Phelodinium* and *Senegalinium*. The temperate Williams suite is defined by the presence of *Alterbidinium*, *Chatangiella* (small forms) *Isabelidinium*, *Spinidinium* and *Trithyrodinium*. The boreal McIntyre suite is characterized by the genera *Laciniadinium* and *Chatangiella* (the larger taxa).

The model proposed by Lentin and Williams (1980) was mostly based on information from the Northern Hemisphere, but incorporated also some data from the few Southern Hemisphere locations that were known at that time. Other authors (e.g., Mao and Mohr, 1992) tested the model of Lentin and Williams (1980). Using their observations on new sections or wells, (Mao & Mohr, 1992) found that the Lentin and Williams (1980) model could be extended to the Santonian-Maastrichtian interval.

The peridiniacean genera *Amphidiadema*, *Nelsoniella*, *Satyrodinium*, *Xenikoon*, *Chatangiella* (the larger form) and *Isabelidinium* were used to distinguish a South Indian Ocean province that was named the Helby suite. This suite of dinoflagellates is characteristic of the Campanian- Maastrichtian of the Southern Hemisphere, and is interpreted to indicate cool water temperatures.

Brinkhuis and Leereveld (1988) reported that Maastrichtian dinoflagellate cyst assemblages show a high level of provincialism. In their study of the Tunisia type section for the Maastrichtian/Paleocene boundary, they found similarities in the composition to low latitude assemblages from Spain, California, and India, but marked differences with respect to dinoflagellate assemblages of northwest Europe. This Maastrichtian provincialism, according to Brinkhuis and Leereveld (1988), does not extend into the Danian, for which the assemblages seem to be more cosmopolitan.

Marheinecke (1992) studied dinoflagellate assemblages from the Upper Lower Maastrichtian to Lower Upper Maastrichtian of northern Germany. He compared the results of his analysis with other known Maastrichtian sections using the Simpson- Index as a coefficient of similarity and presented the results of the comparisons of his section to others from nearby areas, and to European and non-European areas. For nearby areas, he found that the relative similarity varies from 39% to 68%; for European assemblages, between 17% and 53% and for non- European assemblages, from 3% to 36%. He concluded that these Maastrichtian assemblages are characterized by high provincialism and explained this distribution as the result of Late Cretaceous oceanic currents.

The work of Lentin and Williams (1980) was followed by a paper by Cunha Lana and Bothelo Neto (1989), who published one of the first detailed paleobiogeographic studies on dinoflagellate cysts from Southern Hemisphere locations. Their data derive from wells drilled in the Potiguar Basin of northeastern Brazil and the Santos Basin of southeastern Brazil. Cunha Lana and Bothelo Neto (1989) indicated a high degree of provincialism of Maastrichtian- Danian peridiniod cysts in these basins. They suggested that dinoflagellate assemblages from these areas may be identified with the Malloy suite in the case of the Potiguar Basin and are transitional to the Malloy and Willliams suite for the Santos Basin.

### Late Cretaceous Dinocyst Paleobiogeography of Southern South America and Antarctica

Data on dinoflagellate abundance and distribution reported here, when combined with observations on dinoflagellate distribution from other areas in South America and Antarctica taken from the dinoflagellate literature, provide a basis for interpreting the paleobiogeography of south circumpolar dinoflagellates of Late Cretaceous age. A scheme for the spatial distribution of dinoflagellates is proposed here for southern South America and Antarctica, the first in which both peridiniod and gonyaulacoid cysts are considered.

**Areas considered in this study:** The location of the wells or outcrops from which the data for this paleobiogeographical analysis derive are depicted in the map in Fig. 31 and are described below.

Colorado basin ( A): The Maastrichtian/ Danian Pedro Luro Formation was analyzed palynologically by Gamerro and Archangelsky (1980) and Quatrocchio and Sarjeant (1996). The palynologic material was recovered from cutting samples of offshore and inshore boreholes. The temporal distribution is not precise due to the nature of the samples. Cutting samples don't provide results as accurate as core or surface samples. Despite the fact that its use in paleobiogeographic reconstructions is limited, they are used in this study because they help understand the general paleobiogeogrpahic pattern.

Neuquén basin (B):_ Jaguel Formation (Maastrichtian /Danian) analyzed in this contribution.

Chubut Province (C): Lefipan Formation, Maastrichtian (unpublished, personal observations); Salamanca Formation, Danian (Bellosi et al, 2000)

Tierra del Fuego Province (D). Several studies related to the Geology of the Isla Grande de Tierra del Fuego contain information about the dinoflagellate cyst content of Maastrichtian and Danian rocks at the southern tip of South America (Martinioni et al., 1999; Palamarczuk and Olivero, 2000; Olivero et al., 2003).

Magallanes Basin, Chile (E): El Ganso well, Maastrichtian/Danian, (Troncoso and Doubinger, 1980), Magallanes Province, Chile.

Chorrillo Chico Formation, Paleocene, Punta Pratt, Brunswick Peninsula. (Quatrocchio and Sarjeant, 2003).

Antarctica (F): Seymour (Vicecomodoro Marambio) Island, López de Bertodano Formation, Maastrichtian/Danian, (Palamarczuk, 1984; Askin, 1988; Elliot et al, 1994).

Results of the analysis of the paleobiogeography of dinoflagellate cyst assemblages recovered in the considered locations are described below:

Maastrichtian dinoflagellates show a marked degree of provincialism, as previously observed by other authors. (Lentin and Williams, 1980; Mao and Mohr, 1992). Maastrichtian and Danian assemblages can be spatially separated into two clearly distinctive domains, north and south from an imaginary line that runs along Tierra del Fuego (Fig. 30). The Maastrichtian associations from the locations to the north of the line are abundant and diverse, with the presence of *Glaphyrocysta* spp. close to the Lower/Upper Maastrichtian boundary and *Areoligera* spp. in the upper Maastrichtian. Diverse and relatively abundant specimens of the *Spiniferites* group are also characteristic components. These groups of species were not documented, up to the Present, in sections located to the south of the line. Palamarczuk et al. (1994) proposed an *Areoligera* association for the Maastrichtian in locations A, B and D. Their interpretation was confirmed by Quatrocchio and Sarjeant (2003). The Maastrichtian assemblages south of the line show low species richness and dominant presence of peridiniod cysts of the *Manumiella* group and *Palaeocystodinium granulatum*, never registered in the northern

domain. Few species in common have been observed for the Maastrichtian in both domains: *Operculodinium azcaratei*, *Exochospaheridium/Fibrocysta* complex (Askin,

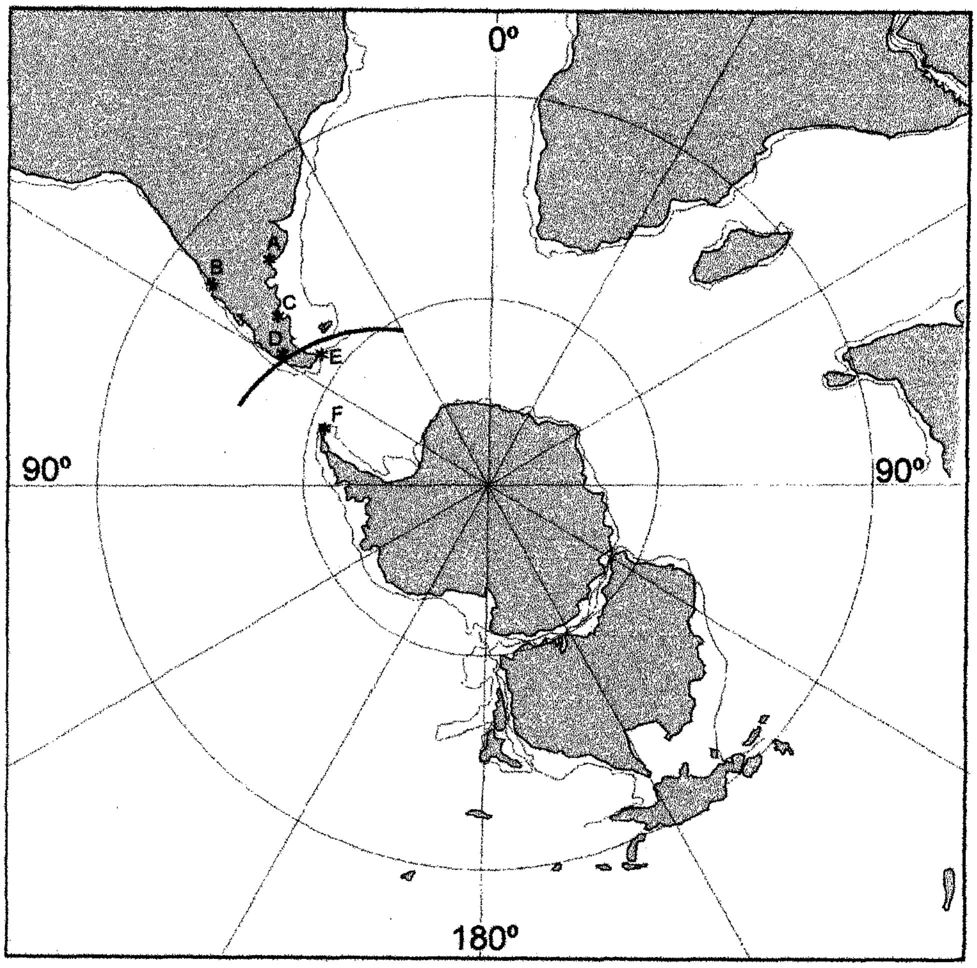


FIGURE 35: Location of the sections and wells discussed in the text, plotted on a paleogeographic reconstruction of the Southern Hemisphere in a polar projection, showing the division between the domains proposed in this study

1988, Elliot et al, 1994). The presence of specimens of the *Isabelidinium* complex, genus related to *Manumiella*, were only observed in the uppermost Maastrichtian 1m interval of the Jaguel Formation. The species that were not affected by the K/Plg boundary, mostly relatively large, fibrous cysts such as *Cyclapophysis monmouthensis*, *Turbiosphaera filosa* and *"Cordosphaeridium" lemniscatum* were not documented in the southern locations.

*Cordosphaeridium* spp., also abundant in the northern domain was not observed in Tierra del Fuego and Antarctic sections but is mentioned, although not illustrated, as a group with low relative abundance from the Filo Negro section, Seymour Island, Antarctica by Elliot et al., (1994). *Alisocysta circumtabulata* is present in both domains in the Maastrichtian and Danian in very low relative abundance, but increases its percentage in the southern locations in the lowermost Danian.

The Danian deposits for both domains show also important compositional differences in the organic-walled microfossil assemblages. These differences are marked enough to maintain the separation between both biogeographic areas. However, some similarities have been observed. *Trithyrodinium evittii* is a marker for the initiation of the Danian in both domains, as it is also the case in New Zealand (Wilson, 1988). The presence of *Oligosphaeridium complex*, species commonly represented worldwide through the Cretaceous , was not documented in the Maastrichtian of both areas, but is a component of the Danian assemblages. (Olivero et al, 2002). A bloom of *Senegalinium obscurum* was mentioned for Seymour Island, Antarctica (Elliot et al, 1994) and also occurs in the Jaguel Formation shortly after the boundary event.

## Causes of dinoflagellate cyst endemism

Even though a clear pattern if provincialism can be observed in the Maastrichtian-Danian time interval for the considered areas, the mechanism through which this distribution was produced is not clearly understood. The information from El Ganso well, Magallanes Province, Chile, very close to the Tierra del Fuego Province sections known from Argentina, shows dinoflagellate assemblages very similar, within the *Areoligera* association, to the areas located to the north, probably related to oceanic circulation patterns combined with latitudinal control.

The latitudinal control proposed by Lentin and Williams (1980) for the Campanian seems to apply for the Maastrichtian-Danian time interval, although a clear assignment to one of the suites could not be established. The dinoflagellate cyst provinces proposed in Lentin and Williams (1980) were based on peridiniacean cysts, while in this study both groups, peridiniacean and gonyaulacacean were analyzed from the paleobiogeographic standpoint.

# CHAPTER 8

# SYSTEMATIC PALYNOLOGY

## Introduction

The approach used in this study for the Systematics of dinoflagellate cysts follows an alphabetical generic order. The suprageneric categories are limited to Division, Class and Order. The Nomenclature, with a few exceptions explained in the text, is based on the Index to Genera and Species of Fossil Dinoflagellates (Williams, Lentin and Fensome, 1998).

As this research focuses mostly on the response of dinoflagellates and other organic-walled microfossils to the Cretaceous/ Paleogene boundary event, no detailed systematic is provided. Morphotypes characteristic for certain paleoenvironments are considered as groups or complexes. This tendency has been increasingly followed by different authors (Ioannides, 1986; Firth, 1993; Elliot et al., 1994; Yepes, 2001; Frederiksen et al., 2002, among others). The classification of the *Spiniferites /Achomosphaera*, *Glaphyrocysta/ Areoligera*, *Isabelidinium /Manumiella* and *Palaeocystodinium* spp. groups is, in many cases, highly subjective at the specific level. However, considered as groups, they are very useful for biostratigraphic as well as for paleoenvironmental interpretations.

For species or groups of species that were not found in the literature, comments or descriptions are given, but no new taxa are proposed. Although few specimens might represent new species, formal designations for them must await further, more comprehensive morphological studies than are attempted in this thesis.

Species common in the bibliography and abundantly recovered are listed and illustrated, with no especial remarks, comments or descriptions. Species that are represented by single or very rare specimens are illustrated only with indication of the sample and assemblage interval in which they were recovered.

Terrestrial components of the assemblages are illustrated and considered only as paleoenvironmental indicators. No systematic for this group of organisms is provided.

### Division DINOFLAGELLATA (Butschli 1885) Fensome et al. 1993

### Subdivision DINOKARIOTA Fensome et al. 1993

### Class DINOPHYCEAE Pascher 1914

### Subclase PERIDINIPHYSIDAE Fensome et al. 1993

### Order GONYAULACALES Taylor 1980

### GENUS *Alisocysta* Stover and Evitt, 1978, p.15-16.

*Alisocysta circumtabulata* (Drugg) Stover and Evitt, 1978

Plate 10 Figs. 1-3

1967 *Eisenackia circumtabulata* Drugg, p. 15, pl 1 Figs 12-13

1978 *Hystrychokolpoma circumtabulata* Schumacker-Lambry, p. 42

1978 *Alisocysta circumtabulata* Stover and Evitt, 1978, p.16.

**Occurrence and Frequency:** Lomas Coloradas and Bajada de Jaguel sections. Uppermost Maastrichtian and Danian. Rare.

### *Alisocysta* sp.

Plate 10 Fig 7

**Comments**: Only one specimen of this species was recovered. It resembles *Eisenackia chilensis*, as defined by Quatrocchio and Sarjeant (2003) for the Chorillo Chico Formation, southern Chile. No further comparisons can be made on the basis of a single specimen.

**Occurrence and Frequency:** Bajada de Jaguel section, Danian interval.

## Genus *Areoligera* Lejeune-Carpentier, 1938a, p.B164. Emend. Williams and Downie, 1966c, p.227-228.

### *Areoligera senonensis* Lejeune-Carpentier, 1938a,

Plate 11 Fig. 1-2

1938a *Areoligera senonensis* Lejeune-Carpentier, 1938a p.B164-B166, text-figs.1-2

**Comments:** Specimens of *A. senonensis* occur abundantly in certain samples along with a group of similar morphotypes, not easily distinguished at the species level.

**Occurrence and Frequency:** Lomas Coloradas and Bajo de Jaguel sections, Upper Maastrichtian interval. Very abundant as one of the components of a species complex in the Assemblage Interval II, decreasing toward the uppermost Maastrichtian.

### Genus *Caligodinium* Drugg, 1970b, p. 814-815, emend. Manum and Williams,1995

*Caligodinium aceras* (Manum and Cookson) Lentin and Williams, 1973, p. 21

Plate 22 Fig. 6

1964 *Kalyptea aceras* Manum and Cookson, p. 27-28, pl. 6, figs. 9-11

1973 *Caligodinium aceras* Lentin and Williams, p. 21

**Occurrence and Frequency:** Lomas Coloradas section. Restricted to sample LC33. Rare.

### Genus *Carpatella* Grigorovich, 1969a, p.74, emen. Fechner and Mohr, 1986, p.183-184; Damassa, 1988, p.168,170, 172.

*?Carpatella* sp. cf. *C. cornuta*

*Carpatella cornuta* Grigorovich, 1969a, p.74-75, pl.1, figs.1-6.

**Comments:** The few specimens recovered differ from the original in having a thinner cyst wall.

**Occurrence and Frequency:** Bajada de Jaguel section. Danian interval. Present in only in few samples. Rare.

## GENUS *Coronifera* Cookson and Eisenack 1958b; emend. Davey, 1974; emend. May, 1980; emend. Mao Shaozhi and Norris, 1988.

### *Coronifera oceanica* Cookson and Eisenack, 1958

Plate 16 Fig. 5-6

1958 *Coronifera oceanica* Cookson and Eisenack, p.45, pl.12, figs.5-6.

**Occurrence and Frequency:** Lomas Coloradas section and Bajo de Jaguel section, Upper Maastrichtian interval. Common to rare.

## GENUS *Cordosphaeridium* Eisenack, 1963b, p.261, emend. Morgenroth, 1968, p.548; Davey, 1969c, p.35; Sarjeant, 1981, p.100-101; He Chengquan, 1991, p.157-158, 213

### *Cordosphaeridium* cf. *exilimurum* Davey and Willimas 1966b

Plate 4 Figs. 1,2,4,5

1966 *Cordosphaeridium exilimurum* Davey and Williams, p. 87-88, pl. 11, fig.2

**Comments:** The assignment to *C. exilimurum* is tentative. Some of the processes show trumpet- like ends that are comparable to *C. cantharellum* (Brosius) Gocht, 1969. This species was transferred to the genus *Tityrosphaeridium*, Sarjeant 1981. However, in the present study it is considered as it was originally described, that is, as *Cordosphaeridium*.

**Occurrence and Frequency:** Lomas Coloradas section and Bajada de Jaguel section, Upper Maastrichtian interval. Fairly common.

### *Cordosphaeridium inodes* (Klumpp) Eisenack 1963b, emend. Morgenroth, 1968; emend. Sarjeant, 1981

Plate 4 Figs. 3-6

1953 *Hystrichosphaeridium inodes* Klumpp, p. 391, pl. 18, figs. 1-2

1963 *Cordosphaeridium inodes* Eisenack, p. 261

**Occurrence and Frequency**: Bajada de Jaguel section, Danian interval. (Assemblage interval IV). Rare.

### *Cordosphaeridium inodes* subsp. *longipes* Hansen, 1977

Plate 7 Figs. 1-4

1977 *Cordosphaeridim inodes* subsp. *longipes* Hansen, 1977, p. 17, 19, figs 17 C-E

**Comments**: Specimens assigned to this subspecies show in some cases processes folded on the central body. The fibrous processes show variability in their width.

**Occurrence and Frequency**: Bajada de Jaguel section. Danian interval. (Assemblage interval IV). Common.

### "?*Cordosphaeridium*" *lemniscatum* Corradini, 1973

Plate 4 Figs 7-9

1973 ? "*Cordosphaeridium*" *lemniscatum* Corradini, p.152-153, pl.22, figs.4a-b,5; pl.33, figs.2,4; pl.39, fig.2.

**Comments**: The criterion adopted in this study is to tentatively assign the specimens recovered from the Jaguel Formation to of "?*C.*" *lemniscatum* as described by Corradini, (1973). The fibrous processes connected distally are characteristic of this taxon. It was considered as a questionable assignment by Stover and Evitt (1978) and transferred to *Disphaerogena* by Lentin and Williams, 1989.

The distinctive characteristic of *Cyclapophysis* Benson, 1976, genus that Sarjeant, (1985b), considered as a junior synonym of *Disphaerogena*, is the distal connection of the pre and post cingular fibrous processes. However, as it is clearly illustrated in this study, (Plate 4, figs 7-9), there is a difference between the distal interconnection, as it seems to be the case in ?"*C. lemniscatum*", apparently not restricted to those areas. Both genera require further studies.

**Occurrence and Frequency**: Bajada de Jaguel section. Uppermost Maastrichtian and Danian. (Top of Assemblage interval II, Assemblage intervals III and IV). Common to rare.

### ?*Cordosphaeridium* sp.

Plate 12 Fig. 9

**Comments:** Small cysts with fibrous processes and precingular archeopyle. Tentatively assigned to the genus *Cordosphaeridium.*

**Occurrence and Frequency:** Bajada de Jaguel section. Danian interval. (Assemblage interval III). Rare to common.

## Genus *Cribroperidinium* Neale and Sarjeant, 1962, p.443

### *Cribroperidinium wetzelii* (Lejeune-Carpentier) Helenes, 1984, emend. Lejeune - Carpentier; emend. Lejeune Carpentier and Sarjeant, 1981

Plate 12 Figs. 4-5

1939 *Gonyaulax wetzelii* Lejeune-Carpentier, p.B526; text-figs.1-2

1969 *Gonyaulacysta wetzelii* Sarjeant, p. 11

1984 *Cribroperidinium wetzelii* Helenes, p.124

**Occurrence and Frequency:** Bajada de Jaguel section. Danian interval (Assemblage intervals III and IV). Common.

## Genus *Cyclapophysis* Benson, 1976, p.182.

### *Cyclapophysis monmouthensis* Benson, 1976

Plate 13 Figs. 1-3

1976 *Cyclapophysis monmouthensis* Benson, p.183, pl.1, figs.9-12; pl.2, fig.1

**Comments:** In this study the specimens that compare with the original description of the genus and species are assigned to *C. monmouthensis* as proposed by Benson (1976). The species was transferred by Sarjeant to *Disphaerogena carposphaeropsis*, because he considered the latter to be a senior synonym. This criterion is not follwed in this study.

