CENOMANIAN AND TURONIAN PALYNOLOGY AND PALAEOCEANOGRAPHY OF THE WESTERN INTERIOR BASIN, UNITED STATES OF AMERICA

by

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Thesis presented in candidature for the Degree of Doctor of Philosophy

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DECLARATION

This work has not previously been accepted in substance for any degree and is not being concurrently submitted in candidature for any degree.

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Family **Areoligeraceae** Evitt, 1963

Suborder **Ceratiineae** Fensome *et al.*, 1993

Family **Ceratiaceae** Willey & Hickson, 1909

Suborder **Goniodomineae** Fensome *et al.*, 1993

Family **Goniodomaceae** Lindemann, 1928

Subfamily **Pyrodinioideae** Fensome *et al.*, 1993

Suborder uncertain

Order **Peridiniales** Haeckel, 1894

Suborder **Peridiniineae** (Autonym)

Family **Peridiniaceae** Ehrenberg, 1831

Subfamily **Palaeoperidinioideae** (Vozzhennikova, 1961) Bujak & Davies, 1983

Subfamily **Deflandreoideae** Bujak & Davies, 1983

Subfamily **Ovoidinioideae** (Norris, 1978b) Bujak & Davies, 1983

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ABSTRACT

The Cretaceous geological record of the Western Interior Seaway of North America has been extensively studied and suggests a complex and dynamic history of interrelated tectonic, eustatic, oceanographic and climatic changes. This seaway linked the Arctic ocean with the subtropical Tethyan ocean and eustatic fluctuations caused mixing of the two very different water masses affecting the sedimentological and palaeontological record. Extensive work on the lithostratigraphy, biostratigraphy, and geochemistry has resulted in a high-resolution chronostratigraphic framework allowing precise bed-by-bed correlation between sections hundreds of kilometres apart.

Cenomanian to Turonian strata from four sections and one core, from Arizona, Utah, Colorado and Kansas have been studied for their marine palynomorph and palynofacies assemblages and the biostratigraphy is described. Precise correlation of samples between the sites shows that many biostratigraphically useful taxa have synchronous ranges and that many taxa also had environmental preferences. These are subsequently used for palaeoenvironmental interpretation.

Strata from the core record the second-order transgressive-regressive eustatic Greenhorn marine cycle with superimposed third- and fourth-order fluctuations. The range of palaeoenvironments studied here include probable freshwater through near-shore to distal pelagic environments. Foraminifera have long been used in the basin for palaeoenvironmental interpretation and a direct comparison shows that the dinoflagellate cyst assemblages are equally as good at tracing sea-level and water mass fluctuations.

A global marine oxygen depletion event is suggested to have occurred at the Cenomanian - Turonian boundary. Integration of palynological data with previous work suggests that burial of amorphous organic matter at this time was related to primary productivity which increased with expansion of the Tethyan water mass at times of third- and fourth-order transgression.

This integrated, high-resolution study with tight chronostratigraphic control credits the use of dinoflagellate cysts, not only as a biostratigraphic tool but also with a very real and precise potential for palaeoenvironmental and palaeoecological interpretation.

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CHAPTER 1

INTRODUCTION

1.1 The Cenomanian - Turonian boundary event

Late Cenomanian and Early Turonian rocks of marine origin are globally characterised by the presence of organic-rich strata and anomalous carbon stable-isotope compositions. Studies of this stratigraphic interval (e.g. Schlanger *et al.*, 1987, Arthur *et al.*, 1987) suggest that they were formed at a time of oxygen depletion in parts of the worlds oceans as a result of an expansion of the oxygen minimum zone (termed an 'oceanic anoxic event' or OAE). The biotic response to this event has been well documented both from European localities (e.g. Jarvis *et al.*, 1988, Marshall & Batten, 1988, Leary *et al.*, 1989) and from the Western Interior Basin of North America (e.g. Elder, 1985, 1987, 1989, Leckie, 1985). The cause of oxygen depletion is suggested to have been slightly different in epicontinental seas such as the one that existed in the Western Interior Basin in the 'mid' Cretaceous and various theories have been proposed to explain this phenomenon (e.g. Arthur *et al.*, 1987, Glancy *et al.*, 1993, Hay *et al.*, 1993).

The original aim of this study was to look at the palynological changes across the Cenomanian - Turonian boundary, from a number of sites in the Western Interior Basin, as a means to investigate the causes of oxygen depletion. However, extensive work on the lithostratigraphy and biostratigraphy coupled with the widespread outcrops and laterally continuous bentonite (volcanic ash) marker beds gives a high-resolution chronostratigraphic framework across the basin which is unsurpassed by any other in the world (Watkins *et al.*, 1993). This provides a unique opportunity for palaeoenvironmental studies using palynological assemblages and hence an expansion of the original project. In addition, the copious amounts of published literature on this stratigraphic interval from the basin provide comparison with other data allowing testing of the palynological results.

1.2 The Western Interior Basin

The most recent published estimation for the age of the Cenomanian-Turonian boundary in the Western Interior Basin (using radiometric methods, chronostratigraphy and biostratigraphy) is 93.3 Ma ± 0.2 Ma (Obradovich, 1993). The stage boundary occurred just before a global eustatic highstand on a first-order scale (Figure 1.1), with the highest sea-levels in post-Palaeozoic eras (Kauffman & Caldwell, 1993).

The Western Interior Basin was formed during the Late Jurassic/Early Cretaceous as a foreland basin to the east of the Cordilleran thrust belt of North America. The basin flooded in the Barremian/Aptian from both the northern Arctic and the southern, subtropical Tethyan oceans, and the seaway joined in the middle from the Late Albian to the Maastrichtian (Figure 1.2), linking the two oceanic masses (Kauffman, 1985a) in a way that has no direct modern analogue (Hay *et al.*, 1993). The pattern of sedimentation in the Western Interior epicontinental sea results from a complex interplay of many factors which resulted in a dynamic palaeo-oceanographic system. These include tectonic variations (affecting subsidence and sediment supply), linked eustatic variations (resulting in a series of transgressive-regressive marine cycles) and linked

Figure 1.1

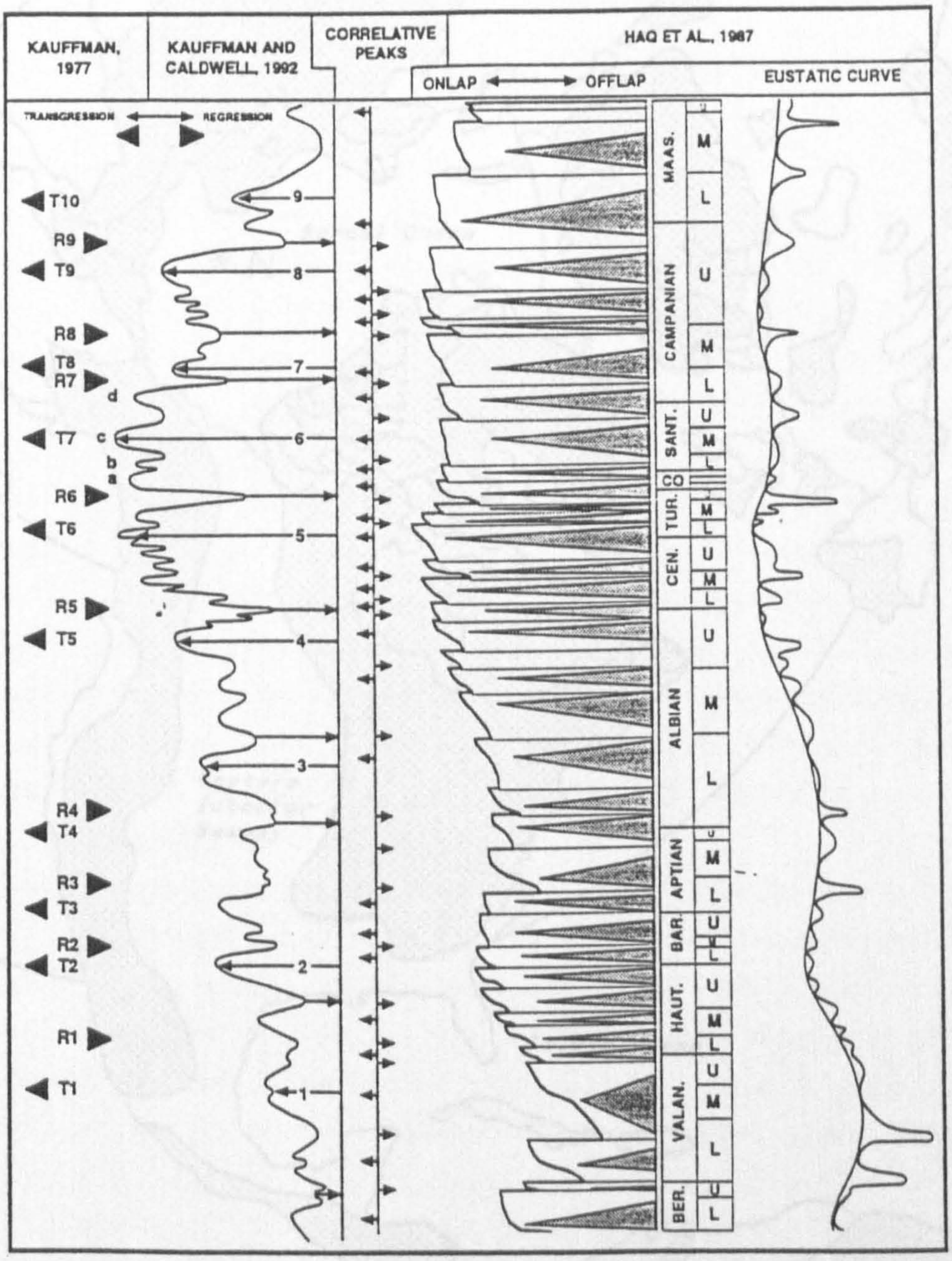


Chart showing the timing and correlation of a relative sea-level curve for first- through third- and fourth-order depositonal cycles in the Cretaceous Western Interior Basin of North America (Kauffman and Caldwell, herein), compared to (centre, right side) the onlap-offlap and eustatic curves of Haq et al. *(1987), and the very generalized system of second-order transgressive-regressive curves (left column) of Kauffman (1977, 1985). Arrows along "correlative peaks" column indicate times of very close correlation to the Haq* et al. *global cycle chart, with right-facing arrows correlative to sequence boundaries and offlap, and left-facing arrows closely correlative to major flooding events and/or eustatic highstands. Note high levels of correlation between the Western Interior Basin and the Haq* et al. *(1987) curves, suggesting a eustatic cause for most sea-level fluctuations. Nine second-order sea-level cycles are defined by numbered arrows (at peak highstand) separated by right-facing arrows marking sequence boundaries in the Western Interior Seaway. Kauffman's (1977) terminology for transgressive-regressive cycles is blended with that of Caldwell* et al., *this volume, to give the following nomenclature for second-order cycles: 1 — Beattie Peaks Cycle; 2 — Mount Goodenough Cycle; 3 — Clearwater Cycle; 4 — Kiowa-Skull Creek Cycle; 5 — Greenhorn Cycle; 6 — Niobrara Cycle; 7 — Claggett Cycle; 8 — Bearpaw Cycle; 9 — Fox Hills Cycle (new name). This numbering system replaces that of Kauffman (1977, 1984a, 1985).*

From Kauffman & Caldwell 1993

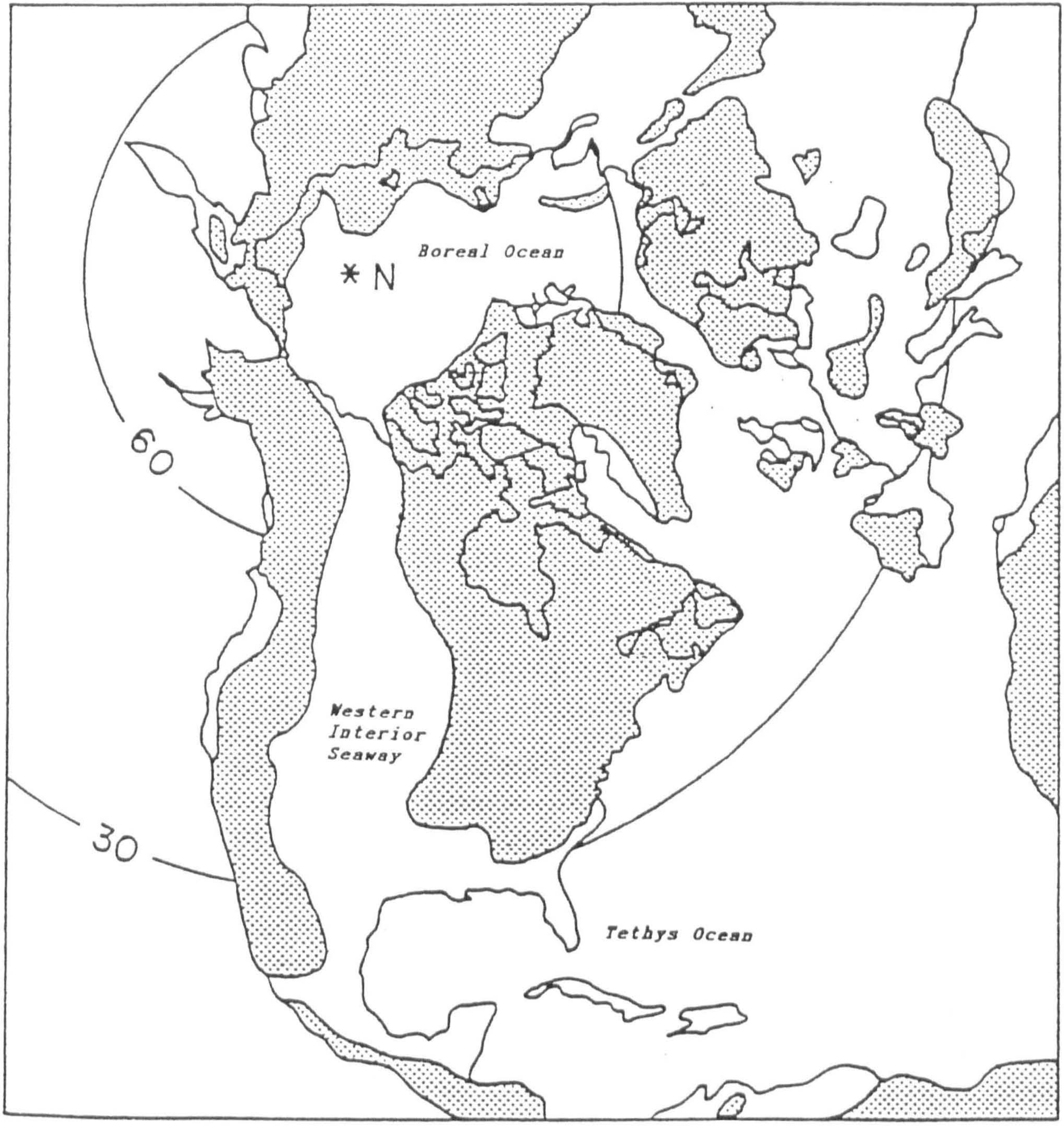


Figure 1.2

From Eicher & Diner 1989

Polar view of the Western Interior Seaway near peak transgression in the Early Turonian.

water mass movements (affecting the distribution of sediment types and fauna/flora). These in turn were modified by the local to regional palaeogeography and by local, regional and global scale climatic and oceanographic changes (Kauffman & Caldwell, 1993).

The section sites were approximately 40°N of the equator during the mid Cretaceous (e.g. Irving *et al.*, 1993). It seems likely from both the terrestrial palynological (am Ende, 1991) and marine macrofaunal (Hattin, 1975) evidence that the climate of the region was warm-temperate.

For most of its history, the seaway as far south as Colorado, was dominated by northern cool-temperate water masses (of Boreal origin) with comparatively low salinities. However, transgressive cycles enabled southern warm-temperate to subtropical waters (of Tethyan origin) to flow northward as far as Canada (Figure 1.3), carrying an associated diverse assemblage of 'normal-marine' microplankton and macrofauna (e.g. Eicher & Diner, 1989). The water mass boundaries migrated north-south over hundreds of kilometres within short time intervals (<0.5 to 1 million years) mainly associated with eustatic fluctuations (Kauffman, 1984). These in turn were linked to many oceanographic changes in terms of water temperature, chemistry, salinity, and oxygen levels as well as changing circulation, stratification and sedimentation patterns, which in turn are also linked with Milankovitch climatic cyclicity (Kauffman, 1985a). The largest and most globally synchronous of the second-order eustatic fluctuations was the Greenhorn marine cycle which began with transgression in the latest Albian and reached peak transgression in the middle Early Turonian (Figure 1.1). A pattern of third- and fourth-order sea level fluctuations are also suggested (but not identified) for the Greenhorn cycle (Kauffman & Caldwell, 1993). The extent of the seaway near peak transgression is illustrated in Figures 1.2 and 1.3.

Two temporal scales of oxygen depletion seem to have occurred within the Western Interior Basin, which are almost certainly linked. The largest is the global "Oceanic Anoxic Event" at the Cenomanian-Turonian boundary, resulting in major faunal and geochemical changes, perhaps from an expanded and intensified oxygen minimum zone occurring just before a time of first- and second-order global eustatic highstand. In addition, smaller-scale, regular, cyclical changes in oxygen levels are thought to have occurred in association with the deposition of interbedded limestone and shale couplets. Various theories are that these were produced by Milankovitch cyclicity forcing of circulation patterns; either by temperature variations with consequent productivity fluctuations (Eicher & Diner, 1985, 1989) or by climatic precipitation variations producing surface salinity fluctuations (e.g. Pratt, 1984, 1985, Arthur *et al.*, 1985, 1987). From radiometric dating, sedimentation modelling and calculations of sedimentation rates, it is thought that the Milankovitch cycles of the Bridge Creek Limestone Member are likely to have been cycles of obliquity (with a 41000 year turnaround). Calculations suggest that the cycles were too short for eccentricity and marginally too long for precession (Fischer *et al.*, 1985). The lithostratigraphic nomenclature will be discussed in detail in Chapter 3.

Much data has been gathered and results/theories documented on the Cretaceous of the Western Interior Basin of the United-States and superb stratigraphic control has been achieved using 'High Resolution Event Stratigraphy' or 'HIRES' (Kauffman, 1988b). This gives an excellent base for comparison with palynological data, collected on both a fine scale across the Cenomanian-Turonian boundary, and on a broader scale through a transgressive-regressive cyclothem. Consequently the basin represents an excellent opportunity to study palynological variations, not only in response to the Cenomanian - Turonian 'anoxic event', but also in response to other palaeoenvironmental changes on a number of temporal scales. These

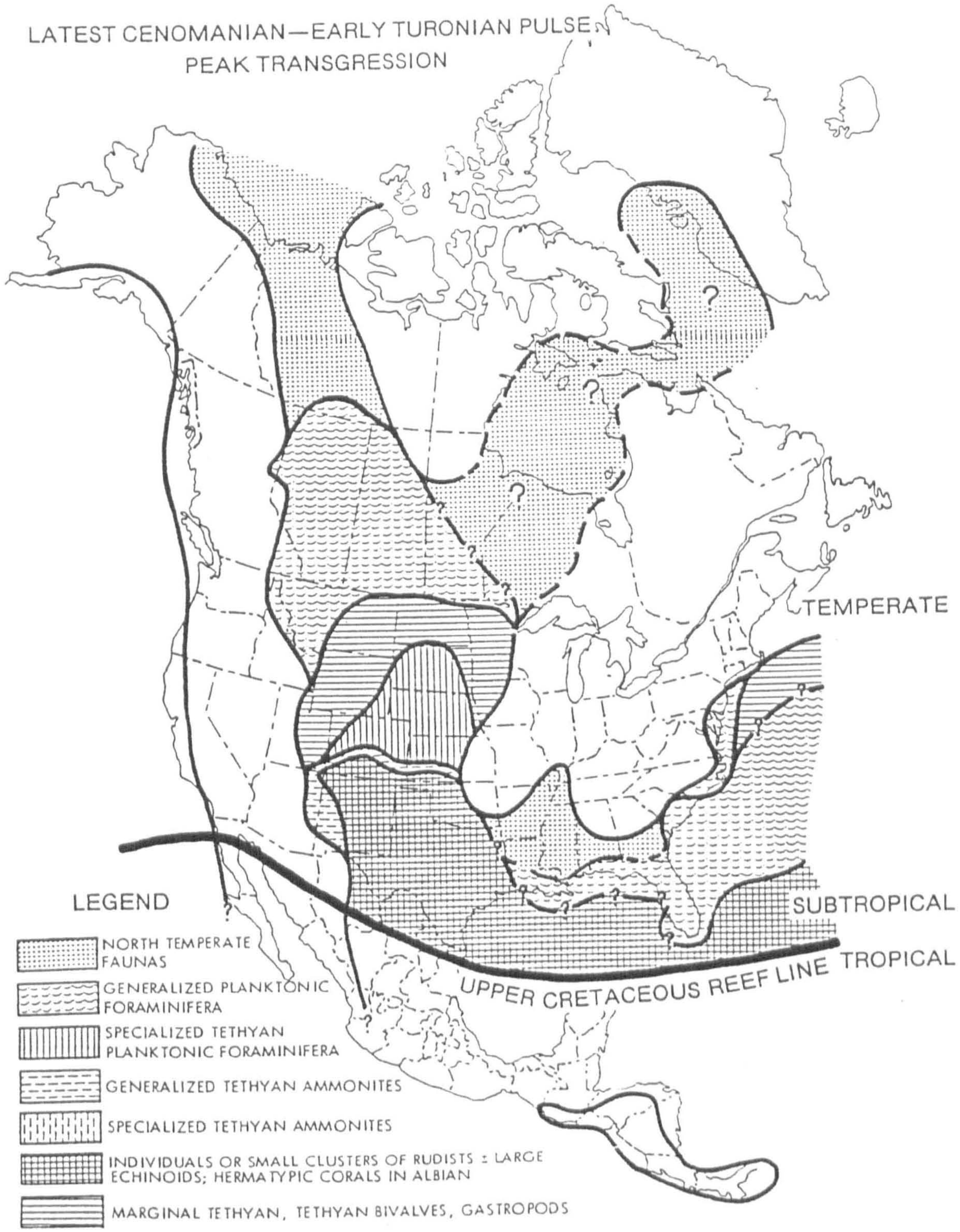


Figure 1.3

Adapted from Kauffman 1984

Generalised map of the Western Interior Seaway of North America during peak transgression of the Greenhorn marine cycle during the Early Turonian. Map shows the distribution of various subtropical organisms, defining extensive, short-term, northward migration of warm temperate and subtropical palaeobiogeographic units during rapid incursion of warm, normal marine waters into the seaway at eustatic highstand.

include palynological assemblage variations through well defined transgressive-regressive cycles; between different basinal subenvironments; with mixing of latitudinally different oceanic water masses; and with salinity and/or productivity fluctuations and potential Milankovitch related climatic fluctuations.

1.3 The aims of this study

Material has been sampled, processed and studied from strata of mid Late Cenomanian to mid Early Turonian age from four outcrop localities from Kansas, Colorado, Utah and Arizona, using the high-resolution chronostratigraphic framework, along a transect across the Western Interior Basin. In addition to the outcrop sections, a suite of samples from a subsurface core in Greeley County, Kansas, have also been examined to study longer-term changes through the second-order Greenhorn cycle.

The layout of the thesis is as follows: sampling, processing and methodology is outlined in Chapter 2; the lithostratigraphy of the core and outcrop sites is detailed in Chapter 3; the marine palynomorph taxonomy and systematics are discussed in Chapter 4; the dinoflagellate cyst biostratigraphic results are discussed in Chapter 5; and previous palynological work relevant to the objectives of the thesis is reviewed in Chapter 6.

The objectives of the thesis are to use the available data from previous work (including geochemistry, macropalaeontology and micropalaeontology) in order to determine: (1) the differences in dinoflagellate cyst and palynofacies assemblages across a basin transect with changing palaeoenvironments (bathymetries, salinities and sedimentation styles) using the available 'HIRES' chronostratigraphic control (Chapter 7); (2) the patterns of dinoflagellate cyst and palynofacies assemblage variations from the Rebecca K. Bounds core through a second-order transgressive-regressive eustatic cycle (Chapter 8); and (3) the changes in the dinoflagellate cyst and palynofacies assemblages across the Cenomanian-Turonian boundary in direct comparison with well-documented lithological, macrofaunal, microfaunal and geochemical changes (Chapter 9).

In addition the patterns of dinoflagellate cyst assemblages through the Greenhorn marine cycle and across the Cenomanian - Turonian boundary may have varied from alternations of Boreal and Tethyan oceanic water masses and some provincial relationships are tentatively suggested for some species (Chapter 8). The patterns of dinoflagellate cyst and palynofacies assemblage variations are also thought to provide some evidence for the origin of the Milankovitch related climatic, circulation and productivity and/or salinity fluctuations (Chapter 9), although the sampling was not designed for this work.

Throughout the thesis, individual marker beds will be referred to using the scheme devised for the Pueblo section by Elder & Kirkland (1985) (Figure 1.4); further discussed in Chapter 3. The locations of the core and section sites used are described in Appendix A and illustrated in Figure 3.1. The samples studied (along with their range-chart plot depths) are listed in Appendix B. Appendix C is a list of the dinoflagellate cyst and marine palynomorph species (in alphabetical order) along with their authors. The species are illustrated in Appendix D. The occurrences and abundances of individual species and of the palynofacies assemblages are illustrated in range charts, located in Appendix E.

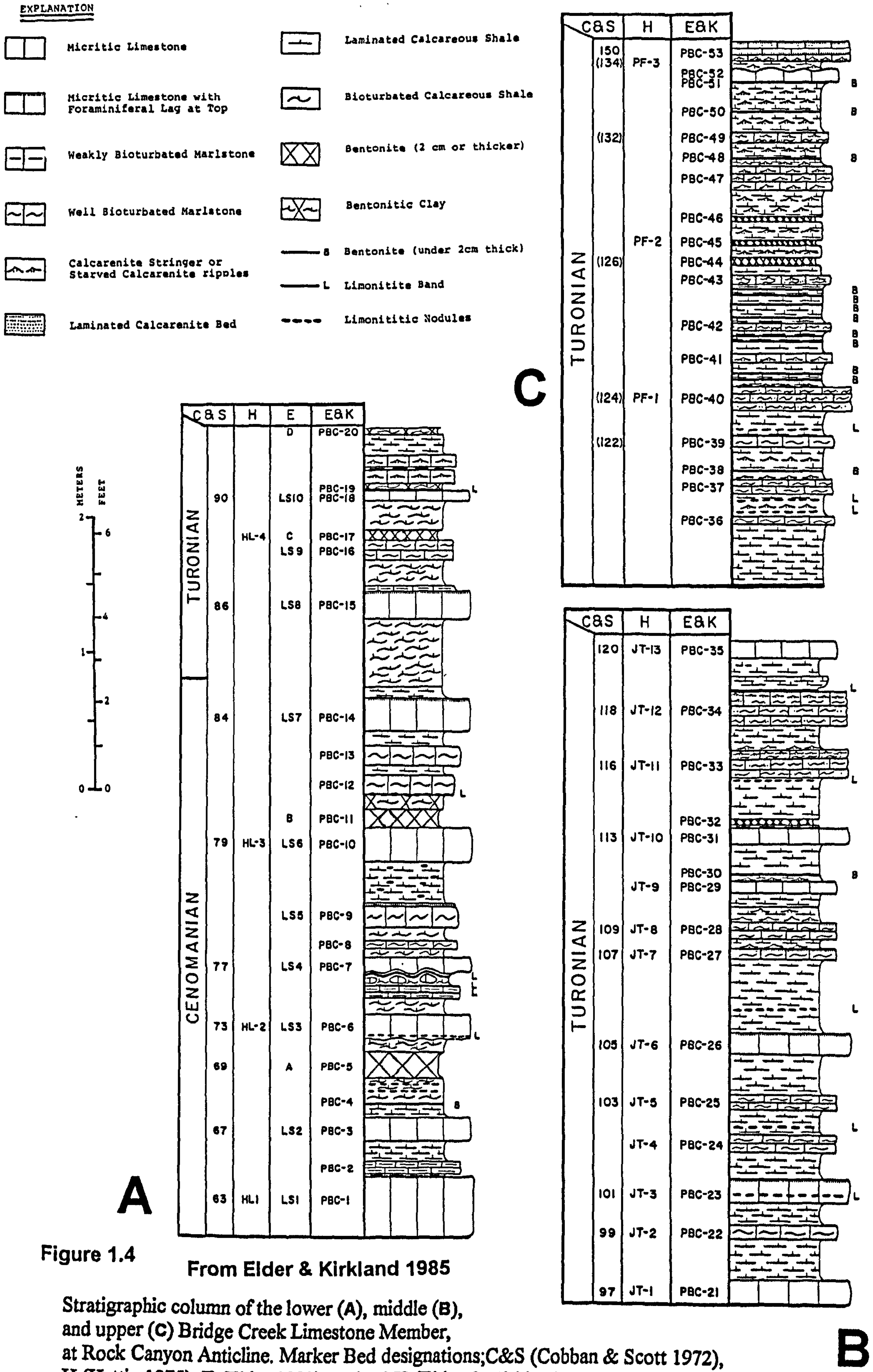


Figure 1.4

From Elder & Kirkland 1985

Stratigraphic column of the lower (A), middle (B), and upper (C) Bridge Creek Limestone Member, at Rock Canyon Anticline. Marker Bed designations;C&S (Cobban & Scott 1972), H (Hattin 1975), E (Elder 1985), and E&K (Elder & Kirkland 1985)

CHAPTER 2

METHODOLOGY

2.1 Section localities

Seven outcrop localities were visited from Kansas, through Colorado and into Utah, along a transect across the Western Interior Basin in 1992 and 1993 (Figure 2.1). One section from Kansas (Bunker Hill) and two from Colorado (Pueblo and Huerfano) were successfully sampled and processed with variable results. Two sections from Colorado (Lyons and Lower Piedra) were also sampled but were found to be palynologically barren. A further section in Colorado (Mesa Verde) was visited but not sampled owing to its very poor exposure (below several feet of regolith). The section in Utah was also visited but not sampled. All the samples taken for this section in Utah (Wahweap Wash near Big Water) and for the section in Arizona (Blue Point in the Black Mesa basin) were subsampled from material previously collected and held in storage at the Department of Geology, Colorado University, Boulder, Colorado. The locations of the sites used in this study are detailed in Appendix A.

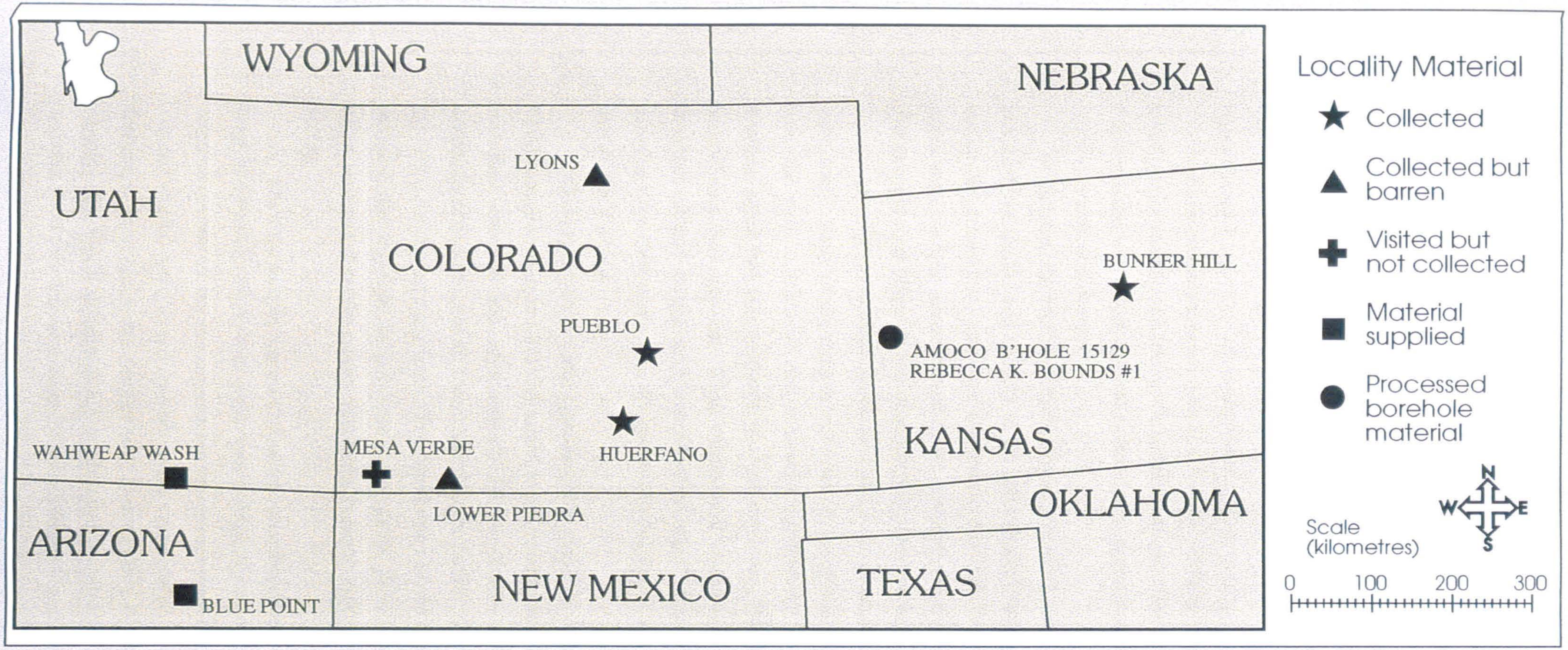
The sedimentology of the sections was not logged but previously published logs were used to locate the relative horizons during sampling. At outcrop, all the sections were found to be fairly heavily weathered and only exposed to varying degrees, but all were easily accessible.

2.2 Field sampling

Material was sampled from rock exposure after removing weathered surface material. Care was taken to ensure that the material was not contaminated by soil or by rock from adjacent horizons. The harder lithologies (for example limestones) were sampled using a hammer. Other sediments, particularly the shales were sampled using a trenching tool. Approximately 50 grams of sediment was collected for each sample, and placed in strong, sealable polybags.

In all cases channel samples (as opposed to point samples) were taken continuously along each of the sections for fixed lengths. The disadvantage of this system is that any biostratigraphic events or peaks occurring at a particular level are reduced by the rest of the material within the sample. However, the advantage is that no biostratigraphic events are missed. Any peaks or troughs in occurrences are simply decreased in magnitude.

In order to study the Cenomanian - Turonian boundary event, the interval sampled was ideally from the top of the *Sciponoceras* Zone to the base of the *Mammites* Zone (see Chapter 3 for details of biozonation schemes). This is effectively from the mid Late Cenomanian through to the mid Early Turonian. This time interval was chosen to run from the start of the extinction events to the time of full recovery, as seen in the macrofauna previously studied at these localities.



Locations of sites visited, sampled, and / or available in the Western Interior Basin, United States of America

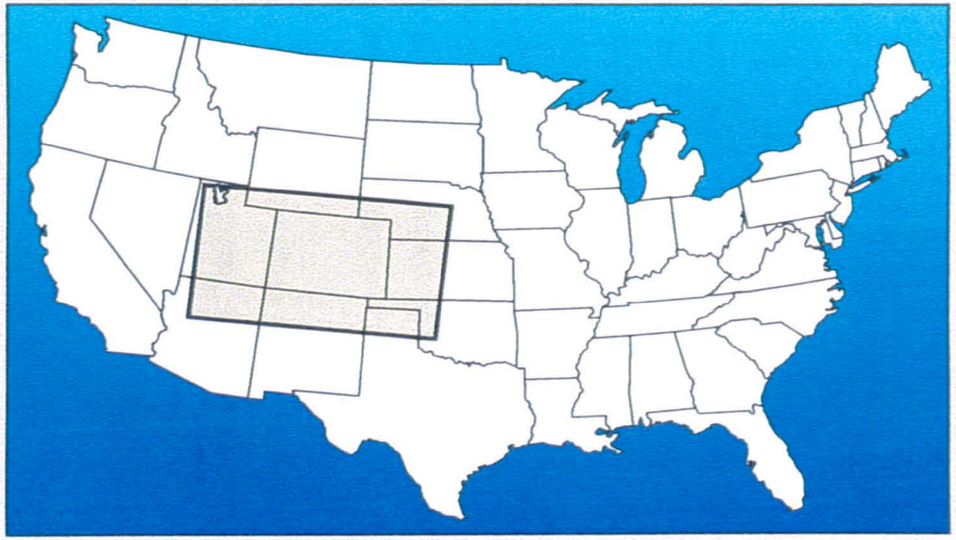


Figure 2.1

2.3 Processing techniques

The sample material covered a range of lithologies including fine-grained limestone, chalk, marl, calcareous shale, shale, siltstone and fine-grained sandstone. The samples were processed systematically, using the standard techniques outlined by Batten & Morrison (1983). Additional modifications were developed to deal with the material as a result of the sampling method (since the material was channel-sampled) and the problems inherent in the material (frequent very high levels of organic residue and pale, thin-walled dinoflagellate cysts).