**Occurrence and Frequency:** Lomas Coloradas and Bajada de Jaguel sections, Uppermost Maastrichtian and Danian interval. Common.

## Genus *Damassadinium* Fensome et al., 1993b, p.90.

### *Damassadinium californicum* (Drugg) Fensome et al., 1993b

Plate 13, Fig. 4 Plate 8 Fig. 6

1967 *Palmickia californica* Drugg, p.30, pl.5, figs.14-15; pl.9, fig.8

1977b *Samlandia californica* Lentin and Williams, p. 141

1977 *Danea californica* Stover and Evitt, p. 152

1993b *Damassadinium californicum* Fensome et al, p. 90

**Occurrence and Frequency:** Bajada de Jaguel section. Danian interval. Rare.

### Genus *Dinopterygium* Deflandre, 1935, p.231. Emend: Stover and Evitt, 1978, p.204-205

*Dinopterigium cladoides* Deflandre, 1935

Plate 14 Figs. 3-5

1935 *Dinopterygium cladoides* Deflandre, p. 231, pl. 8, fig. 6

**Occurrence and Frequency**: Lomas Coloradas section, Upper Maastrichtian. Rare. Restricted to sample LC31, (Assemblage interval II).

### Genus *Diphyes* Cookson, 1965a, p.85. Emend. Davey and Williams, 1966b, p.95-96; Goodman and Witmer, 1985, p.76.

*Dyphies colligerum* (Deflandre and Cookson) Cookson, 1965a

Plate 16 Figs. 7-9

1955 *Hystrichosphaeridium colligerum* Deflandre and Cookson, p.278-279, pl.7,fig.3

1965 *Baltisphaeridium colligerum* Downie and Sarjeant, p. 88

1965a *Dyphies colligerum* Cookson, p. 86-87

**Occurrence and Frequency:** Bajada de Jaguel section. Danian interval (Assemblage interval IV). Rare.

### Genus *Exochosphaeridium* Davey et al., 1966, p.165

*Exochosphaeridium* cf. *bifidum* (Clarke and Verdier) Clarke et al., 1968, emend. Davey, 1969b

Plate 13 Figs. 7-9

1967 *Baltisphaeridium bifidum* Clarke and Verdier, p. 72-73, pl. 17, figs. 5-6; text fig. 30

1968 *Exochosphaeridium bifidum* Clarke et al., p. 182

**Occurrence and Frequency:** Lomas Coloradas section. Assemblage interval I. Rare to common.

## Genus *Fibradinium* Morgenroth, 1968, p.537-538

* *Fibradinium annetorpense* Morgenroth, 1968.

1968 *Fibradinium annetorpense* Morgenroth, p.538, pl.42, figs.4-7; text-figs.1-2

**Occurrence and Frequency**: Bajada de Jaguel section, Danian interval. Rare.

1969

## Genus *Fibrocysta* Stover and Evitt, 1978, p.155.

*Fibrocysta* cf. *vectensis* (Eaton) Stover and Evitt 1978

Plate 6 Figs. 1,2,3,6,9

(Eaton, 1976, p.275-276, pl.12, figs.4-6) Stover and Evitt, 1978, p.155.

1976 *Lanternosphaeridium vectense* Eaton, p. 275-276, pl. 12, figs. 4-6

1977 *Fibrocysta vectensis* Stover and Evitt, p. 155

**Comments**: Specimens assigned tentatively to *F. vectensis* show variability in the distinctively developed apical process. Some specimens clearly show this feature while others do not, even though they show the same general morphology and size range.

**Occurrence and Frequency**: Lomas Coloradas and Bajada de Jaguel sections, Upper Maastrichtian interval. (Assemblage interval II). Common to abundant.

### Genus *Florentinia* Davey and Verdier, 1973, p.185-186, emend. Duxbury, 1980, p.119

*Florentinia ferox* (Deflandre) Duxbury, 1980

Plate 12 Fig.1

1937b *Hystrichosphaeridium ferox* Deflandre, p. 72, pl. 14 (al. Pl. 11), figs. 3-4

1964 *Baltisphaeridium ferox* Downie and Sarjeant, p. 90

1969a *Hystrichokolpoma ferox* Davey, p. 159

1976 *Silicisphaera ferox* Davey and Verdir, p. 322

1979 *Florentinia ferox* Duxbury, p.121

**Occurrence and Frequency:** Lomas Coloradas and Bajada de Jaguel sections, Upper Maastrichtian interval (Assemblage interval II). Rare.

### Genus *Glaphyrocysta* Stover and Evitt, 1978, p.49-50.

*Glaphyrocysta* cf. *retiintexta* (Cookson) Stover and Evitt, 1978

Plate 11 Figs. 3,4,6

1965a *Cyclonephelium retiintextum* Cookson, 1965a, p. 88, pl 11, fig. 4

1978 *Glaphyrocysta retiintexta* Stover and Evitt, p. 50

**Comments:** The specimens recovered for this study are not well preserved. However, some of the characteristics mentioned in the original description of the species were observed, especially some interconnections of the processes close to the central body of the cysts. The specimen illustrated on plate 11, Fig. 4 shows short processes and a different distribution with certain indication of paratabulation. As variability in this complex is high, the specimen was provisionally included in this species. Further analyses are needed for a more precise assignment.

**Occurrence and Frequency:** Lomas Coloradas section, basal 10m interval. ?Lower/ Upper Maastrichtian boundary. Abundant.

### *Glaphyrocysta* sp.1

Plate 11 Fig. 8

**Occurrence and Frequency:** Bajada de Jaguel section. Danian interval (Assemblage interval IV). Rare

### *Glaphyrocysta* sp. 2

Plate 11 Fig. 9

**Occurrence and Frequency:** Bajada de Jaguel section. Danian interval. (Assemblage interval IV). Rare to common.

### ?*Glaphyrocysta* sp. 3

Plate 11 Fig. 7

**Comments:** The specimens recovered are tentatively assigned to *Glaphyrocysta.* They show some characteristics of the genus, but the distribution and distal interconnections of the processes are not restricted to the marginal areas. They form a mesh that connects them on the ventral region of the cyst. Central body with one or two lobes present on the antapical region.

**Occurrence and Frequency:** Bajada de Jaguel section. Danian interval (Assemblage interval IV). Rare.

## **Genus** *Glyphanodinium* Drugg, 1964, p.237-238.

### * *Glyphanodinium facetum* Drugg, 1964

*Glyphanodinium facetum* Drugg, 1964, p.238-239, figs.1-6.

**Occurrence and Frequency:** Bajada de Jaguel section. Danian interval. (Assemblage interval IV)

## Genus *Hafniasphaera* Hansen, 1977, p.13-14.

### *Hafniasphaera septata* (Cookson and Eisenack), Hansen 1977

Plate 2 Figs 8-9

1967b *Baltisphaeridium septatum* Cookson and Eisenack, p. 253-254, pl. 42, figs. 6-10; text fig. 1

1970 *Spiniferites septatus* Mclean, p. 730

1977 *Hafniasphaera septata* Hansen, p. 16

**Comments:** This species occurs together with a highly variable population of vesicular-walled spiniferids.

**Occurrence and Frequency:** Bajada de Jaguel section. Danian interval, (Assemblage intervals III and IV).

## Genus *Hystrichokolpoma* Klumpp, 1953, p.388, emend. Williams and Downie, 1966a; emend. Zevenboom and Santarelli in Zevenboom, 1995, p.136.

### *Hystrichokolpoma bulbosum* (Ehrenberg) emend. Morgenroth, 1968

Plate 16 Figs. 1-3

1838 *Xanthidium bulbosum* Ehrenberg, p. 109-136 pl. 1, fig. 17

1933 *Hystrichosphaera bulbosa* Wetzel, p. 40, pl. 4, fig. 15

1937 *Hystrichosphaeridium bulbosum* Deflandre (nov. comb.) p. 22

1971 *Hystrichokolpoma bulbosum* Morgenroth, p. 546

**Occurrence and Frequency:** Bajada de Jaguel section, Danian interval (Assemblage interval IV). Rare.

## Genus *Hystrichosphaeridium* Deflandre, 1937b, p.68. Emend: Davey and Williams, 1966b, p.55-56.

### *Hystrichosphaeridium* sp. 1

Plate 12 Figs. 7-8

**Comments:** a population showing characteristics that can be considered intermediate between *Hystrichosphaeridium* and *Alisocysta* was recovered from the Jaguel Formation. The assignment to *Hystrichosphaeridiun* will be reviewed in further systematic studies.

**Occurrence and Frequency:** Lomas Coloradas and Bajada de Jaguel sections, Upper Maastrichtian interval. (Assemblage interval II). Common to abundant.

### *Hystrichosphaeridium recurvatum* (White) Lejeune-Carpentier, 1940

Plate 3 Fig. 6

1842 *Xanthidium recurvatum* White, p.39, pl.4, fig.12

1940 *Hystrichosphaeridium recurvatum* Lejeune Carpentier, p.B221-B222.

**Occurrence and Frequency:** Bajada de Jaguel section. Danian interval. Rare.

### *Hystrichosphaeridium salpingophorum* (Deflandre) Davey and Willimas 1966b

Plate 3 Figs. 1-2

1934 *Hystrichosphaera salpingophora*, Deflandre, p. 232, pl. 9, fig. 1

1966b *Hystrichosphaeridium salpingophorum* Davey and Williams, p. 61-62

**Occurrence and Frequency:** Bajada de Jaguel section, Uppermost Maastrichtian. Common.

### *Hystrichosphaeridium tubiferum* (Ehrenberg) Deflandre 1937b, emend. Davey and Williams 1966b

Plate 3 Figs 3-5

1838 *Xanthidium tubiferum* Ehrenberg, pl. 1, fig. 16

1933b *Hystrichosphaera tubifera* O. Wetzel, p. 40, pl. 4 fig. 16

1937b *Hystrichosphaeridium tubiferum* Deflandre (nov. comb.) p. 68

**Occurrence and Frequency:** Lomas Coloradas, top of the section. Rare. Bajada de Jaguel section, Danian interval, (Assemblage intervals III-IV). Common.

### .*Hystrichosphaeridim tubiferum* subsp. *brevispinum* (Davey and Williams) Lentin and Williams, 1973

Plate 10 Figs. 5,6,8,9

1966b *Hystrichospaheridium tubiferum* var. *brevispinum* Davey and Williams, p. 58, pl. 10, fig. 10.

1973 *Hystrichosphaeridium tubiferum* subsp. *brevispinum* Lentin and Williams, p. 80

**Occurrence and Frequency**: Bajada de Jaguel section, Danian interval. Rare to common.

## Genus *Hystrichosphaeropsis* Deflandre, 1935, p.232.

### *Hystrichosphaeropsis* sp.

Plate 12 Fig. 6

**Occurrence and Frequency:** A single specimen was recovered in Assemblage Interval III. It is mentioned and illustrated

## Genus *Impletosphaeridium* Morgenroth, 1966a, p.32, emend. Islam, 1993, p.84-85

### *Impletosphaeridium* sp.

Plate 14 Fig. 7

**Comments:** The genus was created to include morphotypes that do not show a clear indication of the archeopyle position or paratabulation. It comprises specimens with spines randomly distributed on the central body.

**Occurrence and Frequency:** Specimens that can be assigned to the genus occur in both, Lomas Coloradas and Bajo de Jaguel sections, Upper Maastrichtian and Danian interval. The assignment at the specific level is not precise. Common to rare, but its presence throughout the section is not continuos.

### Genus *Kleithriasphaeridium* Davey, 1974, p.55-56.

*Kleisthriasphaeridium* sp. 1

Plate 7 Figs. 4-6

**Occurrence and Frequency:** Lomas Coloradas and Bajada de Jaguel sections, Maastrichtian interval. (Assemblage intervals I and II.). Common to abundant.

### Genus *Lanternosphaeridium* Morgenroth, 1966a, p.37. Emend. Stover and Evitt, 1978, p.168.

*?Lanternosphaeridium* sp.

Plate 8 Figs. 1-5 Plate 9 Figs. 1-9

**Comments:** This highly variable population is assigned provisionally to the genus *Lanternosphaeridium*. It shows some similarities with *L. reinhardtii* Moshkovitz and

Habib (1993) but it differs from that species in the presence of a more flattened hypocyst and the different degree of development of the spongy periphragm.

**Occurrence and Frequency**: Bajada de Jaguel section. Danian interval (Assemblage interval III). Abundant.

*Lanternosphaeridium* sp.

Plate 7 Figs. 5 -6

**Occurrence and Frequency:** Bajada de Jaguel section, Danian interval (Assemblage interval IV). Rare.

### Genus *Oligosphaeridium* Davey and Williams, 1966b, p.70-7

*Oligosphaeridium complex* (White) Davey and Williams 1966b

Plate 3 Figs. 7-9

1842 *Xanthidium tubiferum complex* - White, Page 39, Plate 4/3, Fig 11

1946 b *Hystrichosphaeridium complex* - Deflandre, Page 111

1966 b *Oligosphaeridium complex* - Davey and Williams, page 71-74, Plate 7, fig 1-

**Comments**: the general morphology of the specimens recovered coincides with the original description of the species. The size is somewhat smaller and some processes show a distal end similar to *O. pulcherrimum*.

**Occurrence and Frequency**: Bajada de Jaguel section, Danian interval. The species is very common worldwide throughout the Cretaceous. However, it was not recovered from the Maastrichtian interval at Lomas Coloradas and Bajada de Jaguel sections. Its first occurrence is registered from the lowermost Danian. Rare to common.

## Genus *Operculodinium* Wall, 1967, p.110-111. Emend.

Matsuoka et al., 1997, p.22.

### *Operculodinium azcaratei* Troncoso and Doubinger 1980

Plate 5 Figs. 1-3

1980 *Operculodinium azcaratei* Troncoso and Doubinger, p.104-105, pl.2, figs.1-2.

**Comments**: The specimens recovered coincide with the original description by Troncoso and Doubinger. However, they reported the presence of this species in the Danian interval of the El Ganso well, Province of Magallanes, Chile.

**Occurrence**: Upper Maastrichtian, Lomas Coloradas and Bajada de Jaguel sections. Common.

### Oper*culodinium centrocarpum* (Deflandre and Cookson) Wall 1967

Plate 5 Fig. 6

1955 *Hystrichosphaeridium centrocarpum* Deflandre and Cookson, p. 272-273, pl. 8, fig. 3-4

1961 *Baltisphaeridium centrocarpum* Gerlach, p. 192-193

1965 *Cordosphaeridium centrocarpum* de Coninck, p. 33

1966 *Cordosphaeridium tiara* subsp. *centrocarpum* Morgenroth 1966a, p. 26

1967 *Operculodinium centrocarpum* Wall, p. 111

**Comments**: The species is worldwide cited in the literature for the Cenozoic in marine and transitional environments. Marheinecke, 1992, described a new subspecies, *O. centrocarpum* subsp. *novum*, that differs from *O. centrocarpum* subsp *centrocarpum* in the random distribution of processes compared to the type species. However, his illustration on Plate 10, fig. 4 shows orientation of processes roughly reflecting paratabulation.

In this study, *O. centrocarpum* is considered in a broad sense, as it is mentioned in the abundant literature on the species, comprising both, specimens with no orientation at all, or showing some kind of grouping following paraplate boundaries and paracingulum. The material recovered from the section analyzed in this study shows no orientation of processes. The other characteristics coincide with the original description of the species.

**Occurrence and Frequency**: Bajada de Jaguel section. Danian interval. Rare.

### *Operculodinium* sp. 1

Plate 5 Figs. 4-5

**Comments**: The few specimens recovered show the characteristic features of the genus, that is, wall and process structure and precingular archeopyle. The difference consists of the smaller size of the processes relative to the central body size, and the less widened apices, not showing the small hooklets characteristic of the species *O. centrocarpum*

**Occurrence and Frequency**: Bajada de Jaguel section, Danian interval. Rare.

### *Operculodinium* sp.2

Plate 5 Fig. 6

**Comments**: Few speciems of this species were recovered. They show the characteristic wall and process structure of the genus. The size is small and the non tabular spines scatered. The archeopyle is precingular.

**Occurrence and Frequency**: Bajada de Jaguel section. Danian interval. Rare.

## Genus *Senoniasphaera* Clarke and Verdier, 1967, p.61.

### *Senoniasphaera inornata* (Drugg) Stover and Evitt, 1978

Plate 15 Fig. 1

1970b *Chiropteridium inornatum* Drugg, 1970b, p.811-812, figs.3C-F

1978 *Senoniasphaera inornata* Stover and Evitt, p. 80

**Comments:** Specimens recovered in the Jaguel formation are represented by a highly variable population, with transitional morphotypes with a marginal development of a periphragm supported by pillarlike structures, to a complete development of this wall layer to form a pericoel. The morphotype with incomplete periphragm fisrt occurr at the base of the danian interval, while the morphotypes showing complete pericoel occur more frequently from the 5m interval above the boundary layer. *S. inornata* is considered a marker for the Danian but the morphological interpretation of the population recovered in the Jaguel Formation require further analysis to clearly establish the limits of variability and possible assignment to more than one species.

**Occurrence and Frequency:** Bajada de Jaguel section. Danian interval. Considering this population in a broad sense, it is present from the lowermost Danian (Assemblage intervals III and IV). Rare to common.

### Genus *Spiniferella* (Gerlach, 1961, pl.27, figs.10-12), Stover and Hardenbol, 1994, p.38-39.

*Spiniferella cornuta* (Gerlach) Stover and Hardenbol, 1994

Plate 2 Fig.1

1961 *Hystrichosphaera cornuta* Gerlach, pl. 27, figs. 10-12

1970 *Spiniferites cornutus* Sarjeant, p. 76

1994 *Spiniferella cornuta* Stover and Hardenbol, p. 38-39

**Comments:** The species was created on the basis of material recovered from Oligocene sediments. In later publications it became common place to assign to *Spiniferites cornutus* any spiniferid morphotype with a long apical horn. The species was subdivided into subspecies and tranferred to a new genus, *Spiniferella*, by Stover and Hardenbol. The illustration of the type species shows differences with the material recovered from the Jaguel Formation. It compares well with Maastrichtian and Danian specimens registered in Europe, USA and Antarctica. This morphotype requires further analysis. It is provisionally assigned to *S. cornuta* in a broad sense.

**Occurrence and Frequency:** Bajada de Jaguel section. Danian interval (Assemblage intervals III and IV). Rare to common.

## Genus *Spiniferites* Mantell, 1850, p.191. emend.

Sarjeant, 1970, p.75

### *Spiniferites ramosus* subsp. *granosus* (Davey and Williams) Lentin and Williams, 1973

Plate 1 Fig. 1

1966a *Hystrichosphaera ramosa* var. *granosa* Davey and Williams, 1966a, p 37-38 pl. 4, fig 4.

1973 *Spiniferites ramosus* var. *granosus* Corradini, 1973, p 167.

1973 *Spiniferites ramosus* subsp. *granosus* Lentin and Williams, p 130.

**Occurrence and Frequency:** Lomas Coloradas Section. Upper Maastrichtian. Rare.

### *Spiniferites ramosus* subsp. *maeandriformis* (Corradini) Lentin and Williams 1975

Plate 1 Fig. 6

1973 *Spiniferites ramosus* var. *maeandriformis* Corradini, p.168-169, pl.26, figs.11-12)

1975 *Spiniferites ramosus* subsp. *maeandriformis*.Lentin and Williams p.2155.

**Occurrence and Frequency:** Bajada de Jaguel section. Uppermost Maastrichtian (top of Assemblage interval II). Rare to common.

### *Spiniferites* sp. 1

Plate 1 Fig. 2-3

**Occurrence and Frequency:** Bajada de Jaguel section. Uppermost Maastrichtian interval.

### *Spiniferites wetzelii* (Deflandre) Sarjeant 1970

Plate 1 Fig. 9

1937b *Hystrichosphaera wetzelii* Deflandre p. 65, Pl. 11

1971 *Spiniferites wetzelii* Sarjeant p. 77

**Comments**: Transfer to *Rotnessia* by Slimani (1994) is not followed in this study.

**Occurrence and Frequency**: Assemblage interval II. Uppermost Maastrichtian. Rare to common

*Spiniferites* sp. 2

Plate 1 Fig. 6-7

**Occurrence and Frequency:** Bajada de Jaguel section. uppermost Maastrichtian interval. All the illustrated and other morphotypes of the *Spiniferites/ Achomosphaera* group are abundant components of the uppermost Maastrichtian.

### Genus *Spongodinium* Deflandre, 1936b, p.169-170. Emend. Stover and Evitt, 1978, p.191-192; Lucas-Clark, 1987, p.166

*Spongodinium* cf. *delitiense* (Ehrenberg) Deflandre 1936b, emend. Lucas Clark, 1987

Plate 14 Figs. 1-2

1938 *Peridinium delitiense* Ehrenberg, p. 110, pl. 1, figs. 1-6

1936b *Spongodinium delitiense* Deflandre, p. 170-171

**Comments:** This is the first time that a species of the genus *Spongodinium* is registered for South America. Many of the species illustrated for the Northern Hemisphere differ from the material recovered in the Jaguel formation in the type of spongy periphragm that they show. Until more comparisons can be made, the few specimens considered in this study are provisionally assigned to *S.* cf. *delitiense.*

**Occurrence and Frequency:** Lomas Coloradas section. Upper Maastrichtian Assemblage interval II. Restricted to sample LC31. Rare.