Surface contamination was removed by washing the material, either by scrubbing the harder lithologies or soaking and rinsing the softer lithologies. The material was then broken down to pea-sized fragments and well mixed to try to ensure that a representative sub-sample was removed from all levels of the entire channel sample.

Initially, the Huerfano section was processed and 15 grams were taken from each sample. However, the quality and quantity of the palynological residue was poor. Consequently, for the Pueblo section 20 grams were used, and for the Bunker Hill, Blue Point and Wahweap Wash sections, 25 grams were used, to ensure that sufficient numbers of marine palynomorphs were available for logging. The samples were placed in acid-resistant polypropylene beakers, for acid digestion.

Initially, 20% hydrochloric acid (HCl) was added, slowly and carefully and initial reactions were noted. Many of the samples were rich in calcareous material and reacted vigorously. Exceptions were the more siliciclastic rich sediments, particularly from the Blue Point and Wahweap Wash sections, which had only moderate to slight reactions. The samples were topped up with further 20% hydrochloric acid and left. When effervescent reactions had ceased, the spent acid was carefully decanted off and further acid was added to ensure that all carbonate material was dissolved. The samples were then neutralised by repeatedly filling the beakers with water and decanting after the particles had settled.

Once neutral, the water remaining was decanted, and 30 to 50 millilitres of concentrated (58 - 62%) hydrofluoric acid (HF) was added to the sample, and then left at least 12 hours. The spent acid was then decanted and approximately 30 ml of concentrated hydrochloric acid and 100 ml of concentrated hydrofluoric acid were added to the sample. The beakers were then placed in a water bath (at 90°C) for at least three hours. The liquid was then decanted, and if all mineral matter had not been removed after this time the last stage was repeated. With all mineral matter removed, the samples were again neutralised by repeatedly filling the beakers with water and decanting after the particles had settled.

Once the sample was neutral, it was transferred to a sintered glass funnel, fitted with a rubber bung to a Buchner flask, with a side arm and hand-pump. The sample was then washed with plenty of water to remove all the fine organic detritus smaller than 5 μm. Many samples with very high levels of organic residue were sieved through nylon or polyester mesh screens before placing in the sintered funnels. In most cases, the samples were sieved with a 10 μm mesh but in the case of the Bunker Hill samples, the levels of amorphous organic matter were so high that a 20 μm mesh was used. The samples were then left to soak in 20% hydrochloric acid overnight to assist in removing any mineral matter remaining and then were neutralised by washing. Most of the samples were spiked at this time with *Lycopodium* tablets, as exotics for quantitative work.

Kerogen slides were then prepared by mounting a small amount of material from each sample on a glass slide, suspended in glycerine jelly. A standard amount was used from each sample by using a pipette to transfer four drops onto a glass slide and then mixing with four drops of molten jelly. The slides were then placed on a hot plate to evaporate off any water. The slide was then covered with a glass coverslip, and the following day, was sealed with 'Glyceal' to prevent desiccation. Again, the samples with large volumes of residue presented a problem, and where the kerogen on the initial kerogen slide was too dense to be studied, a further kerogen slide was made with a much thinner distribution of material.

After this basic processing was complete, several methods were used to enhance the palynomorph preparations for subsequent study.

If much fine material was still present in the sample, it could be removed by further, repeated washing of material through the glass sinter. Alternatively, much fine material was also removed by sieving the sample through a 10 μm mesh. If the sample contained many large fragments of organic matter (woody fragments or amorphous clumps), these were removed by sieving through a 150 μm mesh.

Large amounts of amorphous organic matter could be removed by oxidation and/or ultrasonic treatment. Oxidation was used to clear away some of the less resistant organic matter. Some oxidation used fuming nitric acid (98% HNO_3), added (slowly to gauge any reaction) to the sample in the glass sinter for a predetermined time (normally 5 to 15 seconds). Where large amounts of humic acids were produced, it was necessary to leave the residue in dilute ammonium hydroxide (5% NH_4OH) for 2 minutes to be neutralised. Less drastic oxidation methods were normally used, and involved the addition of concentrated nitric acid (70%) for 30 seconds, normally followed after a rinse, by Schultz's solution (a saturated solution of potassium chlorate ($KClO_3$) in concentrated nitric acid) for up to 2 minutes.

Ultrasonic treatment was used, where needed, to disaggregate matter that was clumped, coagulated or adhered to the palynomorphs. For this, the material was transferred to a beaker and placed in an ultrasonic bath for a pre-determined length of time (normally up to 1 minute). Then it was transferred back into the sinter and washed to remove the fine detritus.

After this further treatment, the remaining residue was mounted on slides as described above. If the amount of residue was still large, then it was mounted thinly and evenly over the slide. If further oxidation or ultrasonic treatment was needed, then further slides were made afterwards.

Some of the sample residues contained little organic matter (but were comparatively rich in dinoflagellate cysts) and generally needed no oxidation or ultrasonic treatment. These residues were (after the initial standard kerogen slide) transferred and condensed into concentrated kerogen slides.

Many of the samples (including all those from the Bunker Hill section and the majority from the Pueblo section) were very organic rich but not with dinoflagellate cysts. They were full of marine derived amorphous organic matter, which is fairly resistant to oxidation and small amounts of ultrasonic treatment. In addition, the dinoflagellate cyst assemblages from the basin include many peridiniacean species, many of which (particularly from the palaeoperidinioideae) are thin walled and fragile. To remove most of the amorphous matter would have involved large amounts of oxidation and ultrasonic treatment, which would have also destroyed a significant proportion of the dinoflagellate cyst assemblage. Consequently, in most cases, I restricted the oxidation to 1 minute in concentrated nitric acid and 2 minutes in Schultz's solution, and the ultrasonic treatment to 1 or 1½ minutes. This still left most of these problematical samples highly enriched in amorphous matter. Consequently, many slides had to be made for each sample, with the residue spread out thinly and evenly, to allow the dinoflagellate cysts to be seen and counted.

Once the required number of slides had been made, the remaining residues were transferred to small vials for storage, with phenol and glycerol added to prevent the growth of bacteria or fungi within the samples.

No details are available on the techniques used to process the material and make the slides from the Rebecca K. Bounds core. However, in comparison with the outcrop material, the residue in the slides is comparatively free from amorphous matter, and the palynomorphs are extremely thin-walled. It is probable that these residues have had extensive oxidation treatment and perhaps ultrasonic treatment as well.

2.4 Counting procedures: Marine palynomorphs

At least two hundred dinoflagellate cysts were logged for each sample. All the acritarchs, other algal cysts and foraminiferal test linings seen while logging the dinoflagellate cysts, were also counted in addition.

All the cysts have a tendency to move with the flow of molten glycerine jelly between the slide and cover-slip when the slides are made. Different species with different fluid-dynamic properties (as a product of their varying morphologies) have a tendency to flow different distances and consequently individual species may not be evenly distributed over the surface of the slide. In an effort to minimise this inequality of distribution, where only a small proportion of one slide was needed to achieve this count of two hundred, the cysts were logged along a number of short traverses each covering a different part of the slide.

2.5 Counting procedures: Palynofacies

The palynological slides made before subsequent oxidation or ultrasonic treatment of the kerogen were used for the palynofacies analyses. Two counts each of two hundred 'particles' have been made for each sample. The first includes palynomorphs, phytoclasts and amorphous organic matter. The purpose of the second count, which excludes the amorphous organic matter of marine origin, was to aid the determination of other environmental changes not related to oxygen levels at the sea floor at the time of deposition. It has been noted in previous palynofacies analyses (see, e.g., Steffen & Gorin, 1993) that counts involving more than two hundred particles, lead to only minor changes in relative proportions (differences of around 1%).

The particulate organic matter counted was subdivided entirely on appearance under the transmitted light microscope, based on systems outlined by several authors (e.g. Batten, 1981, Tyson, 1987, Steffen & Gorin, 1993). Palynomorphs and phytoclasts are either of terrestrial origin or of marine origin. Within marine environments, the particles of terrestrial origin are effectively controlled by physical (transportational and depositional) processes, while the particles of marine origin are affected by biological and ecological processes with subsequent redistribution by physical processes.

The fraction of terrestrial origin was subdivided into phytoclasts (black wood, brown wood, membranous material and terrestrially derived amorphous matter), and palynomorphs (pollen and spores), and represents the remains and products of higher plants. The fraction of marine origin was subdivided into marine-derived amorphous organic matter (AOM); dinoflagellate cysts and acritarchs; foraminiferal test linings; and prasinophytes.

Black Wood: These are the black, opaque fragments that are approximately equivalent to inertinite of the coal maceral group. They originate from highly oxidised (carbonised) higher plant debris. In this study the black wood was further subdivided on the basis of size and shape. Fragments larger than 300 μm were counted as 'very large black wood'. These larger fragments were not further subdivided on their shape, due to their small relative abundance in most of the preparations. Fragments smaller than 300 μm were then subdivided on their shape. Those that were elongate with a length of more than approximately twice that of the width were counted as 'elongate black wood'. The remainder, with less-elongate, square or rounded shapes, were counted as 'equidimensional black wood'. In the palynofacies assemblages in this study, the black wood fragments are fairly ubiquitous (though often in small amounts) as they are fairly resistant to degradation (from oxidation and reworking).

Brown Wood: Those fragments with an orange to brown colour (including black fragments with brown edges) were counted as brown wood (Batten, 1973). These represent the approximate equivalents of vitrinite or huminite of the coal maceral group and originate from partially oxidised higher plant debris. As with the black wood, the fragments were subdivided according to size and shape as 'very large brown wood' (fragments over 300 μm long), 'elongate brown wood' (fragments smaller than 300 μm long with a length of more than twice that of the width), and 'equidimensional brown wood' (fragments smaller than 300 μm long with a more equidimensional shape).

Membranous Material: These fragments are yellow to pale yellow and highly translucent membranes of varying thickness, and are the approximate equivalents of the coal maceral cutinite. Material with cellular structure and preserved stomata represents leaf cuticle, but much of the membranous material is of unknown origin and is considered to represent the remains of vascular plant tissue (Batten, 1981). Tyson (1987) suggests that it predominantly occurs in sediments that were deposited close to a source of land vegetation, for example, concentrated in pro-delta sediments opposite the mouths of large distributaries.

Terrestrial Amorphous Matter: This material is highly degraded macrophyte tissue (brown wood and cuticular/membranous material) although it appears very similar to the marine derived amorphous organic matter. It is comparatively easily removed by oxidation in laboratory processing (unlike the marine-derived AOM) and often close examination reveals some internal structure still preserved from the original material.

Miospores/Sporomorphs: The majority of the miospores noted in the preparations were gymnospermous pollen (mostly bisaccate grains and *Classopollis*) though some spores were recorded. No identifications of miospores were attempted apart from the subdivision into pollen and spores. The abundance of sporomorphs in marine sediments is controlled by the climate of the source area, the texture of the sediment and the proximity to fluvial inputs, while aeolian transport is considered to be quantitatively insignificant (Tyson, 1987). Sporomorph assemblages are strongly affected by hydrodynamic sorting processes. One common proximal-distal trend is the gradual reduction in proportions of larger, denser pteridophyte spores. Simple spherical pollen grains (such as *Classopollis*) show little fractionation and as a result gradually increase in proportionate numbers with the decline of other morphotypes (Tyson, 1987).

Amorphous Organic Matter (AOM): This consists of aggregates of granular, floccular, fluffy and structureless organic matter of algal/bacterial origin or of zooplankton faecal origin, and the degraded remains of other particulate organic matter and of faecal pellets. In many samples, particularly from the Bunker Hill section, the faecal pellets are still visible in the palynological preparations in variable proportions as lozenge-shaped clumps. The counting of this matter was not easy when the material was broken up and scattered across the slide preparation but individual pieces or clumps were counted if of a reasonable size (approximately 20 µm or more). The presence of this material indicates low energy, low oxygen (at least anaerobic) conditions in the water column or at the sediment water interface (Tyson, 1987). The material is resistant to oxidation in the palynological preparation techniques (Batten, 1981, Batten & Morrison, 1983).

Foraminiferal Test Linings: The foraminiferal linings are the tough organic linings of some benthic and planktonic foraminifera. Those preserved in the slides are the number of individuals that attained sufficient maturity for their pre-adult chambers to be thick enough to survive microbial degradation and palynological preparation techniques (Powell *et al.*, 1992). The complete lack of foraminiferal linings in the slides from the Rebecca K. Bounds core seems likely to have been due to heavy laboratory preparation techniques.

Dinoflagellate cysts and acritarchs: These two groups were counted as one in the palynofacies study as the acritarchs are probably also cysts of planktonic origin and only occur in comparatively small numbers in this study.

Prasinophytes: In this study the leiospheres were included as they are also probable prasinophyte phycomas.

2.6 The use of exotics

As has been mentioned above, *Lycopodium* tablets were added to most of the samples for subsequent quantitative work. Each tablet contains an average of 13911 *Lycopodium* spores, which are then distributed among the sample in the sinter and can be used to determine the proportion of the starting material seen when counting palynomorphs.

One sample (BMS4 20D-24 / PRCIES 3142) had all of its recoverable residue transferred onto slides (one standard kerogen slide and two concentrated kerogen slides). The exotics were added directly to the processed residue on the sinter, and consequently, none of them could have been lost by processing methods such as decanting or sieving. No further processing (oxidation or ultrasonic treatment) was needed which might have been responsible for destroying these exotics. No residue was left in the sinter to be stored.

All of the slides for this sample were looked at and all of the *Lycopodium* spores were counted. The final total after viewing all of the kerogen from the processing only came to 1203 spores. The number of spores counted was less than 10% of the number that should have been seen, since approximately 13911 spores should have been in those slides. It is possible that somehow the spores were lost, for example lodged in the sinter. However, this seems unlikely. As a result of this test, for the remainder of the samples, no further *Lycopodium* spikes were counted, since this method for determining absolute values within this material was considered highly unsatisfactory.

CHAPTER 3

SECTION DETAILS AND CORRELATION

3.1 INTRODUCTION

Material has been studied from four outcrop localities in a transect across the Western Interior Basin (Figure 3.1). These include sections from Bunker Hill (Kansas), Pueblo (Colorado), Wahweap Wash (Utah) and Blue Point (Arizona). A fifth section has also been kindly donated by Amoco Production Company (already processed) from core material from their Rebecca K. Bounds borehole, from Greeley County, also in Kansas. The locations of these sites are detailed in Appendix A.

These localities were selected to provide a range of environments across the basin in an East-West transect (Figures 3.2 and 3.3). The more eastern parts of the basin in Kansas (Bunker Hill section) have been interpreted as fairly shallow water carbonate-rich environments close to the eastern edge of the basin, with the environments deepening westwards into more "normal" marine conditions, at the centre of the basin (Rebecca K. Bounds core and Pueblo section). The other two localities from further west (Blue Point and Wahweap Wash sections), are more expanded with a much greater terrestrial/clastic input, nearer the western edge of the marine basin.

The core has been studied in order to look at longer-term palynological changes, to hopefully place in perspective the detailed changes noted from the four boundary sections. These include trying to differentiate between environmental, ecological and biostratigraphical reasons for changes in palynological assemblages.

The Cretaceous stratigraphy of the Western Interior Basin ranges through a series of transgressive-regressive marine cycles (Figure 1.1). The Cenomanian-Turonian boundary event occurred near the peak of one of these cycles referred to as the Greenhorn cycle (e.g. Kauffman & Caldwell, 1993). In the Western Interior Basin the resultant cyclothem has been subdivided into a number of lithostratigraphic schemes, depending on locality (Figure 3.4). The samples from the Rebecca K. Bounds core studied cover most of the marine sedimentation from the Greenhorn cycle and range in age from the Early Cenomanian to Middle Turonian. All the samples studied in detail from the remaining (outcrop) sections only cover a small part of the cyclothem and are effectively from sediments from the middle of the Late Cenomanian through to the middle of the Early Turonian.

The sections were not logged for this study and consequently all the information on the lithostratigraphy, petrology and palaeontology has come from the large range of literature published on the Western Interior Basin. Among the articles most heavily utilised were: Elder & Kirkland, 1985 (for the Pueblo section); Hattin, 1975 (for the Bunker Hill section); Elder, 1987, Kirkland, 1991 (for the Blue Point section); Lawrence, 1965, am Ende, 1991, and Elder, 1991 (for the Wahweap Wash section); and unpublished original descriptions of the Rebecca K. Bounds core by R.W. Scott and P.C. Franks kindly donated by AMOCO Production Company.

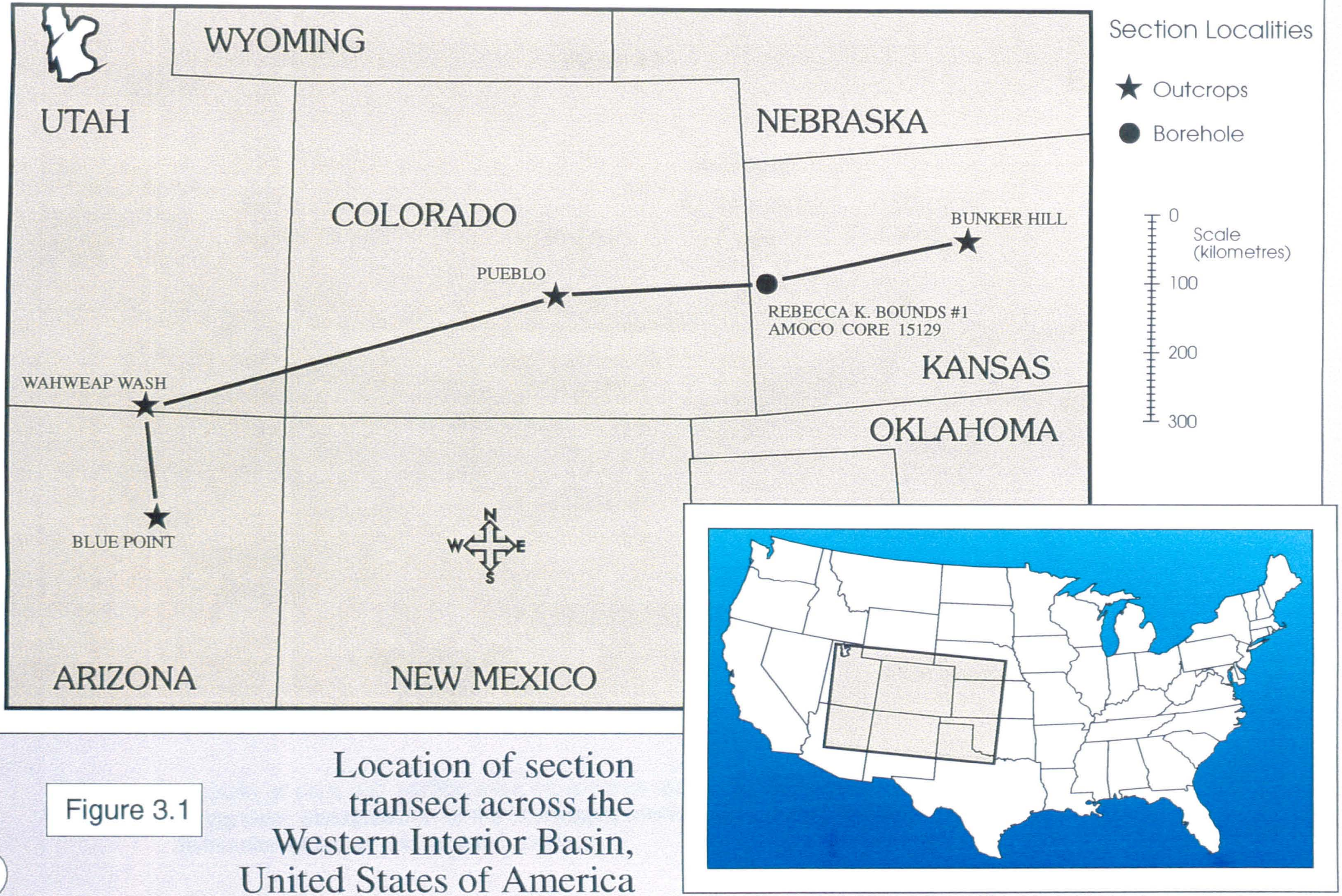
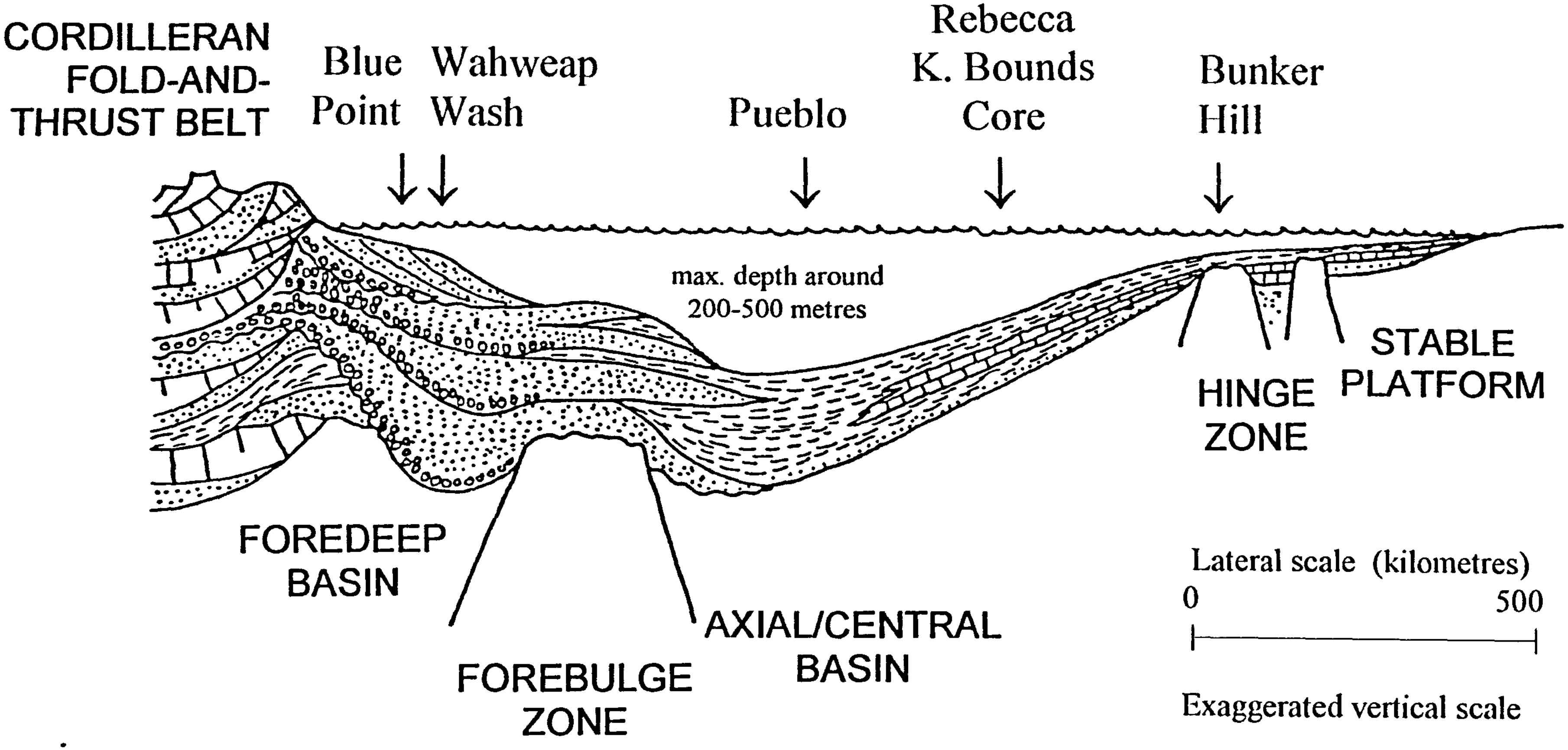


Figure 3.1

Location of section transect across the Western Interior Basin, United States of America

Figure 3.2



Adapted from Kauffman 1988

Location of core and section sites on a cross-section of the Western Interior foreland basin during peak transgression of the Greenhorn marine cycle during the Early Turonian, showing distribution of facies and tectonic zones.

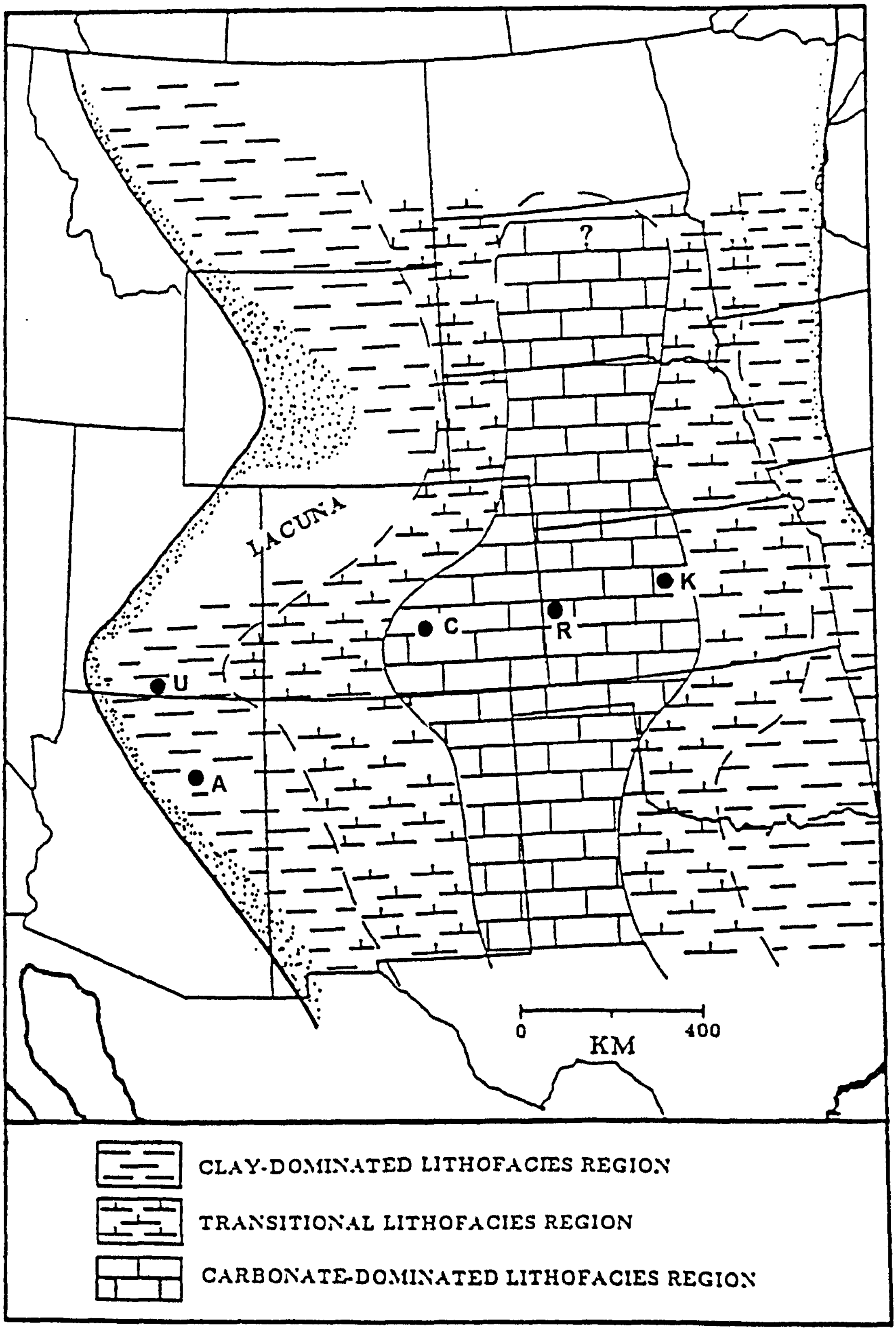


Figure 3.3

Adapted from Elder 1991

Map of the Western Interior of the United States showing shoreline and lithofacies configurations just prior to the Cenomanian - Turonian boundary, during the time of deposition of the material from the *Neocardioceras* Zone. Section sites illustrated are: A - Blue Point, Arizona; U - Wahweap Wash, Utah; C - Pueblo, Colorado; R - Rebecca K. Bounds core, Kansas; K - Bunker Hill, Kansas.

3.2 BIOZONATION AND HORIZON-LABELLING SCHEMES

A number of biostratigraphic schemes have been constructed from work on the Western Interior Basin. For the purposes of this project, the scheme used is that from Kauffman and Pratt (1985), based on inoceramid bivalves and ammonites. In particular, the ammonite zonation (originally proposed by Cobban & Scott, 1972) will be used through this study. The ammonites involved include *Metoicoceras mosbyense*, *Sciponoceras gracile*, *Neocardioceras juddii*, *Watinoceras* spp., and *Collignoniceras woollgari* (see Figure 9.4 for authors). For brevity, through this study, the zones based on the occurrence of these ammonites will be respectively referred to as the *Metoicoceras*, *Sciponoceras*, *Neocardioceras*, *Watinoceras*, and *Collignoniceras* Zones.

A more recent, refined and updated biozonation scheme has been published (Kauffman *et al.*, 1993) but the bulk of the extensive amount of literature used for this study has not been written using this most recent scheme. Hence, to try and apply it to all the work already published would be a time consuming and problematical task and would probably not significantly aid the objectives of this project.

As will be discussed in detail later on, the lithostratigraphic horizons in this high-resolution study have been correlated and labelled according to a number of different schemes. The labelling system adopted for this project is the one outlined by Elder & Kirkland (1985) for the section at Pueblo, Colorado (Figure 1.4).

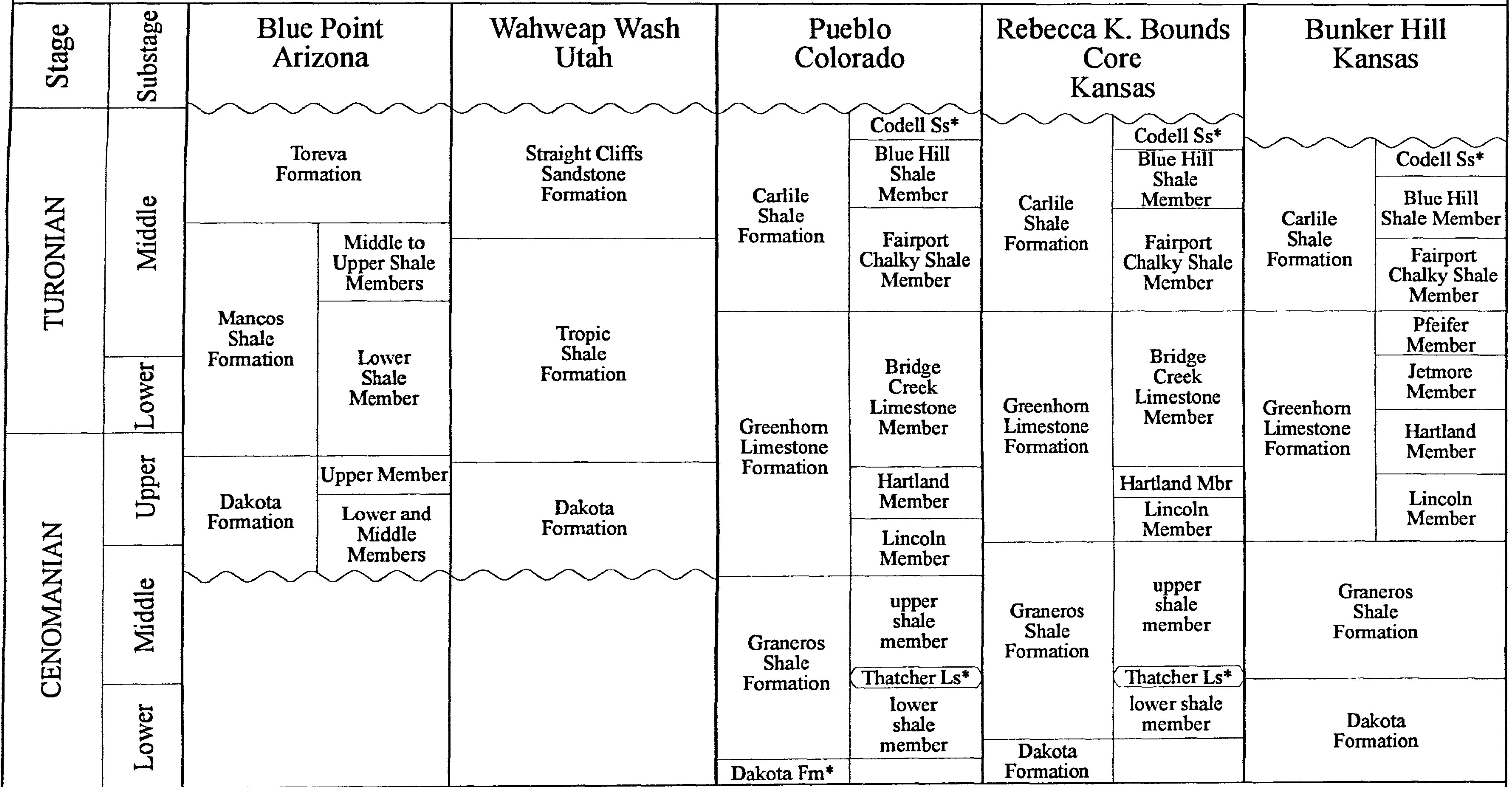
Many other schemes (e.g. Cobban & Scott, 1972, Hattin, 1975, Elder, 1985, 1987, 1989, 1991, Kirkland, 1991) have labelled the horizons not just from Pueblo, but for equivalent sections across the rest of the basin, and thus might be more suitable for applying to basin-wide studies.

However, the Pueblo section is the most intensively studied of all the sections from the basin, and hence represents the key to understanding much of the oceanography and event stratigraphy from the basin. The labelling system used by Elder & Kirkland (1985) is (in this author's opinion) the most detailed one as yet published for the lithostratigraphy of the Pueblo section. Hence, although the bed numbers are labelled from the Bridge Creek Limestone Member at Pueblo (PBC) from limestone and bentonite horizons, their stratigraphically equivalent numbers have been used in this study to label the strata of the other sections studied.

The Blue Point and Wahweap Wash sections have a number of bentonite horizons in the upper half of the stratigraphy studied, which have not been labelled in previously published literature. However, these seem to be correlatable based on the dinoflagellate cyst event stratigraphy (the details of which are discussed later and illustrated in Figure 3.15) and hence will be labelled using a WB (western bentonite) prefix, with numbers based approximately around the stratigraphic levels from the equivalent Pueblo Bridge Creek Limestone Member horizons.