### Genus *Tanyosphaeridium* Davey and Williams, 1966b, p.98.

*Tanyosphaeridium xanthiopyxides* (O. Wetzel) Stover and Evitt, 1978, emend. Morgenroth, 1968; emend. Sarjeant 1985b

Plate 12 Fig.3

1933b *Hystrichosphaera xanthiopyxides* O. Wetzel, p. 44-45, pl. 4, fig. 25

1965 *Baltisphaeridium xanthiopyxides* Downie and Sarjeant, p. 98

1969 *Prolixosphaeridium ? xanthiopyxides* Davey et al., p. 17

1979 *Tanyosphaeridium xanthiopyxides* Stover and Evitt, p. 85

**Occurrence and Frequency:** Bajada de Jaguel section. Very rarely found in the uppermost Maastrichtian. Rare in the Danian interval.

### Genus *Trigonopyxidia* Cookson and Eisenack, 1961a, p.75.

*Trigonopyxidia ginella* (Cookson and Eisenack) Downie and Sarjeant, 1965

Plate 14 Fig. 6

1960a *Trigonopyxis ginella* Cookson and Eisenack p. 11, pl. 3, Figs. 18-20

1965 *Trigonopyxidia ginella* Downie and Sarjeant, p. 149

**Occurrence and Frequency:** Lomas Coloradas and Bajo de Jaguel sections. Upper Maastrichtian and Danian. Rare.

## Genus *Turbiosphaera* Archangelsky, 1969a, p.408.

### *Turbiosphaera filosa* (Wilson) Archangelsky

1967a *Cordosphaeridium filosum* Wilson, p.66, figs. figs.2b,31-32,34

1969a *Turbiosphaera filosa* Archangelsky, 1969a, p.408-411.

**Occurrence and Frequency:** Lomas Coloradas and Bajada de Jaguel sections. Maastrichtian and Danian intervals. Common to rare.

## Order PERIDINIALES Haeckel 1894

## Genus *Alterbidinium*

### cf. *Alterbidinim* sp.

Plate 19 Fig. 6

**Comments:** Small peridiniod cysts that show characteristic that resemble some illustrated morphotypes referred to *Alterbidinium acutulum.* Not deformed specimens resemble the genus *Diconodinium.*Until further comparison can be made, the specimens recovered in this study are provisionally documented as cf. *Alterbidinium* sp.

**Occurrence and Frequency:** Bajada de Jaguel section. Uppermost Maastrichtian (Top of Assemblage interval II). Common.

## GENUS *Cerodinium* Vozzhennikova, 1963, p.181, emend.

Lentin and Williams, 1987, p.114.

### *Cerodinium leptodermum* (Vozzhennikova) Lentin and Williams 1987

Plate 21 Fig.6,9

1963 *Ceratiopsis leptoderma* Vozzhennikova, p. 181, text-fig. 8

1976 *Deflandrea leptoderma* Lentin and Williams, p. 41.

1987 *Cerodinium leptodermun* Lentin and Williams, 1987, p.114.

**Occurrence and Frequency:** Bajada de Jaguel section. Very rare in the upper Maastrichtian interval. It becomes abundant in the Danian.Assemblage interval IV.

*Cerodinium* sp. cf. *C. diebelii*

Plate 21 Fig. 10

1959a *Deflandrea diebelii* Alberti, p. 99-100, pl. 9, figs. 18-21

1967 *Ceratiopsis diebelii* Vozzhennikova, p. 159

1987 *Cerodinium diebelii* Lentin and Williams, p. 114

**Occurrence and Frequency:** Bajada de Jaguel section. Uppermost Maastrichtian interval. Very rare.

### Genus *Deflandrea* Eisenack, 1938b, p.187, emend. Williams and Downie, 1966c, p.231; Stover, 1974, p.169-170; Lentin and Williams, 1976, p.35-36.

*Deflandrea galeata* (Lejeune-Carpentier) Lentin and Williams, 1973

Plate 17 Figs. 1-5

1942 *Peridinium galeatum* Lejeune-Carpentier, p.B186-B188, figs.15-20

1973 *Deflandrea galeata* Lentin and Williams, p. 41

**Occurrence and Frequency:** *Deflandrea galeata* is considered to be a marker for the initiation of the Upper Maastrichtian. In the Jaguel Formation it first occurs in the Lomas Coloradas section (Assemblage interval II). It is also present in the Bajada de Jaguel section, Maastrichtian interval. *D. galeata* has been found in many locations in the Northern Hemisphere and it is a potential guide fossil for regional correlation.

*Deflandrea* sp. 1

Plate 19 Fig 9

**Occurrence and Frequency:** Bajada de Jaguel section. Danian interval. Retricted to sample BJ6. Single specimen.

*Deflandrea* sp.2

Plate 20 Figs. 1-2

**Comments:** Mostly endocysts with wide intercalary archeopyle.

Few speciemens showing a very fine pericyst.

**Occurrence and Frequency:** Bajada de Jaguel section. Uppermost Maastrichtian. Top of Assemblage interval II. Common.

*Deflandrea* sp. 3

Plate 20 Figs. 1-2

**Occurrence and Frequency:** Bajada de Jaguel section. Danian interval. Restricted to sample BJ5. Single specimen.

### *Deflandrea* sp. 4

Plate 20 Fig.4

**Occurrence and Frequency**: Lomas Coloradas section. Sample LC29. Single specimen.

### ?*Deflandrea* sp.

Plate 18 Figs. 1-2

**Occurrence and Frequency:** Bajada de Jaguel section. Danian interval. Rare.

### Gen. et sp. indet 3

Plate 18 Figs. 7-9 Fig.

**Comments:** Peridiniod cyst with a granular wall. Apical horn well developed. Left antapical horn present, right horn absent or vestigial. Intercalary archeopyle. A relatively similar morphotype was illustrated in Zaitzeff and Cross (1970) as *Deflandrea* sp. 4 from the Maastrichtian of Texas. Further analyses are required to assign this morphotype at the generic and specific level.

**Occurrence and Fequency:** Lomas Coloradas section. Maastrichtian interval (Assemblage interval I). Rare.

## Genus *Isabelidinium*, Lentin and Williams, 1977a, p.167, emend. N.G. Marshall, 1988, p.203, 205.

### *Isabelidinium* sp.

Plate 19 Fig. 1-5

**Comments:** A highly variable population showing characteristics of both genera, *Isabelidinium* and *Manumiella*, was recovered from the upermost Maastrichtian interval of the Bajada de Jaguel section. Some specimens resemble *Manumiella seelandica*, but further studies are required to clearly establish the systematic position of this group. For the purpose of this study, the specimens are considered as *Isabelidinium* sp. and the variable characteristics are illustrated on the corresponding plate.

**Occurrence and Frequency:** Bajada de Jaguel section. Uppermost Maastrichtian 1m interval. Very abundant in sample M10.

### Genus *Palaeocystodinium* Alberti, 1961, p.20.

*Palaaeocystodinium* sp. 1

Plate 20 Fig. 7

**Comments:** A single specimen of this morphotype was recovered in sample LC 35, base of the Lomas Coloradas section, Lower/?Upper Maastrichtian boundary. It differs from the other species of the genus in the Jaguel Fm. in the very short development of apical and antapical horns, and the presence of a vestigial second antapical horn.

**Occurrence and Frequency**: Base of Lomas Coloradas section. ? Upper Maastrichtian. Single specimen. Sample LC 35

*Palaeocystodinium australinum* (Cookson) Lentin and Williams, 1976, emend Malloy, 1972 (as *Svalbardella australina*)

Plate 20 Figs. 4,8

1956b *Svalbardella australina*, Cookson, p.140, pl. 25, figs.1-4

1976 *Palaeocystodinium australinum*, Lentin and Williams, p.89

**Occurrence and Frequency**: Lomas Coloradas and Bajada de Jaguel sections, both Upper Maastrichtian and Danian intervals. Common.

### *Palaeocystodinium golzowense* Alberti, 1961

1961 *Palaeocystodinium golzowense* Alberti, p.20, pl.7, figs.10-12; pl.12, fig.16.

Plate 20 Fig. 3

**Occurrence and Frequency:** Lomas Coloradas and Bajada de Jaguel sections, both Upper Maastrichtian and Danian intervals. Common.

## Genus *Phelodinium* Stover and Evitt, 1978, p.117-118. Emend. Mao Shaozhi and Norris, 1988, p.51-52.

### *Phelodinium magnificum* (Stanley) Stover and Evitt, 1978, p.118.

Plate 20 Figs. 1-2

1965 *Deflandrea magnifica* Stanley, p. 218-219, pl. 20, figs. 1-6

1976 *Lejeunia magnifica* Lentin and Williams, p.71

1977 *Senegalinium magnificum* Harland, 1977a, p. 188

1978 *Lejeunecysta magnifica* Artzner and Dorhofer, p. 1381

1978 *Phelodinium magnificum* Stover and Evitt, 1978, p. 118

**Comments:** Specimens assigned to *Ph. magnificum* in this study show some morphological differences. As to the present, those differences were not enough to consider them as two separate taxa. A fact that can lead to separate them in future analyses is the stratigraphic gap between its occurrences. The younger form shows a stronger and finely denticulate paracingulum. This characteristic is not mentioned in the original description of the species.

**Occurrence and frequency**: Lomas Coloradas section, Upper Maastrichtian Assemblage interval I. Bajada de Jaguel section, Danian interval. (Acme in sample BJ5). Rare to common.

### Genus *Pierceites* Habib and Drugg, 1987, p.761.

*Pierceites pentagonus* (May) Habib and Drugg 1987

Plate 20 Fig. 6

1979 *Trithyrodinium pentagonum* May, 1980, p.87-88, pl.10, figs.13-14

1987 *Pierceites pentagonus* Habib and Drugg, p. 762

**Occurrence and Frequency:** Lomas Coloradas and Bajada de Jaguel section. Uppermost Mastrichtian and Danian. Rare.

### Genus *Senegalinium* Jain and Millepied, 1973, p.22-23. Emend. Stover and Evitt, 1978, p.122-123.

*Senegalinium obscurum* (Drugg) Stover and Evitt, 1978

Plate 19 Figs. 7-8

1966 *Deflandrea obscura* Drugg, p.17, pl.2, figs.8-9; pl.9, fig.5

1976 *Alterbia obscura* Lentin and Williams, p. 129, Fig 7

1979 *Senegalinium obscurum* Stover and Evitt, 1978, p.123

**Occurrence and Frequency:** Bajada de Jaguel section. Maastrichtian and Danian intervals. Specimens of this morphotype are rarely present in the Maastrichtian, but dramatically increase in relative abundance shortly after the K/Plg. boundary event.

### Genus *Trithyrodinium* Drugg, 1967, p.20. Emend. Davey, 1969b, p.10; Lentin and Williams, 1976, p.98-100; Marheinecke, 1992, p.94-95.

*Trithyrodinium evittii* Drugg, 1967

Plate 20 Figs. 7-9

1967 *Trythyrodinium evittii* Drugg, p.20, pl.3, figs.2-3; pl.9, fig.2.

**Occurrence and Frequency:** Bajada de Jaguel section. Danian interval. Assemblage intervals III and IV. Common. The species is known from the Northern Hemisphere to first occur in the Maastrichtian. In the Southern Hemisphere, it is a marker for the Lower Danian in New Zealand (Wilson et al., 1988), Antarctica (Askin, 1988). and Neuquén (Palamarczuk et al, 1997, 2001, 2002).

*Trithyrodinium* sp. 1

Plate 20 Fig. 5

**Comments:** Few specimens of this morphotype were recovered. They have a strong endocyst and a very fine pericyst and normally the three opercular pieces are in place.

**Occurrence and Frequency:** Lomas Coloradas section. ?Lower/Upper Maastrichtian boundary (Assemblage interval I). Rare.

### Genus *Vozzhennikovia* Lentin and Williams, 1976, p.65-66.

*Vozzhennikovia* sp.1

Plate 18 Fig.4-6

**Comments:** A highly variable population of peridiniod cysts assigned to *Vozzhennikovia* sp. occur in the bottom 10m of the Lomas Coloradas section. The cysts have spines randomly distributed on the cyst body. The antapical horns are variable in size. The specimens show almost no development to one or two well developed horns. The population is restricted to two stratigraphic levels probably this distribution being related to transitional environmental conditions at the beginning of the transgression.

**Occurrence and Frequency:** Lomas Coloradas section. 10m lowermost interval of the section. ?Lower Maastrichtian/Upper Maastrichtian. (base of Assemblage interval I) Common to abundant.

## Order GYMNODINIALES Apstein 1909

### Genus *Dinogymnium* Evitt et al., 1967, p.4-8. Emend. Lentin and Vozzhennikova, 1990, p.14.

*Dinogymnium acuminatum* Evitt et al., 1967

Plate 14 Figs.8-9

1967 *Dinogymnium acuminatum* Evitt, p. 8., plts. 1-2; pl. 3, Figs. 1-8, 10, 12, 20; text figs. 11-23

**Occurrence and Frequency:** Lomas Coloradas section. Restricted to level LC 33. ?Lower/ Upper Maastrichtian boundary. (Assemblage Interval I). Rare.

## Division Chlorophyta Pascher 1914

## Class Chlorophyceae Kutzing 1843

### Genus *Palambages* O. Wetzel 1961. Emend Gocht and Wille 1972

*Palambages* spp.

Plate 23 Figs. 2-6

**Comments:** Different authors refer to this group of colonial algae under different specific names, both formal and informal. For the purpose of this study, they are grouped under *Palambages* spp, even though the colonies known in the bibliography as Form B of Manum and Cookson and illustrated on plate 23, Figs. 4-6., were documented only from the Danian deposits. Probably they represent different species and the interpretation by Gocht and Wille (1972), who grouped most of them as *Palambages morulosa* should be reviewed.

**Occurrence and Frequency:** Algal colonies of the genus *Palambages* are frequent components of the Maastrichtian intervals in both sections, Bajo de Jaguel and Lomas Coloradas. The relative abundance increase markedly in the Danian interval of Bajo de Jaguel section. Those forms that can be compared to the mentioned *Palambages* Form B, first occur in the lowermost Danian.

On plate 23, fig. 1, a colony of uncertain affinity is illustrated. It is present in both, the Maastrichtian and Danian intervals in the Bajada de Jaguel section. Common.

## Class Prasinophyceae Round, 1971

### Genus *Cymatiosphaera*

*Cymatiosphaera* sp.

Plate 22 Fig. 8

**Occurrence and Frequency:** Lomas Coloradas section. ?Lower/ Upper Maastrichtian boundary. Recovered only from sample LC33. Rare.

### Genus *Pterospermella* Eisenack 1972

*Pterospermella australiensis* (Deflandre and Cookson 1955) Eisenack 1972

Plate 22 Fig.3

**Occurrence and Frequency:** Lomas Coloradas section. Restricted to the Basal 10m interval of the Jaguel Formation. ?Lower/ Upper Maastrichtian boundary. Abundant to very abundant.

*Pterospermella* sp.1

Plate 22 Fig. 4

**Occurrence and Frequency:** Lomas Coloradas section. Recovered only from sample

## Algae incertae sedis

## Group Acritarcha Evitt 1963

### Genus *Epicephalopyxis* Deflandre 1937bp.92

cf. *Epicephalopyxis adhaerens* Deflandre, 1937b

Plate 22 Fig. 7

1937b *Epicephalopyxis adhaerens* Deflandre, p. 92-93, pl. 18, figs. 4-7

**Occurrence and Frequency:** Lomas Coloradas section. Upper Maastrichtian. Very abundant in Sample LC28.

### Genus *Micrhystridium* Deflandre 1937b. emend Staplin 1961

*Micrhystridium* spp.

Plate 22 Figs. 2-5

**Occurrence and Frequency:** Bajada de Jaguel section. Very rarely, specimens of this group were recovered from the Maastrichtian interval. They peak in the Danian interval (Assemblage interval III) and become again very rare in the Assemblage interval IV.

# CONCLUSIONS

This work focuses on organic-walled microfossils contained in Maastrichtian-Danian sediments of the Late Cretaceous Neuquén Basin of Argentina, and involves a detailed investigation of the palynology of the Jaguel Formation, which is a prominent member of the Late Cretaceous stratigraphic record of the Neuquén area. The main results of this study are as follows:

Dinoflagellate cysts and other organic-walled microfossils are abundant and well preserved in the two exposures of the Jaguel Formation, Lomas Coloradas and Bajada de Jaguel, analyzed in this study. The analysis of these microfossils provides valuable biostratigraphic information that shows that the Jaguel Formation was deposited in the Early-Late Maastrichtian/Danian. Many species recovered are described for the first time from the Neuquén Basin; some appear to be new to science altogether, although no formal designation of them is attempted here.

The first appearance of species throughout the Jaguel Formation was used to divide the interval into four informal assemblage intervals designated I to IV from bottom to top and, on the basis of species occurring in common at the two study localities. A tentative correlation of the two sections on the basis of the organic-walled microplankton content was proposed in which the top of the Lomas Coloradas section is viewed as roughly equivalent to the lower part of the section at Bajada de Jaguel.

A turnover in the composition of the organic-walled microfossil assemblages registered at the Bajada de Jaguel section was investigated in detail and was interpreted to represent the Cretaceous/Paleocene boundary on the basis of first appearance of worldwide Danian markers, such as *Damassadinium californicum* and morphotypes related to *Senoniasphaera inornata.* The biostratigraphic boundary identified on the basis of the organic-walled microplankton was confirmed by studies of planktonic foraminifers recovered from the same samples. The biostratigraphic boundary defined by both dinoflagellates and foraminifera was found to coincide with the bottom of a 17cm thick water-lain volcanic ash layer. This ash layer represents the lithologic Cretaceous-Paleogene boundary in the Neuquén Basin. Radiometric dating of a sanidine crystal taken from the ash layer gives an age of 65.97+/-0.19 Ma, which is considered to lie within the range accepted for the K/Pl boundary.

The depositional environment of the of the Jaguel Formation fluctuates from transitional/ near shore marine to inner/outer neritic. The response of the microfossil group considered in this study across the K/Pl boundary coincides, in general terms, with the conclusion of other authors that the K/Pl boundary is not marked by a mass extinction of dinoflagellates, although some lineages do disappear. This is probably due to the fact that the dinoflagellates preserved in the fossil record are cysts. The encysted stage is probably more resistant, and it is possible that cysts helped dinoflagellates survive short-term intervals of inclement environmental conditions.

The detailed study of the changes in dinoflagellate assemblages across the boundary done in this study, show that there was a local disappearance of many species of gonyaulacacean cysts, *Spiniferites* spp in particular, whereas the peridinealean cyst species did not suffer many losses. Extinctions and migrations occur at the boundary and the Danian is characterized by first appearances of many species. In particular, a short term bioevent, similarly registered in other regions of the world, and consisting of the first appearance, peak and disappearance of cysts assigned to *Isabelidinium* sp, morphologically resembling *Manumiella seelandica*, was interpreted as the result of regression and /or a short term water cooling episode.

An unusual abundance of cysts of colonial algae and peaks of the acritarch *Micrhystridium* spp., together with other micro-organisms of uncertain affinity, in the 2m interval above the boundary is attributed to a period of stressed environmental conditions that affected organic-walled marine assemblages above the K/Plg boundary.

The observations made across the boundary in the Bajada de Jaguel section do not suffice to clearly support, in particular, any of the proposed hypotheses that attempt to explain the mass extinction that affected many organisms at this crucial time in the history of life. However, the evidence does point to a short term episode across the boundary that can be attributed to a multiple scenario of local volcanism, global regression prior to the boundary event, and effects on the biota of a decrease of sun light, possibly as a consequence of an impact and/or related to the effects on the atmosphere of the outpouring of the Deccan Traps. The evidence from the Neuquén record, as recorded in the dinoflagellates of the Jaguel Formation, best supports the idea of an extinction event produced by multiple interacting agents.

# POSSIBLE FUTURE STUDIES

The present study opens the possibility for future analyses, and suggests how future work ought to proceed. It is well known that, as a consequence of impacts, enrichment of the element iridium and the presence of shocked quartz, together with spherules, occur in other sections containing the K/Pl boundary. It would be important, for a better understanding of the K/Pl boundary event in the Neuquén Basin of Argentina, to investigate the presence of those impact indicators in the section considered in this study. This would determine whether the Neuquén K/Pl boundary layer has a strong geochemical and mineralogical component, and lend support to the definition of the boundary based on the palynologic evidence discussed here.

The inferred cooling episode of the ocean water occurring in the Neuquén Basin shortly before the deposition of the boundary layer could be corroborated by studies of oxygen isotopes taken from rock specimens and microfossils of the Jaguel Formation. This would be particularly valuable in establishing the role of global climate change in producing the faunal and floral transitions for which the K/Pl boundary is so widely known.

Another avenue for future work is a more complete systematic treatment and formal taxonomic description of those dinoflagellate cysts recovered in this study, which are new to science. This level of analysis was not attempted here, but remains to be completed. This work will prove especially useful in furthering research on the biogeographic distribution of Late Cretaceous dinoflagellates in the Southern

# Appendix 1

List of marine taxa considered in this study in alphabetical order

## Dinoflagellate Cysts

| | |
|---|---|
| *Achomosphaera ramulifera* (Deflandre) Evitt 1963 | Plate 1, fig. 8 |
| *Alisocysta circumtabulata* (Drugg) Stover and Evitt, 1978 | Plate 10, figs. 1-4 |
| *Alisocysta* sp | Plate 10, fig. 7 |
| ? cf. *Alterbidinium* sp | Plate 19, fig. 6 |
| ?*Andalusiella* sp | Plate 21, fig. 4 |
| *Areoligera senonensis* Lejeune-Carpentier, 1938a | Plate 11, figs, 1-2 |
| *Caligodinium aceras* (Manum and Cookson) Lentin and Williams,1973 | Plate 22, fig, 6 |
| *Cannosphaeropsis* cf. *utinensis* | Plate 12, fig. 2 |
| * *Carpatella* sp. cf. *C. cornuta* Grigorovich, 1969a | |
| *Cerodinium* sp. cf. *C. diebelii* (Alberti) Lentin and Williams, 1987 | Plate 21, fig. 10 |
| *Cerodinium leptodermum* (Vozzhennikova) Lentin and Williams, 1987 | Plate 21, figs 6, 9 |
| *Cordosphaeridium exilimurum* Davey and Williams, 1966b | Plate 4, figs, 1,2,4, 5 |
| *Cordosphaeridium inodes* (Klumpp) Eisenack, 1963, emend. Morgenroth, 1968 | Plate 4, figs, 3, 6 |

*Cordosphaeridium inodes* subsp. *longipes* Hansen, 1977...............Plate 7, figs. 1,2,3,4;

and Plate 8, figs. 7-8

*"Cordosphaeridium" ? lemniscatum"* Corradini, 1978......................Plate 4, figs. 7-9

? *Cordosphaeridium* sp. ..........................................................Plate 12, fig. 9

*Coronifera oceanica* (Cookson and Eisenack)

Davey, 1969........................................................................Plate 16, figs. 5-6

*Cribroperidinium wetzelii* (Lejeune-Carpentier)

Helenes, 1984......................................................................Plate 12, figs. 4-5

*Cyclapophysis monmouthensis* Benson, 1976...............................Plate 13, figs. 1-3

*Damassadinium californicum* (Drugg)

Fensome et al., 1993b..............................................Plate 8, fig.6. Plate 13 fig. 4

? *Deflandrea* sp...................................................................Plate 18, figs. 1-2

*Deflandrea galeata* (Lejeune-Carpentier)

Lentin and Williams, 1973.....................................................Plate 17, figs. 1-5

*Deflandrea* sp. 1..................................................................Plate 20, figs. 1-2

*Deflandrea* sp. 2......................................................................Plate 20, fig. 3

*Deflandrea* cf. *pentaradiata*

Cookson and Eisenack, 1965c....................................................Plate 19, fig. 9

*Dinogymnium acuminatum* Evitt et al. 1967.................................Plate 14, figs 8-9

*Dinopterigium cladoides* Deflandre, 1935..................................Plate 14, figs. 3, 5

*Dyphies colligerum* (Deflandre and Cookson)

Davey and Williams, 1966......................................................Plate 16, figs. 7-9

*Exochosphaeridium* cf. *bifidum* (Clark and Verdier) Clark et al.,

emend. Davey, 1969b ........................................................Plate 13, figs. 7-9

* *Fibradinium annetorpense* Morgenroth 1968

*Fibrocysta cf. vectensis* (Eaton) Stover and Evitt, 1978 ..............Plate 6, figs. 1-3, 6, 9

*Florentinia ferox* (Deflandre) Duxbury, 1980 ................................Plate 12, fig. 1

Gen et sp. indet 1..................................................................Plate 13, fig. 5

Gen et sp. indet. 2..................................................................Plate 13, fig. 6

Gen et sp. indet 3...............................................................Plate 18, figs. 7-9

*Glaphyrocysta retiintexta* (Cookson) Stover and Evitt, 1978..............Plate 11, figs. 3, 6

?*Glaphyrocysta* sp............................................................Plate 11, fig. 5, 7

*Glaphyrocysta* sp. 1..............................................................Plate 11, fig. 4

*Glaphyrocysta* sp.2..............................................................Plate 11, fig. 8

*Glaphyrocysta* sp.3..............................................................Plate 11, fig. 9

* *Glyphanodinium facetum Drugg 1964*

*Hafniasphaera septata* (Cookson and Eisenack)

Hansen 1977.........................................................................Plate 2, figs. 8-9

? *Hafniasphaera* sp.1..............................................................Plate 2, fig. 4

*Hafniasphaera* sp. 2 ..............................................................Plate 2, fig. 7

*Hystrichokolpoma bulbosum* (Ehrenberg) Morgenroth, 1968...............Plate 16, fig. 1-4

cf. *Hystrichosphaeridium* sp. ..................................................Plate 12, figs. 7-8

*Hystrichosphaeridium salpingophorum* Deflandre, 1935,

emend. Davey and Williams, 1966b .......................................Plate 3, figs. 1, 2

*Hystrichosphaeridium tubiferum* (Ehrenberg)

Davey and Williams, 1966b.................................................Plate 3, figs. 3, 4, 5

*Hystrichosphaeridium tubiferum* subsp. *brevispinum* (Davey and Williams)

Lentin and Williams ......................................... ......Plate 10, figs. 5, 6, 8, 9

*Hystrichosphaeropsis* sp...........................................................Plate 12, fig. 6

*Impletosphaeridium* sp...........................................................Plate 14, fig. 7

*Isabelidinium* sp..................................................................Plate 19, figs. 1-5

*Kleithriasphaeridium* sp......................................................Plate 7, figs. 7, 8, 9

*Lanternosphaeridium* sp. 1...................................................Plate 7, figs. 5, 6

?*Lanternosphaeridium* sp...................................Plate 8, figs. 1-5. Plate 9 figs. 1-9

* *Microdinium* spp.

*Oligosphaeridium complex* (White)

Davey and Williams, 1966b........................................... ....Plate 3, figs. 7, 8, 9

*Operculodinium azcaratei* Troncoso and Doubinger, 1980...................Plate 5, figs. 1-3

*Operculodinium centrocarpum* (Deflandre and Cookson)

Wall, 1967.............................................................................Plate 5, fig. 7

*Operculodinium* sp. 1...........................................................Plate 5, figs. 4, 5

*Operculodinium* sp.2..............................................................Plate 5, fig. 6

*Palaeocystodinium australinum* (Cookson)

Lentin and Williams, 1976.....................................................Plate 21, figs. 4-8

*Palaeocystodinium golzowense* Alberti, 1961.................................Plate 21, fig. 3

*Palaeocystodinium* sp.............................................................Plate 2, fig. 7

*Phelodinium magnificum* (Stanley) Stover and Evitt, 1978..................Plate 2, figs. 1-2

*Pierceites pentagonus* (May) Habib and Drugg, 1987.........................Plate 20, fig. 6

?*Pterodinium* sp. 1..................................................................Plate 1, figs. 4-5

*Senegalinium obscurum* (Drugg) Stover and Evitt, 1978..................Plate 19, figs. 7-8

*Senoniasphaera inornata* (Drugg) Stover and Evitt, 1978...................Plate 15, fig. 1

*Spiniferella cornuta* subsp. *laevimura* (Davey and Williams)

Williams, Lentin and Fensome, 1998................................................Plate 2, fig. 1

*Spiniferites ramosus* subsp. *granosus* (Davey and Williams)

Lentin and Williams, 1993..........................................................Plate 1, fig. 1

*Spiniferites ramosus* subsp. *maeandriformis* (Corradini)

Lentin and Williams, 1975..........................................................Plate 1, fig. 6

*Spiniferites* sp. 1 ................................................................Plate 1, figs 2-3, 5

*Spiniferites* sp. 2...................................................................Plate 1, fig. 7

*Spiniferites* sp. 3................................................................Plate 2, figs. 2, 3, 5

*Spiniferites* sp. 4 ..................................................................Plate 2, fig. 6

*Spiniferites wetzelii* (Deflandre) Sarjeant 1970.............................. Plate 1, fig. 9

*Spongodinium* aff. *delitiensis* (Ehrenberg) Deflandre 1936b,

emend. Lucas-Clark, 1987.......................................................Plate 14, figs. 1-2

*Tanyosphaeridium xanthiopyxides* (Wetzel)

Stover and Evitt, 1978......................................................... ....Plate 12, fig. 3

*Trigonopyxidia ginella* (Cookson and Eisenack)

Downie and Sarjeant, 1965.....................................................Plate 14, fig. 6

*Trithyrodinium evittii* Drugg...................................................Plate 20, figs. 7-9

## Other organic walled microfossils

## Acritarchs

### Chlorophyceae

### Prasinophyceae

### Uncertain affinitty

* Indicates species or morphotypes not illustrated.

# Appendix 2

## Table I

## Lomas Coloradas Section (sampling intervals)

| **Samples** | **Interval** |
|---|---|
| LC26 | |
| | 40m |
| LC27 | |
| | 4m |
| LC28 | |
| | 4m |
| LC29 | |
| | 5m |
| LC30 | |
| | 10m |
| LC31 | |
| | 6m |
| LC32 | |
| | 11m |
| LC33 | |
| | 4m |
| LC34 | |
| | 4m |
| LC35 | |

# Table II

## Sample intervals in the Bajada de Jaguel Section (first stage of sampling)

| Samples | Interval |
|---|---|
| BJ4 | |
| | 4m |
| BJ5 | |
| | 5m |
| BJ6 | |
| | 3.5m |
| BJ7 | |
| | 4m |
| BJ8 | |
| | 3.5m |
| BJ9 | |
| | 3m |
| BJ10 | |
| | 3.5m |
| BJ11 | |
| | 1.5m |
| BJ12 | |

## Table III

## Bajada de Jaguel section (second stage of sampling)

| Samples | Interval |
|---|---|
| M1 | |
| | 1.35m |
| M2 | |
| | 0.65m |
| M3 | |
| | 0.30m |
| M4 | |
| | 0.60m |
| M5 | |
| | 0.20m |
| M6 | |
| | 0.15m |
| M7 | |
| | 0.22m |
| M8 | |
| | 0.18m |
| **M9** | |
| | 0.20m |
| M10 | |
| | 0.42m |
| M11 | |
| | 0.50m |
| M12 | |
| | 0.27m |
| M13 | |
| | 0.25m |
| M14 | |
| | 0.30m |
| M15 | |
| | 0.25m |
| M16 | |
| | 0.50m |

## Table IV

## Bajada de Jaguel section (third stage of sampling)

| **Samples** | **Interval** |
|---|---|
| BJ35 | |
| | 0.20m |
| BJ34 | |
| | 0.10m |
| BJ32 | |
| | 0.12m |
| BJ30 | |
| | 0.05m |
| BJ29 | |
| | 0.05m |
| BJ28 | |
| | 0.05m |
| BJ27 | |
| | 0.05m |
| BJ26 | |
| | 0.05m |
| BJ25 | |
| | 0.07m |
| BJ24 | |
| | 0.06m |
| BJ23 | |
| | 0.05m |
| BJ22 | |
| | 0.06m |
| BJ21 | |

# Appendix 3

## Slide Numbers

### Lomas Coloradas Section

| Number | Slide |
|---|---|
| 1 | LC25 1 +25 |
| 2 | LC25 2 +25 |
| 3 | LC25 3 +25 |
| 4 | LC26 1 +25 |
| 5 | LC26 2 +25 |
| 6 | LC26 3 +25 |
| 7 | LC27 1 +25 |
| 8 | LC27 2 +25 |
| 9 | LC27 3 +25 |
| 10 | LC28 1 +25 |
| 11 | LC28 2 +25 |
| 12 | LC28 3 +25 |
| 13 | LC29 1 +25 |
| 14 | LC29 2 +25 |
| 15 | LC29 3 +25 |
| 16 | LC30 1 +25 |
| 17 | LC30 2 +25 |
| 18 | LC30 3 +25 |
| 19 | LC31 1 +25 |
| 20 | LC31 2 +25 |
| 21 | LC31 3 +25 |
| 22 | LC31 5 +25 |
| 23 | LC31 6 +25 |
| 24 | LC31 7 -25 |
| 25 | LC32 1 +25 |
| 26 | LC32 2 +25 |
| 27 | LC32 3 +25 |
| 28 | LC32 4 +25 |
| 29 | LC32 5 -25 |
| 30 | LC33 1 +25 |
| 31 | LC33 2 +25 |
| 32 | LC33 3 +25 |
| 33 | LC33 4 +25 |
| 34 | LC33 5 +25 |
| 35 | LC33 6 +25 |

| | | | |
|---|---|---|---|
| 36 | LC34 | 1 | +25 |
| 37 | LC34 | 2 | +25 |
| 38 | LC34 | 3 | +25 |
| 39 | LC34 | 4 | +25 |
| 40 | LC34 | 5 | -25 |
| 41 | LC35 | 1 | +25 |
| 42 | LC35 | 2 | +25 |
| 43 | LC35 | 3 | +25 |
| 44 | LC35 | 4 | +25 |
| 45 | LC35 | 5 | +25 |
| 46 | LC35 | 6 | +25 |

## Bajada de Jaguel section **(First sampling)**

| | | | |
|---|---|---|---|
| 47 | BJ12 | 1 | +25 |
| 48 | BJ10 | 1 | +25 |
| 49 | BJ 8 | 1 | +25 |
| 50 | BJ 7 | 1 | +25 |
| 51 | BJ 6 | 1 | +25 |
| 52 | BJ 5 | 1 | +25 |
| 53 | BJ 4 | 1 | +25 |
| 54 | BJ01 | 1 | +25 |

## Bajada de Jaguel Section (second sampling)

Residues of samples M18, M19, and M20 mounted but not considered in this study)

| | | | |
|---|---|---|---|
| 55 | M20 | 1 | +25 |
| 56 | M19 | 1 | +25 |
| 57 | M18 | 1 | +25 |
| 58 | M18 | 2 | +25 |
| 59 | M17 | 1 | +25 |
| 60 | M17 | 2 | +25 |
| 61 | M16 | 1 | +25 |
| 62 | M16 | 2 | +25 |
| 63 | M15 | 1 | +25 |
| 64 | M15 | 2 | +25 |
| 65 | M14 | 1 | +25 |
| 66 | M14 | 2 | +25 |
| 67 | M13 | 1 | +25 |
| 68 | M13 | 2 | +25 |
| 69 | M12 | 1 | +25 |
| 70 | M12 | 2 | +25 |

| | | | |
|---|---|---|---|
| 71 | M11 | 1 | +25 |
| 72 | M11 | 2 | +25 |
| 73 | M10 | 1 | +25 |
| 74 | M10 | 2 | +25 |
| 75 | M9 | 1 | +25 |
| 76 | M9 | 2 | +25 |
| 77 | M8 | 1 | +25 |
| 78 | M8 | 2 | +25 |
| 79 | M7 | 1 | +25 |
| 80 | M7 | 2 | +25 |
| 81 | M6 | 1 | +25 |
| 82 | M6 | 2 | +25 |
| 83 | M5 | 1 | +25 |
| 84 | M5 | 2 | +25 |
| 85 | M4 | 1 | +25 |
| 86 | M4 | 2 | +25 |
| 87 | M3 | 1 | +25 |
| 88 | M3 | 2 | +25 |
| 89 | M2 | 1 | +25 |
| 90 | M2 | 2 | +25 |
| 91 | M1 | 1 | +25 |
| 92 | M1 | 2 | +25 |

## Bajada de Jaguel Section (third sampling)

| | | | |
|---|---|---|---|
| 93 | BJ21 | 1 | +25 |
| 94 | BJ22 | 1 | +25 |
| 95 | BJ23 | 1 | +25 |
| 96 | BJ24 | 1 | +25 |
| 97 | BJ25 | 1 | +25 |
| 98 | BJ26 | 1 | +25 |
| 99 | BJ27 | 1 | +25 |
| 100 | BJ28 | 1 | +25 |
| 101 | BJ29 | 1 | +25 |
| 102 | BJ30 | 1 | +25 |
| 103 | BJ31 | 1 | +25 |
| 104 | BJ32 | 1 | +25 |
| 105 | BJ33 | 1 | +25 |
| 106 | BJ34 | 1 | +25 |
| 107 | BJ35 | 1 | +25 |

# PLATES

# Plate 1

1 *Spiniferites ramosus* subsp. *granosus* (Davey and Williams) Lentin and Williams 1993.

Upper focus on dorsal view showing precingular archeopyle

Slide 9, coord . 45.5/111.3 x350

2-3 *Spiniferites* sp.1

Slide 93, coord. 35.4/94.4 x600

2- Lower focus, partially showing ventral view.

3- Upper focus, lateral view showing part of the archeopyle.

4-5 ?*Pterodinium* sp. 1

Slide 93, coord. 44.5/107.7 x700

4- Upper focus on ventral surface.

5- Lower focus on dorsal surface.

6- *Spiniferites ramosus* subsp. *maeandriformis* (Corradini) Lentin and Williams 1975

Slide 76, coord. 48.5/101.5 x540

7- *Spiniferites* sp. 2

Slide 97, coord. 36.4/105 x850

8- *Achomosphaera ramulifera* (Deflandre) Evitt 1963

Slide 51, coord. 63.8/28.7 x400

9- *Spiniferites wetzelii* (Deflandre) Sarjeant 1970

Slide 69, coord. 47.7/93.5 x570

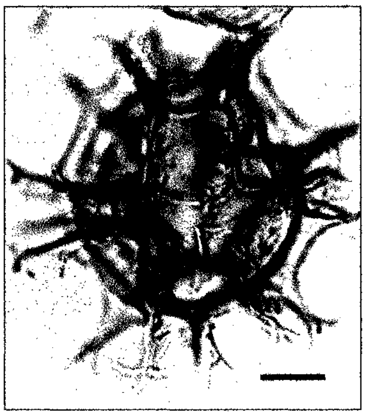
# PLATE 1

1

2

3

4



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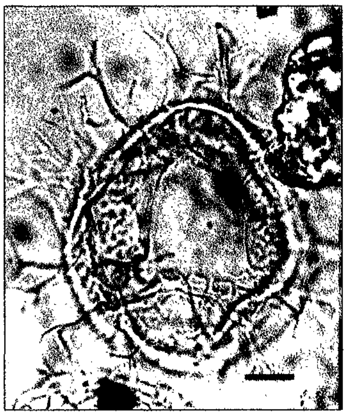

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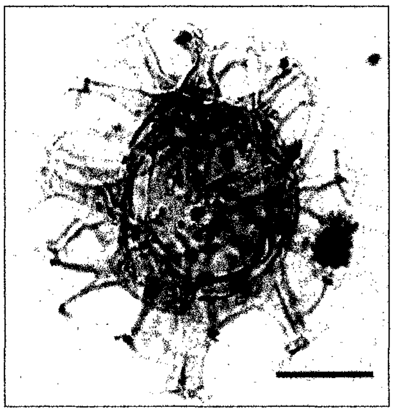

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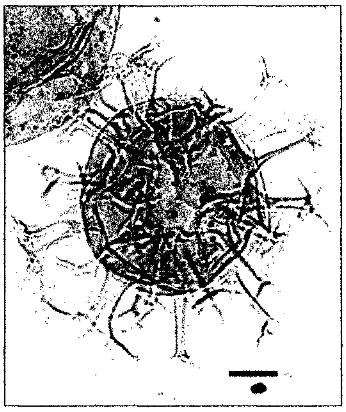


8

Bar:20μm

9

# PLATE 2

1 *Spiniferella cornuta subsp laevimura* (Davey and Williams) Lentin and Williams 1973
Slide 52, coord. 35/104 x362

2,3,5 *Spiniferites* sp. 3
2- Slide 139, coord. 5.4/102.8 (label to the left) x580
Upper focus on dorsal view showing vesicular endophragm, thin periphragm. precingular archeopyle with operculum in situ and development of an apical structure.
3- Slide 139, coord. 27.1/106.5 ( label to the left) x570
Specimen in a lateral, antapical view.
5- Slide 139, coord. 18.9/97.6 (label to the left) x770
Specimen showing mechanical separation of paraplates and very short processes.

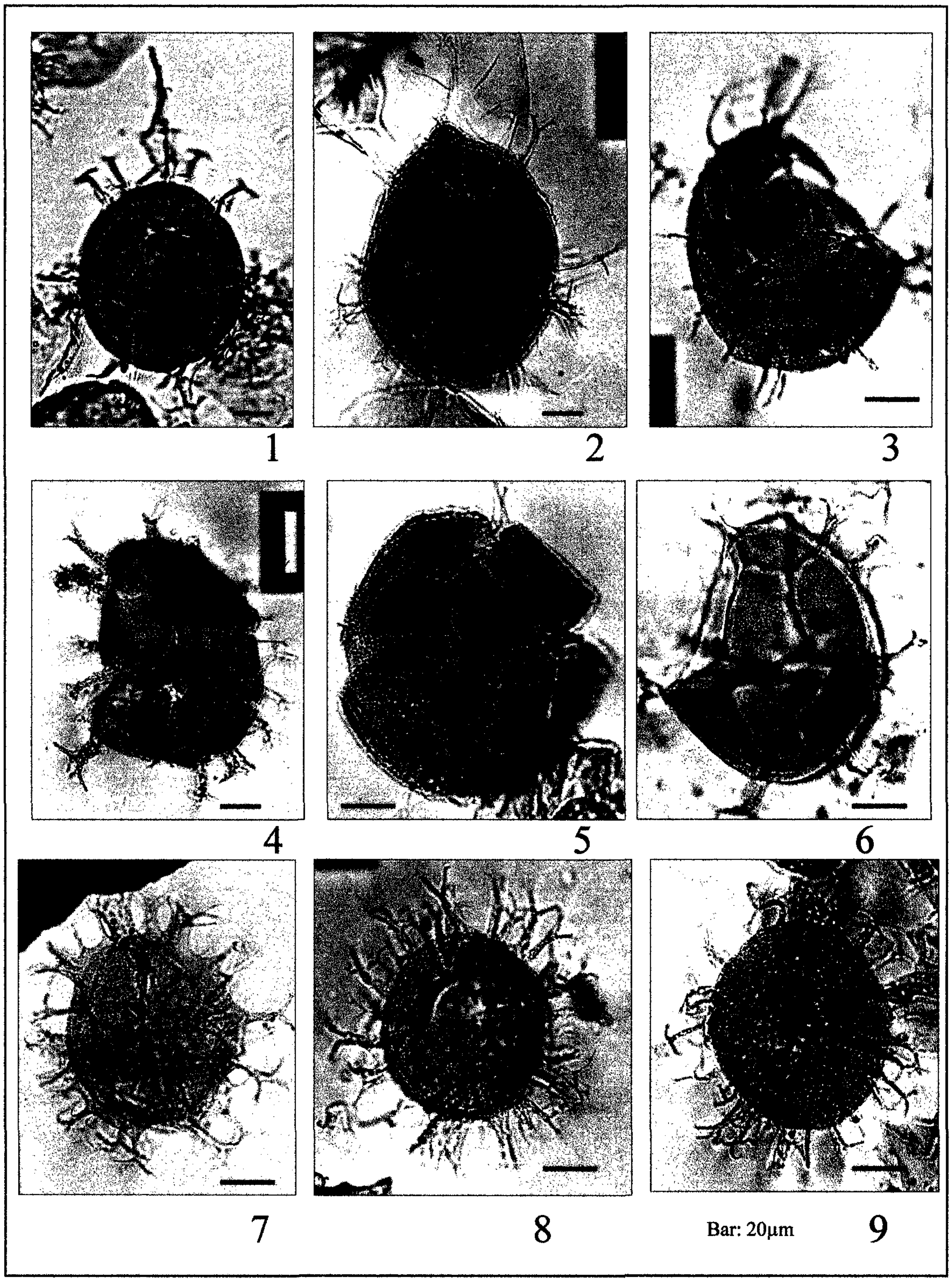
4 ?*Hafniasphaera* sp.
Slide 139, coord. 8.1/100.3 (label to the left) x500
Specimen showing vesicular endo and periphragm and cysts that seems to be divided into paraplates boundaries instead of a single paraplate archeopyle.