Comparison of the lithostratigraphic units of the Greenhorn cyclothem across the Western Interior Basin

Figure 3.4



Stage	Substage	Blue Point Arizona		Wahweap Wash Utah	Pueblo Colorado		Rebecca K. Bounds Core Kansas		Bunker Hill Kansas	
TURONIAN	Middle	Toreva Formation Mancos Shale Formation	 Middle to Upper Shale Members Lower Shale Member	Straight Cliffs Sandstone Formation Tropic Shale Formation	Carlile Shale Formation Greenhorn Limestone Formation	Codell Ss* Blue Hill Shale Member Fairport Chalky Shale Member Bridge Creek Limestone Member	Carlile Shale Formation Greenhorn Limestone Formation	Codell Ss* Blue Hill Shale Member Fairport Chalky Shale Member Bridge Creek Limestone Member	Carlile Shale Formation Greenhorn Limestone Formation	Codell Ss* Blue Hill Shale Member Fairport Chalky Shale Member Pfeifer Member
	Lower									Jetmore Member Hartland Member
CENOMANIAN	Upper	Dakota Formation	Upper Member Lower and Middle Members	Dakota Formation		Hartland Member Lincoln Member		Hartland Mbr Lincoln Member		Lincoln Member
	Middle				Graneros Shale Formation	upper shale member Thatcher Ls*	Graneros Shale Formation	upper shale member Thatcher Ls*	Graneros Shale Formation	
	Lower				Dakota Fm*	lower shale member	Dakota Formation	lower shale member	Dakota Formation	

Adapted from Kauffman *et al.*, 1976, Peterson & Kirk, 1977, Cobban & Hook, 1984, Merewether & Cobban, 1986, Kirkland, 1991, Olesen, 1991, Kauffman *et al.*, 1993

* Dakota Fm = Dakota Formation, Thatcher Ls = Thatcher Limestone Member, Codell Ss = Codell Sandstone Member

3.3 DETAILED LITHOSTRATIGRAPHY AND SEDIMENTOLOGY

3.3.1 Rebecca K. Bounds Core

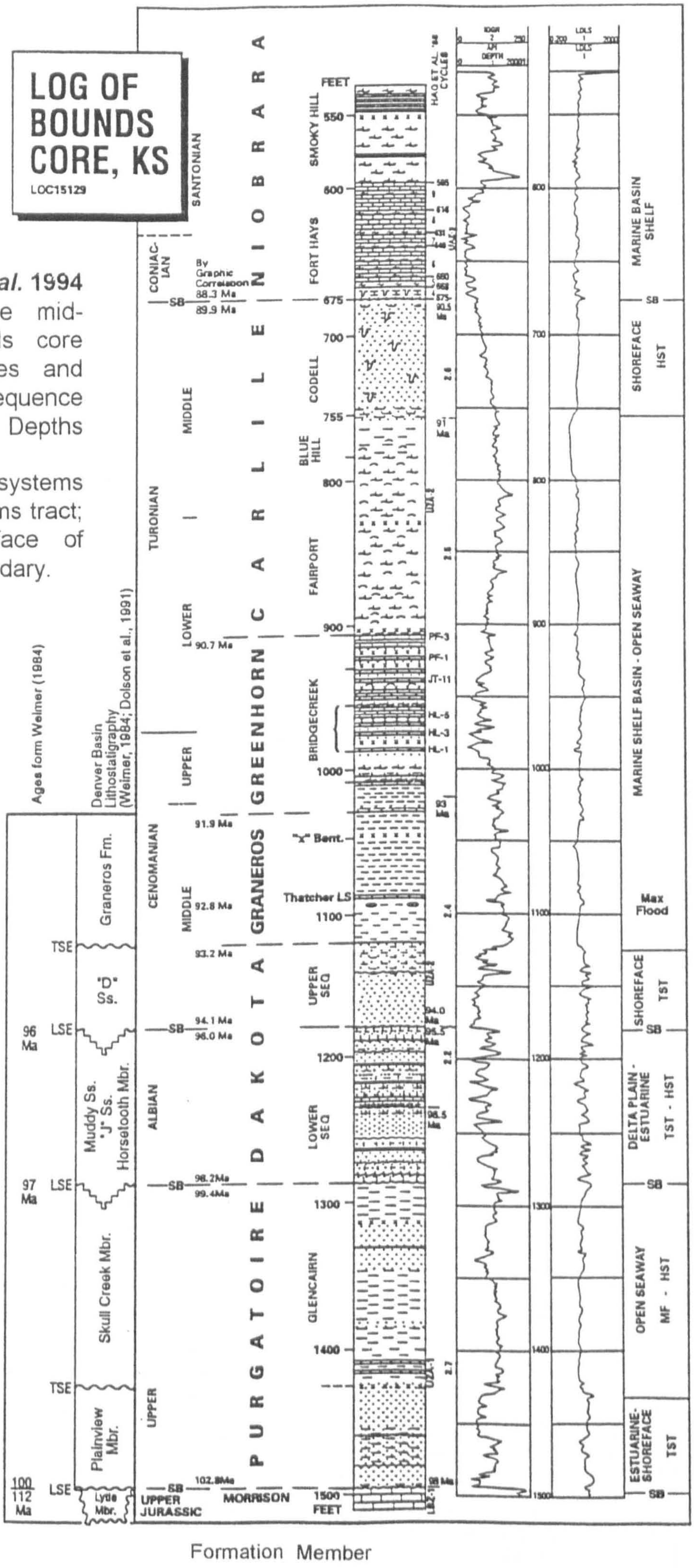
3.3.1.1 Lithostratigraphy: The Rebecca K. Bounds No.1 core (AMOCO locality 15129) from western Kansas has a continuous record through the mid Cretaceous from below the base of the Purgatoire Formation (Upper Albian) to the middle of the Smoky Hill Member of the Niobara Formation (Santonian) (Figure 3.5). This involves a number of transgressive-regressive cycles. In order to study longer term basinal effects in the Cenomanian and Turonian, most of the Greenhorn cyclothem was studied.

In Colorado and Kansas, the Greenhorn cyclothem has been subdivided into four formations; the Dakota (Dakota Fm.), Graneros Shale (Graneros Fm.), Greenhorn Limestone (Greenhorn Fm.) and the Carlile Shale (Carlile Fm.) (originally applied by Gilbert, 1896). The Cenomanian-Turonian boundary sections all lie within the Greenhorn Limestone Formation. At Pueblo the Graneros Shale Formation has been subdivided into the lower shale member (informal), the Thatcher Limestone Member (Thatcher Mbr.) and the upper shale member (informal) (Kauffman, 1985b) and this scheme has been adopted for this study (Figures 3.4 and 3.6). In western Kansas the Greenhorn Limestone Formation has been further subdivided into the Lincoln Limestone Member (now Lincoln Member), Hartland Shale Member (now Hartland Member) and Bridge Creek Limestone Member (Bass, 1926). The Carlile Formation has been further subdivided into the Fairport Chalky Shale Member (Fairport Mbr.), the Blue Hill Shale Member (Blue Hill Mbr.) and the Codell Sandstone Member (Codell Mbr.) (Rubey & Bass, 1925).

The lithostratigraphic contacts are not necessarily temporally equivalent between Colorado (Pueblo section), western Kansas (Rebecca K. Bounds core) and central Kansas (Bunker Hill section) as illustrated in Figure 3.4. The Bridge Creek-Hartland contact is temporally equivalent in Colorado and western Kansas, but it is not temporally equivalent to the Jetmore-Hartland contact of central Kansas (where it occurred later). The Hartland-Lincoln contact is not temporally equivalent in Colorado (where it occurred the earliest), western Kansas or central Kansas (where it occurred the latest). The Lincoln-Graneros contact is temporally equivalent in central and western Kansas, but is not temporally equivalent to the Lincoln-Graneros contact in Colorado (where it occurred earlier).

3.3.1.2 Sampling: Thirty-nine samples were used, from the top of the Blue Hill Member of the Carlile Shale Formation (at a depth of 750' (228.60m)), down to the top of the Dakota Formation (at a depth of 1128' (343.81m)) (Figure 3.6). The samples used were spaced at 10' (3.05m) intervals from 750' (228.60m) down to 1110' (338.33m)) apart from the bottom two at 1119.5' (341.22m) and 1128' (343.81m). The length of the core used was 378' (115.21m). For the sake of simplicity through this study, sample depths will continue to be referred to in feet (rather than metres as in the case of the other sections), owing to the original sampling depths taken at 10' intervals.

Figure 3.5



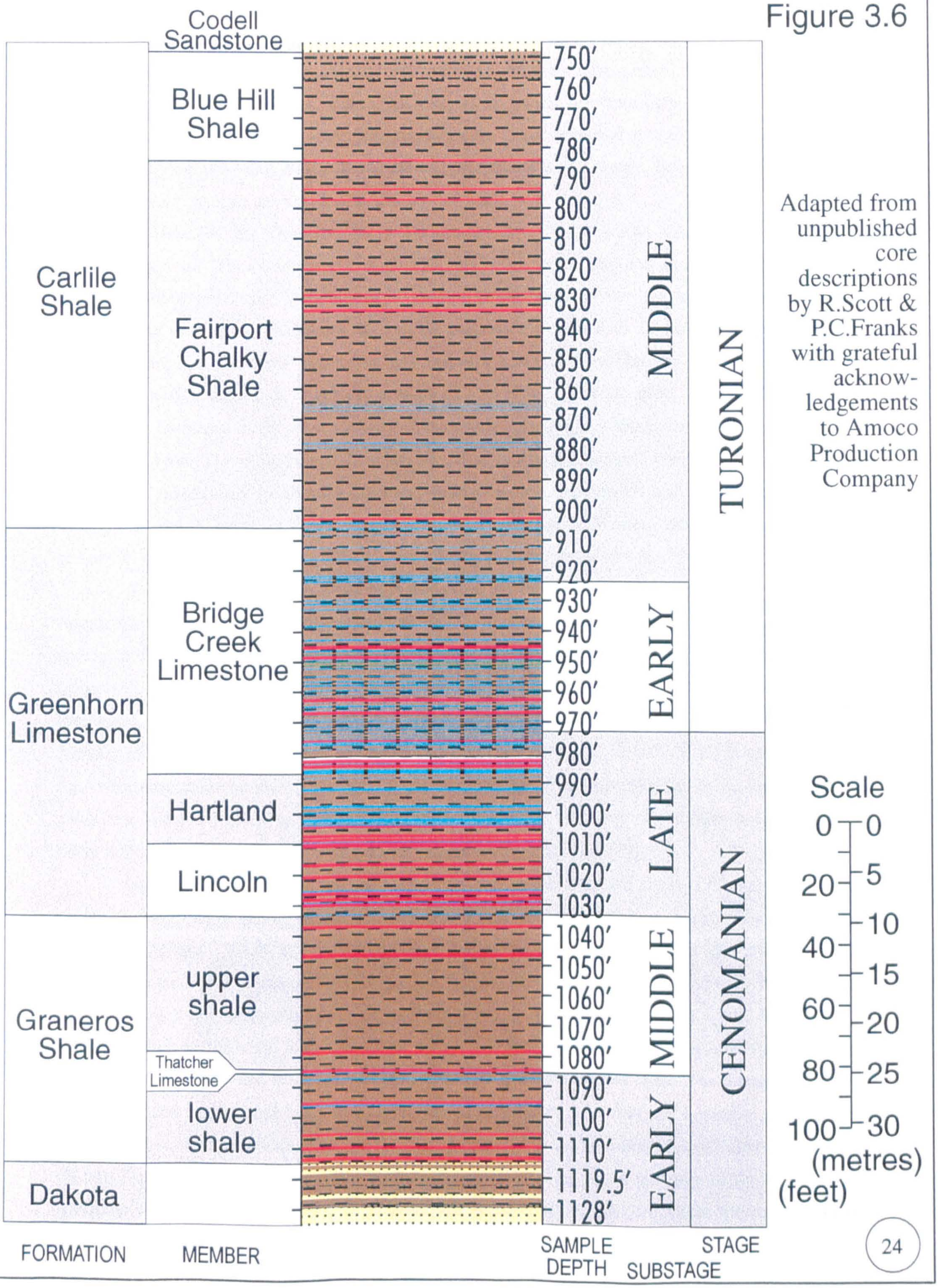
From Scott *et al.* 1994

Lithological section of the mid-Cretaceous in the Bounds core showing depositional cycles and subcycles and a sequence stratigraphic interpretation. Depths are from the well logs.

TST - transgressive systems tract; HST - highstand systems tract; TSE - transgressive surface of erosion; SB - sequence boundary.

Lithostratigraphy of the Greenhorn Marine Cyclothem from the Rebecca K. Bounds Core #1 (Amoco Core 15129), Greeley County, Kansas

Figure 3.6



Adapted from unpublished core descriptions by R.Scott & P.C.Franks with grateful acknowledgements to Amoco Production Company

<u>3.3.1.3</u> **Petrology & Sedimentology:** The descriptions here are taken from unpublished original core descriptions by R.W. Scott and P.C. Franks kindly donated by AMOCO Production Company. Where the original descriptions are sparse, additional information has also been used from other relevant lithostratigraphic studies.

The Dakota Formation consists of layers of dark to light grey, interbedded sandstones, siltstones, shales and mudstones. The sands tend to be poorly to moderately sorted and often well bioturbated and burrowed with some shaly laminations. Basal erosional contacts are common. Below 1119.8' carbonaceous plant flakes and fragments are found in the sands. Below 1126.6' carbonised leaves and plant imprints are also found in shaly horizons.

The base of the Graneros Shale Formation (at 1115.0') grades sharply into the Dakota Formation beneath. The Graneros Fm. is 83' (25.30m) thick in the core and represented by dark grey, slightly to moderately silty, well-laminated, shale with scattered pyrite. The shale is generally non-calcareous to very poorly calcareous, though the carbonate content does increase slightly towards the top. There are also occasional calcisiltite and bentonite horizons. The Thatcher Mbr. (at 1083.6') is a prominent marker across the basin as a thick (1.7'/0.52m), moderate grey, laminated, micritic to calcarenitic limestone bed, with scattered moderate to dark grey, shaly laminae and an erosive calcarenitic base. The shale below the Thatcher Mbr. is thinly laminated with some *Planolites* type burrows in calcarenitic zones, and scattered, though scarce, inoceramid and other shell fragments throughout. The 'X' bentonite is also a significant marker across the Western Interior Basin and occurs at 1046.4'. In Colorado, the base of the Lincoln Member occurs just above the 'X' bentonite.

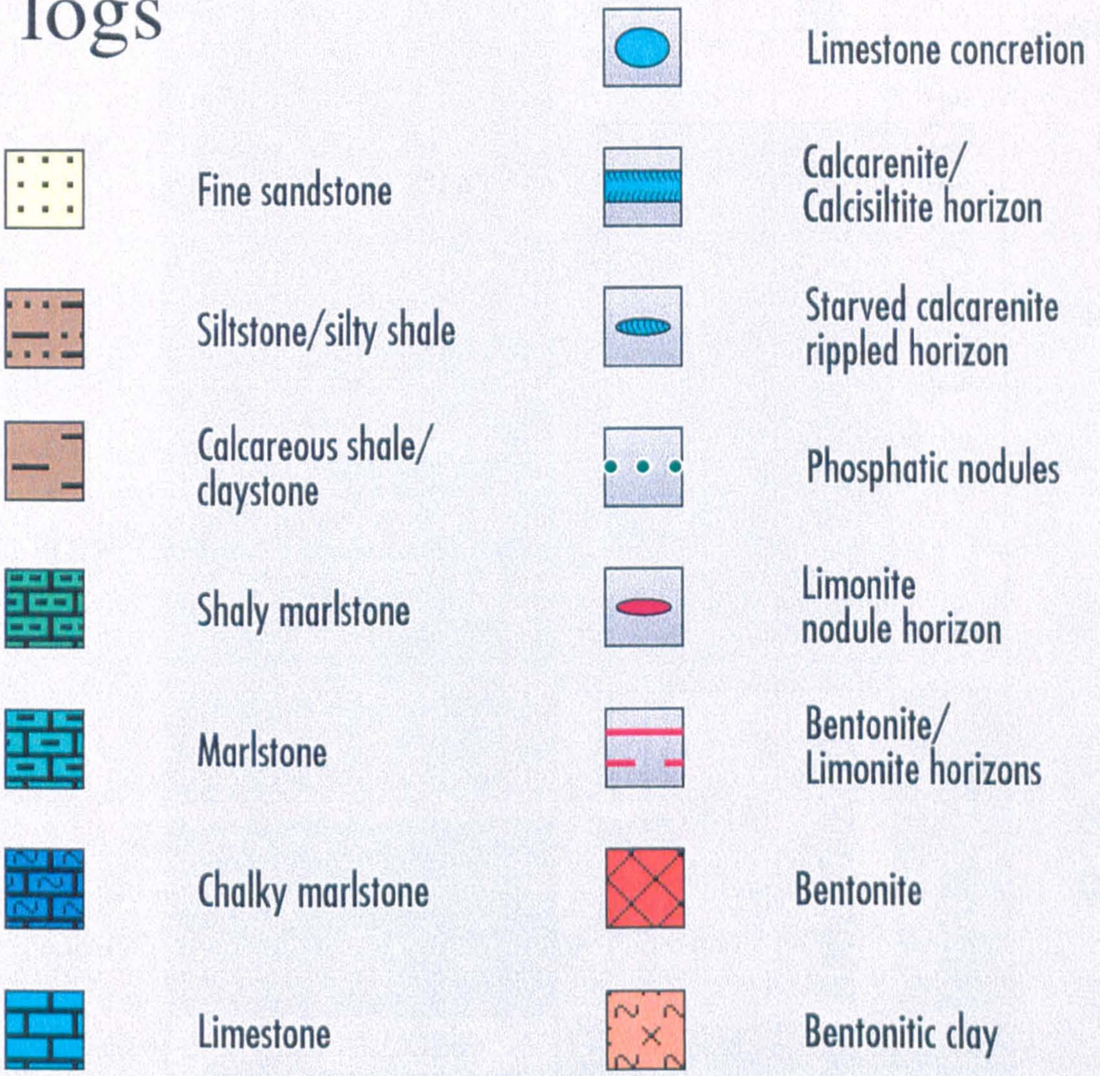
The base of the Lincoln Member is defined at the base of the lowermost, laterally continuous, calcareous layer (which in the core occurs at 1032'). In central Kansas, the base of this member also occurs at this chronostratigraphic level. The Lincoln Member is 22.5' (6.86m) thick in the core, and consists of dark grey, chalky shale with numerous thin lenses or laminations of calcarenite (skeletal limestone), some thicker, chalky limestone layers and several bentonite horizons. The top of the Lincoln Member in western Kansas is taken as the top of a thin carbonate layer at 1009.5'. (If in central Kansas, this lithostratigraphic boundary would have occurred further up the stratigraphy, at the top of a higher calcisiltite layer at 992'. If in Colorado, the lithostratigraphic boundary would have occurred further down in the stratigraphy, at the top of a lower calcisiltite layer at 1025.3'.)

The Hartland Member is also 22.5' (6.86m) thick in the core, and consists of dark grey, chalky shale with horizons of chalky limestone and a number of calcisiltite laminae, particularly near the top between 997.6' and 1003.9', and numerous bentonites, particularly between 1004.4' and 1008.8'.

The base of the Bridge Creek Limestone Member (Bridge Creek Mbr.) is readily marked at the base of a thick and prominent bioturbated limestone unit at 987'. The Bridge Creek Mbr. is 81.2' (24.75m) thick in the core, and consists of many fine grained, moderately grey, micritic to chalky, bioturbated limestones and marls, interbedded with dark grey, calcareous shale. The limestone horizons commonly have bioturbated bases and sharp tops. The member also contains a number of calcisiltite laminae and bentonite markers. A gap in the core is recorded in the unpublished logs between 981.2' and 982.6'. The Cenomanian - Turonian boundary lies 13.6' (4.15m) above the base of the member. For comparison with the other sections, the detailed lithostratigraphy of the core across the stage boundary

Key to lithological symbols for sedimentary logs

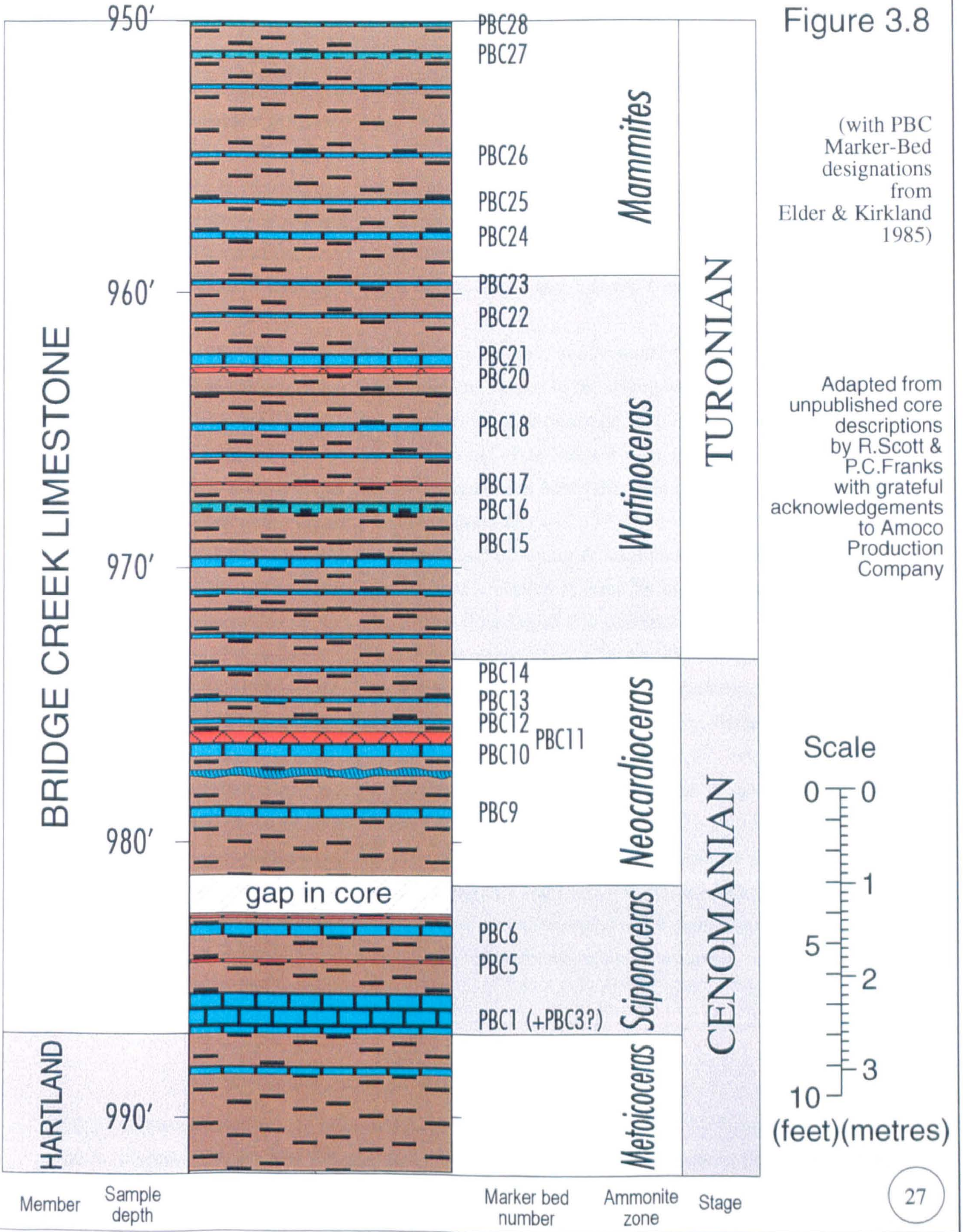
Figure 3.7



Lithostratigraphy of part of the Hartland and Bridge Creek Limestone Members of the Greenhorn Limestone Formation from the **Rebecca K. Bounds Core** #1 (Amoco core 15129), Greeley County, Kansas

For key to lithological symbols see Figure 3.7

Figure 3.8



(with PBC Marker-Bed designations from Elder & Kirkland 1985)

Adapted from unpublished core descriptions by R.Scott & P.C.Franks with grateful acknowledgements to Amoco Production Company is illustrated in Figure 3.8. The key for the lithologies in all of the section logs is illustrated in Figure 3.7. The Fairport-Bridge Creek contact is marked at 905.8' at the top of the uppermost prominent limestone bed of the Bridge Creek Mbr..

The Fairport Mbr. is 121.8' (37.12m) thick in the core, and consists of dark grey, fissile chalky shale, calcareous shale and impure chalk containing a number of bentonites, and many calcisiltite laminae, particularly in the bottom 20' (6.10m). It is recognised as the soft calcareous shale unit between the resistant Bridge Creek Limestone Member and the non-calcareous soft shales of the Blue Hill Shale Member. Numerous inoceramids are also noted. Up-section, the Fairport Mbr. demonstrates a decrease in the number of limestone and resistant calcareous shale beds, an increase in siliceous silt content, a decrease in the levels of lamination in the shales (which may be associated with an increase in microbioturbation), a decrease in calcareous content in the shales, and an increase in organic carbon content with a reduction in the abundance and diversity of benthic fauna.

No level is marked or noted on the original logs, for the Fairport-Blue Hill contact. However, the depth seems to have been taken (from unpublished poster material from Bergen *et al.*, 1990) at around 784'.

The Blue Hill Mbr. is 29' (8.84m) thick in the core, and consists of blocky to fissile, slightly silty, dark-grey, non-calcareous shale containing concretions in the lower portion and grading upwards into the Codell Sandstone Member through a series of increasingly silty and sandy shales (Hattin, 1965). The organic carbon content drops from the top of the Fairport down to 1.0% or less in the Blue Hill. The Blue Hill Mbr. contains the richest arenaceous benthonic foraminiferal assemblage of the Carlile Fm. as well as some calcareous benthic foraminifera.

The base of the Codell Mbr. has been defined (Glenister & Kauffman, 1985) as the base of the first thick storm-deposited sandstone bed. No level is marked or noted for the Blue Hill-Codell contact in the unpublished core descriptions. The highest recording of fine-grained siliciclastic material occurs up to 750' in the core descriptions, and this level is also marked in the geophysical logs by a significant change in resistivity. However, the depth seems to have been taken (from unpublished poster material from Bergen *et al.*, 1990) at 755'. The top of the continuous unit of dark grey, fissile shale occurs at 757'. Ammonites, inoceramids and their debris were noted at 760.9' and 761.8'.

In Kansas, the Codell Sandstone Member consists of sandy shale and thick sandstone beds with shaly sandstone and claystone horizons. The Codell Mbr. is represented in the core by 80' (24.38m) of moderate to light grey medium- and fine-grained sands and silts with laminations of silt and clay. The base contains layers of moderate to dark grey mudstone and shale with lenses of siltstone and starved ripple silt laminations. Burrowing (e.g. *Teichichnus* and *Chondrites*) and bioturbation increases up the core. The top of the member is bounded by a major unconformity/sequence boundary.

3.3.2 Pueblo Section

3.3.2.1 Lithostratigraphy: As mentioned above, in Colorado and Kansas, the Greenhorn cyclothem has been subdivided into four formations; the Dakota, Graneros Shale, Greenhorn Limestone and the

Carlile Shale. The Cenomanian-Turonian boundary sections all lie within the Greenhorn Limestone Formation (Figure 3.4). In Colorado (Pueblo section) as well as in western Kansas (Rebecca K. Bounds core), the Greenhorn Limestone Formation has been further subdivided into the Lincoln, Hartland and Bridge Creek Limestone Members. At Pueblo, the Hartland Member has been informally subdivided into a lower, middle and upper part (Sageman, 1985). Similarly, the Bridge Creek Limestone Member (Bridge Creek Mbr.) has also been informally subdivided into a lower, middle and upper part (Pratt, 1981, Elder, 1985, Elder & Kirkland, 1985) to correlate with the upper Hartland, Jetmore and Pfeifer Members in central Kansas. The material studied ranges from the upper Hartland Member through to the middle Bridge Creek Limestone Member. The Cenomanian-Turonian boundary interval occurs in the lower Bridge Creek Limestone Member.

3.3.2.2 **Sampling:** The sequence at Pueblo is represented by a composite section which provides a relatively well exposed, complete, though fairly condensed, record across the boundary. The interval sampled was from the *Metoicoceras* Zone to the base of the *Mammites* Zone. Forty-two continuous channel samples were taken from 9.3 metres of sediment. The lithostratigraphic interval sampled (using the system set up by Elder & Kirkland (1985)) was from the top 1.2m of the Hartland Member to above unit PBC26 of the middle Bridge Creek Limestone Member. The lower thirty-nine samples were channelled at 20cm intervals, from 1.2 metres below the base of PBC1 (the base of the lower Bridge Creek Mbr.) up to PBC23 (in the middle Bridge Creek Mbr.). The top three samples studied were channelled at 50cm intervals from PBC23 to above PBC26. The detailed lithostratigraphy with biozones is illustrated in Figure 3.9. Photographic comparisons of the outcrops alongside the lithostratigraphic logs are illustrated in Figure 3.10.

3.3.2.3 **Petrology & Sedimentology:** The base of the Hartland Member has been placed above a group of calcarenite beds (skeletal limestones) which mark the top of the Lincoln Member at Pueblo. The top of the Hartland Mbr. has been placed at the base of the laterally persistent, thick basal limestone bed of the Bridge Creek Mbr.. The Hartland Member is 16.75 metres thick at the Rock Canyon Anticline. The lower Hartland Member consists mainly of finely-laminated calcareous shale. The middle member consists of laminated to micro-burrowed calcareous shale and marlstone with calcarenite and limestone beds. The upper Hartland Member is mostly micro-burrowed marlstone and marly shale with a few calcarenite lenses.

The micro-burrowed marlstone is olive-grey, well indurated and slightly silty in the upper unit. The calcareous shale is olive-grey to olive-black and moderately to well indurated. Faecal pellets and abundant planktonic foraminifera are seen throughout. The foraminifera are locally concentrated along with inoceramid prisms into calcarenitic beds, which are often rippled or cross-laminated. The limestone beds are olive-grey, micritic, mostly pelagic in origin and are the most fossiliferously-diverse beds in the Hartland Member. The volcanic ash bands may be represented by bentonites, bands of bentonitic clay or limonitic partings (which probably represent altered, thin ash beds). The Hartland Member contains relatively high values of organic matter (3-4% by weight). Plots of pyrolysis data by Pratt (1984) show that most of the organic matter is of marine origin.

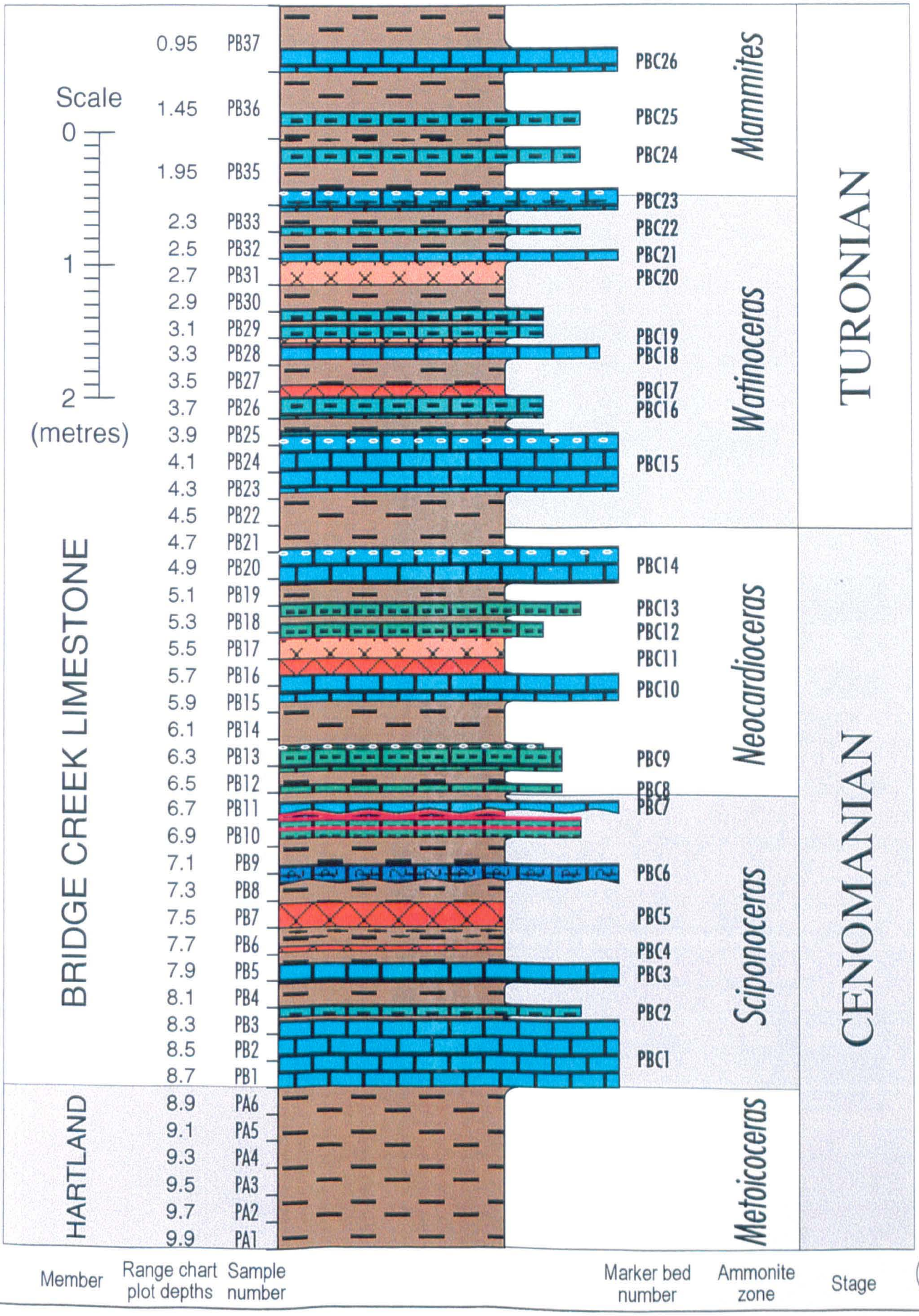
Lithostratigraphy of part of the Hartland and Bridge Creek Limestone Members of the Greenhorn Limestone Formation at the Rock Canyon Anticline, **Pueblo**, Colorado

Figure 3.9

Adapted from
Elder & Kirkland 1985
and Kauffman & Pratt 1985

(with PBC Marker-Bed
designations from Elder & Kirkland 1985)

For key to lithological symbols see Figure 3.7



Lithostratigraphy of the Hartland and Bridge Creek Limestone Members of the Greenhorn Limestone Formation at the Rock Canyon Anticline, **Pueblo**, Colorado

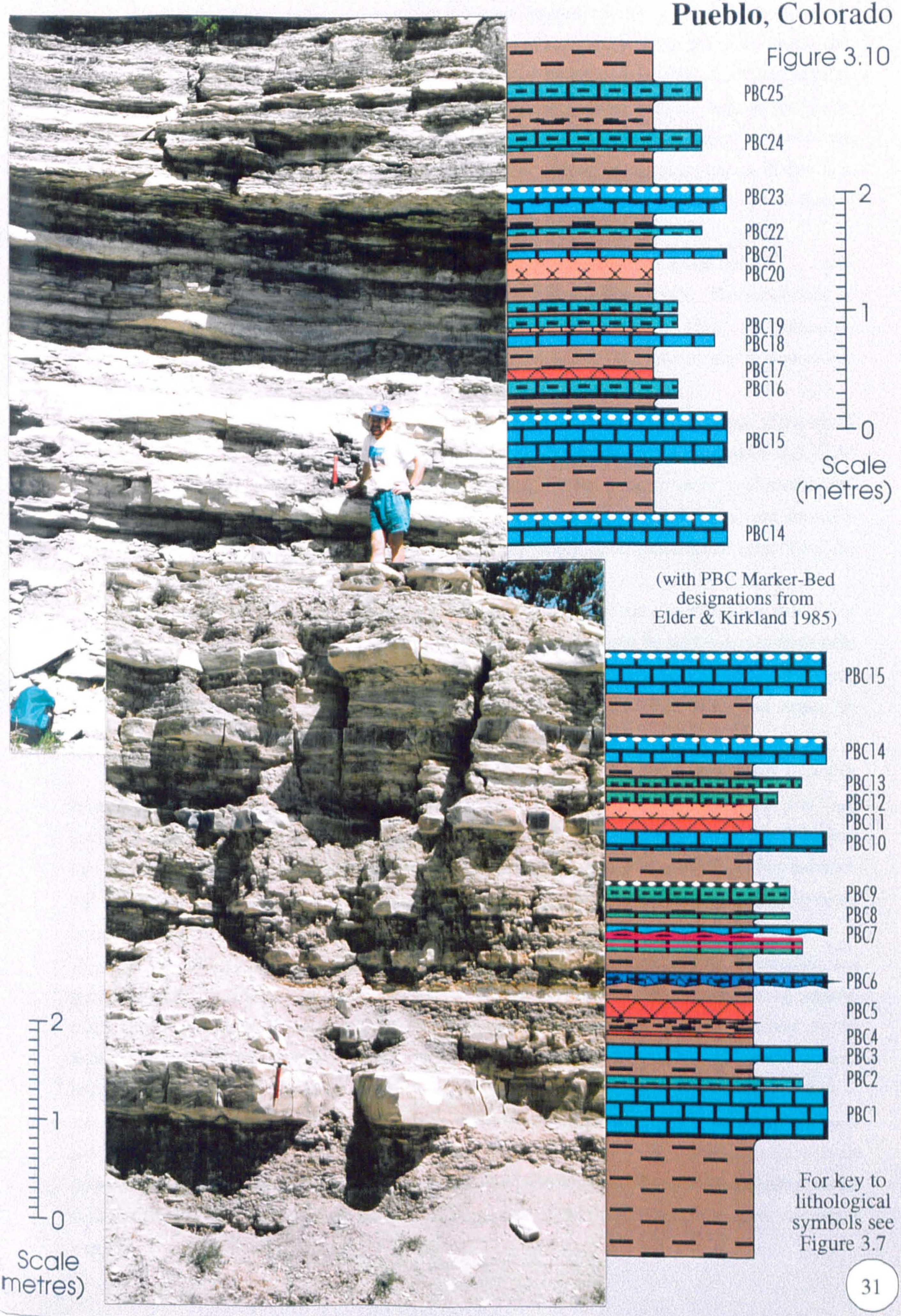


Figure 3.10

(with PBC Marker-Bed designations from Elder & Kirkland 1985)

For key to lithological symbols see Figure 3.7

The Bridge Creek Mbr. is characterised by interbedded micritic to chalky limestones or marlstones and marly to chalky shales. The bottom and top of the member is defined as the lowest and highest of the laterally continuous limestone beds. The basal limestone bed (PBC1) is found at most localities across the Western Interior Basin, and is characterised by fauna from the *Sciponoceras* Zone (defined by Cobban, 1984), by a marked increase in benthonic foraminifera which appear just below the base), and by bentonite marker beds above and below. The uppermost limestone bed at Pueblo is a limestone calcarenite which correlates with the Fencepost Limestone bed of Kansas, based on further bentonite marker horizons.