6 *Spiniferites* sp. 3
Slide 91, coord. 49.7/94 x570
Upper focus on lateral view showing part of the precingular archeopyle, operculum inside the cyst, and thick endophragm.

7 ?*Hafniasphaera* sp. 2
Slide 128, coord. 13.9/100.5 x640
Specimen showing vesicular peri- and endophragm forming processes and parasutural crests.

8-9 *Hafniasphaera septata* (Cookson and Eisenack) Hansen 1977
8- Slide 139, coord. 14.2/99 x700
Upper focus on dorsal view showing precingular archeopyle.
9- Another specimen. Slide 139, x 750. Upper focus on ventral view.

# PLATE 2



# PLATE 3

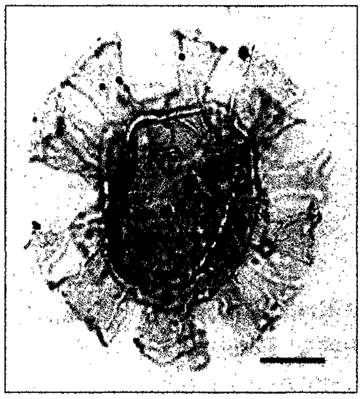
1-2 *Hsytrichosphaeridium salpingophorum* Deflandre 1935, emend. Davey and Williams, 1966b
1- Slide 107, coord. 40/93.1 x 590
2- Detached operculum showing paraplates and intratabular processes. x750.

3-5 *Hystrichosphaeridium tubiferum* (Ehrenberg) Davey and Williams, 1966
3- Slide 52, coord. 42.2/99.7 x 450
4- Slide 50, coord. 33.6/106 x 430
5- Slide 22, coord. 33.2/105.4 x 520

6 *Hystrichospaheridium recurvatum (White) Lejeune-Carpentier, 1940*
Slide 52, coord. 54.2/101 x 620

*7-9* *Oligosphaeridium complex* (White) Davey and Williams, 1966b
7- Slide 139, coord. 6.7/100.5 (Label to the left) x 600
Apical view.
8- Slide 123, coord. 30.8/95.7 x 700
Lateral view.
9- SEM image, taken at x 1700 (Reduced for plate).

# PLATE 3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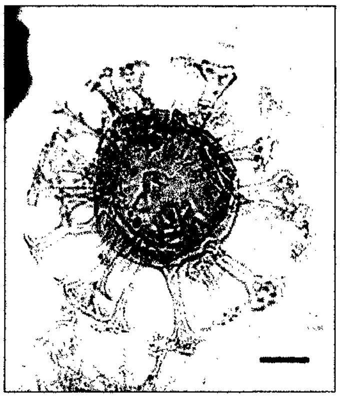
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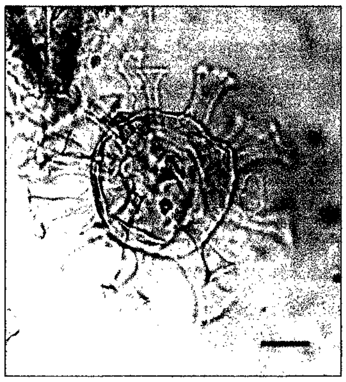
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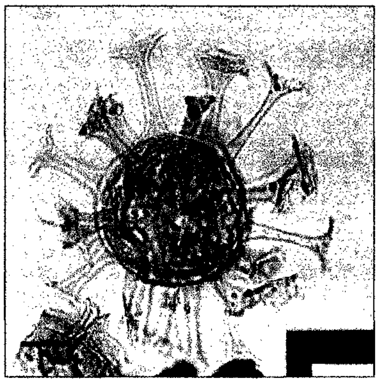
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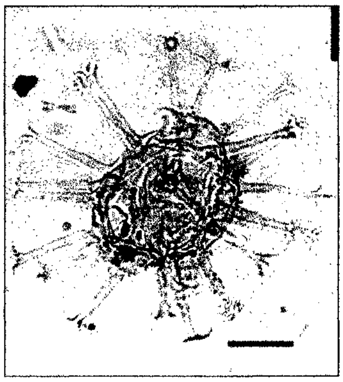
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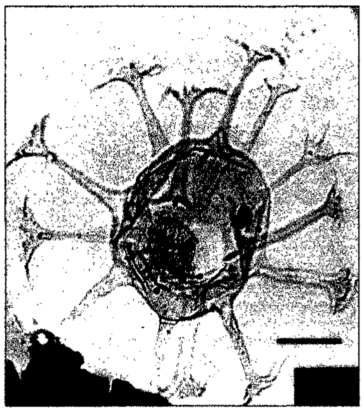
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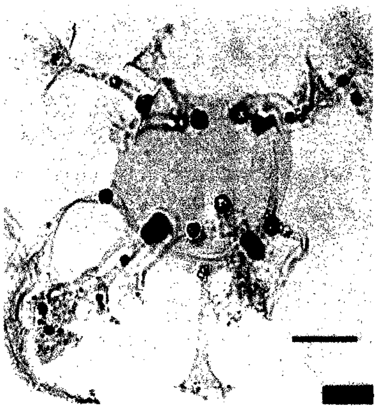

8


Bar: 20μm

9

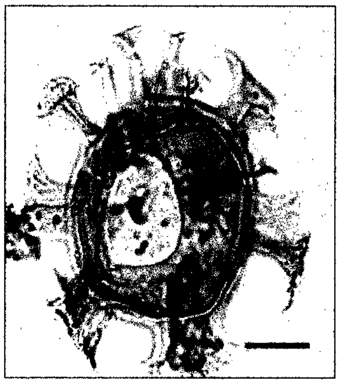
# PLATE 4

1,2,4,5 *Cordosphaeridium exilimurum* Davey and Williams, 1966b
1- Slide 93, coord. 43.2/105.3 x 590.
Upper focus on dorsal surface showing precingular archeopyle
2- Slide 13, coord. 47.5/96.4 x 500.
Specimen in lateral view.
4- SEM Image. Taken at 1200x (Reduced for plate).
5- Same specimen. Detail of one of the processes. Taken at 5000x (Reduced for plate).

3,6 *Cordosphaeridium inodes* (Klumpp) Eisenack1963, emend. Morgenroth,1968
3- Slide 53, coord. 27/100.5 x350
Upper focus on dorsal surface showing precingular archeopyle with operculum in place.
6- Slide 90, coord. 34.9/103.5 x350
Upper focus in dorsal view.

7, 8, 9 *"Cordosphaeridium" ?lemniscatum* Corradini, 1973
7- Slide 51 coord. 27/104.4 x500
8- SEM image showing distal connections of fibrous processes. Taken at 573x (Reduced for plate).
9- Same specimen. Detail of distal connections of processes. Taken at 1150x (Reduced for plate).

# PLATE 4



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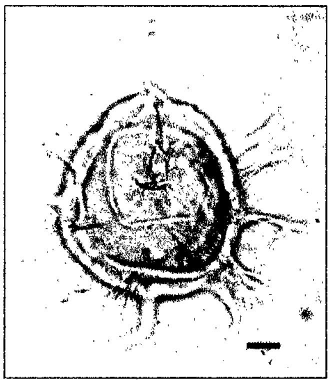

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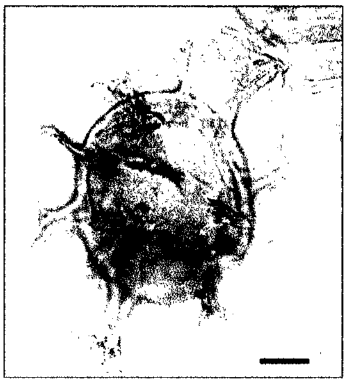

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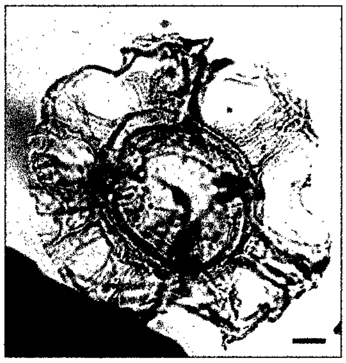


7

8

Bar: 20µm

9

# PLATE 5

1-3 *Operculodinium azcaratei* Troncoso and Doubinger, 1980
1- Slide 93, coord. 44.6/111.6 x 700
2- SEM image. Complete specimen .Taken at 1222x (Reduced for plate).
3- Same specimen. Detail of the wall structure and processes. Taken at 5000x. (Reduced for plate).

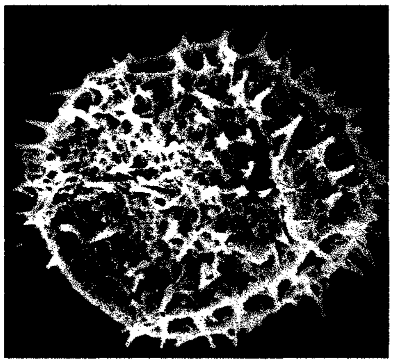
4,5 *Operculodinium* sp. 1
4- Slide 71, coord. 33.6/103.4 x 640. Apical view showing operculum in situ on the upper right corner.
5- SEM image of complete specimen showing precingular archeopyle. Taken at 1770x. (Reduced for plate).

6 *Operculodinium* sp. 2
SEM images. Upper picture showing complete specimen with precingular archeopyle. Lower picture showing detail of processes and wall structure. x 1200 and 5000 respectively.

7 *Operculodinium centrocarpum* (Deflandre and Cookson) Wall, 1967
Slide 51, coord. 54.1/101.2 x 1000.

# PLATE 5

1



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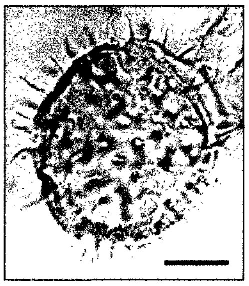

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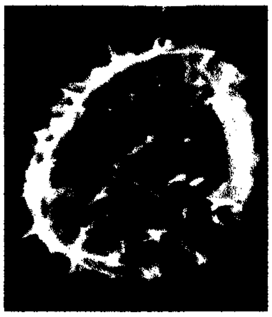

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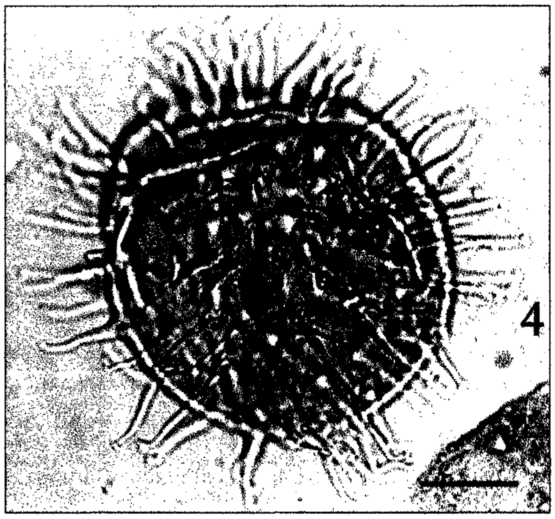


Bar:20μm

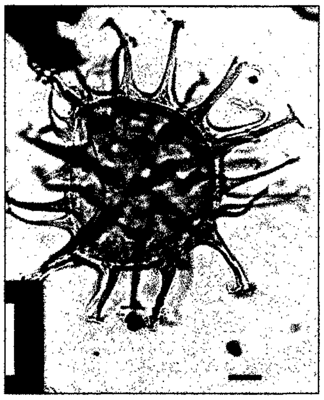
7

# PLATE 6

1,2,3,6,9 *Fibrocysta* cf *vectensis* (Eaton) Stover and Evitt, 1978
1- Slide 76, coord. 48.8/110.5 x255.
Lateral view showing part of the precingular archeopyle.
2- Slide 10, coord. 40.5/93.4 x 375.
Specimen showing distinctive apical process.
3- Slide 96, coord. 39.1/108 x 342. Top left corner. Detached operculum with three intratabular processes.
6- Slide 13, coord. 51.5/98.7 x 393
Polar view. Operculum in situ.
9- SEM image of a complete specimen

4,5,7,8 *Turbiosphaera filosa* (Wilson) Archangelsky, 1969a
4- Slide 139 coord. 29.3/95.4 x 429
5- SEM image of a complete specimen
Taken at 1000x (Reduced for plate)
7-8 -SEM images of same specimen showing detail of antapical process and paracingular, flattened processes. Taken at 2500x and 3000x respectively (Reduced for plate)

# PLATE 6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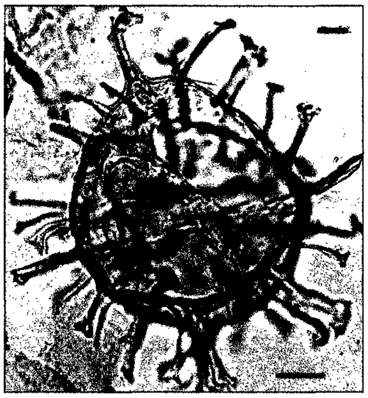
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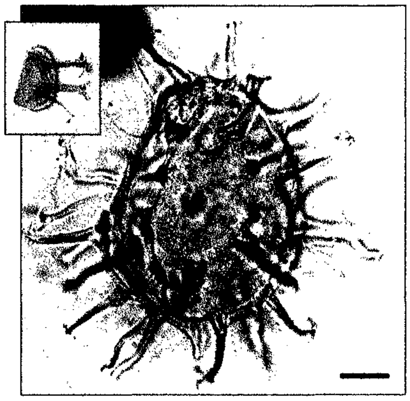
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4


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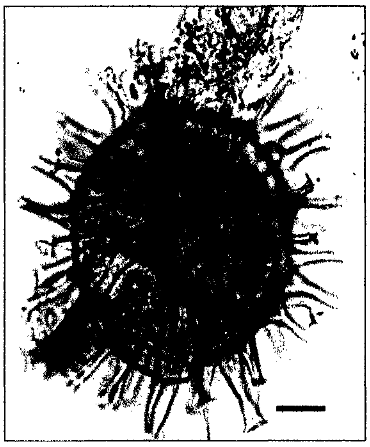

6


7


8


Bar: 20μm

9

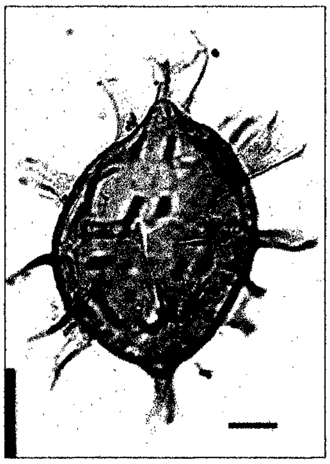
# PLATE 7

1,2,3,4 *Cordosphaeridium inodes* subsp. *longipes* Hansen, 1977
Specimens showing variability within the population.
1-2 Slide 124, coord. 43.7/109.1 x 450. Upper focus on dorsal surface and lower focus on dorsal surface respectively.
3- 4 Transitional morphotypes.
3- Slide 124, coord.38.9/100.7 x 460
4- Slide 124 coord. 42.3/97.8 x 570

5, 6 *Lanternosphaeridium* sp. 1
5- Slide 53 coord. 30.3/99.4 x 570
6- Slide 52 coord. 35.1/105.4 x 570

7, 8, 9 *Kleithriasphaeridium* sp.
4- Slide 19 coord. 36.5/94.5 x 500
5-6 - SEM images of same specimen at different magnifications. Complete specimen, picture taken at 900x and detail of cyst wall and processes at 3000x. (Both pictures reduced for plate).

# PLATE 7



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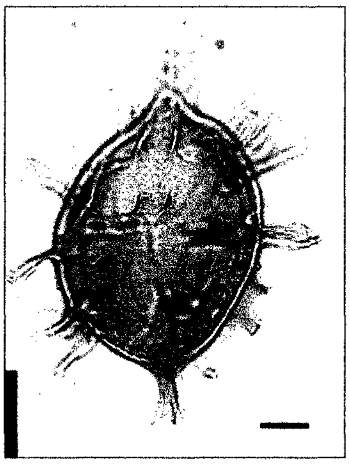

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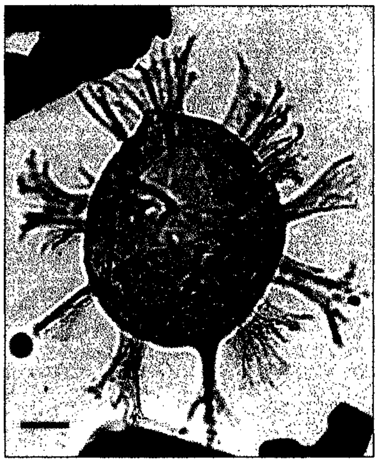

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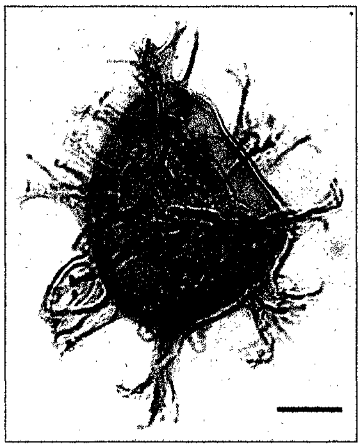

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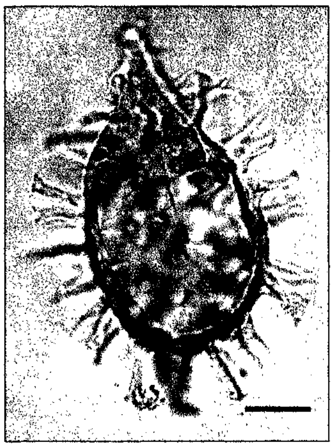

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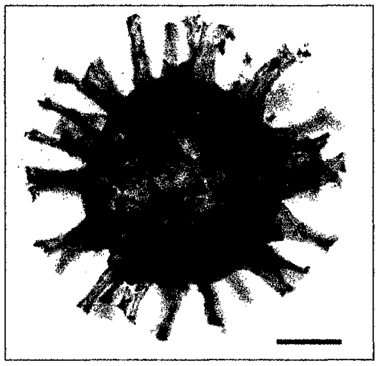

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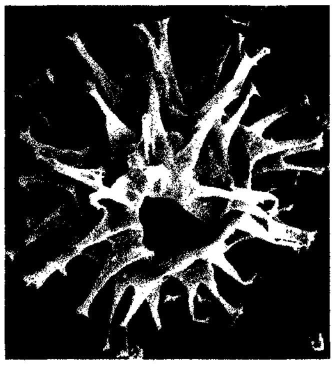


8

Bar: 20μm

9

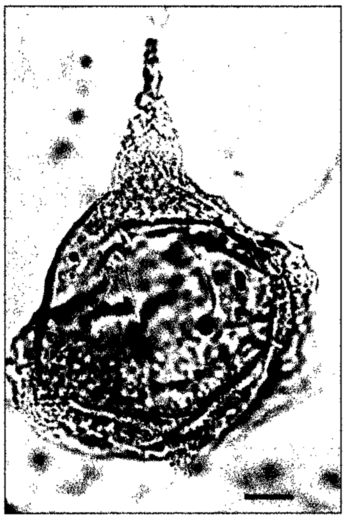
# PLATE 8

1-5 ?*Lanternosphaeridium* sp.
1- Slide 85, coord. 28.8/100.1 x 370
Upper focus on dorsal epicyst.
2- Slide 84 coord. 30.3/102.4 x350
Complete specimen showing large archeopyle and development of spongy periphragm especially on precingular and apical areas.
3- SEM of structure of apical horn. Taken at 2000x (Reduced for plate).
4-5- SEM images showing the structure of the cyst wall taken at 3200x and 8600x respectively (Reduced for plate).

6 *Damassadinium californicum* (Drugg) Fensome et al., 1993b
Slide 88 coord. 32.7/97.4 x 500
Specimen on lateral view.

7,8 *Cordosphaeridium inodes* subsp. *longipes* Hansen, 1977
7- Slide 124, coord. 36/109.1 x 390
Specimen showing processes folded on central body.
8- Slide 123, coord. 29/103 x 360

# PLATE 8



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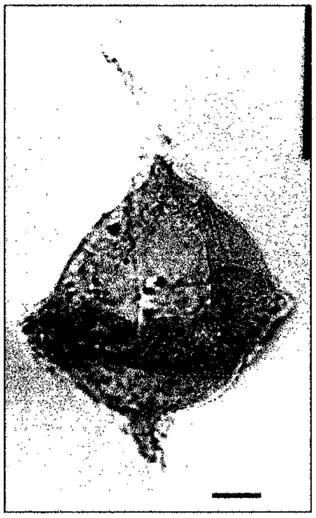

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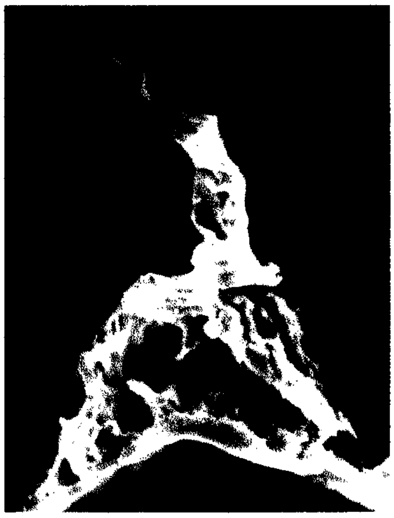

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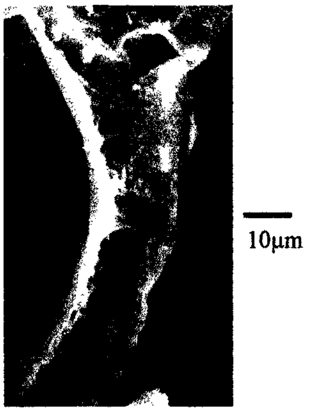

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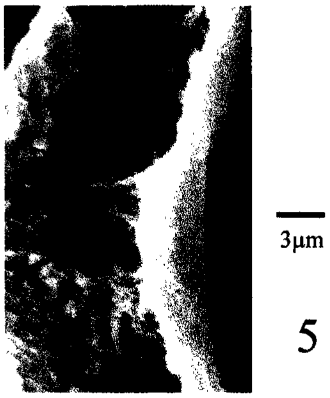

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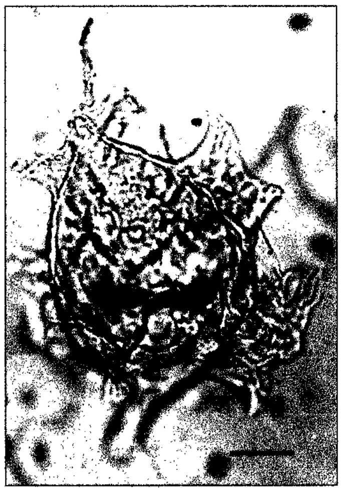

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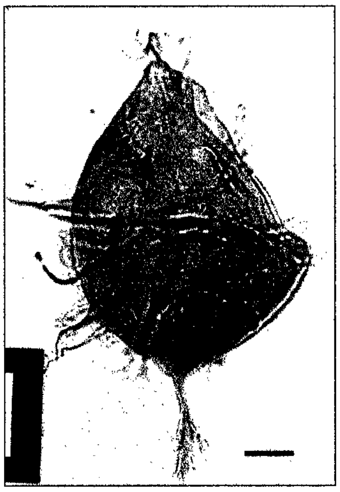


8

Bar: 20μm, unless otherwise stated

# PLATE 9

1-9 ?*Lanternosphaeridium* sp.

Pictures illustrate variability of the population showing different degrees of spongy periphragm development.

1- Slide 85, coord. 28.8/100.1 x 370

2- Slide 84, coord 32.6/93.3 x 370

3- Slide 84, coord. 28.7/104.2 x 370

4- SEM image of a complete specimen showing large archeopyle, almost no development of spongy periphragm and epicyst much larger than hypocyst. Taken at 1250x (Reduced for plate).

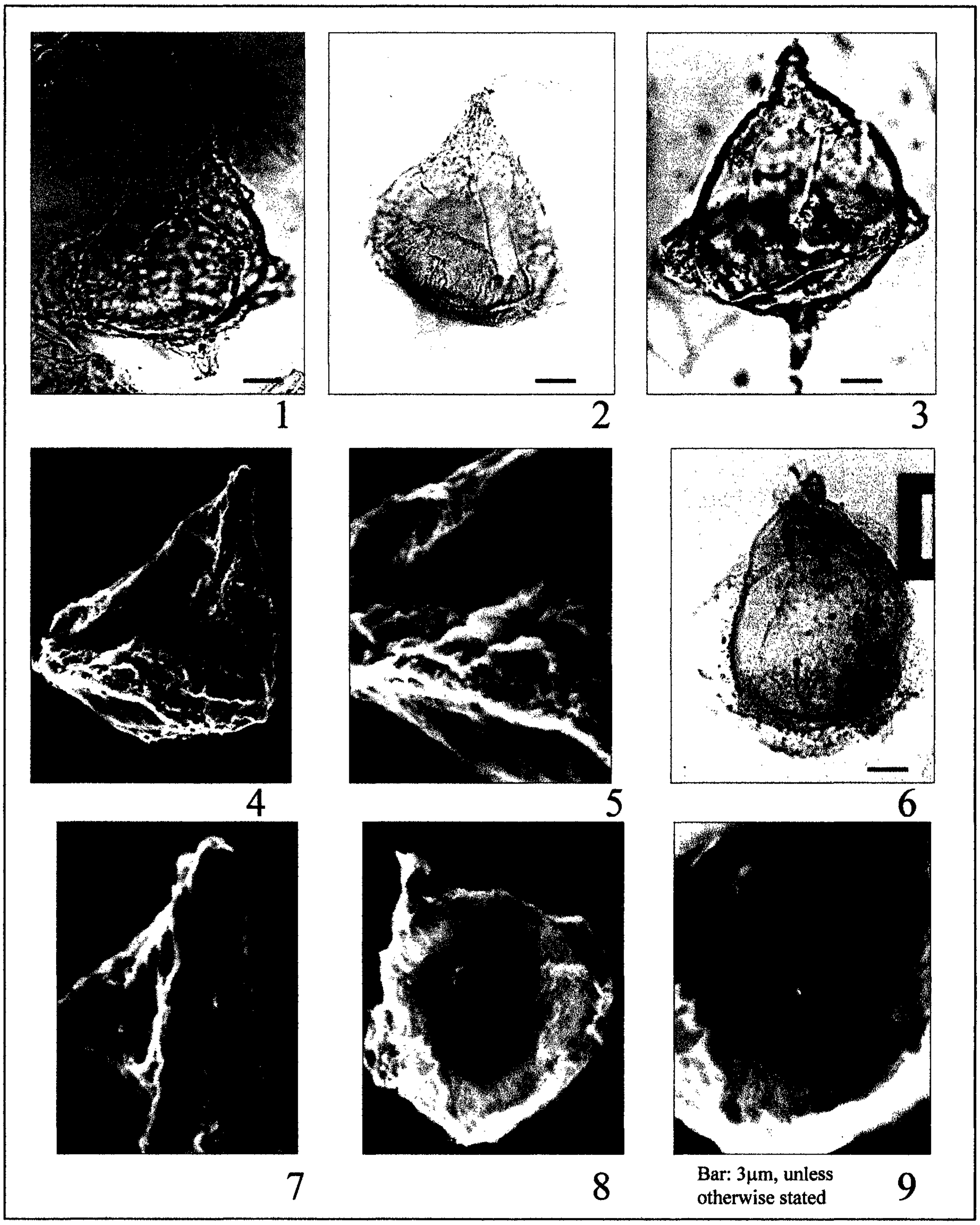
4-5- Details of cingular area and apical horn respectively, taken at 3100x. (Reduced for plate).

6- Slide 139 coord. 11.3/104.1 (Label to the left) x 380

Specimen with a spongy periphragm well developed.

8-9- SEM images taken at 1250x and 2400x respectively. (Reduced for plate)

# PLATE 9



# PLATE 10

1-4 *Alisocysta circumtabulata* (Drugg) Stover and Evitt,1978

1-2 Slide 18, coord. 31.7/100.5 x 1000
Dorsal and ventral view respectively.
3- Slide 85, coord. 33.7/108.5 x 950
4- Slide 14, coord. 37.8/97.9 x 830, showing operculum in place

5,6,8,9 *Hystrichosphaeridium tubiferum* subsp. *brevispinum* (Davey and Williams) Lentin and Williams, 1973.

5- Slide 89, coord. 51.1/107.3 x 750
6- Slide 139, coord. 10/105.3 x600
8-9 – SEM images of complete specimen taken at 1930x and detail of processes taken at 4000x respectively. (Reduced for plate).

7 *Alisocysta* sp.

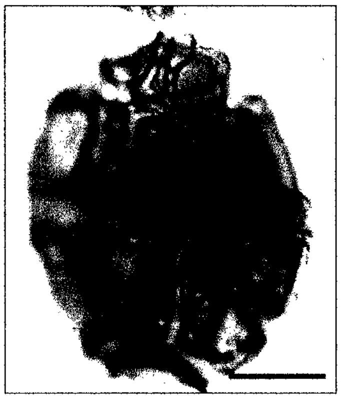
Slide 89, coord. 33.7/102.5 x 750

# PLATE 10

1

2

3



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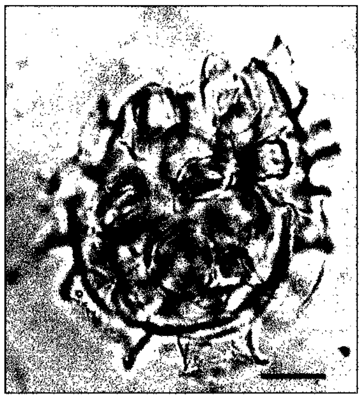

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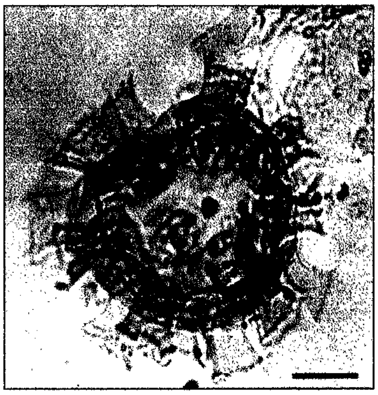

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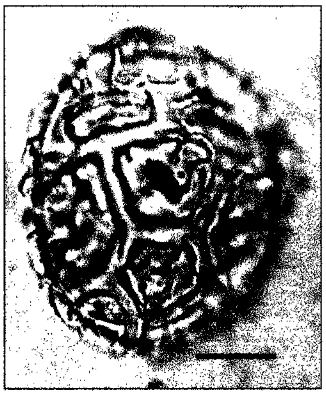

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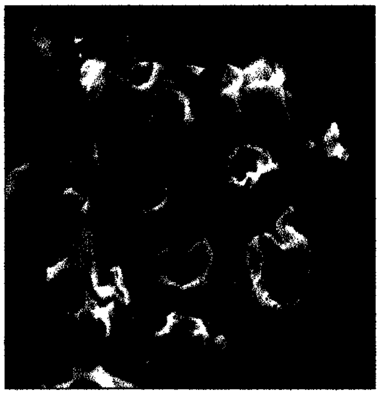


8

Bar: 20μm

9

# PLATE 11

1-2 *Areoligera senonensis* Lejeune-Carpentier, 1938a
1- Slide 62, coord. 31.9/102 x 330
2- Slide 32, coord. 27.8/111.2 x 330

3,6 *Glaphyrocysta retiintexta* (Cookson) Stover and Evitt,1978
3- Slide 41 coord. 31.3/102.3 x 420
6- Slide 41 coord. 42/102.6 x 650 showing detail of distal connections of processes.

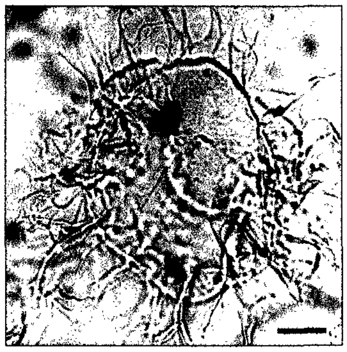
4 *Glaphyrocysta* sp.1
Slide 30, coord.50/97.4 x 430
Specimen with operculum in situ.

5,7 ?*Glaphyrocysta* sp.
7- Slide 51 coord 28.3/95.4 x 290
Specimen showing development of antapical lobes.
5- Detached operculum.

8 *Glaphyrocysta* sp. 2
Slide 51, coord. 41.5/102.9 x 340

9 *Glaphyrocysta* sp.3
Slide 51, coord. 40.5/92.8 x 400

# PLATE 11



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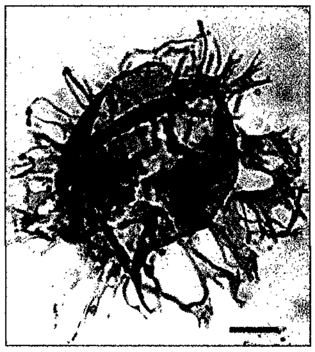

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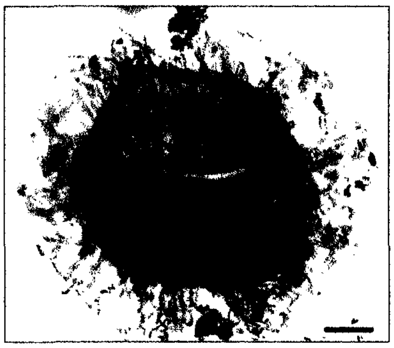

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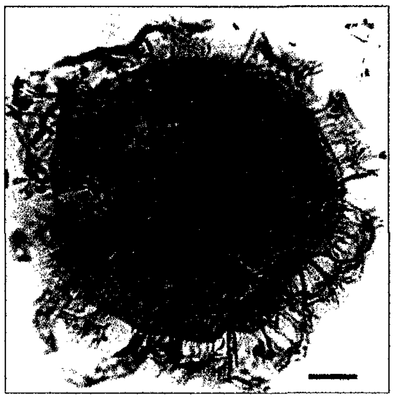

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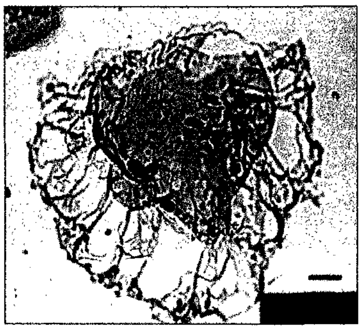

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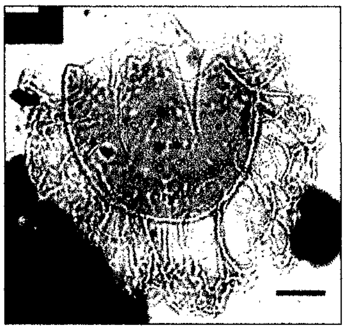

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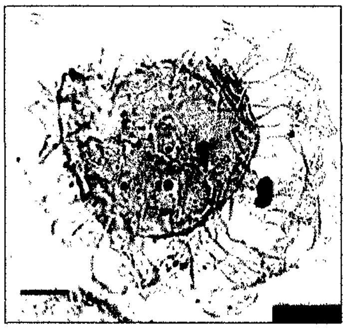


Bar: 20 µm

9

# PLATE 12

1 *Florentinia ferox* (Deflandre) Duxbury, 1980
Slide 50, coord. 41.6/109.4 x 630
Orientation uncertain.

2 *Cannosphaeropsis* cf. *utinensis* Wetzel, 1933
Slide 139, coord 10.1/ 99.8 (label to the left) x 550
Orientation uncertain

3 *Tanyosphaeridium xanthiopyxides* (Wetzel) Stover and Evitt, 1978
Slide 52, coord. 53.6/101.1 x 1000

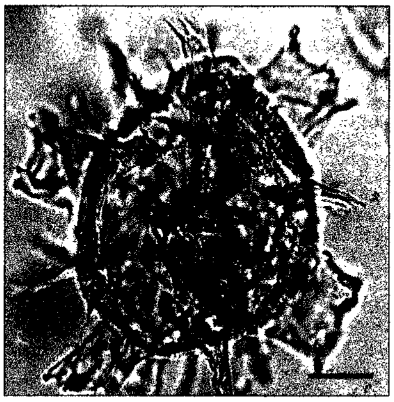
4, 5 *Cribroperidinium wetzelii* (Lejeune-Carpentier) Helenes, 1984
4- Slide 50, coord. 39.2/97.7 x 500
5- Slide 90, coord. 36.4/103.7 x 500
Upper focus on dorsal surface showing precingular archeopyle.

*6 Hystrichosphaeropsis sp.*
Slide 89, coord 44.5/102.1 x 700

7, 8 cf. *Hystrichosphaeridium* sp.
7- Slide 15, coord. 49/102.7 x 750
Lateral view, operculum in place.
8- Slide 15 28.7/98.4 x750
Upper Focus on apical archeopyle.

9 ?*Cordosphaeridium* sp.
Slide 91, coord. 43.1/109.5 x 550

# PLATE 12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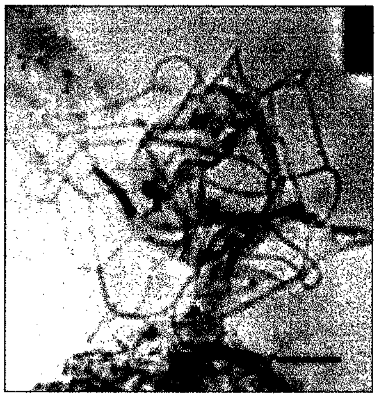
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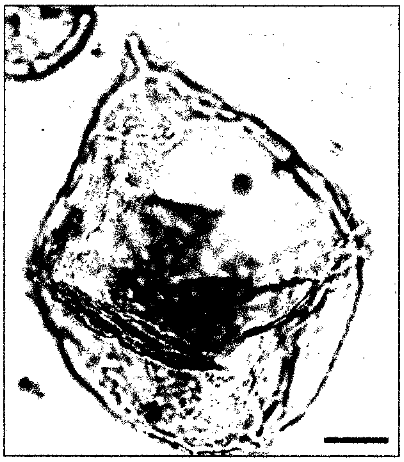
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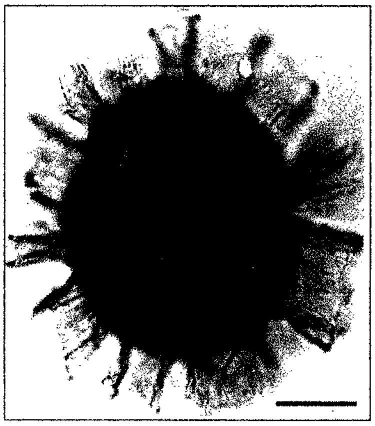
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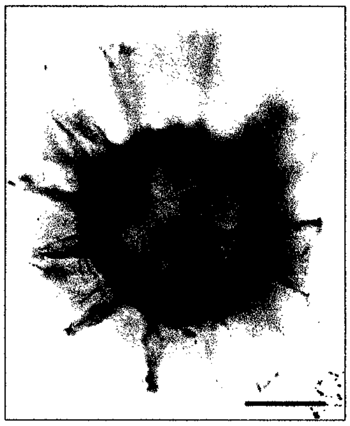
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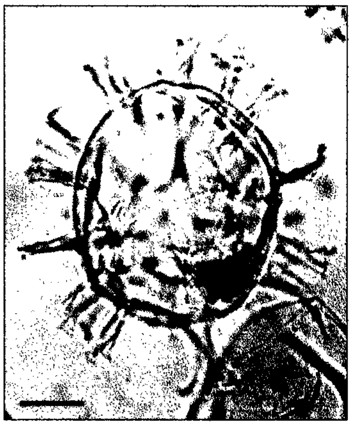
Bar: 20μm


9

# PLATE 13

1-3 *Cyclapophysis monmouthensis* Benson, 1976
Three different specimens showing variable development of distal connection of processes.

| | | |
|---|---|---|
| 1- Slide 25, coord. | 37.6/106.8 | x 350 |
| 2- Slide123, coord. | 33.6/94 | x 470 |
| 3- Slide 51, coord. | 32/95.8 | x 510 |

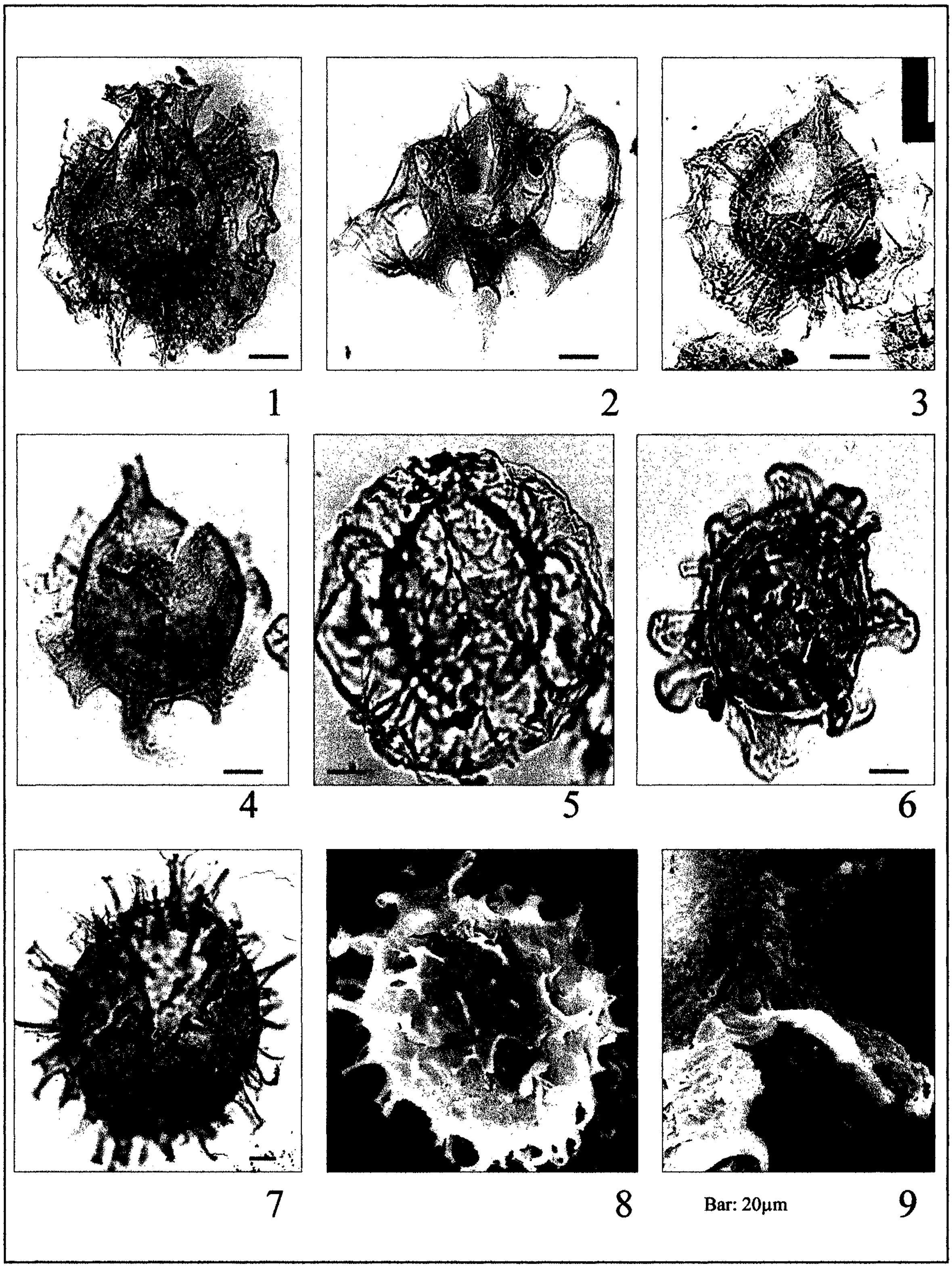
4 *Damassadinium californicum* (Drugg) Fensome et al., 1993b
Slide 109, coord. 103.8/103.9 x 530

5 Gen et sp. indet. 1
Slide 18, coord. 31.7/100.5 x 400

6 Gen. et. sp. indet 2
Specimen showing fibrous processes partially folded on central body.
Slide 51, coord. 27.5/101.6 x 450

*7-9* *Exochosphaeridium* cf. *bifidum* (Clark and Verdier) Clark et al., emend. Davey, 1969b
7- Slide 19, coord. 37/106.2 x 350
8- SEM image of a complete specimen with operculum in place. Taken at 1200x. (Reduced for plate).
9- SEM, same specimen showing detail of processes. Taken at 5000x. (Reduced for plate)

# PLATE 13



# PLATE 14

1,2 *Spongodinium* aff. *delitiensis* (Ehrenberg) Deflandre 1936b, emend. Lucas-Clark, 1987
Slide 18, coord. 49.8/97.4 x 500
1- Ventral view
2- Upper focus on dorsal view showing precingular archeopyle.