The 'lower' Bridge Creek Limestone Member ranges from the lower limestone bed (PBC1) up to the bentonite marker PBC20 and is 6.1 metres thick (Elder & Kirkland, 1985). The subdivision is characterised by micritic, highly bioturbated, pelagic limestones (averaging 15-20 cm thickness), interbedded with dark, organic-rich shales (30-100 cm thickness). It includes the *Sciponoceras*, *Neocardioceras* and the lowest part of the *Watinoceras* Zones.

The 'middle' Bridge Creek Mbr. ranges from the base of limestone PBC21 through to the top of limestone PBC35 and is 4.4 metres thick. The limestones (10-20 cm thick) are interbedded with dark, laminar shales (30-50 cm thick). The limestones are micritic but become more argillaceous and calcarenitic toward the top of the subdivision where they have gradational bases, are intensely bioturbated and frequently have calcarenite immediately above. The submember runs from the *Watinoceras* Zone through to the base of the *Collignoniceras* Zone.

The 'upper' Bridge Creek Mbr. ranges from the top of limestone bed PBC35 to the top of limestone PBC53 and is 3.6 metres thick. The lithologies are characterised by light-coloured shale beds (20-30 cm thick) with scattered rippled calcarenite (1-6 cm thick) interbedded with calcarenitic marlstones (7-15 cm thick) which are generally heavily bioturbated near their bases and topped by calcarenite. The entire submember lies within the *Collignoniceras* Zone.

The shales of the Bridge Creek Mbr. are carbonate rich (50 - 70%), moderately to highly laminated, illite and smectite rich (Pratt, 1981) and increase in calcisiltite content up-section. The C_{org} content is around 2 % near the base of the 'lower' Bridge Creek Mbr. with common, small *Planolites* burrows, around 4% in the middle of the 'lower' Bridge Creek Mbr. with rare, small *Planolites* burrows, and around 2-3 % in the upper 'lower' and 'middle' Bridge Creek Mbr. with common, small *Planolites* burrows. Ammonites are rare in the shales.

The limestones of the Bridge Creek Mbr. are micritic (composed mostly of coccolith and foraminiferal tests) and low in organic carbon (C_{org} of 0.1 - 0.5 %). They are well indurated, massive and highly bioturbated and burrowed. Early cementation occurred before much compaction, as the fossils and burrows are generally neither compressed nor crushed. The clay and calcarenite content increases up-section.

The marlstones of the Bridge Creek Mbr. are reasonably indurated, poorly laminated and have low C_{org} contents of 0.5 - 1.5 % (Pratt, 1981). They contain partially crushed bivalves, some ammonites (particularly in the 'middle' and 'upper' member) and burrows. They are particularly common in the 'upper' Bridge Creek Mbr. and many in the upper half of the Bridge Creek Mbr. have calcarenite ripples.

The calcarenites of the Bridge Creek Mbr. are generally well bedded except where bioturbated and are commonly wavy to lenticular. The grain size is silt to fine sand. In the lower and middle Bridge Creek Members they occur as thin layers of planktonic foraminifera along the tops of limestone and marlstone beds, but they are uncommon.

The bentonites are altered smectite-rich volcanic ash beds and are abundant in the Bridge Creek Limestone Member. The thicker ones are dark yellowish-orange to cream, and are bioturbated near their upper contacts. The thinner ones are commonly altered and are represented by dark yellowish-orange, limonitic-rich bands.

3.3.3 Bunker Hill Section

3.3.3.1 Lithostratigraphy: As mentioned above, in Colorado and Kansas, the Greenhorn cyclothem has been subdivided into four formations; the Dakota, Graneros Shale, Greenhorn Limestone and the Carlile Shale. The Cenomanian-Turonian boundary sections all lie within the Greenhorn Limestone. In central Kansas the subdivisions of the Greenhorn Limestone Formation are the Lincoln, Hartland, Jetmore and Pfeifer Members. The Hartland/Bridge Creek boundary of western Kansas and Colorado is not chronostratigraphically equivalent to the Hartland/Jetmore boundary of central and eastern Kansas (Figure 3.4). The uppermost part of the Hartland Member of central and eastern Kansas is stratigraphically equivalent to the lower Bridge Creek Limestone Member of western Kansas and Colorado. The Jetmore Member of central and eastern Kansas is stratigraphically equivalent to the middle Bridge Creek Limestone Member of western Kansas and Colorado. The Pfeifer Member of central and eastern Kansas is stratigraphically equivalent to the upper Bridge Creek Limestone Member of western Kansas and Colorado. The material studied was sampled from the Hartland and Jetmore Members. The Cenomanian-Turonian boundary interval occurs near the top of the Hartland Member.

3.3.3.2 Sampling: The interval sampled was from the top of the *Sciponoceras* Zone to the base of the *Mammites* Zone. Much of the material from the *Sciponoceras* Zone at the base of this section is poorly exposed and hence was not sampled for this study. The section is quite weathered. Thirty-nine samples were continuously channelled at 20cm intervals from 7.8 metres of sediment, from the equivalent of units PBC6 to around PBC25, in the Hartland and overlying Jetmore Chalk members. The detailed lithostratigraphy with biozones is illustrated in Figure 3.11. A photographic comparison of the outcrop alongside the lithostratigraphic log is illustrated in Figure 3.12.

3.3.3.3 Petrology & Sedimentology: The Graneros-Greenhorn contact is placed at the lowest bed or concentration of skeletal or chalky limestone. Across much of central Kansas this contact is sharp, marked by an unconformity (Hattin, 1975). Elsewhere this contact is conformable or even gradational. The Lincoln Member consists mostly of shaly chalk, with thin beds and lenses of skeletal limestone, seams of bentonite and some discontinuous layers of chalky limestone. Comparatively coarse,

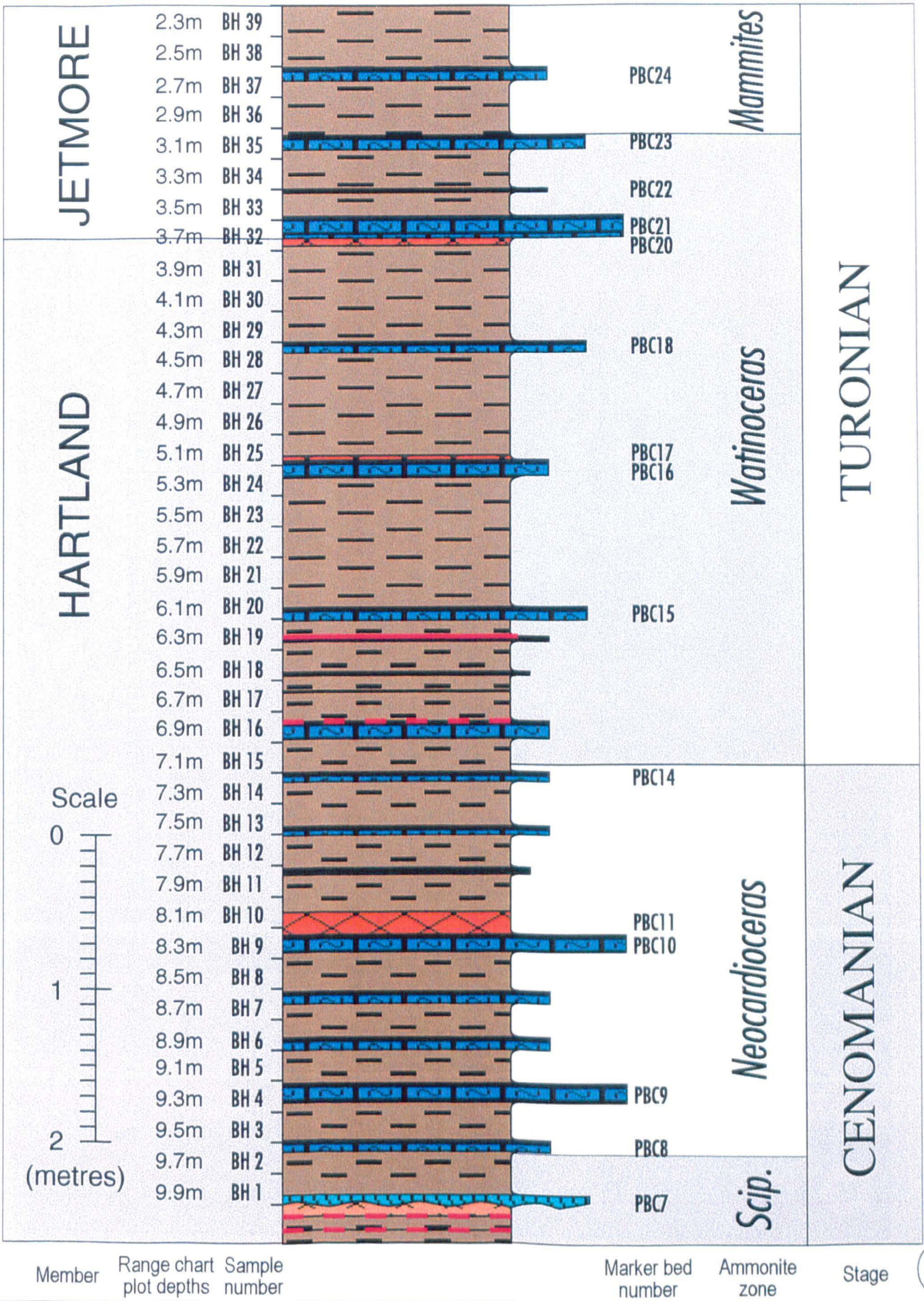
Lithostratigraphy of part of the Hartland and Jetmore Members of the Greenhorn Limestone Formation at **Bunker Hill**, Kansas

Figure 3.11

Adapted from Elder 1989 and Harries & Kauffman 1990

(with PBC Marker-Bed equivalent designations from Elder & Kirkland 1985)

For key to lithological symbols see Figure 3.7



Lithostratigraphy of the Hartland and Jetmore Members of the Greenhorn Limestone Formation at **Bunker Hill**, Kansas

Figure 3.12

Adapted from Elder, 1989

(with PBC Marker-Bed equivalent designations from Elder & Kirkland, 1985)

For key to lithological symbols see Figure 3.7

arenaceous, terrigenous detritus (silt and fine sand) is common in the basal beds of the Lincoln Member, possibly from reworking of the Graneros Shale.

The Hartland Shale Member was emended to the Hartland Member by Hattin (1975). The Hartland Member consists mostly of shaly chalk, with horizons of chalk and chalky limestone, skeletal limestone and bentonite. The shaly chalk is olive-black to olive-grey when fresh, and characteristically separates along its fine laminations as it weathers. Most of the shaly chalk contains calcareous silt or fine-sand sized particles and is speckled with compressed, nearly-white faecal pellets. Many of the shaly chalk units have thin zones of non-laminated, burrow-mottled chalk.

The chalk and chalky limestone layers are olive-grey to light olive-grey in colour when fresh. They are unevenly distributed through the member and are partially to extensively mottled and bioturbated, as is the shaly chalk directly adjacent. Many of these beds are micro-grained but others consist largely of planktonic foraminifera and in some cases, contain many inoceramid prisms as well. Many of the chalk and chalky limestone beds are also speckled by nearly-white, spheroidal faecal pellets.

The skeletal limestone beds are thin to very thin and occur only sparingly and locally (e.g. equivalent of PBC7 at Bunker Hill). They are mostly composed of inoceramid prisms and broken valves, and of planktonic foraminiferal tests.

The bentonites are deeply weathered and coloured white, light grey, and dark orange (from limonite staining). They are chiefly composed of clays (montmorillonite and kaolinite) with traces of quartz, and represent devitrified volcanic ash.

The Jetmore Member consists of shaly chalk and numerous, closely spaced beds of resistant, brittle-weathering chalky limestone. The base of the Jetmore Member closely overlies a distinctive bentonite marker (the equivalent of PBC20). Hattin (1975) divided the Jetmore into four submembers. All the material sampled from Bunker Hill lies in the basal submember. The basal submember is characterised by nine closely spaced, thin to medium beds of chalky limestone separated by thicker units of chalky shale. The limestones are mottled from numerous chalk-filled burrow structures (e.g. *Planolites* and *Chondrites*), and are light to dark olive grey when fresh, weathering to a characteristic light yellowish grey. Some of the beds also contain pyrite nodules.

The shaly chalk beds are like those of the Hartland Member. They are olive-grey to olive-black when fresh and speckled with the nearly-white oblate spheroidal faecal pellets. The beds are thinly laminated, particularly near the bottom of the submember.

The second submember contains three hard limestone beds separated by shaly chalk beds. The third submember consists largely of shaly chalk. The fourth submember is thick, hard, resistant, chalky limestone informally called the Shellrock Limestone (Hattin, 1975), which marks the top of the Jetmore Member.

The Pfeifer Member extends from the top of the Shellrock Limestone Bed to the top of another hard limestone bed termed the Fencepost Limestone Bed (Logan, 1897), which marks the top of the Greenhorn Limestone. The Pfeifer Member primarily consists of shaly chalk with scattered layers of chalky limestone, either as continuous beds, or characteristically as discontinuous shell-rich concretionary beds, or horizons of spheroidal concretions. The calcareous content of the Pfeifer Member is much less in the chronostratigraphically equivalent strata of the Bridge Creek Member further west in Kansas and less again in Colorado.

Throughout the Greenhorn Limestone Formation of Kansas, the most common lithology is the shaly chalk. This rock is micritic, consisting of poorly lithified calcitic mud together with variable amounts of allochems, organic matter, micro-grained terrigenous detritus and secondary minerals (e.g. pyrite, haematite and limonite). The main component of the shaly chalk matrix are coccoliths. The allochems include two main components. One is faecal pellets which, when concentrated, are the common cause of the laminations within the rock. The other is foraminiferal tests which show variable preservation. Inoceramid fragments are also an important constituent which along with the foraminiferal tests may also be concentrated in laminations as layers or lenses of biosparite (calcarenite beds). This is thought to be from periodic winnowing of the bottom sediments by gentle currents. The percentages of HCl-insoluble residue (including iron compounds, organic matter, gypsum, clays and silica) in the shaly chalks averages 31.9% for 88 samples (Hattin, 1975). These insoluble residue percentages generally decrease upwards in the Greenhorn Limestone Formation and increase in a westward direction.

Hattin (1975) also states that the shaly chalk samples contain from less than 1% up to approximately 10% matter of questionable composition, as minute, lenticular to wispy bodies of opaque material aligned parallel to the general laminations. Hattin considered these to be some kind of organic matter as the proportions of opaque bodies are accordant with the percentages of organic matter determined by chemical analysis.

The biosparites are composed of inoceramid fragments and foraminiferal tests. The thin layer equivalent to PBC22 is a laminated biosparite, with the laminae composed of calcispheres, pellets and foraminiferal tests, cemented by sparry calcite.

The chalky limestones are largely composed of microsparite, largely formed from neomorphosed micrite, and have a wackestone to packstone texture. The principal grain types include planktonic foraminiferal tests, inoceramid fragments, faecal pellets and calcispheres. Within the limestones, the faecal pellets have suffered little compaction and are not uniformly distributed, often occurring in laminae. The chalky limestones also contain silt-sized grains and wispy bodies of the organic matter, but only in small amounts (0.5 to 1%), which are aligned parallel to stratification unless the rocks are bioturbated when the matter is dispersed irregularly. The percentages of HCl-insoluble residue (including iron compounds, organic matter, gypsum, clays and silica) in the shaly chalks averages 7.9% for 75 samples (Hattin, 1975).

Diagenetically, the shaly chalks seem to have been least modified. The original stratification is well preserved since little bioturbation has occurred except in the vicinity of the chalky limestones. The large amounts of organic matter suggest strong reducing conditions below the sediment-water interface. Compaction was also important, resulting in the oblate and fusiform faecal pellets. Cementation and neomorphism could have been inhibited from one or more of a number of reasons including a larger clay content, the reducing conditions. and/or the lack of bioturbation suppressing circulation of pore waters.

The chalky limestones have received the greatest amount of post-depositional alteration, with the alteration of the micrite to microsparite. The original composition of the micrite was also of coccoliths and coccolith debris, which have mostly been obliterated by the neomorphism to calcite spar.

Since the faecal pellets are only slightly, if at all, compressed and macrofossils found in burrows also show little compression, it is likely that lithification happened early on in diagenesis. Apart from the original micrite, the source for the carbonate cement and neomorphism was probably from circulating pore waters, which would have been increased through the sediment by burrowing organisms. The best cemented beds of the Greenhorn Limestone contain the greatest concentrations and diversities of the macrofauna.

3.3.4 Wahweap Wash Section

3.3.4.1 Lithostratigraphy: In the Kaiparowits Basin in southern Utah the Greenhorn cyclothem is represented by the Dakota Sandstone (applied to the area by Dutton, 1880), Tropic Shale and Straight Cliffs Sandstone Formations (Gregory & Moore, 1931). Van de Graaff (1963) changed the name of the Dakota Sandstone Formation to the Dakota Formation due to lithological variability. The Tropic Shale and Straight Cliffs Sandstone Formations are the stratigraphic equivalent of the Mancos Shale and part of the Mesaverde Group of New Mexico and Arizona (Figure 3.4), but owing to their distance from the type locality were separately named. The marine strata of the Greenhorn cycle occurred here on a shorter time scale than further east, due to the greater proximity to the palaeo-shoreline. Comparing the section to Pueblo, the whole marine cyclothem occurred in/at the same time as the Bridge Creek Limestone Member and Fairport Chalky Shale Member. The material studied across the Cenomanian-Turonian boundary was entirely taken from the Tropic Shale Formation.

3.3.4.2 Sampling: The interval sampled was from the base of the *Sciponoceras* Zone to the base of the *Mammites* Zone wholly within the Tropic Shale Formation. Fifty-two subsamples were taken from channel samples collected by W. Elder (University of Colorado, Boulder), from the base of the *Sciponoceras* Zone (equivalent of PBC4) up into the *Watinoceras* Zone. The sample distances ranged from 27cm to 130cm. A further sixteen subsamples were taken from point samples (chipped off macrofossil samples) collected by P. Harries (University of Colorado, Boulder) for a study on macrofaunal recovery, into the *Mammites* Zone at intervals of 3m. Overall, the samples were collected from approximately 43 metres of sediment. The detailed lithostratigraphy with biozones is illustrated in Figure 3.13. This locality was also visited and photographed. The entire section was covered by a veneer of weathered debris and was very expanded in comparison to sections from further east. A photographic comparison of the outcrop alongside the lithostratigraphic logs is illustrated in Figure 3.14.

3.3.4.3 Petrology & Sedimentology: The base of the Dakota Formation lies unconformably on Jurassic strata. The Dakota Formation was divided into three members by Peterson (1969). The lower member consists of conglomerate. The middle member is made up of interbedded sandstone, mudstone, carbonaceous mudstone and coal. The upper member also consists of sandstone, mudstone, shale and coal, and contains marine fossils. The Dakota-Tropic contact was originally defined by Gregory &

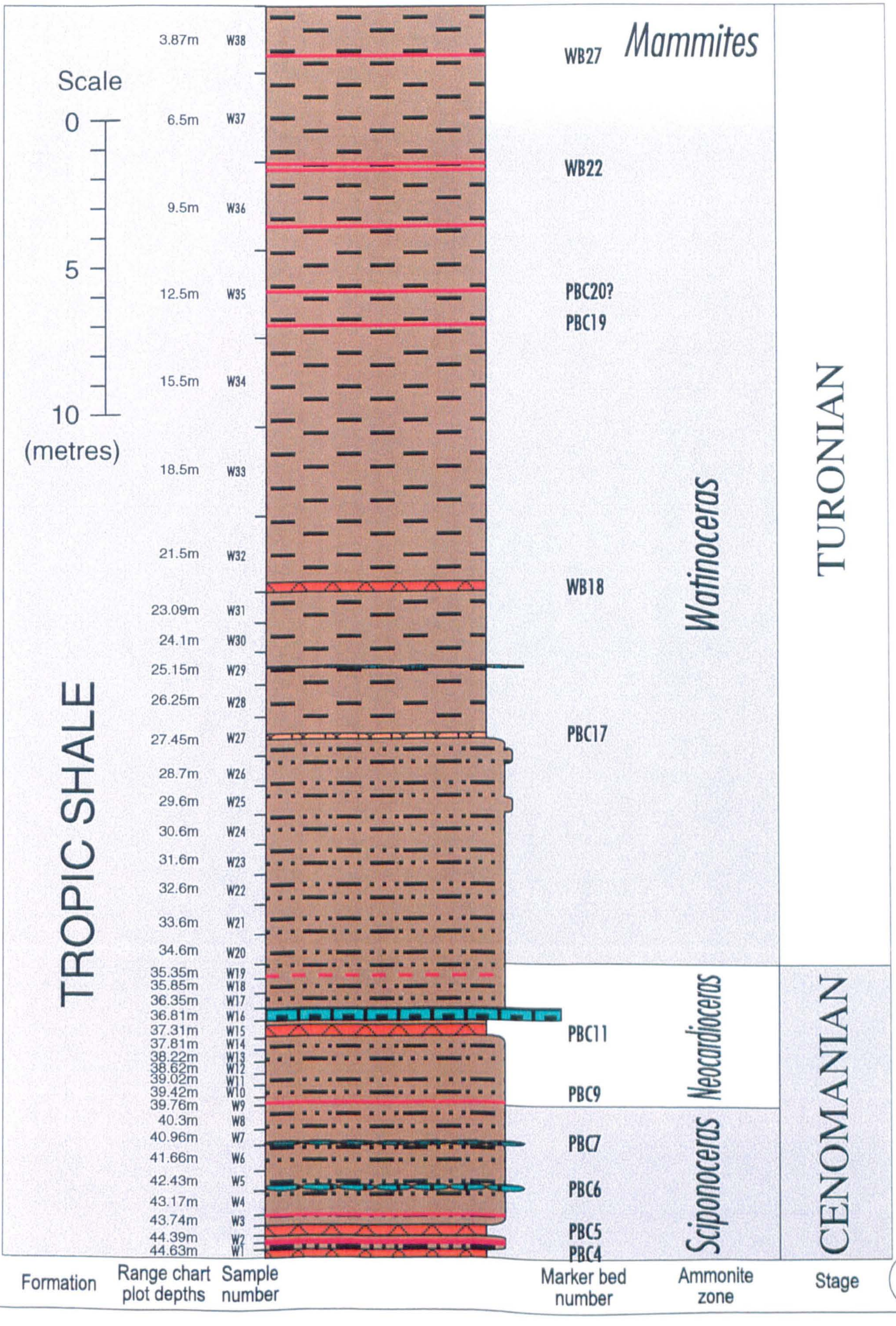
Lithostratigraphy of part of the Tropic Shale Formation from **Wahweap Wash**, Utah

For key to lithological symbols see Figure 3.7

Figure 3.13

Adapted from Elder 1989, 1991

(with PBC Marker-Bed equivalent designations from Elder & Kirkland 1985)



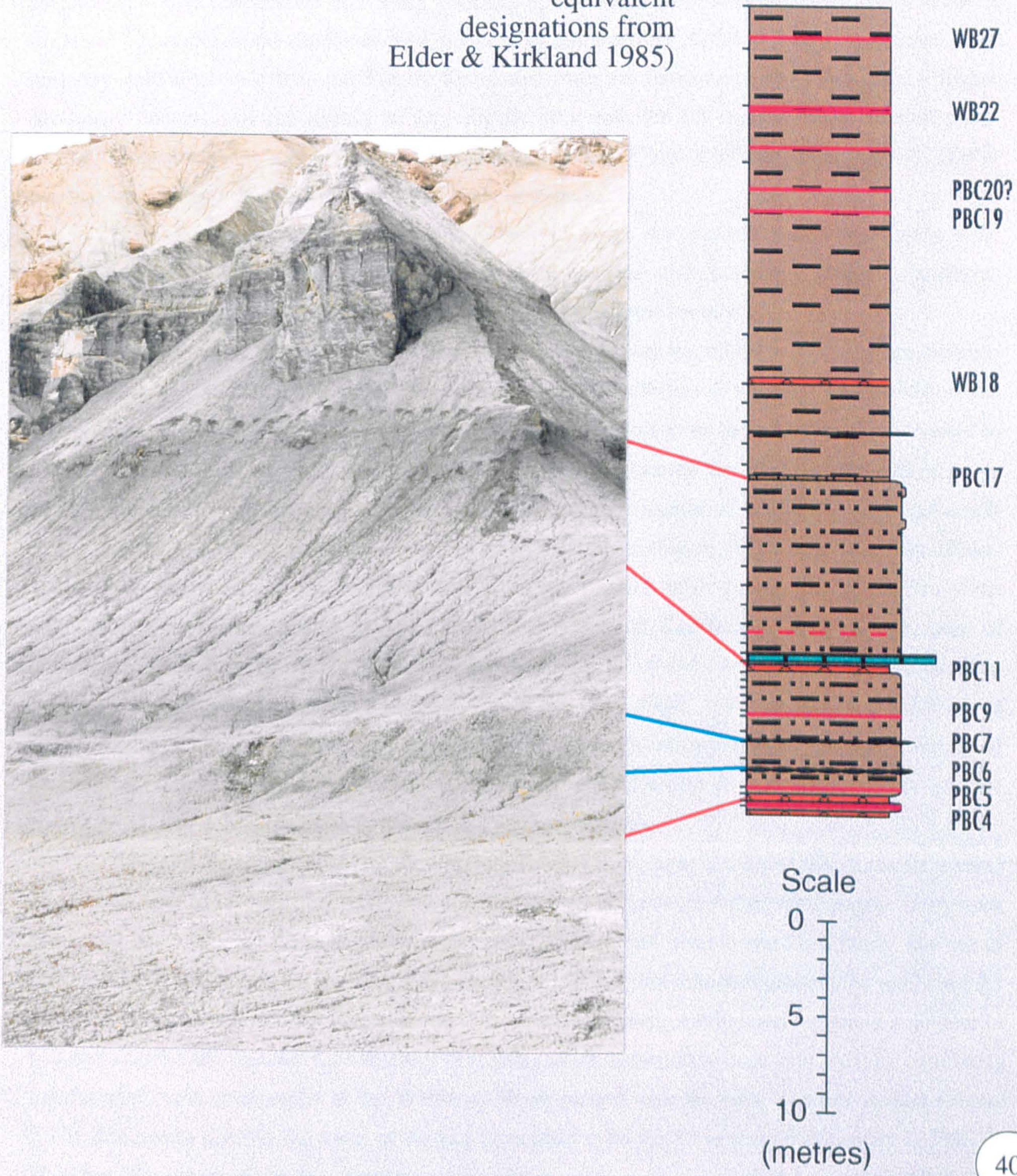
Lithostratigraphy of part of the Tropic Shale Formation at **Wahweap Wash** near Big Water, Utah

Figure 3.14

Adapted from
Elder 1991 and
Harries & Kauffman 1990

(with PBC
Marker-Bed
equivalent
designations from
Elder & Kirkland 1985)

For key to lithological
symbols see Figure 3.7



Moore (1931) as the 'lowest marine fossil-bearing beds'. These beds are now included within the upper member of the Dakota Formation as the Dakota-Tropic contact was redefined by Lawrence (1965) at the top of the highest ledge-forming sandstone.

The Tropic Shale Formation conformably overlies and intertongues with the Dakota Formation. It consists of light olive-grey silty, calcareous claystone and shale with some bentonites and horizons of chalky limestone and sandstone. The silt content of the shale decreases upwards from the base of the formation. The beds of bentonite and limestone are particularly common near the base of the Tropic Shale Formation, in the *Sciponoceras* and *Neocardioceras* Zones.

The shales sampled from the *Sciponoceras* Zone are silty to slightly silty and generally slightly calcareous, with the silt content decreasing gradually up-section. Numerous bentonitic horizons occur in the basal 1.5 metres of the section studied, overlain by two laterally persistent limestone concretionary horizons equivalent to PBC6 and PBC7. The shales from the *Neocardioceras* Zone have a higher calcareous content, and are slightly to very slightly silty with the silt content again decreasing up-section. Occasional thin bentonites occur along with a single (27cm) thick bentonitic horizon. This is overlain by a (40cm) thick, poorly laminated shaly limestone.

The shales from the *Watinoceras* and *Mammites* Zones are calcareous and very slightly silty, with numerous bentonites, some harder, more indurated horizons, and occasional calcarenite horizons. No data was available for placing the *Watinoceras-Mammites* Zone boundary.

The correlation of the bentonite horizons in these biozones has revealed discrepancies between authors who have studied this section. The discrepancies start with two of the thicker bentonites within the *Watinoceras* Zone. Elder (1989, 1991) suggests the uppermost to be the bentonite 'C' equivalent to PBC17. Harries (*pers. comm.*) has marked the lower of the two as the 'C' bentonite equivalent to PBC17, and has marked the upper of the two as the 'D' bentonite equivalent to PBC20. Close inspection of the original sedimentological logging sheets as well as the published lithostratigraphic logs (Elder, 1989, 1991, Harries & Kauffman, 1990) have revealed numerous other thinner bentonites. Use of the published ranges of macrofauna (Elder, 1989, 1991, Harries & Kauffman, 1990) has only been of limited value in solving this problem. Comparing the ranges of *Mytiloides opalensis* between the Blue Point and Wahweap Wash sections (Harries & Kauffman, 1990, Elder, 1991) suggests that the lower of the two bentonites is the 'C' bentonite (equivalent to PBC17). The ranges of other individual species of macrofauna comparing Wahweap Wash with Bunker Hill (Harries & Kauffman, 1990) are not consistent enough across the basin to provide any further solutions.

The dinoflagellate cyst event stratigraphy (range bases, tops and especially the acme events) has proved itself to be extremely reliable in correlation with the high-resolution stratigraphic framework across the basin between the better known sections of Bunker Hill, Pueblo and Blue Point. The use of the original logging sheets for the Blue Point section along with the lithostratigraphic log published for the upper part of the Wahweap Wash section (Harries & Kauffman, 1990) have suggested a number of tentative correlations between the numerous bentonites which in turn have been supported by correlating the dinocyst event stratigraphy at the Wahweap Wash section with the other sections studied (Figure 3.15). The results confirm the lower of the two bentonites to be the 'C' bentonite, equivalent to PBC17. However, the upper of the two bentonites in question seems to be equivalent to an unlabelled, thin

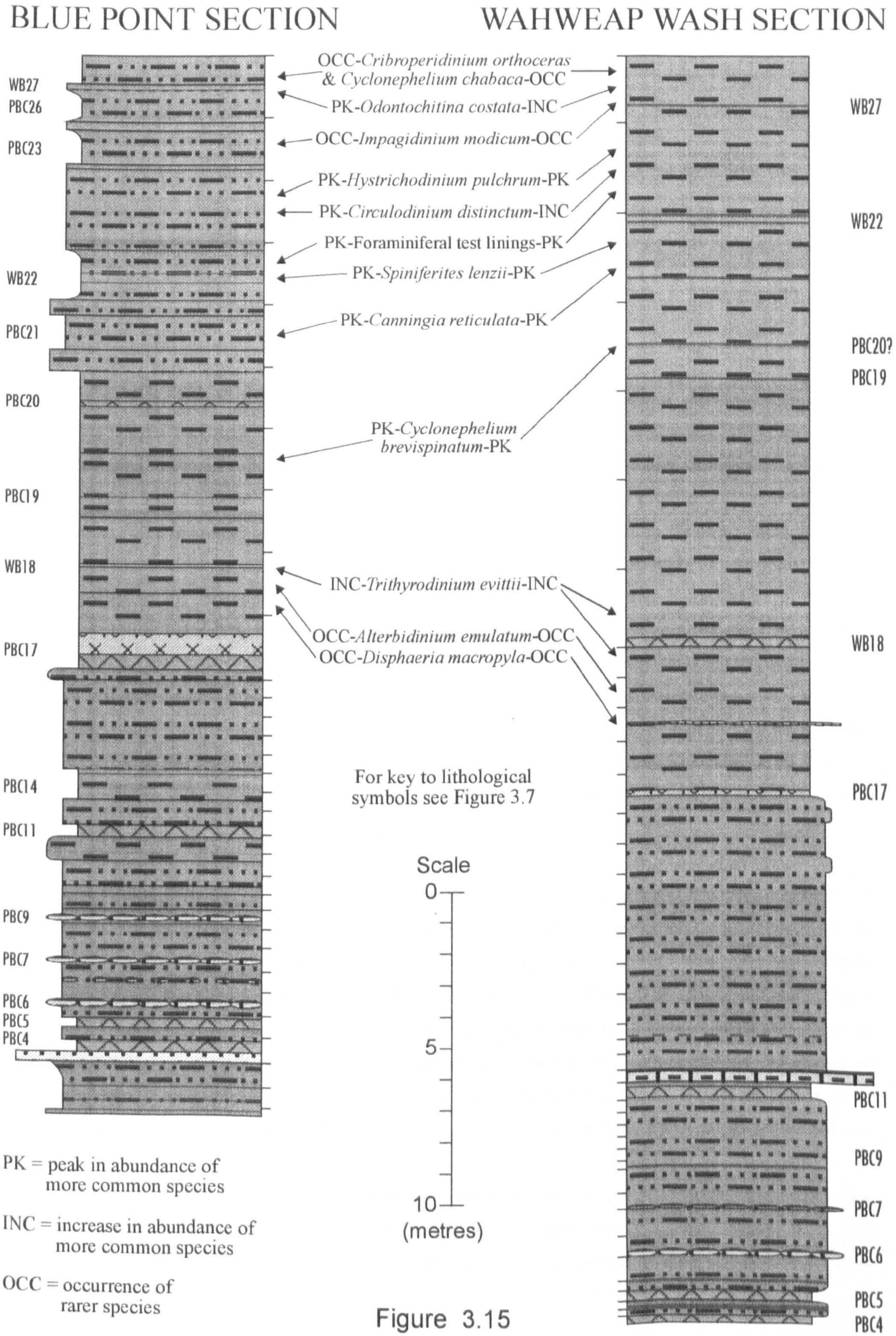


Figure 3.15

Correlation of marker beds between upper parts of western sections using dinoflagellate cyst biostratigraphy bentonite at Blue Point, 5 metres below the 'D' bentonite. Other unlabelled bentonites are also noted from the original sedimentary logging sheets of Blue Point and Wahweap Wash, which do not occur in the sections further east. These have been labelled as western bentonites (WB).

The top of the Tropic Shale Formation contains numerous resistant light-grey very fine- to medium-grained calcareous sandstone beds. The upper boundary lies at the base of the first prominent ledge-forming sandstone of the Straight Cliffs Sandstone Formation.

3.3.5 Blue Point Section

3.3.5.1 Lithostratigraphy: In the Black Mesa Basin in Arizona the Greenhorn cyclothem is represented by the Dakota Sandstone, Mancos Shale (names applied to this locality by Gregory, 1917) and Toreva (Repenning & Page, 1956) Formations. The Dakota Formation has been informally subdivided (Kirkland, 1991) into the lower sandstone member, middle carbonaceous member and upper sandstone member. The Mancos Shale has similarly been informally subdivided into the lower shale member, middle shale member, the Hopi Sandy Member (formal), and the upper shale member. The Toreva Formation of the Mesaverde Group has had the formal addition of the Blue Point Tongue at the Blue Point section (Kirkland, 1991). The marine strata of the Greenhorn cycle occurred here on a shorter time scale than further east, due to the greater proximity to the palaeo-shoreline. Comparing the section to Pueblo, the whole marine cyclothem occurred in/at the same time as the Bridge Creek Limestone Member and Fairport Chalky Shale Member (Figure 3.4). The Mancos Shale is the stratigraphic equivalent of the Tropic Shale Formation of the Kaiparowits Basin of Utah. The material studied was sampled from the upper Dakota and lower Mancos Shale Formations. The Cenomanian-Turonian boundary lies in the lower Mancos Shale Formation.

3.3.5.2 Sampling: The interval sampled was from the *Sciponoceras* Zone (below the equivalent of PBC4), from the base of the upper sandstone member of the Dakota Formation to the base of the *Mammites* Zone (above the equivalent of PBC26) in the Mancos Shale Formation. Sixty subsamples were taken from channel samples collected by J. Kirkland and W. Elder. The sample distances ranged from 49cm to 100cm. Where the samples were taken at metre intervals, a channel of the top 20 cm of each metre was actually collected. The samples were collected from approximately 34 metres of sediment. The detailed lithostratigraphy with biozones is illustrated in Figure 3.16. This section is on Hopi Tribal Reservation lands and is not accessible to the general public, hence it was not visited and has not been photographed.

It is important to note that material from the limestone and concretionary horizons (including the equivalents to PBC6, PBC7 and PBC9) were not included in the channel samples taken and processed from the Blue Point section. Consequently, no Milankovitch cyclicity can be studied from these horizons.

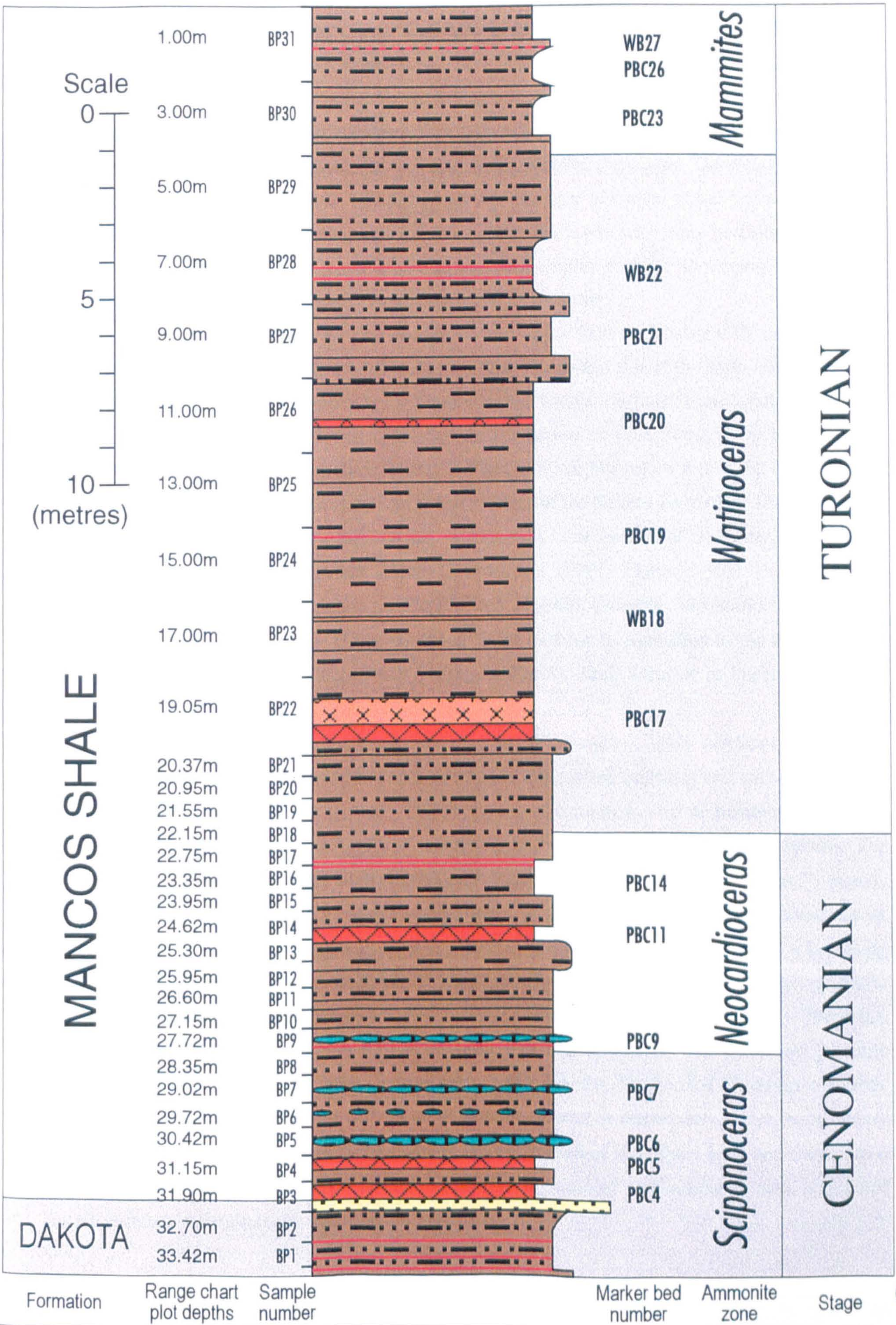
Lithostratigraphy of part of the Dakota and Mancos Shale Formations from **Blue Point**, Arizona

Figure 3.16

Adapted from Elder 1991
and Kirkland 1991

(with PBC Marker-Bed equivalent
designations from Elder & Kirkland 1985)

For key to lithological symbols see Figure 3.7



3.3.5.3 **Petrology & Sedimentology:** The information for the section on petrology and sedimentology has been taken from Repenning & Page, 1956, Elder, 1987, Kirkland, 1991, and Olesen, 1991. As a unit, the Dakota Formation ranges from 15 to 40 metres in thickness across the Black Mesa Basin. It has been informally subdivided into a lower sandstone member, a middle carbonaceous member and an upper sandstone member. The lower sandstone member is discontinuous and not present at Blue Point. The middle carbonaceous member is mostly composed of carbonaceous shale and siltstone interbedded with coals and fine-grained quartz arenites. The upper member of the Dakota Formation has an irregular erosive base and is composed of very fine sands and silty claystones. The composition of the sandstone was of a subfeldspathic to feldspathic arenite with later alteration of the feldspar to clay or replacement by calcite. The fine sands and silts often form thin layers with shaly horizons. These flat, parallel bedded sands are heavily bioturbated with only vague scour surfaces as primary stratification. Cementation and shell content increase towards the top of the member.

The Mancos Shale rests disconformably on the upper Dakota Sandstone Member and the contact is diachronous across the Black Mesa Basin. Along the eastern side of the basin, sediments from the *Metoicoceras* Zone (stratigraphically equivalent to the middle Hartland Shale of the Greenhorn Limestone of Colorado) rest on the top of the Dakota Sandstone. At Blue Point, in the south-western corner of the basin, the lowermost strata from the Mancos Shale Formation fall in the *Sciponoceras* Zone, as do the sediments from the upper sandstone member of the Dakota Formation. The lower shale member of the Mancos Shale Formation extends 54.13 metres from the base of the formation to the top of a thick bentonite marker labelled BM54 by Kirkland (1991; Figure 3.18). This marker is stratigraphically equivalent to bentonite marker PF5 from Pueblo, Colorado, just above the top of the Bridge Creek Limestone Member. Hence the lower shale member is equivalent to the Bridge Creek Limestone Member and basal 3 metres of the Fairport Chalky Shale Member at Pueblo. The entire Mancos Shale Formation at Blue Point is 157 metres thick.

The lower shale member predominantly consists of olive-grey, highly calcareous shale. The base of the section (in the *Sciponoceras* Zone) is silty but silt content decreases and carbonate content increases rapidly from the base of the unit. The shales are moderately to well bioturbated and contain calcareous silt- and fine sand-sized particles consisting of foraminifera and inoceramid prisms. The lower part of the section contains several prominent bentonites and within the lowermost 5 metres, contains four laterally persistent limestone concretionary horizons. The base of the *Neocardioceras* Zone is marked by a shark-tooth lag, a *Pycnodonte* (oyster) shell bed and patchy thickets of a branching coral, immediately below the uppermost concretionary horizon (equivalent to PBC9). This horizon is laterally equivalent to calcisiltite horizons further out in the Black Mesa Basin (Elder, 1987). The shales of the *Neocardioceras* Zone are also silty at the base, and fine up-section. The shales are generally moderately indurated except for those immediately underlying the Cenomanian-Turonian boundary which are poorly indurated. Silt content and induration increase at or immediately above the boundary and continue to increase up-section. The boundary is also marked at Blue Point by a non-fossiliferous septarian concretionary horizon. An abrupt increase in silt content and induration was also noted immediately below the bentonite equivalent to PBC17.

The middle shale member consists mostly of well laminated, silty, olive-grey shale, with occasional thin sands and bentonites. The lower part of the member is moderately calcareous, the middle of the member is more bioturbated and the top contains two concretionary horizons. The silt-sized fraction consists of faecal pellets, quartz and plant fragments. The Hopi Sandy Member consists of interbedded fine sands and shales. The upper shale member consists of non-calcareous silty shale with some argillaceous sandstone. The contact above with the Blue Point Tongue Member of the Toreva Formation is gradational into sandy shale and argillaceous sandstone, and is diachronous across the Black Mesa basin.

3.3.6 Summary of depositional environments

The sections represent a series of depositional environments along a transect across the Western Interior Basin, characterised by different sedimentary regimes (Figure 3.3). The two sections from the west (Blue Point and Wahweap Wash) are dominated by clastic sediments and are consequently much thicker than the sections from further east, due to a much higher rate of sedimentation. The Bunker Hill section is dominated by pelagic carbonate deposition, with negligible siliciclastic input, and hence sedimentation rates were relatively slow. The Pueblo section from the centre of the basin is transitional between the siliciclastic dominated western side and the pelagic, siliciclastic starved eastern side of the basin, with a result that sedimentation patterns fluctuated from varying amounts of allochthonous siliciclastic material and relatively autochthonous pelagic material. The Rebecca K. Bounds core is also from the transitional centre of the basin but biased more towards the pelagic dominated sedimentary regime.

3.4 CORRELATION BETWEEN SECTIONS

3.4.1 Lithostratigraphic correlation

The lithostratigraphy of the sections has been fully correlated across the Western Interior Basin by numerous authors (e.g. Rubey & Bass, 1925, Kauffman *et al.*, 1969, Hattin, 1971, 1975, Peterson & Kirk, 1977) to varying degrees of detail.

As mentioned above, the lithostratigraphic contacts are not necessarily chronostratigraphically equivalent between Colorado (Pueblo section), western Kansas (Rebecca K. Bounds core) and central Kansas (Bunker Hill section). The reasons for this are effectively that the lithological contacts are based on proportions of carbonate material within the rock. In turn, this was mostly dictated by the number of calcareous plankton living in the water column at the time of deposition. The palaeogeographic distribution of the plankton at any one time was affected by the salinity of the water column which was a product of shoreline proximity and freshwater input into the basin. Consequently, as eustatic levels rose, the shorelines were pushed back and salinity levels in the water column were increased allowing the calcareous plankton to proliferate and hence increase the carbonate content of the sediment. In particular the Graneros-Lincoln and Fairport-Blue Hill contacts are based on carbonate composition and hence were a product of eustatic levels.

The marine strata of the Greenhorn cycle occurred in Arizona and Utah on a shorter time scale than further east, due to the greater proximity to the palaeo-shoreline. Comparing the section to Pueblo, the whole marine cyclothem occurred in/at the same time as the Hartland, Bridge Creek Limestone and Fairport Chalky Shale Members. The beds from the coarser-grained, siliciclastic, basin-margin deposits are naturally thicker in comparison to the offshore-basinal, fine-grained deposits, from the centre of the seaway.

3.4.2 Method of high-resolution correlation

Highly detailed correlation has been achieved on a very fine scale using 'high-resolution event stratigraphy' (HIRES) (Kauffman, 1988, Kauffman *et al.*, 1991).

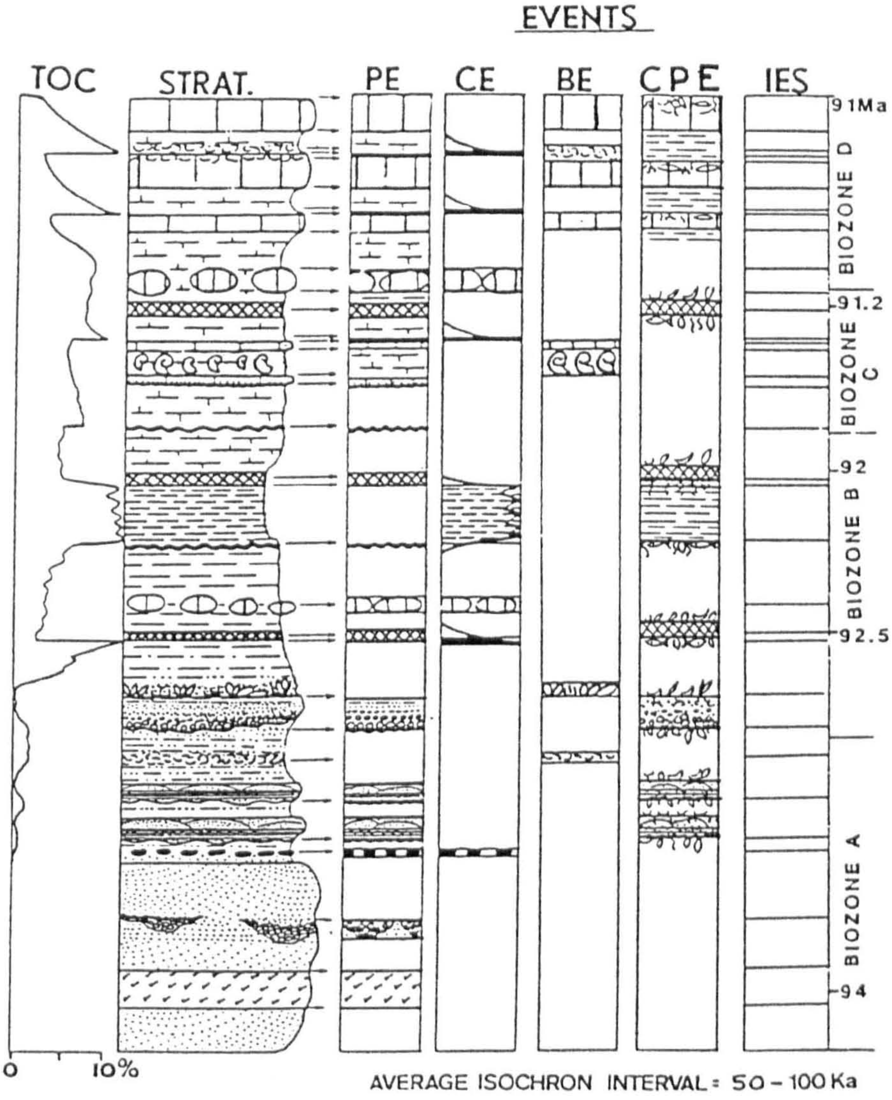
This system uses the identification and tracing of time-lines (isochronous surfaces) across the basin based on a number of short-term phenomena. These may either be caused by local scale changes (autocyclic phenomena) with limited geographic distribution, or by regional to global scale changes (allocyclic phenomena) with an extensive distribution. Many of these phenomena are 'geologically instantaneous' (may have ranged from a few hours to 100 000 years and are hence isochronous (or near-isochronous). They involved a number of physical, chemical and/or biological changes, with a resulting record in the fine-grained marine sediments of the basin. The rock record may include bentonites (volcanic ash falls), Milankovitch climatic cycle deposits (e.g. limestone-shale bedding rhythms), oxygen depletion event deposits (dark, laminated shales), concretion horizons, sediment bypass or starvation surfaces, horizons resulting from increased current action, regional storm deposits and other event strata. The product of this is a detailed chronostratigraphy within the rock record, which is laterally correlatable between the sections. The variety of relevant marker beds resulting from physical, chemical and biological events, are detailed by Kauffman (1988), summarised below, and illustrated in Figure 3.17.

The most important marker horizons from physical events are from the volcanic activity along the western Cordilleran fold-thrust belt which resulted in numerous ash falls deposited as bentonites (over 750 traceable over more than 100 kilometres from the Late Albian to Early Campanian). These are the most trusted of event markers for the Western Interior Basin, and are ideal isochronous surfaces.

Storm beds are particularly useful in correlating shoreface and proximal offshore deposits where not destroyed by subsequent bioturbation.

Regional bypass and disconformity surfaces also prove to be useful surfaces in shoreface sequences and during early transgression. However, they are regionally diachronous and so only useful on a local level. On a regional to global scale, they can be useful in offshore basinal sequences around maximum flooding surfaces, representing bypass and condensation intervals reflecting siliciclastic sediment starvation. A good global example of this is the bypass/starvation/condensation surface

Figure 3.17



MODEL FOR HIGH RESOLUTION EVENT STRATIGRAPHY

Schematic model for components and methods of high-resolution event stratigraphy (HIRES), plotted against an upward-fining transgressive (eustatic rise) stratigraphic sequence. Physical (PE), chemical (CE), biological (BE), and composite events (CPE) determined from centimeter-scale description of a stratigraphic column are composited to right into an integrated event stratigraphy (IES) with an average HIRES interval of 50–100 kyr at present. Key (left to right): TOC, total organic carbon (in weight percent) curve; STRAT, stratigraphic column; PE, physical events such as (down-column) Milankovitch climate cycle and/or productivity event limestones, volcanic ash or bentonite deposits (dark bands and X's), early diagenetic concretion zones, storm beds (thin sandstones), regional bypass surfaces or disconformities of short duration (wavy lines), mass flow deposits (graded beds), ferruginous and phosphatic nodule horizons (dark spheres), channelization events, paleosols, and volcanic flows; CE, chemical events from isotopic, carbon, and elemental analyses; BE, biological events such as mass mortalities, immigration and emigration events, colonization and productivity events, and mass extinctions; CPE, composite events such as Milankovitch climate cycle beds, ash falls (mass mortality, recolonization, physical and chemical events), storm beds (mass mortality, recolonization, physical events); IES, integrated event stratigraphy for each column and collectively for many columns in a basin as correlated by graphic techniques. IES can be integrated with both geochronologic and biostratigraphic data, as diagramatically shown on right. Based on actual data from papers in Pratt et al (1985).

From Kauffman 1988

associated with the mid Early Turonian eustatic peak transgression (*Watinoceras* and lower *Mammites* Zones) in many parts of the world (seen in Deep Sea Drilling Project and Ocean Drilling Program data).

Chemical events can be seen from analyses of the sediments as either major anomalies (high magnitude/short duration) or longer term fluctuations and excursions. These include fluctuations in light stable isotopes (e.g. $\delta^{13}C$, $\delta^{18}O$), in organic carbon (C_{org}) and other elements (e.g. Mn) which have been correlated on a regional and global scale (Pratt, 1985, Pratt *et al.*, 1991).

Concretion horizons and nodular layers (e.g. of limestone, siderite, limonite) are found to retain their relative stratigraphic position in comparison with bentonite markers and hence can be seen as regional (allocyclic), short-term depositional events. The limestone beds of the 'lower' Bridge Creek extend into the areas of more rapid deposition near the western margin of the seaway as limestone concretions (Elder & Kirkland, 1985).

The biological events include a number of types of events, which may also be used as biostratigraphic boundaries. These also occur on a number of scales from a global to a regional or basin-wide scale (important in HIRES) and on a local scale.

The appearance and disappearance of taxa are some of these bioevents, which occur for a variety of reasons. The origin of new species or subspecies, coupled with a rapid marine dispersal results in a 'geologically instantaneous' and geographically widespread first appearance of new taxa. Extinction events, particularly noticeable with groups of species, also make important event horizons. Examples are the step-wise extinction patterns in the macrofauna and foraminifera at the Cenomanian - Turonian boundary. Mass mortality events, particularly noticeable in macrofaunal communities, may also make regionally correlatable horizons due to deterioration in environmental conditions in a basin. Immigration - emigration events may also occur as flora/fauna follow moving water-masses, for example with transgression and regression. The Western Interior Basin was filled with cold-temperate waters (circulating from the Boreal ocean to the north) except at times of transgression and highstand where the subtropical to warm-temperate waters from the south flooded the basin as far north as Canada, carrying in many subtropical species of bivalves, ammonites, foraminifera etc..

Population bursts from favourable environmental conditions may be regionally rapid and leave a sedimentary marker. Productivity events are similar but involve more than one group of fauna/flora and even whole palaeocommunities. In the case of calcareous microplankton, these may result in changing sedimentation patterns, towards a more calcareous lithology.

Widespread changes in community structure may result from regional changes in environment. For example, these may involve one or a combination of changes in climate, oceanography, bathymetry, water chemistry (salinity, oxygen levels, etc.), water temperature, substrate conditions, etc..

Composite events are those which may combine physical, chemical and/or biological events. For example, some of the thick bentonite horizons are seen to have caused a mass mortality among the macrofauna below (by suffocation) and a new, and unique colonisation surface on top from the change in sediment grain size or the sealing off of toxic pore waters below.

The second most important event units (after the bentonites) for HIRES correlation in the Western Interior Basin are the Milankovitch driven, climatic cycle deposits. These are represented by the alternations in limestones and shales (or chalky limestones and shaly chalk) thought to be caused by regular cyclical changes in oxygen levels. Various theories are that these are driven by Milankovitch cyclicity forcing of circulation patterns; either by temperature variations with consequent productivity fluctuations (Eicher & Diner, 1985, 1989) or by climatic precipitation variations producing surface salinity and siliciclastic input fluctuations (e.g. Pratt, 1984, 1985, Arthur *et al.*, 1985, 1987).

The correlation of these bioturbated, calcareous-rich horizons across the basin is not completely straightforward. Some of the limestones in the centre of the basin (e.g. PBC21, PBC23 and PBC26 at Pueblo) correlate with marlstone horizons on the northeast side of the Black Mesa Basin. However, these in turn correlate to intervals of calcareous shale separating calcisiltite horizons in the southwest of the Black Mesa Basin at Blue Point (Kirkland, 1991) as illustrated in Figure 3.18. The calcisiltite horizons represent periods of sediment bypass at Blue Point, with the fine grained siliciclastics carried further out into the Western Interior Seaway before deposition as calcareous shale in the centre of the seaway, between the limestones beds.

The isochronous regional framework has been tested by precise correlation of event units among numerous stratigraphic sections, with each event unit maintaining a constant position in relation to other event units, some of which must be indisputable chronostratigraphic surfaces (i.e. bentonite horizons). The correlation techniques involve both visual stratigraphic matching and graphic correlation.

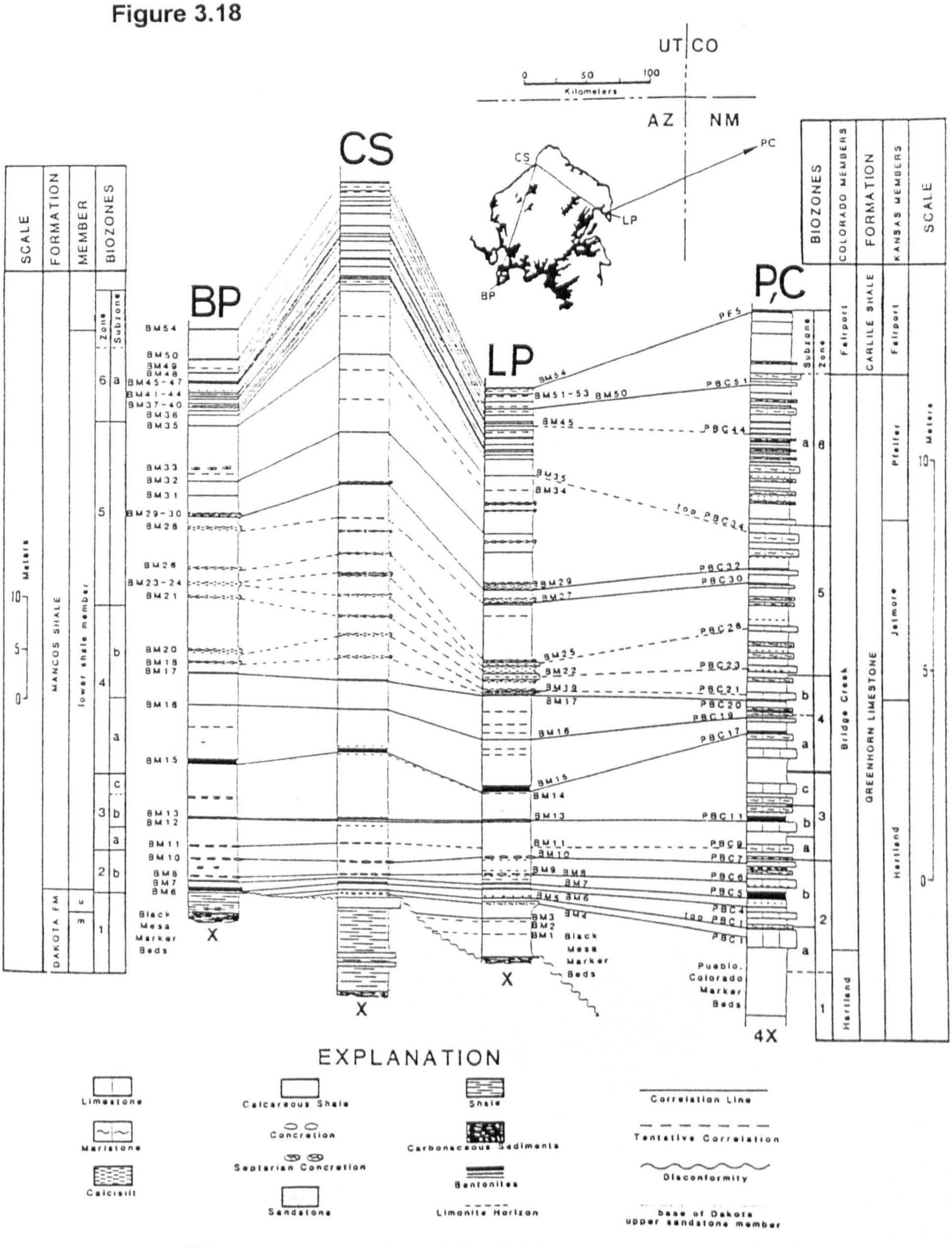
3.4.3 Application of high-resolution correlation

Regional HIRES correlation has been successfully implemented from central Kansas to central Colorado (Hattin, 1971, 1975, 1985, Elder, 1989), into north-eastern Arizona (Elder & Kirkland, 1985, Elder, 1991, Kirkland, 1991) and into south-central Utah (Elder, 1989, 1991, Harries & Kauffman, 1990). The HIRES correlation between the sections and core in this study, is illustrated in Figure 3.19.

Use of the HIRES system has meant that the middle and Late Cretaceous sequences of the Western Interior Basin have (between many localities) been precisely correlated to within 40 to 50 thousand year (average) event units for basinal settings. The resolution for event units in marginal facies is about 100 to 150 thousand years (Kauffman, 1988). The result is a highly detailed chronostratigraphic framework across the basin, currently unsurpassed by any other in the world within the field of pre-Quaternary geology (Watkins *et al.*, 1993).

The high resolution chronostratigraphic framework forms an ideal basis for looking at the patterns of geological, biological, oceanographic and climatic development across the basin. Kauffman, 1988, looking at macrofossil biological events suggests that most biostratigraphic indices for the basin correlate closely to the event stratigraphy, suggesting near- (but not absolute) isochronous boundaries. First appearances of biostratigraphically useful taxa were found to fall closer to the 'time lines' than last appearances.

Figure 3.18



High resolution stratigraphic correlation of the lower sandstone member of the Dakota Formation through lower shale member of the Mancos Shale at Black Mesa, with correlations to the Pueblo, Colorado, section (PC). BP = Blue Point section. CS = Coal Chute section. LP = Lohali Point section.

Ammonite biozones are as follows: 1 - *Metoicoceras*, 2 - *Sciponoceras*, 3 - *Neocardioceras*, 4 - *Watinoceras*, 5 - *Mammites*, 6 - *Collignoniceras*. For further details of Black Mesa marker beds (BM prefix) see Kirkland (1991). Marker beds for Pueblo, Colorado, from Elder & Kirkland (1985).

From Kirkland 1991

High-resolution stratigraphic correlation between the Cenomanian - Turonian boundary sections across the Western Interior Basin

Adapted from Elder 1989, Elder 1991, Elder & Kirkland 1985, Harries & Kauffman 1990, Kauffman & Pratt 1985, Kirkland 1991, and unpublished core descriptions by R.Scott and P.C.Franks with grateful acknowledgements to Amoco Production Company

For key to lithological symbols see Figure 3.7

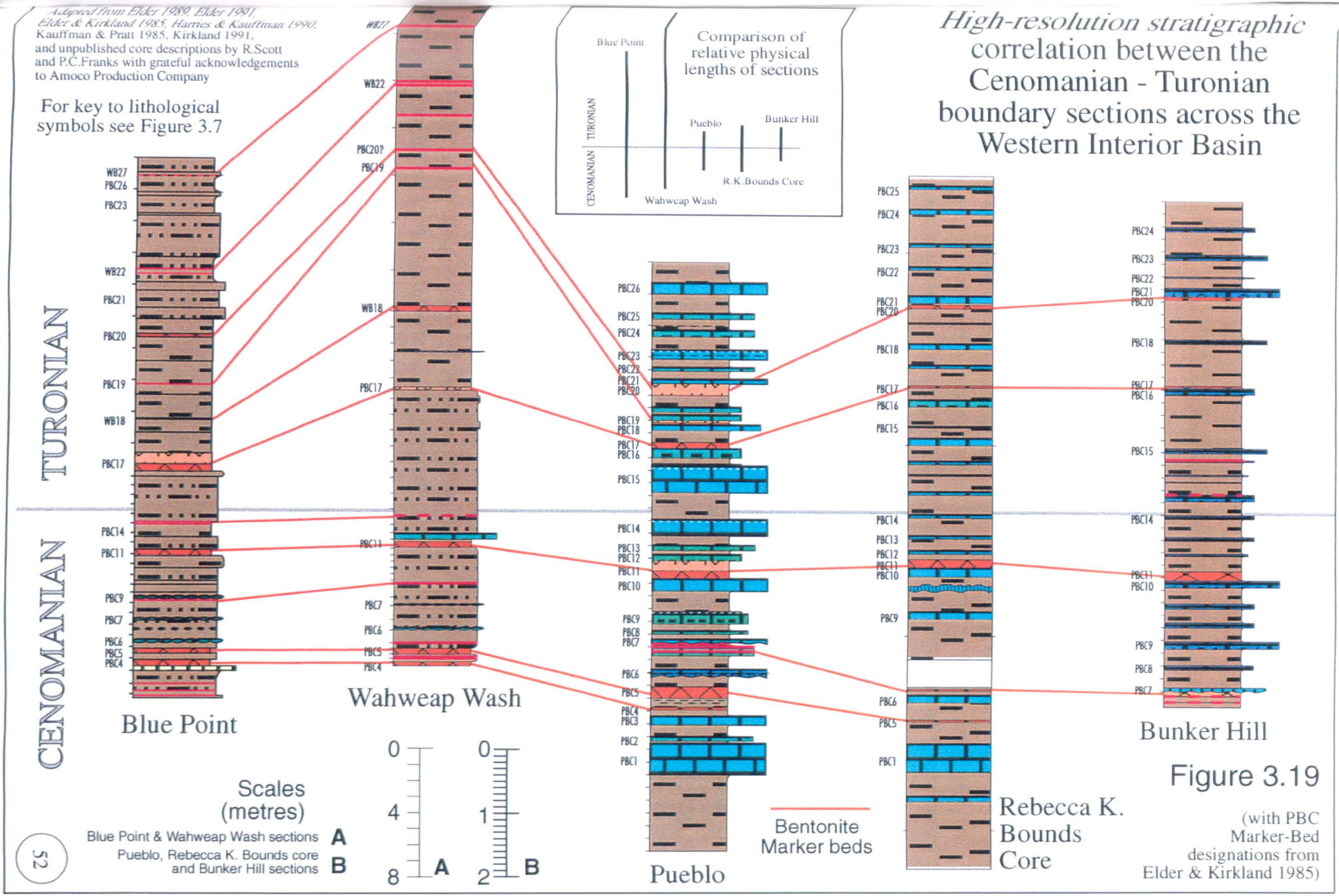


Figure 3.19

(with PBC Marker-Bed designations from Elder & Kirkland 1985)

CHAPTER 4

SYSTEMATIC PALYNOLOGY

4.1 INTRODUCTION

The dinoflagellate genera found during this study have been grouped according to the classification of Fensome *et al.* (1993). Each taxonomic division is described in alphabetical order within the hierarchy. The genera are described in alphabetical order, within the lowest taxonomic division to which they can be assigned.

The previous occurrences recorded below were selected to provide stratigraphic and palaeogeographic comparisons. Full synonymy lists are not provided. For further bibliographic details see Lentin & Williams (1993) for dinoflagellate cyst taxa and Fensome *et al.* (1990) for acritarch, ?chlorophyte and prasinophyte taxa. Diagnoses and descriptions in indented, single spaced paragraphs are direct quotations from the original descriptions of the species. For each dimension recorded, generally three figures are given. The first is the smallest of the measured population, the second (in brackets) is the mean average, and the third is the largest. Figures, including the averages, have been rounded to the nearest micron (μm) unless they are less than 5 μm.

The locations of the core and section sites used are described in Appendix A and illustrated in Figure 3.1. For quick reference, the dinoflagellate cysts and other palynomorph species are listed in alphabetical order along with their authors in Appendix C. The plates illustrating all of the species are located in Appendix D.

The stratigraphic ranges of individual species are illustrated in the range charts, located in Appendix E. These include the ranges of the acritarchs, chlorophytes and prasinophytes (all collectively grouped under acritarchs) and of the dinoflagellate cysts. For each section two charts are available with the taxa in order of first appearance datum (chart 'A') and last appearance datum (chart 'B'). The charts are numbered for the sections as follows: Chart 1A and 1B for the Rebecca K. Bounds core, Kansas; Chart 2A and 2B for the section at Blue Point, Arizona; Chart 3A and 3B for the section at Wahweap Wash, Utah; Chart 4A and 4B for the section at Pueblo, Colorado; and Chart 5A and 5B for the section at Bunker Hill, Kansas. For detailed comparison of stratigraphic occurrences of taxa alongside the lithostratigraphy, the chart plot-depths are included against the lithological logs in Chapter 3: Figures 3.6 and 3.8 for the Rebecca K. Bounds core, Figure 3.16 for the Blue Point section, Figure 3.13 for the Wahweap Wash section, Figure 3.9 for the Pueblo section, and Figure 3.11 for the Bunker Hill section.

4.2 DIVISION DINOFLAGELLATA (Butschli, 1885) Fensome *et al.*, 1993

Subdivision **Dinokaryota** Fensome *et al.*, 1993
Class **Dinophyceae** Pascher, 1914

Subclass **Gymnodiniphycidae** Fensome *et al.*, 1993
Order **Ptychodiscales** Fensome *et al.*, 1993

Family **Ptychodiscaceae** Willey & Hickson, 1909

Subfamily **Dinogymnioideae** (Sarjeant & Downie, 1974) Fensome *et al.*, 1993

Genus *Dinogymnium* Evitt, Clarke & Verdier, 1967; emend. Lentin & Vozzhennikova, 1990

Dinogymnium vozzhennikovae Lentin & Williams, 1973

nom. subst. pro Gymnodinium albertii Vozzhennikova, 1967,

non Dinogymnium albertii Clarke & Verdier, 1967

Plate 39, Figure 3

1967 Vozzhennikova (Siberia: **Turonian**) as *Gymnodinium albertii*

1970 Davey (Saskatchewan, Canada: **Cenomanian**) as *Dinogymnium* sp. B

1990 Lentin & Vozzhennikova (Siberia: **Turonian**)

Original description: Vozzhennikova, 1967, p.41-42: *Gymnodinium albertii*
Theca broadly elliptical, divided by a shallow, wide furrow into two almost equal parts. Epitheca and hypotheca broadly rounded at the poles. Slightly raised ribs run from the transverse furrow towards the poles; these ribs are situated at varying distances from each other. The position of the longitudinal furrow is indistinct, possibly because it is difficult to discern among the ribs. The theca is thin, pale yellow in colour, smooth or finely granular, covered with ribs.