3,5 *Dinopterigium cladoides* Deflandre, 1935
3- Slide 21, coord. 55.5/109.8 x 430
Polar view
4- Slide 21, coord. 44.9/92.4 x 400
Specimen on lateral view.
5- Slide 21, specimen on antapical- lateral view.

6 *Trigonopyxidia ginella* (Cookson and Eisenack) Downie and Sarjeant, 1965

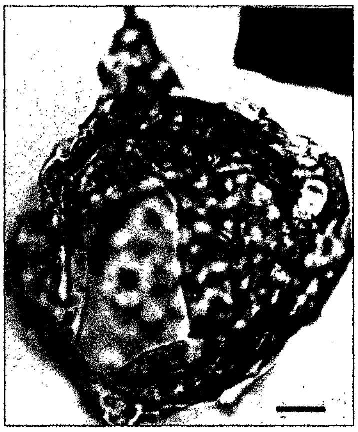
Slide 52, coord. 31.5/96.5 x 650

7 *Impletosphaeridium* sp.
Slide 107, coord. 31.9/111.1 x 630

8, 9 *Dinogymnium acuminatum* Evitt et al.,1967
Slide 31, coord. 44.4/92.7 x 890
8- Lateral-ventral view
9- Lateral- dorsal view

# PLATE 14

1



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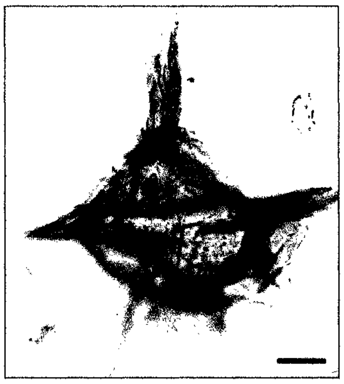

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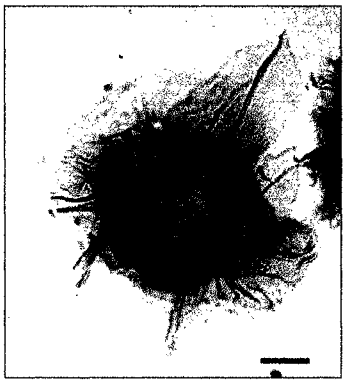

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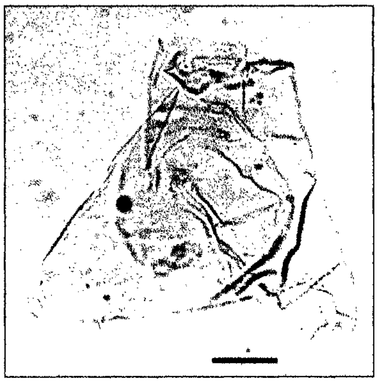

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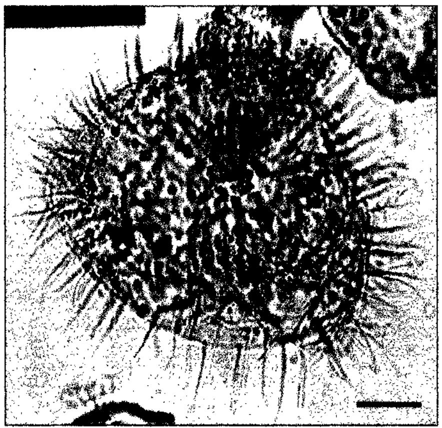


7

8

Bar: 20μm

9

# PLATE 15

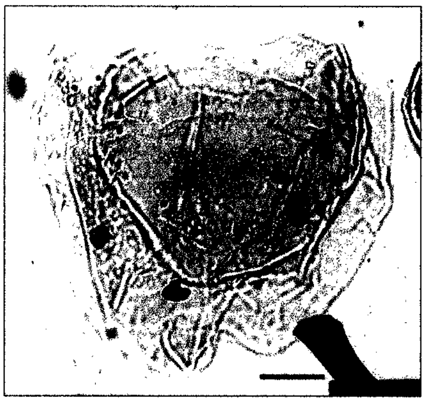
1 *Senoniasphaera inornata* (Drugg) Stover and Evitt, 1978
Slide 51 coord. 36/95.5 600 x

2,3,4,5 Different specimens showing variablility in the development of periphragm expansions. Transitional forms between *S. inornata* and *Glaphyrocysta semitecta.* All showing operculum in place.
4- SEM image showing marginally peripharm supported by ?processes.

6 ? *Glaphyrocysta semitecta*
Slide 139 coord. 6/103.4 (Label to the left) x 530

7, 8, 9 Morphotype showing characteristics similar to ?*Lanternosphaeridium* sp. but with spongy periphragm restricted to the paracingular area.
7- Slide 119 coord x
8-Slide 119 coord. x
9- SEM image showing detail of the paracingular area. Taken at 3000x. (Reduced for plate).

# PLATE 15



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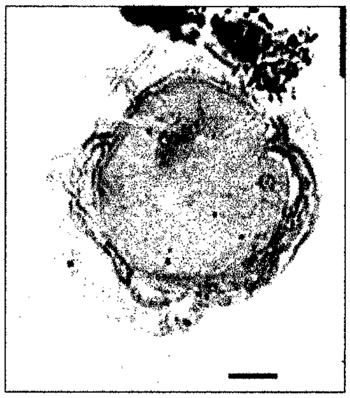

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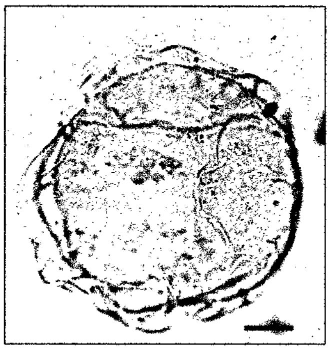

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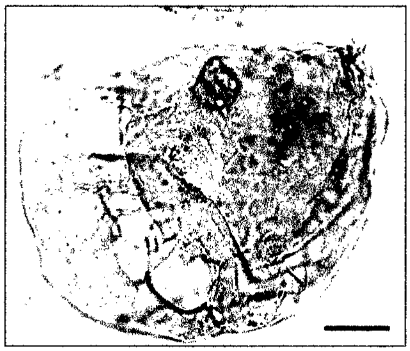

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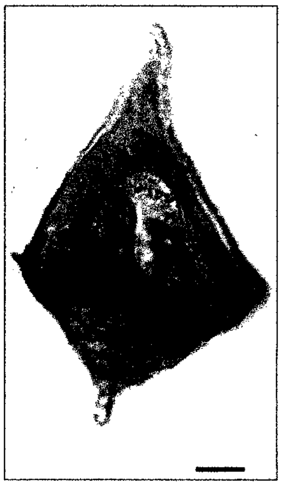

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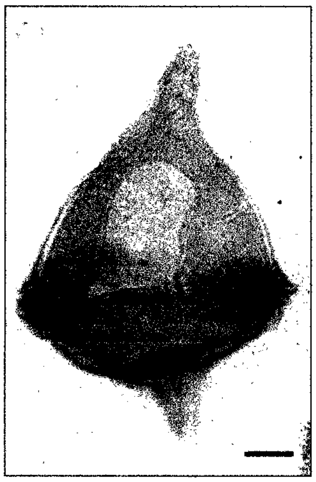


8

9

Bar: 20μm

# PLATE 16

1-4 *Hystrychokolpoma bulbosum* (Ehrenberg) Morgenroth, 1968

1- Slide 53, coord. 48.4/95.6 x 550
2- Same specimen , upper focus on apical archeopyle.
3- Slide 53, coord. 33.3/94.3 x 545
4- Specimen on lateral view showing apical process. X 480

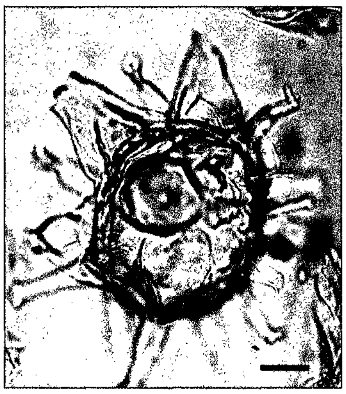
5-6 *Coronifera oceanica* (Cookson and Eisenack) Davey 1969

Slide 31, coord. 28.2/111.3 x 640
5- Lower focus on ventral surface.
6- Upper focus on dorsal surface showing precingular archeopyle.

7-9 *Dyphies colligerum* (Deflandre and Cookson) Davey and Williams, 1966

| | |
|---|---|
| 7- Slide 53, coord. 33.3/94.8 | x 700 |
| 8- Slide 53, coord. 43/105.7 | x 690 |
| 9- Slide 52, coord. 54.2/101.4 | x 600 |

# PLATE 16



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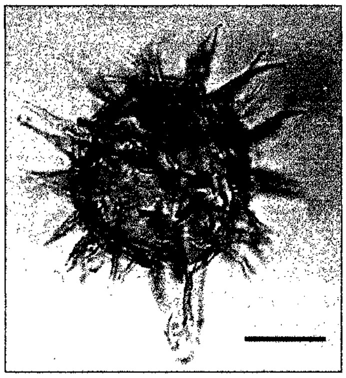

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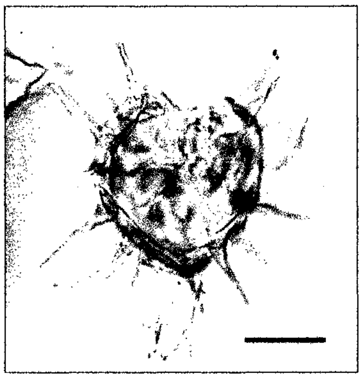

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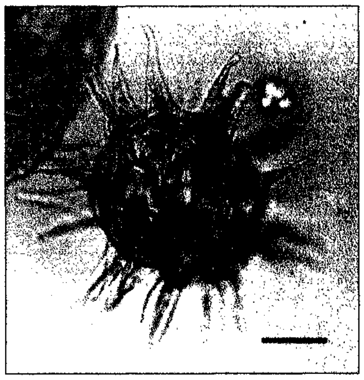


Bar: 20μm

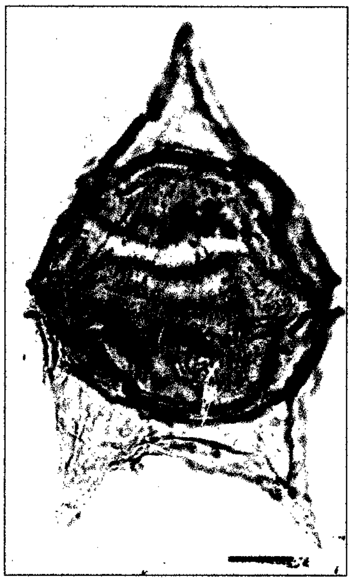
9

# PLATE 17

*1-5 Deflandrea galeata* (Lejeune-Carpenter) Lentin and Williams, 1973

1- Slide 18 coord. 36.6/96 x 560
2- Slide 62 coord. 42.1/108.1 x 600
3- SEM image of a complete specimen. x 900
4- SEM image of part of a specimen showing peri and endo archeopyle. x 1800.
5- SEM image of same specimen in picture 3 showing detail of paratabulation, parasulcal region and flagelar scars. x 3000.

# PLATE 17



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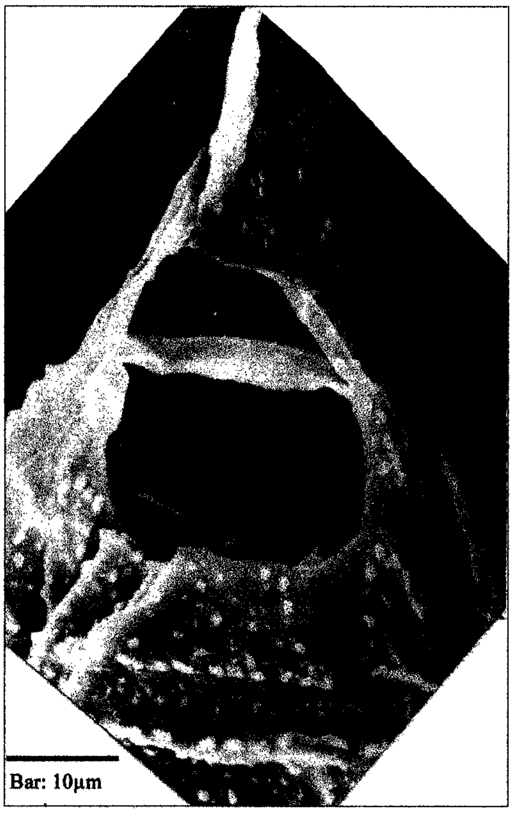


4

5

Bar: 20μm, unless otherwise stated

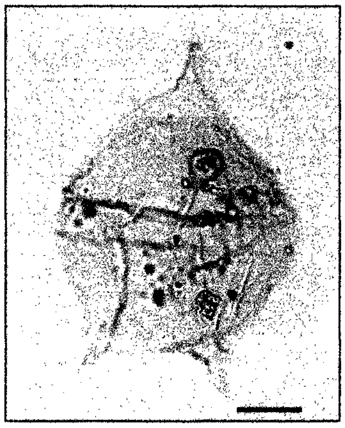
# PLATE 18

1-2 ?*Deflandrea* sp.
1- Slide 91, coord. 27.5/107 x 720
2- SEM image on ventral surface. Taken at 1500x. (Reduced for plate).

3-6 *Vozzhennikovia* sp.
Specimens recovered from the same level showing variability of the population.
3- Slide 44, coord. 42.2/98.5 x 720
4- Slide 44, coord. 50.9/100.8 x 520
5- Slide 44, coord. 38.2/109.2 x 500
6- slide 43, coord. 41.8/94 x 520

7-9 Gen et sp. indet. 3
7- Slide 19, coord. 29.1/102 x 595
8- Slide 30, coord. 34.2/97 x 570
9- SEM of complete specimen . Image on ventral surface. Taken at 1000x (Reduced for plate).

# PLATE 18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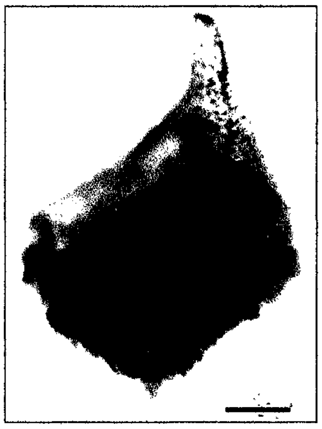
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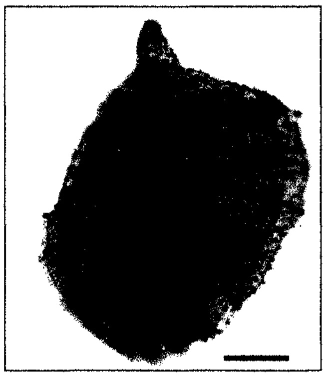
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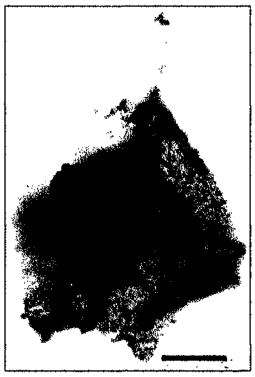
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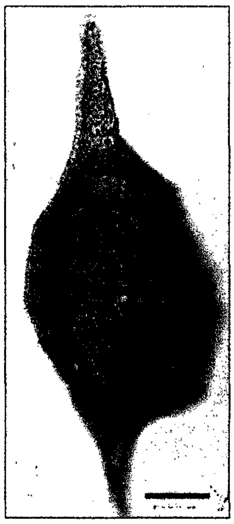
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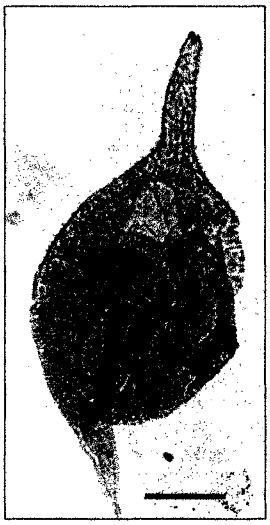

8


Bar: 20µm

9

# PLATE 19

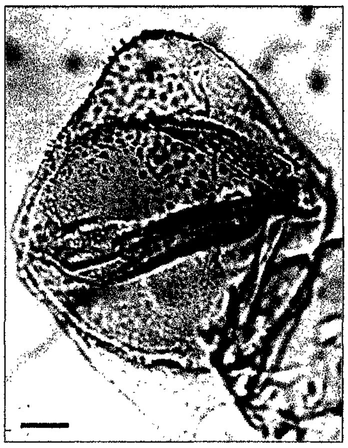
1-5 Specimens of the *Isabelidinium /Manumiella* complex.
  1- Slide 76, coord. 34.4/109 x 450
  Specimen slightly circumcavate
  2- Slide 76, coord. 28.1/106.2 x 440
  3- Slide 74, coord. 37.9/103 x 440
  4- SEM image of compressed and folded specimen. Taken at 2000x (Reduced for plate).
  5- Detail of same specimen showing paracingular area with punctuation on cyst wall. Taken at 3000x. (Reduced for plate).

6 cf. *Alterbidinium* sp.
  Slide 122,coord x 1000

7-8 *Senegalinium obscurum* (Drugg) Stover and Evitt, 1978
  7- Slide 88, 36.1/112 x 690
  8- SEM image of compressed specimen showing
  very fine pericyst. Taken at 2400x (Reduced for plate).

9 *Deflandrea* sp. cf. *D. pentaradiata* Cookson and Eisenack, 1965c
  Slide 51, coord. 47.7/96.8 x 430

# PLATE 19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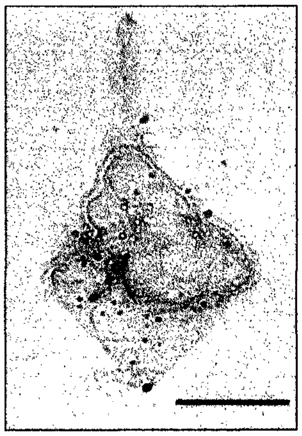
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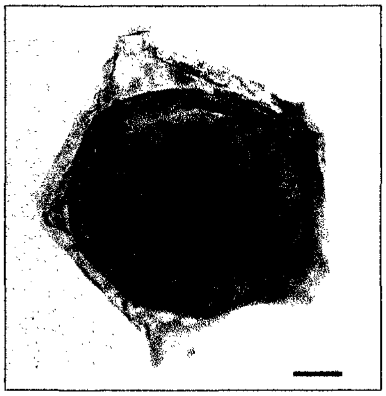

Bar: 20μm

9

# PLATE 20

1-2 *Deflandrea* sp. 1
1- Slide 101, coord. 42.2/98.7 x 715
2- Slide 101, coord. 34.7/110.1 x 715
Endocyst showing broad archeopyle.