Emended description: Lentin and Vozzhennikova, 1990, p. 23
Cyst shape oval, epicyst and hypocyst broadly conical; autophragm finely granulose: well defined, narrow longitudinal ridges extend from the apex to the antapex interupted only by the paracingulum; archeopyle formed by two arcuate sutures, about 5 μm long resulting in the separation of an apical paraplate along two arcuate sutures about 5 μm long; paracingulum shallow, wide, dividing the cyst into two nearly equal portions, the epicyst being slightly longer than the hypocyst; parasulcus very shallow, suggested by an indistinct interruption of the paracingulum.
Size: Holotype, length 55 μm, width 40 μm, width of paracingulum about 5 μm; additional specimen, length 62 μm, width 46 μm width of paracingulum 4.5-5.5 μm.

Dimensions: Range of observed specimens: length of autophragm 32 (44) 55 μm, width of autophragm 25 (36) 49 μm. 8 specimens measured.

Comparisons: This species is smooth to finely granular and conforms well with the original and emended descriptions. *Dinogymnium albertii* is very similar in shape and size, but is micro-perforate.

Occurrence: Rebecca K. Bounds core (Kansas): Late Cenomanian - Middle Turonian. Bunker Hill (Kansas), Pueblo (Colorado): Late Cenomanian - Early Turonian.

Subclass **Peridiniphycidae** Fensome *et al.*, 1993

Order **Gonyaulacales** Taylor, 1980

Suborder **Cladopyxiineae** Fensome *et al.*, 1993

Family **Cladopyxiaceae** Stein, 1883

Genus *Histiocysta* Davey, 1969a

Histiocysta palla Davey, 1969a

Plate 13, Figure 4

1969a Davey (Fetcham Mill Borehole, Surrey; Compton Bay, Isle of Wight, England; Escalles, France: **Cenomanian)**

1973 Davey & Verdier (France and Switzerland: **Late Vraconian - Early Cenomanian)**

1983 Foucher (Paris Basin, France: **Early Cenomanian - Early Campanian)**

1992 Costa & Davey (England and the North Sea: **Cenomanian - latest Turonian)**

Dimensions: Range of observed specimens: length of cyst 28 (30) 33 μm, width of cyst 28 (31) 35 μm. 3 specimens measured.

Comparisons: This is a distinctive small species, with parasutural ridges and a thinner intratabular reticulum over the surface of the paraplates. *Microdinium reticulatum* is similar but is larger, with a much finer reticulum, and a much smaller epicyst than hypocyst. *Rhiptocorys veligera* is also similar but has higher parasutural crests on the cingulum and hypocyst. *Valensiella reticulata* lacks any form of parasutural marking and is larger. *Elytrocysta circulata* is also similar but lacks any parasutural features other than a paracingulum.

Occurrence: Rebecca K. Bounds core (Kansas): Late Cenomanian - Middle Turonian.

Genus *Microdinium* Cookson & Eisenack, 1960; emend. Sarjeant, 1966b; emend. Stover & Evitt, 1978; emend. Slimani, 1994

Microdinium ornatum Cookson & Eisenack, 1960a

Plate 13, Figure 2

1960a Cookson & Eisenack (Perth & Carnarvon Basins, Australia: **Albian - Late Turonian)**

1964 Manum & Cookson (Arctic Canada: **'mid Cretaceous')**

1967 Clarke & Verdier (Isle of Wight, England: **Early Turonian - Early Coniacian)**

1973 Davey & Verdier (France and Switzerland: **Early Vraconian)**

1976 Norvick *in* Norvick & Burger (Bathurst Island, Australia: **Middle Cenomanian - Early Turonian)**

1978 Bujak & Williams (Offshore South-eastern Canada: **earliest - latest Santonian)**

1980 Morgan (Australia: **Late Albian - latest Cenomanian)**

1983 Foucher (Paris Basin, France: **Early Cenomanian - Middle Turonian)**

1983 Singh (North-west Alberta, Canada: **Early Cenomanian)**

1986 Ioannides (Bylot Island, Arctic Archipelago: **Santonian/Campanian)**

1988 Marshall & Batten (Lower Saxony Basin, North Germany: **Late Cenomanian - Early Turonian)**

1989 Aurisano (New Jersey & Delaware, USA: **Early Santonian - Late Maastrichtian)**

1990 Harker *et al.* (Interior Plains of Canada: **Early - Late Campanian)**

1992 Mohr & Gee (Kerguelan Plateau, Southern Indian Ocean: **Late Cenomanian - Late Turonian)**

1993 Courtinat (Pueblo, Colorado, USA: **Late Cenomanian**)

Dimensions: Range of observed specimens: length of cyst 30 (36) 38 μm, width of cyst 32 (35) 37 μm. 8 specimens measured.

Comparisons: The paratabulation is determined by rows of tubercles which are generally fused together. The intratabular areas are sometimes ornamented with small tubercles. *Microdinium distinctum* appears very similar but lacks visible cingular parasutures.

Occurrence: Rebecca K. Bounds core (Kansas): Late Cenomanian - Middle Turonian. Pueblo (Colorado): Late Cenomanian. Blue Point (Arizona), Wahweap Wash (Utah): Early Turonian.

Microdinium? reticulatum Vozzhennikova, 1967

Plate 13, Figure 3

1980 Morgan (Australia: **Late Albian - latest Vraconian**)
1983 Foucher (Paris Basin, France: **Late Cenomanian**)
1992 Costa & Davey (England and the North Sea: **earliest Cenomanian - Late Santonian**)

Dimensions: Range of observed specimens: length of cyst 31 (39) 48 μm, width of cyst 37 (42) 50 μm. 4 specimens measured.

Comparisons: This species is ornamented with a fine intratabular reticulum between the low parasutural ridges. *Histiocysta palla* is similar but is smaller, with a coarser reticulum, and less of a difference in size between epicyst and hypocyst, which is characteristic of the genus *Microdinium*. *Rhiptocorys veligera* is also similar but has higher parasutural crests on the cingulum and hypocyst. *Elytrocysta circulata* is also similar but lacks any parasutural features other than a paracingulum. *Valensiella reticulata* lacks any form of parasutural marking and is larger.

Occurrence: Pueblo (Colorado): Late Cenomanian. Rebecca K. Bounds core (Kansas): Early Turonian - Middle Turonian.

Microdinium setosum Sarjeant, 1966b; emend. Below, 1987b

Plate 13, Figure 1

1966b Sarjeant (Fetcham Mill Borehole, Surrey, England: **Earliest Cenomanian**)
1967 Clarke & Verdier (Isle of Wight, England: **Early - latest Cenomanian**) as *Microdinium echinatum*
1969a Davey (Fetcham Mill Borehole, Surrey, England: **Albian - Cenomanian**, Compton Bay, Isle of Wight, England; Escalles, France: **Cenomanian**)
1973 Davey & Verdier (France and Switzerland: **Early Vraconian - Early Cenomanian**)
1978 Bujak & Williams (Offshore South-eastern Canada: **earliest - latest Cenomanian**)
1980 Morgan (Australia: **mid - Late Albian**)
1983 Foucher (Paris Basin, France: **Early - latest Cenomanian**)
1989 Habib & Milner (South Carolina & Georgia, USA: **Late Campanian**)

1990 Prössl (nr. Salzgitter, North-west Germany: **Early Albian - Late Turonian)** as *Phanerodinium setosum*

1992 Costa & Davey (England and the North Sea: **Late Aptian - Middle Turonian)**

Dimensions: Range of observed specimens: length of cyst without apex 25 (28) 31 µm, length of cyst with apex 27 & 32 µm (2 specimens), width of cyst 26 (30) 33 µm, maximum height of crests 2 (2.7) 4 µm. 7 specimens measured.

Comparisons: This species of *Microdinium* is ornamented with spiny/denticulate parasutural ridges, and lightly to coarsely granular, intratabular areas. *Microdinium dentatum* is very similar with serrate parasutural crests and a dense intratabular ornamentataion of baculae. *Microdinium? crinitum* is also similar but the crests and intratabular areas are ornamented with long, acicular, hair-like spines.

Occurrence: Rebecca K. Bounds core (Kansas): Middle Cenomanian - Middle Turonian. Pueblo (Colorado), Wahweap Wash (Utah): Late Cenomanian.

Family uncertain

Genus *Rhiptocorys* Lejeune-Carpentier & Sarjeant, 1983; emend. Lentin & Vozzhennikova, 1990; emend. Slimani, 1994

Rhiptocorys veligera (Deflandre, 1937b) Lejeune-Carpentier & Sarjeant, 1983

Plate 13, Figure 6

1969a Davey (Fetcham Mill Borehole, Surrey, England: **Cenomanian - Turonian,** Compton Bay, Isle of Wight, England; Escalles, France: **Cenomanian)** as *Microdinium veligerum*

1973 Davey & Verdier (France and Switzerland: **Early Vraconian - Early Cenomanian)** as *Microdinium veligerum*

1978 Bujak & Williams (Offshore South-eastern Canada: **earliest - latest Campanian)** as *Microdinium veligerum*

1980 Morgan (Australia: **Late Albian - Middle Cenomanian)** as *Microdinium veligerum*

1983 Foucher (Paris Basin, France: **Early Cenomanian - Late Campanian)** as *Microdinium veligerum*

1987 Firth (Georgia, USA: **Early-Late Maastrichtian)**

1988 Marshall & Batten (Lower Saxony Basin, North Germany: **Late Cenomanian - Early Turonian)**

1991 Kirsch (Germany: **Late Santonian - Early Maastrichtian)**

Dimensions: Range of observed specimens: length of central body 26 (33) 42 µm, width of central body 23 (30) 38 µm, maximum height of muri 2 (3.7) 5 µm. 7 specimens measured.

Comparisons: *Rhiptocorys veligera* is a distinctive, small species which has high parasutural crests on the cingulum and hypocyst and is ornamented with a fine intratabular reticulum between these parasutural ridges. *Microdinium reticulatum* is similar but has much lower parasutural thickenings.
Occurrence: Rebecca K. Bounds core (Kansas): Late Cenomanian - Middle Turonian. Pueblo (Colorado): Late Cenomanian - Early Turonian. Blue Point (Arizona): Early Turonian.

Family **Pareodiniaceae** Gocht, 1957

Subfamily **Pareodinioideae** (Autonym)

Genus *Pareodinia* Deflandre, 1947; emend. Gocht, 1970; emend. Johnson & Hills, 1973; emend. Wiggins, 1975; emend. Stover & Evitt, 1978; emend. Below, 1990

Pareodinia ceratophora Deflandre, 1947; emend. Gocht, 1970; emend. Below, 1990

Plate 39, Figure 1

1971 Singh (North-west Alberta, Canada: **mid - Late Albian)**
1978 Bujak & Williams (Offshore South-eastern Canada: **Portlandian - Middle Cenomanian)** [specimens with kalyptra]
1980 Morgan (Australia: **Late Neocomian - Late Albian)**
1981 Below (South-west Morocco: **Hauterivian)**
1982 Below (Morocco: **Late Hauterivian)**
1983 Singh (North-west Alberta, Canada: **Early - Middle Cenomanian)**
1990 Prössl (nr. Salzgitter, North-west Germany: **Late Hauterivian - Late Aptian)**

Translation Deflandre, 1947: Stover and Evitt, 1978, p. 116, Laboratory of Palaeobotany and Palynology, State University of Utrecht, The Netherlands
Translation Gocht, 1970: Laboratory of Palaeobotany and Palynology, State University of Utrecht, The Netherlands
Translation Below, 1990: Laboratory of Palaeobotany and Palynology, State University of Utrecht, The Netherlands
Original description: Deflandre, 1947, p. 4
Diagnosis of the genus valid for the species: Microfossil with an apparently cellulosic membrane, deprived of any trace of furrows and tabulation, general form ellipsoidal or oval, drawn out at one of the poles into a strong horn; transverse section circular.
Membrane brownish, apprently smooth in the well-preserved specimens, sometimes more or less granular.
Total length 65-78 μm, width about 35-38 μm.

Emended diagnosis: Gocht, 1970, p. 154-156
Body elongate, apically stretched into a single horn. Membrane smooth or weakly granulate. Girdle located beyond the middle, shallow, often entirely absent. Sometimes remainders of the precingular and postcingular plates. Antapex convex or flattened, exceptionally with antapical tip.
Archaeopyle large, intercalary, two-plated. Outer mantle ("kalyptra") consisting of fluffy organic substance.
Dimensions (without kalyptra): Length 61-87 μm, width 31-42 μm (ca. 40 specimens).

Emended description: Below, 1990, p. 66-67L *Pareodinia ceratophora* emend. var. *ceratophora* Vesicle-/plate arrangement of the dinoflagellate amphiesma cop, pop, cap, 3', 2a, 6", 7c, 6"', 2"", as, FM, ls, rs, ps; 1' exsert, quadragonal 1a and hexagonal 2a. Growth of thecal plates ?gonyaulacoidal. Zygote cyst proximate, acavate, cornucavate, elongate tear-shaped to ellipsoidal, stretched into the long, slender, only slightly offset apical horn, antapex lobate, or with a central indentation between unequally large, flat antapical bulges, or rounded; wall consisting of thin pedium and granular luxuria, surface evenly chagrinate, with or without surrounding kalyptra, nontabulate; tabulation scheme NR PR/XPR, NR', 1a(arch), 2a(arch), NR", NRc, NR"', NR"", NRs; IV 1a (DDL) and VI 2a (DR); anteriorly geniculate 2" (L), anteriorly geniculate 3" (DDL), anteriorly linear 4" (DDR), anteriorly geniculate 5" (R); suture 3"/4" dorsal; archaeopyle anterior intercalary, 1a +2a; operculum solvate, opercular plates sectae, general opercular formula 1a(s) + 2a(s).

Dimensions: Range of observed specimens: length of kalyptra 46 (72) 90 µm, width of kalyptra 45 (60) 81 µm, length of autophragm 40 (62) 82 µm, width of autophragm 22 (41) 52 µm. 10 specimens measured.

Remarks: The specimens found conform with the original and emended descriptions, and all specimens possessed the outer kalyptra or cloud of fluffy organic matter. It is possible that this species may be reworked.

Comparisons: Species of *Kalyptea* differ in having a distinctive antapical horn.

Occurrence: Blue Point (Arizona), Pueblo (Colorado), Wahweap Wash (Utah): Late Cenomanian - Early Turonian. Bunker Hill (Kansas): Early Turonian.

Suborder **Gonyaulacineae** (Autonym)

Family **Gonyaulacaceae** Lindemann, 1928

Subfamily **Leptodinioideae** Fensome *et al.*, 1993

Genus *Acanthaulax* Sarjeant, 1968 (*nom. subst. pro Acanthogonyaulax* Sarjeant, 1966b); emend. Sarjeant, 1982b; emend. Brenner, 1988

Acanthaulax wilsonii Yun, 1981

Plate 26, Figures 8 & 9

1981 Yun (Germany: **Early Santonian)**

1988 Marshall & Batten (Lower Saxony Basin, North Germany: **Late Cenomanian - Early Turonian)**

1990 Prössl (Salzgitter, North-west Germany: **Middle Turonian - Late Turonian)**

1991 Kirsch (Germany: **?Turonian, Coniacian - mid Campanian)**

Translation Yun, 1981: Fensome *et al.*, 1991, p. 774

Original diagnosis: Yun, 1981, p.7-8

Proximochorate, tabulate cyst with a globular to ovoidal central body and isolated intratabular and proximally or medially interconnected penitabular spines which are usually capitate, rarely acuminate. The paraplates, which are marked by penitabular spines, show the same arrangement as in *Gonyaulacysta*. A relatively small, triangular archeopyle is formed through the loss of paraplate 3".

Original description: Yun, 1981, p. 8
The central body is of oval, rounded or angularly rounded outline and consists of a single wall layer which may be finely perforate (perforations below 1 µm). The central body has numerous, solid, penitabular and intratabular spines which taper distally, their free end either thickened and flared or occasionally pointed. The penitabular spines are arranged in rows, generally interconnected proximally and commonly also medially or distally, so that they appear to form a perforated [spine] wall. Apart from these [spines] there are also 2-12 isolated, occasionally distally forked intratabular spines per plate. Between the 'spine walls' is a spinefree, pandasutural zone. The 4 - 5 µm wide paracingulum is weakly helicoidal and not subdivided. The narrow parasulcus is recognizable by an interruption of the cingulum and an absence of spines. The paratabulation shows the following arrangement: 3' (?4'), 6'', 6''', lp, 1''''. Occasionally, there is an apical horn (?) comprised of spines.

Dimensions: Range of observed specimens: length of central body 41 (48) 54 µm, width of central body 40 (47) 52 µm, height of ornamentation 1 (2.5) 5 µm. 6 specimens measured.

Remarks: Previous occurrences of *A.wilsonii* were originally thought to have been restricted to Coniacian to Campanian strata. However, more recent studies from Germany (Marshall & Batten, 1988, Prossl, 1990, Kirsch, 1991) have also recorded this species from Cenomanian and Turonian strata. The specimens found in this study were conformable with the original description.

Comparisons: A gradation occurs between this species and *Trichodinium castanea* which has no parasutural alignment of spines or connections between spines. Only specimens with strong parasutural connections between spines were recorded as *A. wilsonii*. *Tehamadinium coummia* is also very similar in form and appearance to this species, but has a two paraplate precingular archaeopyle (type 2P).

Occurrence: Blue Point (Arizona), Pueblo (Colorado): Late Cenomanian - Early Turonian. Bunker Hill (Kansas): Early Turonian.

Genus *Endoscrinium* (Klement, 1960) Vozzhennikova, 1967; emend. Gocht, 1970

Endoscrinium campanula (Gocht, 1959) Vozzhennikova, 1967

Plate 26, Figure 1

1964 Cookson & Hughes (Cambridgeshire, England: **Late Albian - Early Cenomanian**) as *Scriniodinium campanula*

1967 Clarke & Verdier (Isle of Wight, England: **Early Cenomanian - Early Turonian**) as *Scriniodinium campanula*

1970 Davey (Fetcham Mill Borehole, Surrey, England: **Albian - Turonian**, Compton Bay, Isle of Wight, England; Escalles, France; Texas, USA: **Cenomanian**) as *Scriniodinium campanula*

1971 Singh (North-west Alberta, Canada: **mid - Late Albian**) as *Scriniodinium campanula*

1973 Davey & Verdier (France and Switzerland: **Late Albian - Early Cenomanian**) as *Scriniodinium campanula*

1975 Brideaux & McIntyre (District of Mackenzie, Canada: **Early Barremian - Middle Albian**)

1978 Bujak & Williams (Offshore South-eastern Canada: **earliest Berriasian - mid Coniacian**)

1979 May (Alaska, USA: **Middle Albian**)

1980 Morgan (Australia: **Late Albian**)

1981 Below (South-west Morocco: **Hauterivian - Early Cenomanian**)

1983 Foucher (Paris Basin, France: **Early Cenomanian - Late Santonian**) as *Scriniodinium campanula*

1983 Habib & Drugg (Blake-Bahama Basin, Western Atlantic: **Late Berriasian - latest Vraconian**) as *Scriniodinium campanula*

1983 Singh (North-west Alberta, Canada: **Early - Middle Cenomanian**)

1986 Ioannides (Bylot Island, Arctic Archipelago: **Santonian - Campanian**) as *Scriniodinium campanula*

1987 Habib & Drugg (Offshore USA, Western North Atlantic: **Late Berriasian - Late Albian**) as *Scriniodinium campanula*

1988 Marshall & Batten (Lower Saxony Basin, North Germany: **Late Cenomanian - Early Turonian**)

1990 Prössl (nr. Salzgitter, North-west Germany: **Early Hauterivian - Late Turonian**)

1991 Kirsch (Germany: **Late Santonian**)

1992 Costa & Davey (England and the North Sea: **Late Ryazanian - Early Santonian**)

1993 Williams *et al.* (N. Hemisphere: **Late Jurassic/Cretaceous boundary - Turonian**)

1993 Nøhr-Hansen (North-east Greenland: **Early Barremian - Late Albian/ Early Cenomanian?**)

1994a Tocher & Jarvis (Fumichon, Normandy, France: **Early Cenomanian**)

1996 Stover *et al.* (World wide: **Late Jurassic - Turonian**) as *Scriniodinium? campanula*

Dimensions: Range of observed specimens: length of periphragm 79 (86) 93 µm, width of periphragm 60 (72) 80 µm, length of endophragm 61 (69) 75 µm, width of endophragm 49 (60) 65 µm. 6 specimens measured.

Remarks: This is a very distinctive species of proximo-cavate cyst, with a rhombic outline, and precingular archaeopyle.

Occurrence: Blue Point (Arizona): Late Cenomanian. Pueblo (Colorado): Late Cenomanian - Early Turonian. Rebecca K. Bounds core (Kansas): Middle Turonian.

Genus *Kleithriasphaeridium* Davey, 1974

Kleithriasphaeridium readei (Davey & Williams, 1966b) Davey & Verdier, 1976; emend. Davey & Verdier, 1976

Plate 2, Figure 6

1966b Davey & Williams (Fetcham Mill Borehole, Surrey; England: **Late Cenomanian**) as *Hystrichosphaeridium readei*

1969a Davey (Fetcham Mill Borehole, Surrey, England: **Albian - Cenomanian**, Compton Bay, Isle of Wight, England; Escalles, France: **Cenomanian**) as *Hystrichosphaeridium readei*

1973 Davey & Verdier (France and Switzerland: **Early - Late Vraconian**) as *Hystrichosphaeridium readei*

1976 Davey & Verdier (North-west Europe: **Late Albian - Late Senonian**)

1978 Bujak & Williams (Offshore South-eastern Canada: **earliest Cenomanian - mid Santonian**)

1980 Morgan (Australia: **Late Albian**)

1983 Foucher (Paris Basin, France: **Early Cenomanian - latest Coniacian**)

1988 Marshall & Batten (Lower Saxony Basin, North Germany: **Late Cenomanian - Early Turonian**)

1990 Prössl (nr. Salzgitter, North-west Germany: **Late Albian - Late Cenomanian**)

1994a Tocher & Jarvis (Fumichon, Normandy, France: **Early Cenomanian**)

Dimensions: Range of observed specimens: length of endophragm 39 (44) 48 µm, width of endophragm 37 (43) 48 µm, maximum length of processes 22 (24) 28 µm, maximum width of processes 7 (9) 10 µm. 5 specimens measured.

Comparisons: This species has a psilate central body, tubular, ribbed processes, surface ridges extending between adjacent processes, and a precingular archaeopyle. *Kleithriasphaeridium corrugatum* is very similar but has a granulate central body, and more surface ridges. Both *K. eoinodes* and *K. loffrense* have no surface ridges on the central body. Species of *Oligosphaeridium*, for example *O. totum*, may appear similar but have an apical archaeopyle.

Occurrence: Rebecca K. Bounds core (Kansas): Middle Turonian.

Genus *Litosphaeridium* Davey & Williams, 1966b; emend. Davey & Verdier, 1973; emend. Lucas-Clarke, 1984

Litosphaeridium siphoniphorum (Cookson & Eisenack, 1958)
Davey & Williams, 1966b; emend. Lucas-Clark, 1984

Plate 2, Figures 3 & 4

1958 Cookson & Eisenack (Australia: **Albian - Cenomanian**) as *Hystrichosphaeridium siphoniphorum*

1964 Cookson & Hughes (Cambridgeshire, England: **Late Albian - Early Cenomanian**) as *Hystrichosphaeridium siphoniphorum*

1966b Davey & Williams (Fetcham Mill Borehole, Surrey, England: **Cenomanian**)

1967 Clarke & Verdier (Isle of Wight, England: **Early - latest Cenomanian**) as *Hystrichosphaeridium siphoniphorum*

1969a Davey (Fetcham Mill Borehole, Surrey, England; Saskatchewan, Canada: **Albian - Cenomanian**, Compton Bay, Isle of Wight; Escalles, France: **Cenomanian**)

1973 Davey & Verdier (France and Switzerland: **Late Albian**)

1976 Norvick *in* Norvick & Burger (Bathurst Island, Australia: **Early Cenomanian - Early Turonian**)

1978 Bujak & Williams (Offshore South-eastern Canada: **Late Albian - latest Turonian**)
1980 Morgan (Australia: **Late Albian - latest Cenomanian**)
1982 Below (Morocco: **Albian - Vraconian**)
1983 Foucher (Paris Basin, France: **Early Cenomanian - earliest Coniacian**)
1983 Habib & Drugg (Blake-Bahama Basin, Western Atlantic: **Vraconian**)
1984 Below (Mazagan Plateau, Offshore North-west Africa: **Late Aptian - Early Cenomanian**)
1984 Lucas-Clark (California, USA: **Albian - Cenomanian**, Kansas, USA: **Cenomanian - Turonian**)
1987 Habib & Drugg (Offshore USA, Western North Atlantic: **Middle Albian - Cenomanian/Turonian**)
1988 Masure (Bahamas: **Vraconian - Middle Cenomanian**)
1988 Marshall & Batten (Lower Saxony Basin, North Germany: **Late Cenomanian**)
1988 Mao Shaozhi & Norris (Kashi Area, Xinjiang Province, China: **Late Cretaceous**)
1989 Aurisano (New Jersey & Delaware, USA: **Cenomanian**)
1990 Prössl (nr. Salzgitter, North-west Germany: **Late Albian - Late Cenomanian**)
1992 Costa & Davey (England and the North Sea: **Late Albian - Early Turonian**)
1992 Mohr & Gee (Kerguelan Plateau, Southern Indian Ocean: **Late Cenomanian - Early Turonian**)
1993 Courtinat (Pueblo, Colorado, USA: **Late Cenomanian**)
1993 Nøhr-Hansen (North-east Greenland: **Late Albian**)
1993 Williams *et al.* (N. Hemisphere: **Late Albian - Early Turonian**)

Dimensions: Range of observed specimens: length of central body 25 (34) 40 µm, width of central body 25 (34) 39 µm, maximum length of processes 12 (15) 17 µm, maximum width of processes 10 (13) 16 µm. 8 specimens measured.

Remarks: This is a distinctive skolochorate species with large, hollow, distally open processes, which are conical to sub-cylindrical. Subspecies were erected by Lucas-Clark (1984) based on surface ornamentation. Within this material the ornamentation on specimens varied, which was probably due as much to variable preservation as to sculpture, so no attempt was made to sub-speciate.

Comparisons: This species has fewer, larger processes than *Litosphaeridium* sp. A., *L. arundum* and *L. conispinum*.

Occurrence: Rebecca K. Bounds core (Kansas): Early Cenomanian - Middle Turonian. Pueblo (Colorado): Late Cenomanian - Early Turonian. Wahweap Wash (Utah): Late Cenomanian.

Litosphaeridium sp. A

Plate 2, Figure 5

Description: Skolochorate cyst with a sub-circular central body. The periphragm forms approximately twenty-three, tapering to cylindrical, open-ended processes with entire to slightly denticulate margins. The processes are relatively thin and of uniform width and length. The surface of the processes are slightly striate to foveolate. The periphragm and endophragm are closely appressed between processes, and the surface of the central body is psilate to sparsely and finely granulate. The archaeopyle is apical, type tA, the operculum free, with accessory archaeopyle sutures and a sulcal notch. The paracingulum and parasulcus have no processes.

Dimensions: Size of observed specimen: length of central body 36 μm, width of central body 36 μm, maximum length of processes 8 μm, maximum width of processes across the proximal end 3 μm. 1 specimen measured.

Occurrence: Only one specimen has been found, from the base of the Blue Point Section.

Comparisons: This species appears most similar to *L. arundum* but has less processes which are narrower and taper distally, with no distal flaring, and no ornamentation on the central body. *Litosphaeridium conispinum* is also similar but has more processes, and possesses narrow, distally closed cingular and sulcal processes. *Litosphaeridium siphoniphorum* is also similar but has far fewer processes.

Occurrence: Blue Point (Arizona): Late Cenomanian.

Genus *Occisucysta* Gitmez, 1970; emend. Jan du Chêne *et al.*, 1986b

Occisucysta hinzii Below, 1984; emend. Jan du Chêne *et al.*, 1986b

Plate 26, Figure 4

1984 Below (Mazagan Plateau, Offshore North-west Africa: **mid - Late Aptian**)

Dimensions: Size of observed specimen: length of periphragm 81 μm, width of periphragm 74 μm, length of endophragm 68 μm, width of endophragm 69 μm, maximum height of ornamentation (at apical horn) 6 μm. 1 specimen measured.

Remarks: Only one specimen of this distinctive species was found, from the uppermost Cenomanian of the Pueblo section. This conforms with the original description and illustrations. The cyst has a complex wall structure. The periphragm appears alveolate to varying degrees, and forms narrow, perforated parasutural septa. Though distorted, the two-plate precingular archaeopyle is still discernible. It is possible that this specimen may have been reworked.

Occurrence: Pueblo (Colorado): Late Cenomanian.

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

Oligosphaeridium albertense (Pocock, 1962) Davey & Williams, 1969

Plate 6, Figure 3

1969a Davey (Saskatchewan, Canada: **Albian - Cenomanian**) as *Oligosphaeridium reniforme*
1979 May & Stein (Alaska, USA: **mid - Late Albian**) as *Oligosphaeridium irregulare*
1982 Below (Morocco: **Albian**)

1984 Below (Mazagan Plateau, Offshore North-west Africa: **Late Aptian - Late Albian)**

1988 Jarvis *et al.* (Dover, Kent, England: **Late Cenomanian)**

1990 Prössl (nr. Salzgitter, North-west Germany: **latest Hauterivian - Early Albian)**

1992 Costa & Davey (England and the North Sea: **? - Early Cenomanian)**

Dimensions: Range of observed specimens: length of endophragm 37 (43) 52 µm, width of endophragm 40 (48) 65 µm, maximum length of processes 19 (26) 30 µm, maximum width of processes (at distal extremities before aculei) 9 (13) 17 µm. 7 specimens measured.

Comparisons: This species has processes which gently widen and flare distally, and terminate with aculeate or secate margins which extend to form slender spinules. With occasional distal fusing of these spinules, it forms a gradation with *O. pulcherrimum* which has similar processes but with fenestrate ends. Any specimens displaying fenestrations were placed in *O. pulcherrimum.*

It also forms a gradation with *O. complex* which has narrower processes which flare at the distal ends to form aculei or secae which may be simple or branched. Any specimens displaying any proximally flaring processes were placed within *O. albertense*. *Oligosphaeridium dividuum* is very similar but has some processes which branch either proximally or medially, to form the aculei or secae. *Oligosphaeridium totum* may appear similar but has entire processes terminations.

Occurrence: Rebecca K. Bounds core (Kansas): Early Cenomanian - Middle Turonian. Blue Point (Arizona): Late Cenomanian. Bunker Hill (Kansas), Wahweap Wash (Utah): Late Cenomanian - Early Turonian. Pueblo (Colorado): Early Turonian.

Oligosphaeridium complex (White, 1842) Davey & Williams, 1966b

Plate 6, Figure 1

1964 Cookson & Hughes (Cambridgeshire, England: **Late Albian - Early Cenomanian)** as *Hystrichophaeridium complex*

1966b Davey & Williams (Specton, Yorkshire: **Barremian,** Fetcham Mill Borehole, Surrey; Ypresian, England: **Cenomanian)**

1967 Clarke & Verdier (Isle of Wight, England: **Early Cenomanian - Late Campanian)** as *Hystrichosphaeridium complex*

1969a Davey (Fetcham Mill Borehole, Surrey, England: **Albian - Turonian,** Compton Bay, Isle of Wight; Escalles, France: **Cenomanian,** Saskatchewan, Canada: **Albian - Cenomanian)**

1971 Brideaux (Central Alberta, Canada: **mid - Late Albian)**

1971 Singh (North-west Alberta, Canada: **mid - Late Albian)**

1973 Davey & Verdier (France and Switzerland: **Late Albian - Early Cenomanian)**

1975 Brideaux & McIntyre (District of Mackenzie, Canada: **Early Aptian - Middle Albian)**

1976 Norvick *in* Norvick & Burger (Bathurst Island, Australia: **Early Cenomanian - Early Turonian)**

1978 Bujak & Williams (Offshore South-eastern Canada: **mid Valanginian - latest Campanian)**

1980 May (New Jersey, USA: **Latest Campanian - Early Maastrichtian)**

1980 Morgan (Australia: **Late Neocomian - Cenomanian)**

1983 Foucher (Paris Basin, France: **Early Cenomanian - Early Campanian)**
1983 Habib & Drugg (Blake-Bahama Basin, Western Atlantic: **latest Valanginian - latest Vraconian)**
1983 Singh (North-west Alberta, Canada: **Early - Middle Cenomanian)**
1984 Below (Mazagan Plateau, Offshore North-west Africa: **Early Aptian - Early Cenomanian)**
1986 Ioannides (Bylot Island, Arctic Archipelago: **Santonian/Campanian - Maastrichtian)**
1988 Jarvis *et al.* (Dover, Kent, England: **Late Cenomanian - Early Turonian)**
1988 Mao Shaozhi & Norris (Kashi Area, Xinjiang Province, China: **Late Cretaceous)**
1988 Masure (Bahamas: **Late Albian - Middle Cenomanian)**
1988 Marshall & Batten (Lower Saxony Basin, North Germany: **Late Cenomanian - Early Turonian)**
1990 Harker *et al.* (Interior Plains of Canada: **earliest Campanian - Early Maastrichtian)**
1990 Prössl (nr. Salzgitter, North-west Germany: **Early Hauterivian - Late Turonian)**
1993 Courtinat (Pueblo, Colorado, USA: **Late Cenomanian)**
1993 Nøhr-Hansen (North-east Greenland: **Early Barremian - Late Albian/Early Cenomanian?)**
1994a Tocher & Jarvis (Fumichon, Normandy, France: **Early - Middle Cenomanian)**
1996 Stover *et. al.* (World Wide: **Early Valanginian - Palaeocene)**

Dimensions: Range of observed specimens: length of endophragm 35 (38) 45 µm, width of endophragm 35 (43) 57 µm, maximum length of processes 21 (28) 33 µm. 7 specimens measured.

Comparisons: *Oligosphaeridium complex* has comparatively narrow processes which flare distally to form aculei or secae which may be simple or branched. With the occasional process that divides medially, it forms a gradation with *O. dividuum* which is very similar but has a number of processes which branch either proximally or medially to form aculei or secae. Any specimens displaying any processes with proximal or medial branching were placed in *O. dividuum*.

With wider-than-normal processes that start to flare medially, it also forms a gradation with *O. albertense* which has processes that are wider and which flare more gently towards the aculeate or secate terminations which extend to form thin spinules. Any specimens displaying any proximally flaring processes were placed within *O. albertense*. *Oligosphaeridium pulcherrimum* also has wider processes which have fenestrate terminations. Species of *Hystrichosphaeridium* may appear similar but possess cingular (i.e. more) processes. *Callaiosphaeridium asymmetricum* may also appear superficially similar, but only possesses six large tubular processes.

Occurrence: Rebecca K. Bounds core (Kansas): Early Cenomanian - Middle Turonian. Blue Point (Arizona), Bunker Hill (Kansas), Pueblo (Colorado), Wahweap Wash (Utah): Late Cenomanian - Early Turonian.

Oligosphaeridium dividuum Williams, 1978

Plate 6, Figure 6

1978 Bujak & Williams (Offshore South-eastern Canada: **Portlandian - latest Barremian)**

1984 Below (Mazagan Plateau, Offshore North-west Africa: **mid Aptian - earliest Cenomanian)**

1990 Prössl (nr. Salzgitter, North-west Germany: **Late Hauterivian - mid Barremian)**

1993 Courtinat (Pueblo, Colorado, USA: **Late Cenomanian)**

Dimensions: Range of observed specimens: length of endophragm 28 (38) 47 µm, width of endophragm 36 (41) 50 µm, maximum length of processes 20 (25) 31 µm. 8 specimens measured.

Comparisons: This species has some distinctive processes which divide proximally or medially to form long aculei or secae. With no proximally and few medially dividing processes, and shorter aculei, it forms a gradation with *O. complex* which only has processes which divide distally. Any specimens displaying any processes with proximal or medial branching were placed in *O. dividuum.*

Occurrence: Rebecca K. Bounds core (Kansas): Early Cenomanian - Middle Turonian. Blue Point (Arizona), Pueblo (Colorado), Wahweap Wash (Utah): Late Cenomanian - Early Turonian. Bunker Hill (Kansas): Early Turonian.