3- *Deflandrea* sp. 2
Slide 52, coord. 40.1/104 x 500

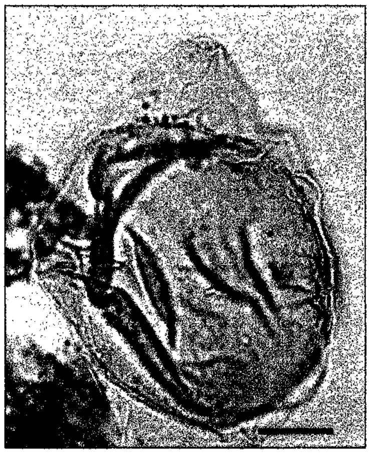
4- *Deflandrea* sp.3
Slide 13, coord. 40.7/108 x 450. Upper focus on dorsal view.

5- *Trithyrodinium* sp.
Slide 35, coord. 28/108.5 x 500
Specimen showing thin pericyst and thicker endocyst with three opercular pieces of the endoarcheopyle in place.

*6- Pierceites pentagonus* (May) Habib and Drugg, 1987
Slide 13, coord. 36.9/102 x 840

*7-9 Trithyrodinium evittii* Drugg, 1967
7- Slide 52, coord. 29.5/105.3 x 950
Endocyst with two opercular paraplates in place
8- Slide 52, coord. 34.2/103.8 x 670
9- Slide 50, coord. 41.1/110.2 x 580
Specimen showing dark brown endocyst.

# PLATE 20



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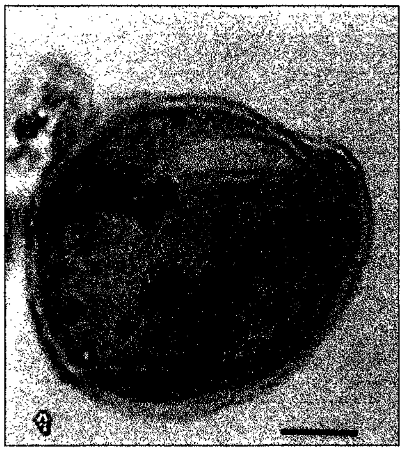

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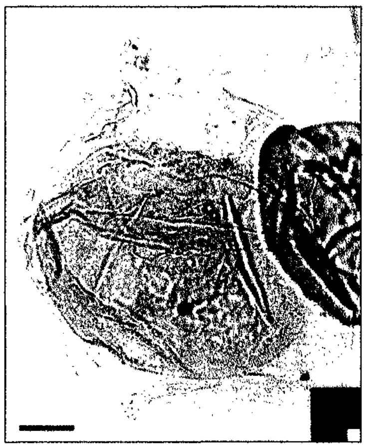

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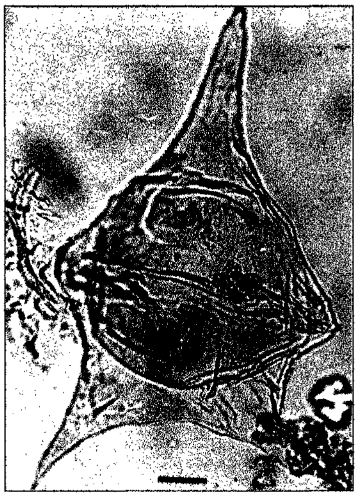

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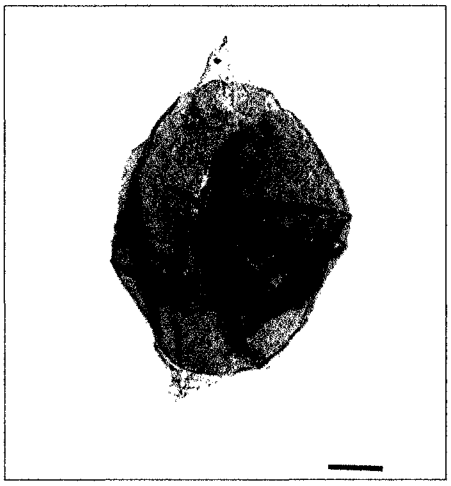

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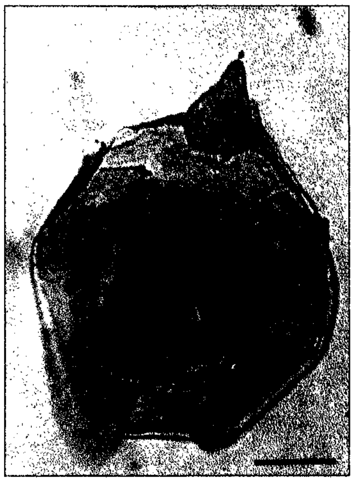

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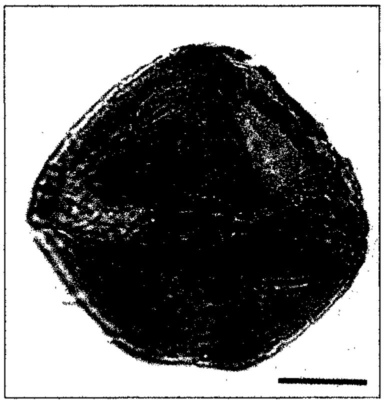

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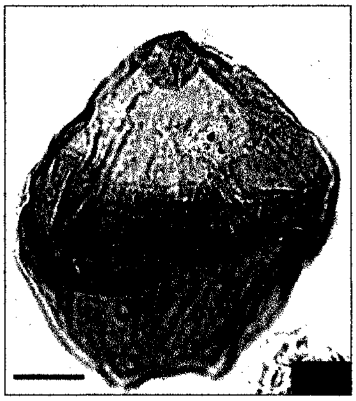


8

Bar: 20μm

9

# PLATE 21

1,2 *Phelodinium magnificum* (Stanley) Stover and Evitt, 1978.
1- Slide 44, coord. 27.2/94.4 x 430
Poorly preserved specimen with collapsed epicyst.
2- Slide 50, coord. 41.4/93 x 430

3 *Palaeocystodinium golzowense* Alberti, 1961
Slide 13, coord. 31.1/111.2 x 370

4,8 *Palaeocystodinium australinum* (Cookson) Lentin and Williams, 1976
4- Slide 93, coord. 43.3/104 x 350
8- Another specimen showing the small antapical projection on the antapical horn. x 450

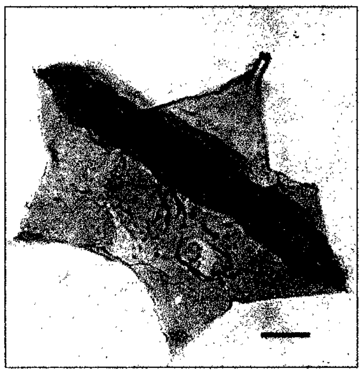
4 ?*Andalusiella* sp.
Slide 18, coord. 43.2/103.5 x 420

6,9 *Cerodinium leptodermun* (Vozzhennikova) Lentin and Williams, 1987
6- Slide 139, coord. 17.3/95 ( label to the left) x 290
Specimen with antapical horns folded.
9- Slide 51, coord. 27.6/98.3 x 390
High focus on ventral surface.

7 *Palaeocystodinium* sp.
Slide 31, coord. 28.2/99.7 x 350
Specimen showing operculum and a vestigial development of one of the antapical horns.

10 *Cerodinium* sp. cf. *C. diebelii* (Alberti) Lentin and Williams, 1987
Slide 82, coord. 36.6/103 x 311

# PLATE 21



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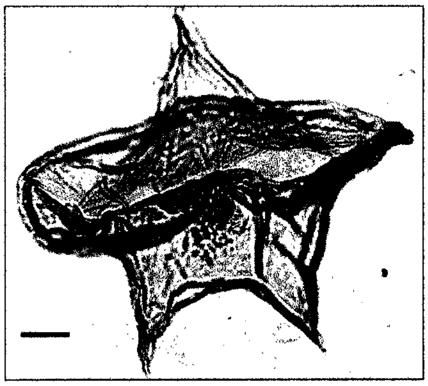

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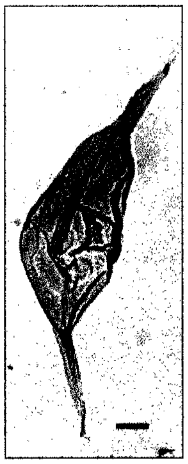

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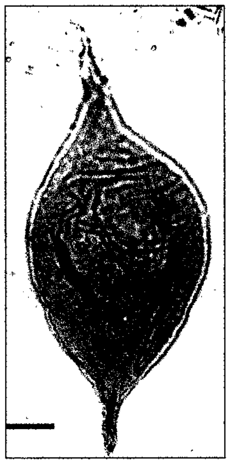

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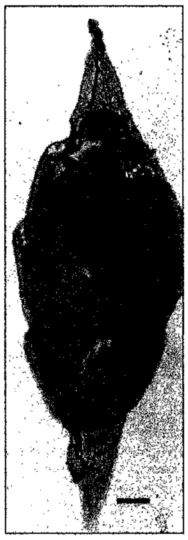

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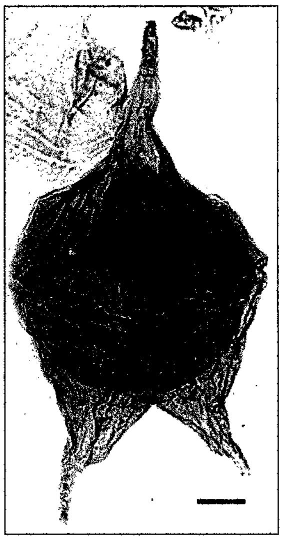


9

Bar: 20μm

10

# PLATE 22

1- Cyst of ? single celled alga of uncertain affinity
Slide 84 coord. 36.4/97 x 280

2,5 *Michrystridium* sp.
2- SEM image x 950
5- Slide 84 coord. 34.2/105.9 x 500

3 *Pterospermella australiensis* Cookson and Eisenack, 1958
Slide 36 coord. 39.7/110 x 450

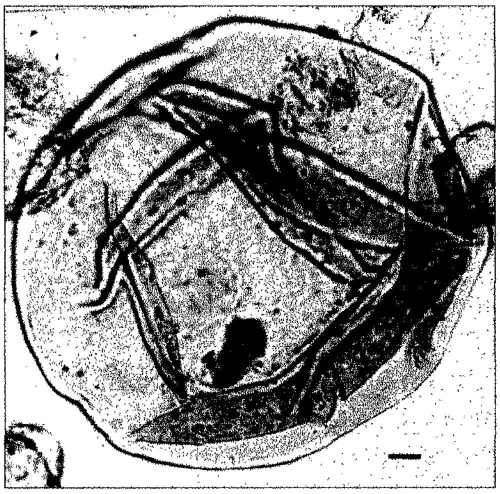
4 *Pterospermella* sp.
Slide 33 coord. 27.2/95.4 x 400

6 *Caligodinium aceras* (Manum and Cookson) Lentin and Williams, 1973
Slide 32 coord. 47.7/96.3 x 350

7 cf. *Epicephalopyxis adhaerens* Deflandre. 1937b
Slide 10 coord. 40.4/108.4 x 450

8 *Cymatiosphaera* sp.
Slide 31 coord. 52.1/110.6 x 730

# PLATE 22



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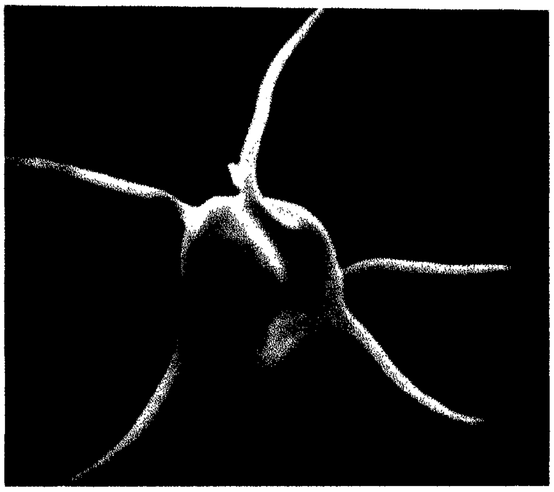

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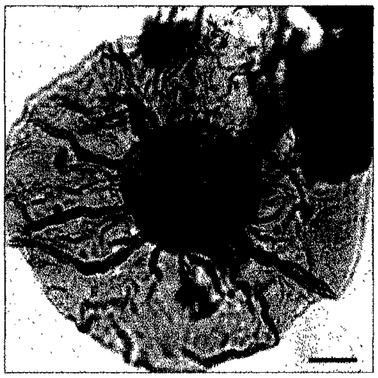

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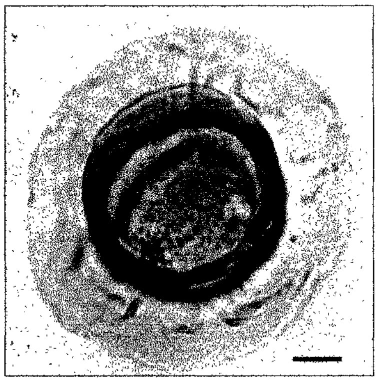

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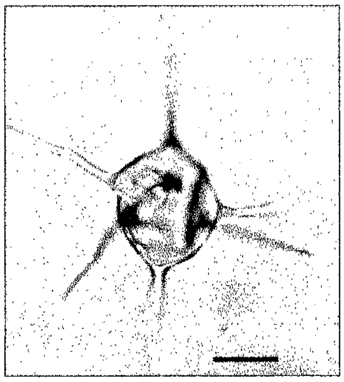

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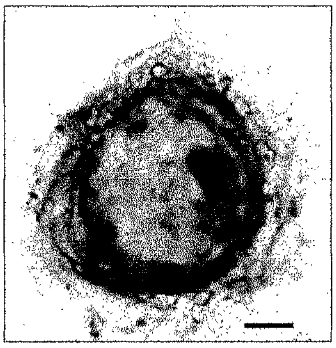
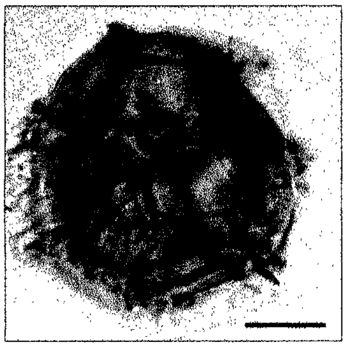


6

7

Bar: 20μm



8

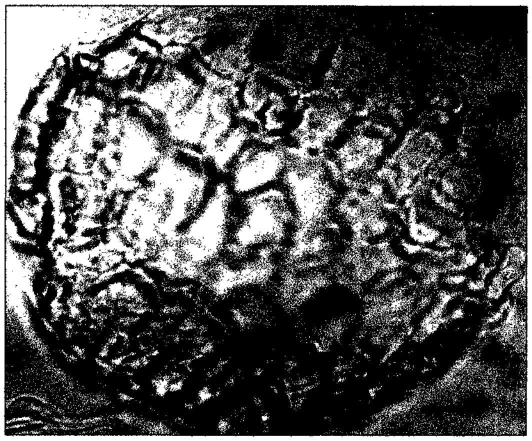
## PLATE 23

1 Colony of algae of uncertain affinity
Slide 92, coord. 36/97.1 x 570

2,3 *Palambages* spp.
2- SEM image of a colony. Taken at 1150x (Reduced for plate).
3- Slide 50, coord. 47.3/101.4 x 570

4,5,6, *Palambages* form B of Manun and Cookson
4- Slide 52, coord. 33.2/107.1 x 1000
5- SEM image of a complete colony. x 1200
6- Another specimen showing detail of opening and cell wall with punctuation. Taken at 5000x (Reduced for plate).

# PLATE 23



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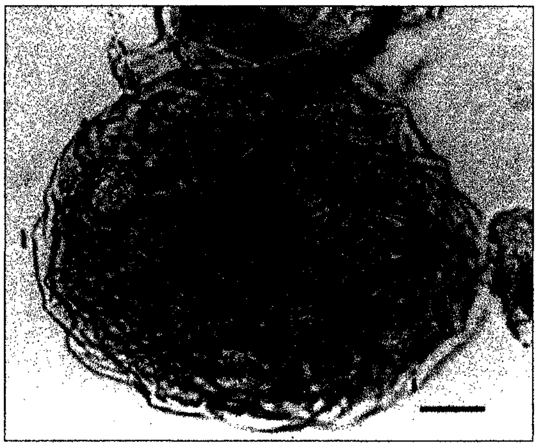

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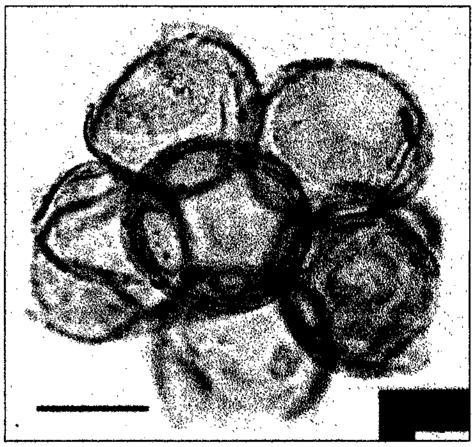

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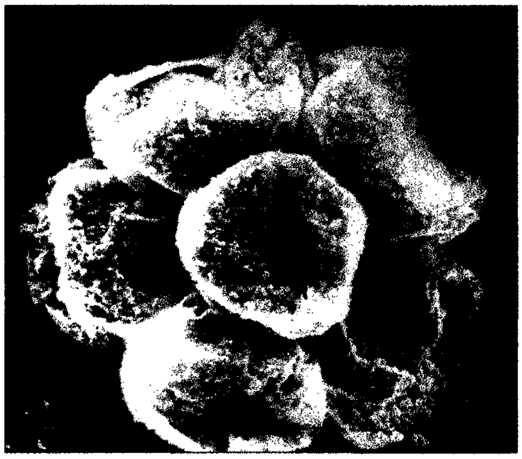

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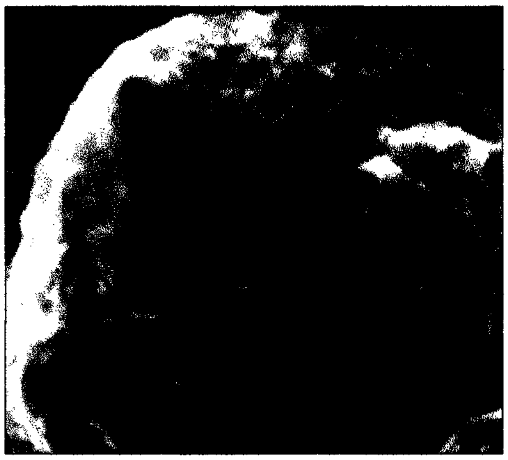


Bar: 20μm, unless otherwise stated

6

# PLATE 24

1 Spore tetrade

Slide 89 coord. 34.3/111.1 x 1000

2-3 *Grapnelispora evansii* Stover and Partridge, 1984
2- Slide 49, coord. 33.1/94.5 x 430
3- Slide 49, coord. 49.9/110.8 x 230

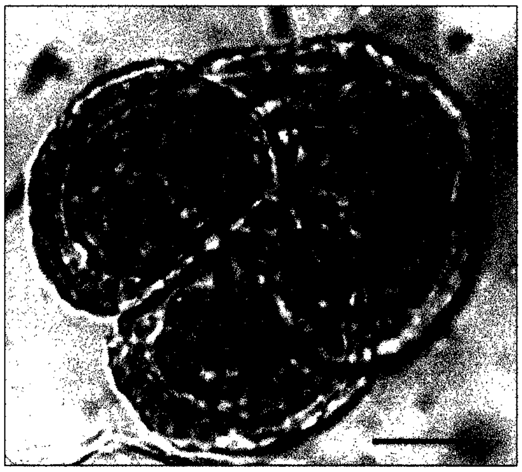
4-5 *Azollopsis* sp.
4-Slide 73, coord. 37/98.3 x 400. Masulla with microspores.
5- Detail of glochidia and microspores. x 625

6 *Azolla* cf. *cretacea* Stanley, 1965
Slide 93, coord. 35/105.4 x 470

7 *Azolla* sp.
Slide 82, coord. 33/104.2 x 370

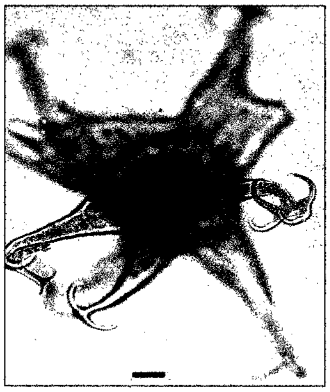
8 *Botryoccocus* sp.
Slide 85, coord. 30.8/97.3 x 620

# PLATE 24



1

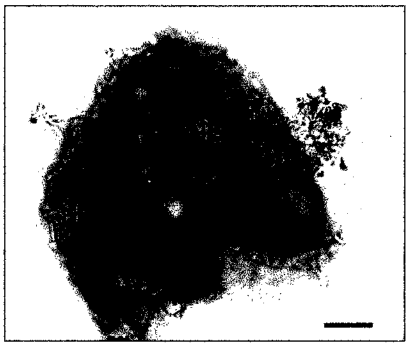
2



3

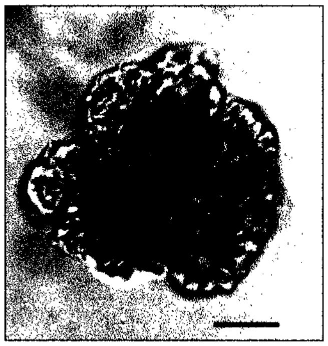
4

5



6

7



Bar: 20μm

8

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