Oligosphaeridium pulcherrimum (Deflandre & Cookson, 1955)

Davey & Williams, 1966b

Plate 6, Figure 4

1967 Clarke & Verdier (Isle of Wight, England: **Early Cenomanian - Early Coniacian)** as *Hystrichosphaeridium pulcherrimum*

1971 Singh (North-west Alberta, Canada: **mid - Late Albian)**

1975 Brideaux & McIntyre (District of Mackenzie, Canada: **Early Aptian - Middle Albian)**

1976 Norvick *in* Norvick & Burger (Bathurst Island, Australia: **Early Cenomanian - Early Turonian)**

1978 Bujak & Williams (Offshore South-eastern Canada: **Portlandian - latest Coniacian)**

1980 Morgan (Australia: **Late Neocomian - Cenomanian)**

1983 Foucher (Paris Basin, France: **Early Cenomanian - earliest Coniacian)**

1983 Habib & Drugg (Blake-Bahama Basin, Western Atlantic: **Valanginian - Early Barremian)**

1983 Singh (North-west Alberta, Canada: **Early - Middle Cenomanian)**

1984 Below (Mazagan Plateau, Offshore North-west Africa: **Late Aptian - earliest Cenomanian)**

1986 Ioannides (Bylot Island, Arctic Archipelago: **Santonian/Campanian - Maastrichtian)**

1987 Firth (Georgia, USA: **Late Maastrichtian - Danian)**

1987 Habib & Drugg (Offshore USA, Western North Atlantic: **Late Valanginian - Middle Albian)**

1988 Masure (Bahamas: **Late Albian - Early Cenomanian)**

1989 Habib & Milner (South Carolina & Georgia, USA: **Late Campanian - Early Maastrichtian)**

1990 Harker *et al.* (Interior Plains of Canada: **Late Santonian - Early Maastrichtian)**

1990 Prössl (nr. Salzgitter, North-west Germany: **Early Hauterivian - Late Turonian)**

Dimensions: Range of observed specimens: length of endophragm 40 (46) 52 µm, width of endophragm 42 (50) 59 µm, maximum length of processes 15 (26) 36 µm. 7 specimens measured.

Comparisons: This species has wide processes with fenestrate terminations and aculeate to secate margins. It forms a gradation with *O. albertense* if it only posseses a few, slightly fenestrate processes. Any specimens displaying fenestrations were placed in *O. pulcherrimum.*

Occurrence: Rebecca K. Bounds core (Kansas): Early Cenomanian - Middle Turonian. Blue Point (Arizona), Bunker Hill (Kansas), Pueblo (Colorado), Wahweap Wash (Utah): Late Cenomanian - Early Turonian.

Oligosphaeridium reticulatum Davey & Williams, 1966b

Plate 6, Figure 2

1966b Davey & Williams (Fetcham Mill Borehole, Surrey, England: **Cenomanian)**
1969a Davey (Fetcham Mill Borehole, Surry, England: **Early Cenomanian)**
1983 Foucher (Paris Basin, France: **Late Turonian - earliest Santonian)**

Dimensions: Size of observed specimen: length of endophragm 44 µm, width of endophragm 41 µm, maximum length of processes 28 µm. 1 specimen measured.

Comparisons: This species of *Oligosphaeridium* is very distinctive with a reticulate central body. *Oligosphaeridium complex* is very similar but has a psilate to finely granulate central body.

Occurrence: Pueblo (Colorado): Early Turonian.

Oligosphaeridium totum Brideaux, 1971

Plate 6, Figure 5

1971 Brideaux (Central Alberta, Canada: **mid - Late Albian)**
1971 Singh (North-west Alberta, Canada: **mid - Late Albian)**
1975 Brideaux & McIntyre (District of Mackenzie, Canada: **Late Aptian - Middle Albian)**
1978 Bujak & Williams (Offshore South-eastern Canada: **earliest Albian - latest Cenomanian)**
1982 Below (Morocco: **Albian)**
1983 Singh (North-west Alberta, Canada: **Early Cenomanian)**
1984 Below (Mazagan Plateau, Offshore North-west Africa: **Early Aptian - earliest Cenomanian)**

Dimensions: Range of observed specimens: length of endophragm 30 (35) 44 µm, width of endophragm 27 (37) 43 µm, maximum length of processes 20 (26) 40 µm. 7 specimens measured.

Comparisons: *Oligosphaeridium totum* is a distinctive species with entire, circular terminations to its buccinate processes, which may be slightly serrate. Other species of *Oligosphaeridium* in this material have aculeate to secate process terminations. *Kleithriasphaeridium readiae* may appear similar but has a precingular archaeopyle and ridges along, and connecting the bases of the processes.

Occurrence: Rebecca K. Bounds core (Kansas): Late Cenomanian - Middle Turonian. Pueblo (Colorado): Late Cenomanian - Early Turonian. Bunker Hill (Kansas), Wahweap Wash (Utah): Early Turonian.

Genus *Systematophora* Klement, 1960; emend. Brenner, 1988; emend. Stancliffe & Sarjeant, 1990

Systematophora sp. A

Plate 3, Figures 5, 6 & 8

Diagnosis: A small, subspherical species of *Systematophora* with a finely granular to faintly reticulate/striate wall which bears processes arranged in annular complexes, with capitate tips. The archaeopyle is apical, type (tA)a and almost always remains in place.

Description: Often the archaeopyle is only poorly developed, creating a problem in orientating specimens (the archaeopyle is only developed on 3 specimens), which is not helped by the complexity of the processes. The surface of the periphragm varies from finely granular to faintly reticulate and striate. Proximally the annular complexes form from circular to polygonal outlines where the periphragm and endophragm are appressed. Each complex gives rise proximally, to a number of processes which in turn may be simple, compound or complex, often subdividing medially. The processes are smooth to faintly striate and terminate with capitate tips. The process complexes vary in size, probably in proportion to the size of the paraplates. The largest seem to be in the antapical, postcingular and precingular areas. The apical complexes are smaller, while the cingular and sulcal are the smallest. The parasulcal region has only thinner, simple and compound processes.

Dimensions: Range of observed specimens: length of central body 31 (36) 44 µm, width of central body 26 (37) 43 µm, maximum length of processes 10 (13) 18 µm. 12 specimens measured.

Comparisons: This skolochorate species has intratabular annular (circular) complexes of distally sub-dividing processes. *Florentinia ferox* appears very similar with processes that are simple or medially bifurcating and trifurcating, with truncate tips. *Florentinia buspina* is distinguished by its number of large, distally-closed, complex processes. *Florentinia clavigera* has many, rigid, broad-based processes, which are generally simple but may be compound (joined proximally) and are truncate, with a larger antapical process. *Systematophora cretacea* is similar but has a densely granular central body and is much larger (original dimensions from the type material: Endocyst length (operculum attached); Holotype 72 µm. Endocyst length (operculum detached); range 60 - 64 µm. Endocyst width; Holotype 69 µm; range 56 - 69 µm. Length of processes; Holotype 12 - 20 µm; Range 16 (20) 24 µm (maxima)).

Occurrence: Rebecca K. Bounds core (Kansas): Late Cenomanian - Middle Turonian. Blue Point (Arizona): Late Cenomanian. Bunker Hill (Kansas), Pueblo (Colorado), Wahweap Wash (Utah): Late Cenomanian - Early Turonian.

Genus *Tehamadinium* Jan du Chêne *et al.*, 1986b

Tehamadinium coummia (Below, 1981a) Jan du Chêne *et al.*, 1986b

Plate 26, Figure 7

1981 Below (South-west Morocco: **Aptian - Albian**) as *Occisucysta coummia*

1982 Below (Morocco: **Albian**) as *Occisucysta coummia*

1984 Below (Mazagan Plateau, Offshore North-west Africa: **Late Albian - earliest Cenomanian**) as *Occisucysta coummia*

Dimensions: Range of observed specimens: length of central body 41 (47) 56 µm, width of central body 42 (53) 63 µm, maximum length of ornamentation 1 (2.1) 4 µm. 9 specimens measured.
Comparisons: This species has a two-plate precingular archaeopyle and many fine, pointed to slightly capitate spines, some of which are intratabular, but many of which are parasuturally aligned and sometimes proximally joined by low parasutural septa. *Acanthaulax wilsonii* has almost identical surface ornamentation but has a narrower body width and only a one-plate precingular archaeopyle. *Trichodinium castanea* also has a one-plate precingular archaeopyle and similar ornamentation, but ideally, this is nontabular, with no parasutural septa or alignment of spines except along the paracingulum.
Occurrence: Rebecca K. Bounds core (Kansas): Late Cenomanian - Middle Turonian. Blue Point (Arizona), Wahweap Wash (Utah): Late Cenomanian. Pueblo (Colorado): Late Cenomanian - Early Turonian.

Genus *Trichodinium* Eisenack & Cookson, 1960; emend. Clarke & Verdier, 1967

Trichodinium castanea (Deflandre, 1935) Clarke & Verdier, 1967

Plate 26, Figure 6

1962b Cookson & Eisenack (Australia: **Aptian - Cenomanian**) as *Palaeoperidinium castaneum*

1964 Cookson & Hughes (Cambridgeshire, England: **Early Cenomanian**) as *Palaeoperidinium castaneum*

1967 Clarke & Verdier (Isle of Wight, England: **Early Cenomanian - Early Turonian**)

1969a Davey (Compton Bay, Isle of Wight; Fetcham Mill Borehole, Surrey, England; Escalles, France: **Cenomanian**)

1973 Davey & Verdier (France and Switzerland: **Late Albian - Early Cenomanian**)

1976 Norvick *in* Norvick & Burger (Bathurst Island, Australia: **Early Cenomanian - Early Turonian**)

1978 Bujak & Williams (Offshore South-eastern Canada: **Middle Albian - mid Campanian**)

1980 Morgan (Australia: **mid Aptian - latest Cenomanian**)

1981 Below (South-west Morocco: **Hauterivian - Early Cenomanian**)

1982 Below (Morocco: **Late Hauterivian - Early Cenomanian**)

1983 Foucher (Paris Basin, France: **Early Cenomanian - Early Campanian**)

1983 Singh (North-west Alberta, Canada: **Early Cenomanian**)

1984 Below (Mazagan Plateau, Offshore North-west Africa: **Early Aptian - Early Cenomanian)**

1986 Ioannides (Bylot Island, Arctic Archipelago: **Santonian/Campanian)**

1987 Habib & Drugg (Offshore USA, Western North Atlantic: **mid - Late Albian)**

1988 Masure (Bahamas: **Late Albian - Middle Cenomanian)**

1988 Marshall & Batten (Lower Saxony Basin, North Germany: **Late Cenomanian - Early Turonian)**

1990 Harker *et al.* (Interior Plains of Canada: **Early Campanian - Early Maastrichtian)**

1990 Prössl (nr. Salzgitter, North-west Germany: **Late Aptian - Late Cenomanian)**

1991 Kirsch (Germany: **Turonian - Late Campanian)**

1992 Costa & Davey (England and the North Sea: **Early Barremian - Early Campanian)**

1993 Courtinat (Pueblo, Colorado, USA: **Late Cenomanian)**

1993 Williams *et al.* (N. Hemisphere: **Ryazanian/ Early Valanginian boundary - Late Campanian)**

Dimensions: Range of observed specimens: length of central body 46 (53) 58 µm, width of central body 46 (48) 49 µm, maximum length of ornamentation 1 (1.3) 2 µm. 9 specimens measured.

Comparisons: This species has a single-plate precingular archaeopyle and is ornamented with a non-tabular cover of small, solid spines with capitate or sometimes bifurcate tips. The spines ideally have no basal connections and show no parasutural alignment except along the paracingulum. A gradation occurs between this species and *Acanthaulax wilsonii* which possesses many fine, pointed to slightly capitate spines, some of which are intratabular, but many of which are parasuturally aligned and sometimes proximally joined by low parasutural septa. Only those specimens with strong parasutural connections between spines were recorded as *A. wilsonii*. *Tehamadinium coummia* is also very similar in form and appearance to this species, but has a two paraplate precingular archaeopyle (2P) and also shows parasutural alignment and low parasutural septa.

Occurrence: Rebecca K. Bounds core (Kansas): Early Cenomanian - Middle Turonian. Blue Point (Arizona), Bunker Hill (Kansas), Pueblo (Colorado), Wahweap Wash (Utah): Late Cenomanian - Early Turonian.

Subfamily **Cribroperidinioideae** Fensome *et al.*, 1993

Genus *Apteodinium* Eisenack, 1958a; emend. Sarjeant, 1985a; emend. Lucas-Clark, 1987

Apteodinium deflandrei (Clarke & Verdier, 1967) Lucas-Clark, 1987;
emend. Lucas-Clark, 1987
Plate 28, Figures 5 & 6

1967 Clarke & Verdier (Isle of Wight, England: **Early Cenomanian - Late Santonian)** as *Gardodinium deflandrei*

1987 Habib & Drugg (Offshore USA, Western North Atlantic: **Late Coniacian/Santonian**) as *Aldorfia deflandrei*
1987 Lucas-Clark (California, USA: **Late Albian**)
1988 Jarvis *et al.* (Dover, Kent, England: **Late Cenomanian**) as *Aldorfia deflandrei*
1988 Masure (Bahamas: **Middle Cenomanian**) as *Aldorfia deflandrei*
1991 Kirsch (Germany: **Coniacian - mid Campanian**)
1993 Williams *et al.* (N. Hemisphere: **Late Albian/Cenomanian boundary - Late Campanian**)

Dimensions: Range of observed specimens: length of ectophragm 47 (58) 70 µm, width of ectophragm 38 (48) 58 µm, length of autophragm 39 (50) 58 µm, width of autophragm 34 (46) 56 µm, length of horn above autophragm 5 (8) 10 µm, maximum length of ornamentation elsewhere 1 µm. 5 specimens measured.

Comparisons: *Apteodinium deflandrei* is very similar to *A. granulatum* but has a thicker and more evident ectophragm, with a clear separation of wall structure beneath the apical horn. The ornamentation on *A. granulatum* appears as a dense covering of granules, partially joined to give an irregular and fuzzy ectophragm with little separation between wall layers.

Occurrence: Bunker Hill (Kansas): Early Turonian.

Apteodinium maculatum grande (Cookson & Hughes, 1964) Below, 1981a

Plate 28, Figure 7

1964 Cookson & Hughes (Cambridgeshire, England: **Early Cenomanian**) as *Apteodinium grande*
1973 Davey & Verdier (France and Switzerland: **Late Albian - Early Vraconian**) as *Apteodinium grande*
1978 Bujak & Williams (Offshore South-eastern Canada: **earliest Albian - latest Cenomanian**) as *Apteodinium grande*
1981 Below (South-west Morocco: **Aptian**)
1990 Prössl (nr. Salzgitter, North-west Germany: **Late Albian - Late Cenomanian**) as *Apteodinium grande*
1992 Costa & Davey (England and the North Sea: **Late Albian**)

Dimensions: Range of observed specimens: length of cyst 82 (98) 124 µm, width of cyst 70 (88) 124 µm. 7 specimens measured.

Comparisons: This species is much larger than other species of the genus *Apteodinium*, within this material. It is distinguishable by its large size, thicker wall and its finely perforate wall surface. It is similar to *Cribroperidinium cooksoniae* but has no parasutural markings other than a thickening around the cingulum.

Occurrence: Pueblo (Colorado): Late Cenomanian. Rebecca K. Bounds core (Kansas): Early Turonian - Middle Turonian.

Apteodinium reticulatum Singh, 1971

Plate 28, Figures 3 & 4

1971 Singh (North-west Alberta, Canada: **Late Albian)**
1983 Singh (North-west Alberta, Canada: **Early Cenomanian)**
1993 Nøhr-Hansen (North-east Greenland: **Late Barremian - Late Albian)**

Dimensions: Range of observed specimens: length of periphragm 42 (48) 55 µm, width of periphragm 32 (42) 50 µm, length of endophragm 37 (44) 54 µm, width of endophragm 32 (42) 49 µm. 8 specimens measured.

Comparisons: This species is distinguishable from other species of the genus by its fine reticulate ornamentation.

Occurrence: Rebecca K. Bounds core (Kansas): Early Cenomanian - Middle Turonian. Blue Point (Arizona), Bunker Hill (Kansas), Pueblo (Colorado): Late Cenomanian - Early Turonian. Wahweap Wash (Utah): Early Turonian.

Genus *Cribroperidinium* Neale & Sarjeant, 1962; emend. Davey, 1969a; emend. Sarjeant, 1982b; emend. Helenes, 1984

Cribroperidinium cooksoniae Norvick *in* Norvick & Burger, 1976

Plate 29, Figures 3 to 5

1976 Norvick *in* Norvick & Burger (Bathurst Island, Australia: **Early Cenomanian - Early Turonian)**
1981 Below (South-west Morocco: **Hauterivian - Early Cenomanian)**
1984 Below (Mazagan Plateau, Offshore North-west Africa: **mid Aptian - earliest Cenomanian)**
1990 Prössl (nr. Salzgitter, North-west Germany: **Middle Albian - Late Turonian)**
1992 Mohr & Gee (Kerguelan Plateau, Southern Indian Ocean: **Late Cenomanian - Late Turonian)**

Dimensions: Range of observed specimens: length of autophragm 79 (87) 97 µm, width of autophragm 61 (75) 87 µm. 8 specimens measured.

Comparisons: *Cribroperidinium cooksoniae* differs from other species of *Cribroperidinium* by its thin psilate to shaghreenate wall, fine irregular crests, and the presence of paracingular parasutural markings. *Cribroperidinium exilicristatum* is very similar, but has a thicker wall, is granulate and has no paracingular paraplates.

Occurrence: Rebecca K. Bounds core (Kansas): Early Cenomanian - Middle Turonian. Blue Point (Arizona), Bunker Hill (Kansas), Pueblo (Colorado), Wahweap Wash (Utah): Late Cenomanian - Early Turonian.

Cribroperidinum orthoceras (Eisenack, 1958a) Davey, 1969a; emend. Sarjeant, 1985a

Plate 29, Figure 1

1958 Eisenack (Australia: **Late Aptian**) as *Gonyaulax orthoceras*
1970 Habib (Bahamas: **Albian/Cenomanian**) as *Gonyaulax orthoceras*
1971 Brideaux (Central Alberta, Canada: **Late Albian**)
1971 Singh (North-west Alberta, Canada: **mid - Late Albian**)
1978 Bujak & Williams (Offshore South-eastern Canada: **earliest Hauterivian - Middle Cenomanian**)
1981 Below (South-west Morocco: **Hauterivian - Albian**)
1982 Below (Morocco: **Late Hauterivian - Early Cenomanian**)
1983 Singh (North-west Alberta, Canada: **Early Cenomanian**)
1984 Below (Mazagan Plateau, Offshore North-west Africa: **Early Aptian - earliest Cenomanian**)

Dimensions: Range of observed specimens: length of autophragm 90 (114) 132 μm, width of autophragm 61 (84) 116 μm. 4 specimens measured.
Comparisons: No whole specimens were found. This species is considerably larger and thicker walled than other species of *Cribroperidinium* in this material. It is distinguished from other species of *Cribroperidinium* (for example *C. edwardsii*) by the presence of a diagonal crest which crosses plate 2'''. The only other species to show this crest is *C. intricatum* which has a shorter apical horn and higher, membranous, antapical crests.
Occurrence: Rebecca K. Bounds core (Kansas): Middle Cenomanian. Pueblo (Colorado): Late Cenomanian. Blue Point (Arizona): Early Turonian.

Cribroperidinium aceras (Eisenack, 1958a) Sarjeant, 1985a

1958 Eisenack (Marne, Feld Heide, North Germany: **Aptian**) as *Gonyaulax aceras*

Translation Eisenack, 1958: Sarjeant, 1985
Original diagnosis: Eisenack, 1958, p.391: *Gonyaulax aceras*
Shell oval, without horns. Epi- and hypotheca almost equal. Transverse furrow spiral, narrow, delimited by solid but low crests. Plate boundaries only partially marked by crests, these and the plate surfaces being set with short, pointed tubercles, so that the tabulation is scarcely discernible.

Emended description: Gitmez and Sarjeant, 1972, p.215: *Leptodinium aceras*
Cyst broadly ovoidal to subsphaerical, without appendages, with tabulation 4', 1a, 6'', 6c, 6''', 1p, 1pv and 1''''. Cingulum helicoid, laevorotatory; sulcus narrow, extending on both epitract and hypotract. Sutures in the form of low membraneous crests. Surface coarsly granular. Archaeopyle rarely developed, formed by the loss of plate 3''.

Emended diagnosis: Sarjeant, 1985, p.57, 59
Proximate, acavate, holotabulate cysts of moderately large size, ovoidal, with epitract and hypotract of closely comparable size and shape. Horns are lacking, though a slight prominence may be simulated by crests traversing the apex. Boundaries of cingulum marked by continuous, very low crests of undulose to irregularly echinate form; similar crests, continuous or discontinuous, or lines of tubercles mark the boundaries of the sulcus and paraplates. Accessory crests, similarly marked,

are developed on most paraplates, singly or in concentric sets; and tubercles or short spines occur rarely in other positions within paraplates.
The paratabulation is thus determined only with difficulty, as follows: ?0pr, 4', 6", 6c, 6"', 1p, 1pv, 1"". Paraplate 4' is elongate, of a blunted wedgeshape; the crest dividing it from 6" is quite short and joins that bordering 1' in a position markedly anterior to the junction of the latter paraplate with the sulcus. Paraplate 6" is larger in size than 4' and of asymmetrically pentagonal shape. Paraplates 1"' and 2"' are reduced to accommodate an especially large 1p. Paraplate 1pv is also unusually large, whereas 1"" is relatively small. The sulcus is short and broad, occupying only the central portion of the ventral surface; however, its boundary with 1' and 1pv is marked only feebly (typically by lines of tubercles) so that, in some specimens, the sulcus may appear to extend almost from apex to antapex. The cingulum is of moderate breadth and degree of spirality, its two ends differing in anteroposterior position by only slightly more than its breadth. Archaeopyle not developed in specimens seen.
Dimensions: Length 70 - 95 μm. Width 60 - 71 μm.

Cribroperidinium sp. cf. *C. aceras* (Eisenack, 1958a) Sarjeant, 1985a

Plate 27, Figure 1

Dimensions: Range of observed specimens: length of autophragm 45 & 51 μm, width of autophragm 39 & 40 μm, respectively. 2 specimens measured.
Remarks: Two specimens have been found, from one sample in the Middle Turonian of the Rebecca Bounds Core, that as far as can be ascertained, match the description and illustration of *C. aceras*, in all respects, except for their sizes. From these two specimens found, it is not possible to verify the paratabulation, owing to poor orientation. It is possible that they may be reworked. No other species are particularly similar.
Occurrence: Rebecca K. Bounds core (Kansas): Middle Turonian.

Cribroperidinium vexillum Prössl, 1990

1990 Prössl (nr. Salzgitter, North-west Germany: **Late Turonian**)

Original Diagnosis: Translation of Prössl, 1990, p. 101
The rounded cyst has an oblate apical horn and two or three processes formed by the extension of parasutures at the antapex.
Original Description: Translation of Prössl, 1990, p. 101
The acavate cyst has an apparently corrugated autophragm with paratabulation characterised by mostly low sutures. The paratabulation scheme appears to most resemble that of *Cribroperidinium ventriosum* as described by Lejeune, Carpentier & Sarjeant (1981): 4', 6", 6c, 6"', 1p, ?2"". The cingulum is characterised by two septa approximately 10 μm high. At the antapex there are high septa and processes where the other low sutures meet. Septa up to 17 μm in height are formed at the meeting of the sutures, particularly between those of the following plates: 1p and 1"", 1"" and 2"" and sometimes 1"' and 1p. The archaeopyle is formed through the loss of plate 3" (type P).
Original Remarks: The species looks similar to *Cribroperidinium ventriosum*, but it possesses no definite intratabular crests. In particular it is distinguished by the antapical septa and the high parasutural crests of the cingulum.
Original Measurements: Translation of Prössl, 1990, p. 101
Total length: 105-114 μm, Holotype: 114 μm. Total width: 87-92 μm, Holotype: 92μm. Apical horn: 24-26 μm, Holotype: 26 μm. Antapical septa: 7-17 μm, Holotype: 7 μm. Cingular septa: 9-10 μm, Holotype: 10 μm.

Cribroperidinium sp. aff. *C. vexillum* Prössl, 1990

Plate 28, Figures 1 & 2

Dimensions: Range of observed specimens: length of cyst including flanges and apical horn 65 & 74 µm, length of central body 55 & 58 µm, width of cyst including flanges 70 & 74 µm, width of central body 66 & 67 µm, length of apical horn 14 & 27 µm, respectively. 2 specimens measured.

Remarks: Two specimens were found which resemble the original descriptions and illustrations. In particular they have similar oblate apical horns and very high paracingular crests. However, the orientation of the specimens (both from a near-apical position) meant that the distinctive antapex characteristic of the species was not visible and the paratabulation could not be verified. The specimens found are also a little smaller than the original material described.

Occurrence: Rebecca K. Bounds core (Kansas): Middle Turonian.

Genus *Florentinia* Davey & Verdier, 1973; emend. Duxbury, 1980

Florentinia buspina (Davey & Verdier, 1976) Duxbury, 1980

Plate 4, Figure 3

1976 Davey & Verdier (North-west Europe: **Early Turonian - Late Senonian**) as *Silicisphaera buspina*

1991 Kirsch (Germany: **Coniacian - Early Campanian**)

Dimensions: Range of observed specimens: length of endophragm 32 (44) 59 µm, width of endophragm 28 (42) 57 µm, length of processes 10 (14) 19 µm. 6 specimens measured.

Comparisons: This species of *Florentinia* is distinguished by its number of large, complex processes. *Florentinia ferox* appears similar but does not have these large complex processes. *Florentinia laciniata* is much larger and has a long antapical process.

Occurrence: Blue Point (Arizona), Bunker Hill (Kansas), Pueblo (Colorado): Early Turonian. Rebecca K. Bounds core (Kansas): Middle Turonian.

Florentinia clavigera (Deflandre, 1937b) Davey & Verdier, 1973; emend. Davey & Verdier, 1976

Plate 4, Figures 1 & 2

1976 Davey & Verdier (North-west Europe: **earliest - latest Turonian**)

1983 Foucher (Paris Basin, France: **earliest Turonian - latest Santonian**)

1988 Masure (Bahamas: **Early Cenomanian**)

1988 Marshall & Batten (Lower Saxony Basin, North Germany: **Late Cenomanian - Early Turonian**)

1990 Prössl (nr. Salzgitter, North-west Germany: **mid - Late Turonian**)

1993 Courtinat (Pueblo, Colorado, USA: **Late Cenomanian**)

Dimensions: Range of observed specimens: length of endophragm 37 (42) 52 μm, width of endophragm 38 (47) 62 μm, length of processes 10 (14) 19 μm, length of antapical process 9 (13) 20 μm. 9 specimens measured.

Comparisons: This species is distinguished by its many, rigid, broad-based processes, which are generally simple but may be compound (joined proximally) and are truncate. The species also possesses a wider but short antapical process which is not always visible, depending on the orientation of the cyst. *Florentinia laciniata* is similar but has complex processes and a longer antapical process. *Florentinia ferox* also appears similar but is smaller and has no large antapical process. *Florentinia resex* is similar but is also smaller, and is ornamented with many more, thinner simple processes.

Occurrence: Rebecca K. Bounds core (Kansas): Early Cenomanian - Middle Turonian. Blue Point (Arizona), Bunker Hill (Kansas), Pueblo (Colorado), Wahweap Wash (Utah): Late Cenomanian - Early Turonian.

Florentinia cooksoniae (Singh, 1971) Duxbury, 1980

Plate 5, Figure 6

1971 Singh (North-west Alberta, Canada: **Late Albian**) as *Hystrichosphaeridium cooksoniae*
1978 Bujak & Williams (Offshore South-eastern Canada: **earliest Albian - latest Cenomanian**) as *Hystrichosphaeridium cooksoniae*
1983 Singh (North-west Alberta, Canada: **Early - Middle Cenomanian**)
1990 Prössl (nr. Salzgitter, North-west Germany: **Late Hauterivian - Late Albian**)
1993 Nøhr-Hansen (North-east Greenland: **Early Barremian to Late Albian**)
1996 Stover *et al.* (World wide: **Late Hauterivian - Late Turonian**)

Dimensions: Range of observed specimens: length of endophragm 40 (50) 67 μm, width of endophragm 36 (49) 67 μm, length of processes 13 (18) 23 μm, length of antapical process 12 (18) 24 μm. 7 specimens measured.

Comparisons: *Florentinia cooksoniae* has large, tubular processes, which are parallel sided, may be slightly constricted roughly two-thirds of the way along their length, and generally have entire margins which are not distally expanded. *Florentinia mantellii* is extremely similar but has processes which constrict much closer to the central body, expand again distally, and may branch into compound processes. *Florentinia deaniae* is also similar but is larger, has distally expanded processes and has a much larger, lagenate antapical process.

Occurrence: Rebecca K. Bounds core (Kansas): Early Cenomanian - Middle Turonian. Blue Point (Arizona), Bunker Hill (Kansas), Pueblo (Colorado), Wahweap Wash (Utah): Late Cenomanian - Early Turonian.

Florentinia deanei (Davey & Williams, 1966b) Davey & Verdier, 1973

Plate 5, Figure 5

1966b Davey & Williams (Fetcham Mill Borehole, Surrey, England: **Cenomanian**) as *Hystrichosphaeridium deanei*

1969a Davey (Fetcham Mill Borehole, Surrey, England: **Middle Cenomanian - Early Turonian,** Compton Bay, Isle of Wight, England; Escalles, France: **Cenomanian)** as *Hystrichosphaeridium deanei*

1973 Davey & Verdier (France and Switzerland: **Early Vraconian - Early Cenomanian)**

1976 Davey & Verdier (North-west Europe: **Late Albian - earliest Senonian)**

1980 Morgan (Australia: **earliest Albian - latest Cenomanian)**

1983 Foucher (Paris Basin, France: **Early Cenomanian - Late Coniacian)**

1988 Masure (Bahamas: **Middle Cenomanian)**

1988 Marshall & Batten (Lower Saxony Basin, North Germany: **Late Cenomanian - Early Turonian)**

1990 Prössl (nr. Salzgitter, North-west Germany: **Late Aptian - Middle Albian)**

1992 Costa & Davey (England and the North Sea: **Late Aptian - latest Coniacian)**

1994a Tocher & Jarvis (Fumichon, Normandy, France: **Early - Middle Cenomanian)**

Dimensions: Range of observed specimens: length of endophragm 38 (49) 61 µm, width of endophragm 35 (45) 60 µm, length of processes 14 (20) 27 µm, length of antapical process 19 (24) 29 µm, width of antapical process across its proximal end 14 (18) 25 µm. 7 specimens measured.

Comparisons: This is a large species of *Florentinia* with a large, lagenate antapical process and simple processes with distally expanded tips. *Florentinia mantellii* is very similar but is generally smaller, lacks the distinctively large, lagenate antapical process and may have compound processes. *Florentinia cooksoniae* also is generally smaller, lacks the distinctively large, lagenate antapical process and does not have distally expanded process terminations. *Florentinia laciniata* is also large, with a large antapical process, but has several complex processes.

Occurrence: Rebecca K. Bounds core (Kansas): Early Cenomanian - Middle Turonian. Blue Point (Arizona), Bunker Hill (Kansas), Pueblo (Colorado), Wahweap Wash (Utah): Late Cenomanian - Early Turonian.

Florentinia ferox (Deflandre, 1937b) Duxbury, 1980

Plate 4, Figures 4 & 6

1962b Cookson & Eisenack (Australia: **Albian - Cenomanian)** as *Hystrichosphaeridium ferox*

1964 Cookson & Hughes (Cambridgeshire, England: **Early Cenomanian)** as *Baltisphaeridium ferox*

1967 Clarke & Verdier (Isle of Wight, England: **Early Cenomanian - Late Santonian)** as *Baltisphaeridium ferox*

1969a Davey (Fetcham Mill Borehole, Surrey, England: **Cenomanian - Turonian,** Escalles, France; Saskatchewan, Canada: **Cenomanian)** as *Hystrichokolpoma ferox*

1976 Davey & Verdier (North-west Europe: **Early Turonian - Late Senonian)** as *Silicisphaera ferox*

1978 Bujak & Williams (Offshore South-eastern Canada: **Early Aptian - mid Campanian)** as *Silicisphaera ferox*

1980 May (New Jersey, USA: **Latest Campanian - Early Maastrichtian)**

1983 Foucher (Paris Basin, France: **Early Cenomanian - Early Campanian**) as *Silicisphaera ferox*
1988 Marshall & Batten (Lower Saxony Basin, North Germany: **Late Cenomanian - Early Turonian**)
1990 Prössl (nr. Salzgitter, North-west Germany: **Middle Albian - Late Turonian**)
1991 Kirsch (Germany: **mid Campanian - Maastrichtian**)

Dimensions: Range of observed specimens: length of endophragm 29 (45) 58 μm, width of endophragm 32 (45) 63 μm, length of processes 11 (14) 17 μm. 7 specimens measured.

Comparisons: This species has a number of simple and medially bifurcating and trifurcating processes with truncate tips. It is similar to *F. buspina* but does not have any large, complex processes. *Florentinia tridactylites* is also similar but has longer, thinner, medially trifurcating processes. *Florentinia clavigera* is similar but is larger and has mostly simple processes, with broader bases, and a large antapical process. *Florentinia resex* has many slender processes, which are only simple, and has a larger antapical process. *Systematophora* sp. A appears very similar but is ornamented with a number of annular complex processes.

Occurrence: Rebecca K. Bounds core (Kansas): Early Cenomanian - Middle Turonian. Blue Point (Arizona), Bunker Hill (Kansas), Pueblo (Colorado), Wahweap Wash (Utah): Late Cenomanian - Early Turonian.

Florentinia laciniata Davey & Verdier, 1973

Plate 5, Figure 3

1973 Davey & Verdier (France and Switzerland: **Late Albian - Early Cenomanian**)
1976 Davey & Verdier (North-west Europe: **Late Aptian - latest Turonian**)
1976 Norvick *in* Norvick & Burger (Bathurst Island, Australia: **Early Cenomanian - Early Turonian**)
1978 Bujak & Williams (Offshore South-eastern Canada: **earliest Aptian - latest Cenomanian**)
1980 Morgan (Australia: **Late Albian - Middle Cenomanian**)
1983 Singh (North-west Alberta, Canada: **Late Albian - Middle Cenomanian**)
1984 Below (Mazagan Plateau, Offshore North-west Africa: **earliest - Early Cenomanian**)
1988 Masure (Bahamas: **Vraconian - Middle Cenomanian**)
1988 Marshall & Batten (Lower Saxony Basin, North Germany: **Early Turonian**)
1990 Prössl (nr. Salzgitter, North-west Germany: **Late Barremian - Late Cenomanian**)
1991 Kirsch (Germany: **Coniacian - Late Santonian**)
1993 Courtinat (Pueblo, Colorado, USA: **Late Cenomanian**)
1994a Tocher & Jarvis (Fumichon, Normandy, France: **Early - Middle Cenomanian**)

Dimensions: Range of observed specimens: length of endophragm 36 (46) 57 μm, width of endophragm 39 (46) 50 μm, length of processes 15 (19) 23 μm, length of antapical process 16 (25) 31 μm, width of antapical process across its proximal end 12 (17) 22 μm. 7 specimens measured.

Comparisons: This is a large distinctive species, with slender, simple processes, several large, complex processes and a large tubular antapical process. *Florentinia deaniae* is also large with a large antapical process, but only has simple processes with expanded tips. *Florentinia buspina* has large, complex processes, but is smaller and lacks the large antapical process.

Occurrence: Rebecca K. Bounds core (Kansas): Early Cenomanian - Middle Turonian. Blue Point (Arizona), Pueblo (Colorado), Wahweap Wash (Utah): Late Cenomanian - Early Turonian. Bunker Hill (Kansas): Early Turonian.

Florentinia mantellii (Davey & Williams, 1966b) Davey & Verdier, 1973

Plate 5, Figure 4

1966b Davey & Williams (Fetcham Mill Borehole, Surrey, England: **Early Cenomanian)** as *Hystrichosphaeridium mantelli*

1969a Davey (Fetcham Mill Borehole, Surrey, England: **Cenomanian - Turonian,** Compton Bay, Isle of Wight, England; Escalles, France: **Cenomanian)** as *Hystrichosphaeridium mantelli*

1973 Davey & Verdier (France and Switzerland: **Late Albian - Early Cenomanian)**

1976 Davey & Verdier (North-west Europe: **earliest Barremian - Early Turonian)**

1976 Norvick *in* Norvick & Burger (Bathurst Island, Australia: **Early Cenomanian - Early Turonian)**

1978 Bujak & Williams (Offshore South-eastern Canada: **earliest Albian - latest Coniacian)**

1980 Morgan (Australia: **Early Albian)**

1982 Below (Morocco: **mid Aptian - Early Cenomanian)**

1984 Below (Mazagan Plateau, Offshore North-west Africa: **Early Aptian - Early Cenomanian)**

1986 Ioannides (Bylot Island, Arctic Archipelago: **Santonian/Campanian - Maastrichtian)**

1988 Masure (Bahamas: **Vraconian - Middle Cenomanian)**

1988 Marshall & Batten (Lower Saxony Basin, North Germany: **Late Cenomanian - Early Turonian)**

1988 Mao Shaozhi & Norris (Kashi Area, Xinjiang Province, China: **Late Cretaceous)**

1990 Prössl (nr. Salzgitter, North-west Germany: **Late Aptian - Late Turonian)**

1992 Costa & Davey (England and the North Sea: **Early Hauterivian - latest Turonian)**

1993 Nøhr-Hansen (North-east Greenland: **Early Barremian - Late Albian)**

1993 Williams *et al.* (N. Hemisphere: **Hauterivian - Turonian)**

1994a Tocher & Jarvis (Fumichon, Normandy, France: **Early - Middle Cenomanian)**

Dimensions: Range of observed specimens: length of endophragm 36 (44) 54 µm, width of endophragm 37 (45) 57 µm, length of processes 16 (19) 23 µm, length of antapical process 17 (22) 31 µm, width of antapical process across its proximal end 7 (10) 12 µm. 7 specimens measured.

Comparisons: This species has simple and compound processes which are distally expanded and has a larger antapical process. *Florentinia cooksoniae* is very similar but has parallel-sided (and often wider) processes which may be slightly constricted at their ends, and terminate with entire margins. *Florentinia* *deaniae* is larger and has a distinctive, larger, lagenate antapical process. *Florentinia radiculata* is also similar but is smaller, with slenderer and more deeply divided compound processes.

Occurrence: Rebecca K. Bounds core (Kansas): Early Cenomanian - Middle Turonian. Blue Point (Arizona), Bunker Hill (Kansas), Pueblo (Colorado), Wahweap Wash (Utah): Late Cenomanian - Early Turonian.

Florentinia radiculata (Davey & Williams, 1966b) Davey & Verdier, 1973;
emend. Davey & Verdier, 1976
Plate 5, Figures 1 & 2

1966b Davey & Williams (Fetcham Mill Borehole, Surrey, England: **Late Cenomanian)** as *Hystrichosphaeridium radiculatum*
1969a Davey (Fetcham Mill Borehole, Surrey, England: **Albian - Cenomanian**, Compton Bay, Isle of Wight; Escalles, France: **Cenomanian)** as *Hystrichosphaeridium radiculatum*
1973 Davey & Verdier (France and Switzerland: **Late Albian)**
1976 Davey & Verdier (North-west Europe: **earliest Albian - Late Senonian)**
1978 Bujak & Williams (Offshore South-eastern Canada: **earliest Albian - latest Coniacian)**
1980 Morgan (Australia: **mid Aptian - Late Albian)**
1982 Below (Morocco: **Late Hauterivian - Vraconian)**
1983 Foucher (Paris Basin, France: **Early Cenomanian - Late Santonian)**
1984 Below (Mazagan Plateau, Offshore North-west Africa: **Early Aptian - Early Cenomanian)**
1988 Masure (Bahamas: **Vraconian - Middle Cenomanian)**
1988 Marshall & Batten (Lower Saxony Basin, North Germany: **Late Cenomanian - Early Turonian)**
1990 Prössl (nr. Salzgitter, North-west Germany: **Late Aptian - Late Cenomanian)**
1994a Tocher & Jarvis (Fumichon, Normandy, France: **Middle Cenomanian)**

Dimensions: Range of observed specimens: length of endophragm 30 (37) 44 μm, width of endophragm 31 (39) 46 μm, length of processes 12 (14) 16 μm, length of antapical process 6 (12) 18 μm. 7 specimens measured.

Comparisons: This species is distinguished by its number of medially or proximally divided compound processes (which give the appearance of more processes than are actually present) and its larger tubular antapical process. *Florentinia mantellii* is larger and does not have compound processes that are medially or proximally divided.

Occurrence: Rebecca K. Bounds core (Kansas): Middle Cenomanian - Middle Turonian. Blue Point (Arizona), Bunker Hill (Kansas), Pueblo (Colorado), Wahweap Wash (Utah): Late Cenomanian - Early Turonian.

Florentinia resex Davey & Verdier, 1976
Plate 4, Figure 5

1976 Davey & Verdier (North-west Europe: **earliest - Middle Turonian)**

1982 Below (Morocco: **mid Aptian - Early Cenomanian)**
1983 Singh (North-west Alberta, Canada: **Early - Middle Cenomanian)**
1984 Below (Mazagan Plateau, Offshore North-west Africa: **Late Albian - earliest Cenomanian)**
1988 Masure (Bahamas: **Vraconian - Middle Cenomanian)**

Dimensions: Range of observed specimens: length of endophragm 30 (36) 40 µm, width of endophragm 30 (36) 45 µm, length of processes 10 (14) 17 µm, length of antapical process 7 (10) 12 µm. 9 specimens measured.

Comparisons: This species has numerous simple, slender processes with truncate tips, and a larger, conical antapical process, which narrows and is closed distally with a truncate margin. *Florentinia clavigera* is similar but larger with fewer, wider-based processes, some of which are compound. *Florentinia ferox* also has compound processes and does not have a larger antapical process. *Coronifera oceanica* is very similar but has many more, thinner acuminate processes and a larger antapical process that is distally flared and open.

Occurrence: Rebecca K. Bounds core (Kansas): Early Cenomanian - Middle Turonian. Blue Point (Arizona), Pueblo (Colorado), Wahweap Wash (Utah): Late Cenomanian - Early Turonian. Bunker Hill (Kansas): Early Turonian.

Genus *Hapsocysta* Davey, 1979b

Hapsocysta peridictya (Eisenack & Cookson, 1960) Davey, 1979b

Plate 24, Figure 5

1980 Morgan (Australia: **Early Albian)** as *Cannosphaeropsis peridictya*
1984 Below (Mazagan Plateau, Offshore North-west Africa: **mid Aptian - Late Albian)**
1987 Habib & Drugg (Offshore USA, Western North Atlantic: **Aptian - Albian)**
1990 Prössl (nr. Salzgitter, North-west Germany: **Early - Late Albian)**
1992 Costa & Davey (England and the North Sea: **Late Aptian - Late Cenomanian)**

Dimensions: Range of observed specimens: length of periphragm 66 (75) 87 µm, width of periphragm 59 (79) 99 µm, length of endophragm 36 (48) 55 µm, width of endophragm 35 (40) 47 µm. 7 specimens measured.

Comparisons: This species is very distinctive, with a periphragm composed of high parasutural trabeculae which only join the endophragm at the one-plate precingular archaeopyle. *Adnatosphaeridium tutulosum* also has a high trabeculum but is much smaller and thinner-walled with the trabeculum connecting the distal ends of a much larger number of processes, and with an apical archaeopyle.

Occurrence: Rebecca K. Bounds core (Kansas): Middle Turonian.

Genus *Kallosphaeridium* De Coninck, 1969; emend. Jan du Chêne *et al.*, 1985a

Kallosphaeridium? granulatum (Norvick *in* Norvick & Burger, 1976)
Stover & Evitt, 1978

Plate 14, Figures 5 & 6

1976 Norvick *in* Norvick & Burger (Bathurst Island, Australia: **Early Cenomanian - Early Turonian)** as *Membranosphaera granulata*

Dimensions: Range of observed specimens: length of cyst with apex 31 (41) 49 µm, width of cyst 31 (37) 42 µm. 9 specimens measured.

Remarks: The periphragm is variably to densely ornamented with granulae, clavulae and baculae up to 0.5 µm long. The archaeopyle is apical, type (tA)a. The principle archaeopyle suture is zigzag. The operculum is always attached, and comparatively small in comparison with the diameter of the cyst. The accessory archaeopyle sutures are generally small.

Comparisons: This species is very similar to *Kallosphaeridium? ringnesiorum* but is smaller with less dense ornamentation of a more variable length. *Kallosphaeridium? helbyi* is also larger and has a scabrate surface. *Kallosphaeridium* sp. A is also similar but the surface is punctate. Several species of *Batiacasphaera* are also similar, but do not have an attached operculum. *Batiacasphaera euteiches* is densely granular, and *Batiacasphaera granulosa* has a sparse but even covering of granulae.

Occurrence: Rebecca K. Bounds core (Kansas): Early Cenomanian - Middle Turonian. Blue Point (Arizona): Late Cenomanian - Early Turonian. Wahweap Wash (Utah): Late Cenomanian.

Kallosphaeridium? helbyi Lentin & Williams, 1989

nom. subst. pro Kallosphaeridium? minus (Cookson & Hughes, 1964) Helby, 1987

non Kallosphaeridium? minor (Jiabo, 1978) Lentin & Williams, 1981

Plate 14, Figure 10

1964 Cookson & Hughes (Cambridgeshire, England: **Late Albian - Early Cenomanian)** as *Canningia minor*

1964 Manum & Cookson (Arctic Canada: **'mid Cretaceous')** as *Canningia minor*

1969 Habib (Bahamas: **Albian/Early Cenomanian)** as *Canningia minor*

1970 Habib (Bahamas: **Albian/Cenomanian)** as *Canningia minor*

1973 Davey & Verdier (France and Switzerland: **Late Albian - Early Vraconian)** as *Canningia minor*

1981 Below (South-west Morocco: **Barremian - Albian)** as *Canningia minor*

1986 Ioannides (Bylot Island, Arctic Archipelago: **Santonian/Campanian)** as *Canningia minor*

1988 Mao Shaozhi & Norris (Kashi Area, Xinjiang Province, China: **Late Cretaceous)** as *Canningia minor*

1990 Harker *et al.* (Interior Plains of Canada: **Late Santonian - Late Campanian)** as *Canningia minor*

Dimensions: Range of observed specimens: length of cyst with apex 50 (55) 59 µm, length of cyst without apex 41 (47) 52 µm, width of cyst 49 (56) 65 µm. 3 specimens measured.

Comparisons: This species has a thickish, scabrate wall. *Kallosphaeridium? ringnesiorum* is similar but is clavate. *Batiacasphaera euteiches* is similar but is thicker walled, is densely granular, and does not have an attached operculum. *Canninginopsis colliveri* is also similar but is generally lenticular in shape, and is finely ornamented with granules and cones.

Occurrence: Rebecca K. Bounds core (Kansas): Early Turonian - Middle Turonian. Pueblo (Colorado): Early Turonian.

Kallosphaeridium? ringnesiorum (Manum & Cookson, 1964) Helby, 1987

Plate 14, Figure 9

1964	Manum & Cookson (Arctic Canada: **'mid Cretaceous'**) as *Canningia ringnesii*
1975	Brideaux & McIntyre (District of Mackenzie, Canada: **Middle Albian**) as *Canningia ringnesiorum*
1981	Below (South-west Morocco: **Early Cenomanian**) as *Canningia ringnesiorum*
1982	Below (Morocco: **Early Cenomanian**) as *Canningia ringnesiorum*
1984	Below (Mazagan Plateau, Offshore North-west Africa: **Early Aptian - earliest Cenomanian**) as *Canningia ringnesiorum*
1986	Ioannides (Bylot Island, Arctic Archipelago: **Santonian/Campanian**) as *Canningia ringnesiorum*
1988	Jarvis *et al.* (Dover, Kent, England: **Late Cenomanian - Early Turonian**)
1988	Marshall & Batten (Lower Saxony Basin, North Germany: **Late Cenomanian - Early Turonian**) as *Canningia ringnesiorum*
1993	Courtinat (Pueblo, Colorado, USA: **Late Cenomanian**)
1994a	Tocher & Jarvis (Fumichon, Normandy, France: **Middle Cenomanian**)

Dimensions: Range of observed specimens: length of cyst with apex 51 (61) 68 µm, width of cyst 52 (59) 68 µm. 7 specimens measured.

Comparisons: This species is ornamented with a dense covering of clavae. *Kallosphaeridium? helbyi* only has scabrate ornamentation. *Batiacasphaera euteiches* is similar but is smaller, densely granular, and does not have an attached operculum.

Occurrence: Bunker Hill (Kansas), Wahweap Wash (Utah): Late Cenomanian - Early Turonian. Pueblo (Colorado): Late Cenomanian. Blue Point (Arizona): Early Turonian. Rebecca K. Bounds core (Kansas): Middle Turonian.

Kallosphaeridium sp. A

Plate 13, Figures 11 & 12

Description: Proximate, two-walled cyst with a subspherical outline. The periphragm is uniformly, but finely punctate to puncto-reticulate. The periphragm and endophragm are closely appressed, except for slight separation in the paracingular area. Paratabulation and parasulcus are not expressed at all. The archaeopyle is apical, type (tA)a. The principle archaeopyle suture is zigzag. The operculum is always attached, and comparatively small in comparison with the diameter of the cyst. The accessory archaeopyle sutures are generally small.

Dimensions: Range of observed specimens: length of cyst with apex 39 (47) 60 µm, width of cyst 38 (52) 67 µm. 7 specimens measured.

Comparisons: *Kallosphaeridium? helbyi* is similar but thicker walled and scabrate. *Kallosphaeridium? ringnesiorum* is also thicker walled and is larger and densely clavate. *Kallosphaeridium? granulatum* is variably to densely granulate to baculate.

Occurrence: Rebecca K. Bounds core (Kansas): Middle Cenomanian - Late Cenomanian. Blue Point (Arizona), Wahweap Wash (Utah): Late Cenomanian - Early Turonian. Pueblo (Colorado): Early Turonian.

Genus *Operculodinium* Wall, 1967

Operculodinium sp. A

Plate 16, Figures 1 & 2

Description: Skolochorate cyst with a spherical to subspherical central body and numerous processes. These are broad based, gradually tapering, hollow, acuminate and distally closed. The process terminations are acicular, finely capitate, or occasionally bear a number of tiny, stiff spines. The periphragm is closely appressed to the endophragm over the central body and is finely and densely granulate. The cyst exhibits no evidence of paratabulation, paracingulum (except by transverse alignment of processes) or parasulcus. The archaeopyle is a single-plate precingular one (presumably plate 3"); operculum free.

Dimensions: Range of observed specimens: length of endophragm 25 (30) 35 µm, width of endophragm 24 (30) 34 µm, maximum length of processes 9 (10) 10 µm, maximum width of processes at proximal end 1 (1.3) 1.5 µm. 10 specimens measured.

Comparisons: *Downiesphaeridium armatum* appears identical but is slightly larger and has an apical archaeopyle instead of a single plate precingular one. *Downiesphaeridium multispinosum* is also similar but has much thinner, acicular processes which occasionally bifurcate, with an apical archaeopyle. Species of *Exochosphaeridium* are larger with more numerous, solid processes, a better defined paracingulum and often a short apical horn.

Occurrence: Blue Point (Arizona), Pueblo (Colorado), Wahweap Wash (Utah): Late Cenomanian. Rebecca K. Bounds core (Kansas): Middle Turonian.

Genus *Spongodinium* Deflandre, 1936b; emend. Stover & Evitt, 1978; emend. Lucas-Clark, 1987

Type species: *Spongodinium delitiense* (Ehrenberg, 1838); Deflandre, 1936; emend. Lucas-Clark, 1987

Translation Deflandre, 1936: Stover and Evitt, 1978, p. 191

Original description: Deflandre, 1936, p. 169-170

The theca is ellipsoidal, ovoid or subspherical in shape, and carries a strong, short asymmetrically placed horn at one pole. The whole tegument is alveolate and divided into unequal and irregular fields by fine membranes perpendicular to its surface, membranes which thicken at their points of junction, forming there a kind of apparently robust pillar. Around the equator a series of alveoli are better developed and show a higher membrane, bent and in places closed by junctions with that which faces it. It thus forms a kind of girdle, sometimes difficult to see but constant.

Emended description: Stover and Evitt, 1978, p. 191-192

Synopsis: Cysts proximate, subspherical to subpolyhedral with prominent apical horn; autophragm only, in part vesicular; vesicle distribution indicates paracingulum and other traces of paratabulation; archeopyle precingular, Type P; operculum free.

Modified description: Shape: Subspherical to subpolyhedral with prominent apical horn and, usually, two broadly rounded antapical prominences.

Wall relationships: Autophragm only, unevenly vesicular; separated periphragm and endophragm simulated in highly vesiculate areas such as paracingulum and apical horn.

Wall features: Parasutures incompletely indicated by narrow strips, along which the wall may be thicker and more vesiculate than elsewhere; vesicular structure concentrated along paracingulum and at bases of horns.

Paratabulation: Incompletely indicated by archeopyle, paracingulum, and distribution of vesicular areas. Probably gonyaulacacean; formula unknown.

Archeopyle: Precingular, Type P (presumably 3" only); large and rounded, evidently enlarged; operculum free.

Paracingulum: Indicated by an equatorial bulge in coarsely vesicular wall.

Parasulcus: Indicated by interruption in paracingulum and partly outlined by vesicular wall.

Size: Large.

Affinities: Stover and Evitt, 1978, p. 192

The vesicular autophragm is unique. Genus Spongodinium Deflandre, 1936.

Emended descripton: Lucas-Clark, 1987, p. 166

Large acavate, subspherical to subpolyhedral cysts, circular in equatorial section, with prominent apical horn. Cyst basically an autophragm with vesiculate structure. An outer wall (which could be considered periphragm or ectophragm) is simulated in highly vesicular areas by a thin membrane enclosing the vesicles. Amount of vesiculation variable. Vesicles most numerous around cingulum, where they form a broad-based flange, around the apical horn, and on the antapical paraplate. Some specimens completely covered by vesicles. Archeopyle precingular, type P(4), operculum enlarged along cingular and precingular margins, rounded, free. Paratabulation usually incompletely expressed and obscured by vesiculation, but sometimes indicated by parasutural ridges, alignment of vesicles along parasutures, or confinement of vesicles to intratabular areas. Growth bands variably expressed by accessory ridges and variations in vesiculation.

Paratabulation gonyaulacoid and similar to that of Cribroperidinium. The following paraplates can be demonstrated in some specimens: One preapical (P), four apicals (I u, B, C, A), six precingulars (1 i, 2-6), four sulcals (ai, Ii, Im, Z), one posterior intercalary (X), six postcingulars (Iu, II-VI), and one antapical (Y). Ventral organization: elongated A and lu both contact pentagonal li; ends of cingulum offset slightly. Apical organization: A, B, and lu contact P; C does not contact P; A appears to contact B; Q probably not present. Posterior sulcal organization: elongate X, crescent-shaped Z; small Ii, Im, and Iu. Dorsal organization: IV/V parasuture offset in position to the left of 4/5. Hypocystal organization: sexiform, Y asymmetrical with V/Y parasuture longer than III/Y parasuture. Y usually has an angular contact with V, expressing contact with trace of wide growth band. Y is rotated so that the IV/V/Y triple junction is approximately middorsal.

Affinities: Lucas-Clark, 1987, p. 167:
The emendation here differs from previous descriptions primarily in recognizing the detailed paratabulation pattern. Although indications of paratabulation are typically obscured by the complexity of the vesicular wall, in specimens of S. delitiense from the Bearpaw formation of Montana, the sparseness of the vesicles in the wall and their alignment along parasutures allowed observation of part of the paratabulation. Other specimens (provided by J. Lentin) from an Arctic Ocean core permitted observation of the parasutures after the vesicles had burst or collapsed from drying and exposure to the vacuum of the SEM. The combination of the Bearpaw and Arctic Ocean specimens allowed documentation of a nearly complete paratabulation pattern for Spongodinium, except that contacts in the preapical region are still uncertain.

Spongodinium delitiense (Ehrenberg, 1838) Deflandre, 1936b; emend. Lucas-Clark, 1987

1978 Bujak & Williams (Offshore South-eastern Canada: **earliest - latest Maastrichtian)**

1980 May (New Jersey, USA: **Late Campanian - Early Maastrichtian)**

1987 Lucas-Clark (Montana, USA: **Late Campanian**, New Jersey, USA: **Palaeocene**, Cesar Hole, Alpha Ridge, Amerasian Basin, Arctic Ocean: **Late Campanian?-K/T Boundary?)**

1987 Firth (Georgia, USA: **Early Maastrichtian)**

1989 Habib & Milner (South Carolina & Georgia, USA: **Late Campanian)**

1990 Harker *et al.* (Interior Plains of Canada: **Early - Late Campanian)**

1991 Kirsch (Germany: **Early Maastrichtian)**

1992 Costa & Davey (England and the North Sea: **Late Santonian - Tertiary?)**

1993 Williams *et al.* (N. Hemisphere: **Early Campanian - Tertiary)**

Emended description: Lucas-Clark, 1987, p.167
Large acavate, subspherical to subpolygonal cysts with prominent apical horn. Cingulum marked by two ridges "overgrown" by vesicles or "alveoli" which form a single broad-based flange. Wall partly or completely vesicular, i.e., having the appearance of enclosing bubbles that are distributed over the entire cyst or may be restricted to some parts of it.
Outline in dorsal-ventral view highly variable, varying from biconical to subrhomboidal (with anterolateral angulations formed by the dorsal apical paraplates) to spherical. Outline in apical view circular with sulcus indicated by a slight indentation or only by a break in cingular flange. Paratabulation usually expressed incompletely and indistinctly by parasutural ridges, distribution of vesicles, and archeopyle. Paratabulation as described for genus.

Apteodinium frontierense (Burgess, 1971) Stover & Evitt, 1978

1971 Burgess (Central Wyoming, USA: **Albian - Early Cenomanian)** as *Coniferatium frontierensis*

Original Description: Burgess, 1971, p. 81: *Coniferatium frontierensis*
Test dorsoventrally flattened, rounded polygonal in outline. A prominent girdle divides the epitheca from the hypotheca. The sculpture consists of a fine to coarse reticulum, being the coarsest in the apical, antapical and girdle areas. The outer reticulate wall is in contact with the capsule except at the poles. Precingular archaeopyle is always present as a triangular to arch-shaped opening. The epitheca terminates in a rounded knob-like reticulate mass of spongy tissue.
Measurements: Holotype length 57.6 µm, width 56.0 µm. Range length 53 - 63 µm, width 50 - 72 µm.

Comments: The generic name is derived from the similarity of the reticulum to that of coniferous bladders.

Spongodinium sp. cf. *S. delitiense* (Ehrenberg, 1838) Deflandre, 1936b; emend. Lucas-Clark, 1987
Plate 29, Figure 2

Dimensions: Range of observed specimens: length of periphragm 114 (121) 128 µm, width of periphragm 102 (109) 115 µm, length of endophragm 94 (104) 113 µm, width of endophragm 101 (104) 108 µm, length of apical horn 11 (14) 17 µm. 3 specimens measured.

Remarks: Three specimens of a species which matches the original and emended descriptions of *Spongidinium delitiense* (in all but the paratabulation, which cannot be determined) have been found in the Rebecca K. Bounds Core. However, since the earliest previously published range of the species is from the late Santonian, the identification is only tentative.

The possible exception to this is the description of a species from the Albian to Cenomanian of Wyoming by Burgess (1971). He describes a new genus and species, *Coniferatium frontierensis*. Stover and Evitt (1978) transferred this species to *Apteodinium* without discussion. The genus is named after the similarity of the wall sculpture to gymnosperm pollen bladders or sacci, which Burgess suggests are reticulate. In fact, sacci do not have surface ornamentation or sculpture, but have internal structure. It is possible, therefore that his genus has a complex wall structure similar to gymnosperm sacci, which can be equated with the genus *Spongodinium*. Burgess also suggested in his generic description that no paratabulation was evident. His photographic plates seem to suggest otherwise, as the wall appears to show some folding or thickening and concentration of the 'reticulum' in some longitudinal linear areas. A partial expression of paratabulation by the concentration of alveoli and the thickening of the wall layer is also symptomatic of the genus *Spongodinium*. All the features in Burgess' description of the species *C. frontierensis* are also shared with the original and emended descriptions of *Spongodinium delitiense* and also with my own specimens. The only difference is the size of the species *C. frontierense* which appears to be approximately half the size of *S. delitiense*.

Owing to the fact that no recorded stratigraphic occurrences of *S. delitiense* occur as early as the Cenomanian and Turonian, I have recorded three specimens of identical description as *S.* sp. cf. *S. delitiense*. It seems likely, however, that I am not the first to have found material of this type from strata of this age in this basin. Careful examination of the holotype of *C. frontierense* is needed before any further conclusions can be drawn.

Occurrence: Rebecca K. Bounds core (Kansas): Early Cenomanian - Middle Turonian.

Subfamily **Gonyaulacoideae** (Autonym)

Genus *Achomosphaera* Evitt, 1963

Achomosphaera crassipellis (Deflandre & Cookson, 1955) Stover & Evitt, 1978

Plate 7, Figure 4

1966a Davey & Williams (Fetcham Mill Borehole, Surrey, England: **Cenomanian**) as *Hystrichosphaera crassipellis*

1967 Clarke & Verdier (Isle of Wight, England: **Early Cenomanian - Late Santonian**) as *Hystrichosphaera crassipellis*

1969a Davey (Fetcham Mill Borehole, Surrey; Compton Bay, Isle of Wight, England; Escalles, France: **Cenomanian**) as *Hystrichosphaera crassipellis*

1983 Foucher (Paris Basin, France: **Early Cenomanian - Early Campanian**)

1988 Marshall & Batten (Lower Saxony Basin, North Germany: **Late Cenomanian - Early Turonian**)

Dimensions: Range of observed specimens: length of central body 40 (48) 55 µm, width of central body 38 (46) 54 µm, maximum length of processes 14 (17) 19 µm, maximum width of processes <1 (1.3) 2 µm. 8 specimens measured.

Comparisons: The thick, coarsely reticulate periphragm, differentiates this species from most other species of *Achomosphaera*, except for *A. sagena* which does not have faint, parasutural markings.

Occurrence: Rebecca K. Bounds core (Kansas): Early Cenomanian - Middle Turonian. Blue Point (Arizona), Pueblo (Colorado), Wahweap Wash (Utah): Late Cenomanian - Early Turonian. Bunker Hill (Kansas): Early Turonian.

Achomosphaera neptunii (Eisenack, 1958a) Davey & Williams, 1966a

Plate 7, Figure 3

1966a Davey & Williams (Speeton, Yorkshire, England: **mid Hauterivian**)

1976 Brideaux & Myhr (Canada: **Hauterivian - Aptian**)

1977 Brideaux (Canada: **Hauterivian - Aptian**)

1978 Bujak & Williams (Offshore South-eastern Canada: **earliest Berriasian - latest Valanginian**)

1980 Morgan (Australia: **Late Neocomian**)

1982 Below (Morocco: **Late Hauterivian - Albian**)

1984 Below (Mazagan Plateau, Offshore North-west Africa: **Early Aptian**)

1987 Habib & Drugg (Offshore USA, Western North Atlantic: **Late Berriasian - Late Albian**)

1990 Prössl (nr. Salzgitter, North-west Germany: **Early Hauterivian - uppermost Barremian**)

1992 Costa & Davey (England and the North Sea: **Ryazanian - Late Aptian**)

1993 Williams *et al.* (Northern Hemisphere: **Early Valanginian - Late Aptian**)

1993 Nøhr-Hansen (North-east Greenland: **Early - Late Barremian**)

1996 Stover *et al.* (World wide: **Late Ryazanian - Late Aptian**)

Translation Eisenack, 1958: Laboratory of Palaeobotany and Palynology, Utrecht
Original description: Eisenack, 1958, p. 399: *Baltisphaeridium neptuni*
Diagnosis: Shell with thin wall, spherical to oval, covered with few, broadly based, cylindrical to weakly conical appendices; these are thin-walled, hollow and distally usually divided into 3 (more

rarely 2 or 4) strongly diverging, mostly widely diverging, pointed processes. The length of the appendices is about half the central body diameter, or slightly shorter.
Dimensions: 12 specimens: shell diameter 40-60 µm, total diameter 75-95 µm; Holotype 48 µm and 88 µm respectively.

Davey and Williams, 1966, p. 51: *Achomosphaera neptuni*
Diagnosis: *Achomosphaera neptuni* possesses a central body with a reticulate or sometimes slightly fibrous surface. The processes are gonal in position, taeniate or taeniate-triangular and may be bifurcate or trifurcate. In the cingular zone the processes are branched. The processes are fibrous, the fibres sometimes radiating from the bases of the processes and these may be slightly thickened along the reflected plate boundaries joining the processes. A precingular archaeopyle is often present.
Dimensions: 1st specimen diameter of central body 61x66 µm, length of processes up to 28µm. 2nd specimen diameter of central body 47x52 µm, length of processes up to 21 µm.

Emended description: Sarjeant, 1985, p.90, 92: *Florentinia? neptuni*
Proximochorate to chorate cysts, intratabulate, with a spheroidal to broadly ovoidal central body. Processes all closed distally and of three principal types: (a) Large and cylindrical or compressed-cylindrical or saddle-shaped processes, giving rise to 4-6 short, bifurcate or ramifying branches, correspond to the largest paraplates. These processes exhibit, frequently or consistently, perforations of variable size and density; (b) Tubiform to ipniate or slightly tapering processes of smaller dimension, trifurcate or tetrafurcate distally and again often perforate, corresponding to the other paraplates of the epitract and hypotract. These vary in size in relation to the paraplate to which they correspond; (c) Unbranched processes, acuminate or tapering, correspond to some, at least, of the small sulcal paraplates. Length of processes around 30% of the central body breadth. Sutures between paraplates not marked. Paratabulation gonyaulacacean, probably 4', 0a, 6'', 6c, 5'?, 6''', 1p, 1''''. Surface of phragma granulate to shagreenate or reticulate.
Archaeopyle probably single-plate precingular (type P), formed by loss of paraplate 3''.

Dimensions: Range of observed specimens: length of periphragm 80 & 79 µm, width of periphragm 82 & 82 µm, length of central body 49 & 52 µm, width of central body 46 & 45 µm, maximum length of processes 22 & 20 µm, respectively. 2 specimens measured.
Remarks: Only two specimens of *A. neptunii* were found, both in the Wahweap Wash section and are probably reworked.
Comparisons: This species is very similar to one end range of *Achomosphaera?* sp. A, but seems to be larger, and thicker walled, appearing to be of a more regular shape with better defined, and more methodically placed processes. These processes are of a more uniform length, width and shape with neater and more consistent trifurcations and bifurcations, compared with those of *Achomosphaera?* sp. A. Membranes linking adjacent processes are generally restricted to the cingular area.
Occurrence: Wahweap Wash (Utah): Late Cenomanian.

Achomosphaera ramulifera (Deflandre, 1937b) Evitt, 1963

Plate 7, Figures 1 & 2

1964	Cookson & Hughes (Cambridgeshire, England: **Late Albian - Early Cenomanian)**
1966a	Davey & Williams (Fetcham Mill Borehole, Surrey: **Cenomanian**, England: **Ypresian)**
1967	Clarke & Verdier (Isle of Wight, England: **Early Cenomanian - Late Santonian)**
1969a	Davey (Fetcham Mill Borehole, Surrey; Compton Bay, Isle of Wight, England; Escalles, France: **Cenomanian)**

1973 Davey & Verdier (France and Switzerland: **Late Albian - Early Cenomanian)**

1978 Bujak & Williams (Offshore South-eastern Canada: **earliest Cenomanian - latest Santonian)**

1980 Morgan (Australia: **Late Neocomian - latest Vraconian)**

1983 Foucher (Paris Basin, France: **Early Cenomanian - Late Campanian)**

1983 Habib & Drugg (Blake-Bahama Basin, Western Atlantic: **Late Aptian - Late Albian)**

1984 Below (Mazagan Plateau, Offshore North-west Africa: **Late Albian - earliest Cenomanian)**

1986 Ioannides (Bylot Island, Arctic Archipelago: **Santonian/Campanian - Early Palaeocene)**

1987 Firth (Georgia, USA: **Late Maastrichtian)**

1987 Habib & Drugg (Offshore USA, Western North Atlantic: **earliest - Late Albian)**

1988 Marshall & Batten (Lower Saxony Basin, North Germany: **Late Cenomanian - Early Turonian)**

1988 Masure (Bahamas: **Vraconian - Middle Cenomanian)**

1990 Harker *et al.* (Interior Plains of Canada: **earliest Campanian - Early Maastrichtian)**

1990 Prössl (nr. Salzgitter, North-west Germany: **mid Barremian - Late Turonian)**

1993 Courtinat (Pueblo, Colorado, USA: **Late Cenomanian)**

Dimensions: Range of observed specimens: length of central body 37 (44) 48 µm, width of central body 34 (41) 48 µm, maximum length of processes 15 (17) 21 µm. 7 specimens measured.

Comparisons: This species frequently has a rhomboidal central body and has the appearance of two thicknesses of processes due to the frequent fusing together of adjacent processes. It has more numerous processes than *Achomosphaera* sp. A and *A. neptunii*, and lacks the parasutural markings of *Spiniferites ramosus gracilis*.

Occurrence: Rebecca K. Bounds core (Kansas): Early Cenomanian - Middle Turonian. Blue Point (Arizona), Bunker Hill (Kansas), Pueblo (Colorado), Wahweap Wash (Utah): Late Cenomanian - Early Turonian.

Achomosphaera regiensis Corradini, 1973

Plate 7, Figures 5 & 6

1973 Corradini (Northern Appenines, Italy: **Late Cretaceous)**

Dimensions: Range of observed specimens: length of central body 41 (46) 57 µm, width of central body 38 (44) 56 µm, maximum length of processes 11 (17) 25 µm, maximum width of processes 1.5 (1.8) 2 µm. 7 specimens measured.

Comparisons: This species is very similar to *Achomosphaera ramulifera* but has a spherical central body and is generally larger with a thicker wall. In addition, the processes are generally more numerous, seldom fused at all, and are often medially bifurcate. Other species of *Achomosphaera* within this material have far fewer processes.

Occurrence: Pueblo (Colorado), Rebecca K. Bounds core (Kansas): Late Cenomanian. Blue Point (Arizona), Wahweap Wash (Utah): Early Turonian.

Achomosphaera? sp. A

Plate 8, Figures 1 to 6

Diagnosis: Cysts skolochorate, body subspherical to polygonal, bearing numerous, short processes, with a wide morphological variation in wall shape, separation and process development. The wall layers are variably appressed and cysts can be apiculocavate, camocavate or circumcavate, with numerous furcating processes, which are variably proximally expanded. The endophragm is psilate, while the periphragm is psilate to finely perforate or sparsely and finely granulate. The archaeopyle is not always easily discernible or well defined, but when developed is precingular with the loss of one paraplate, presumably plate 3".

Description: The endophragm and periphragm are variably appressed between process bases. The endophragm is subspherical to ellipsoidal, the periphragm is subspherical / ellipsoidal or polygonal depending on amount of wall separation and the degree of expansion of the process bases. Wall separation can be variably developed both on individual specimens and between specimens, and can occur simply as large expansions at the bases of processes, or covering sections of the cyst body (this may be apically, laterally, antapically, or in combination), or entirely surrounding the endocyst. Faint parasutural markings of low ridges may join adjacent process bases. Occasionally these may be expanded into sutural cavities linking adjacent processes.

The processes are formed as extensions of the periphragm and are hollow and of variable length; the length of their shafts depending on the extent of the pericoel underneath (long with little pericoel development and short with a large pericoel development). In comparison with other species of the genus, the length of the processes is generally quite short. The processes are also of variable width, depending on the degree of basal expansion, with adjacent processes commonly fused or linked by an extension of the periphragm. They occupy gonal or occasionally intergonal positions. Primary furcations on gonal processes may be regular and trifurcate or irregular, even appearing compound or complex (with processes fused along their lengths), and occur at medial to distal positions. Intergonal processes tend to be medially bifurcate. Processes are distally closed, with secondary and even occasionally tertiary furcations, generally terminating with bifid tips.

Dimensions: Range of observed specimens: length of periphragm 45 (57) 88 µm, width of periphragm 37 (54) 67 µm, length of central body 30 (42) 65 µm, width of central body 25 (37) 49 µm, maximum length of processes 5 (10) 14 µm. 21 specimens measured.

Comparisons: It seems likely that this species occupies an intermediate position between species of *Achomosphaera* which are apiculocavate, species of *Hystrichostrogylon*, which are camocavate, and species of *Catastomocystis* which are circumcavate. *Achomosphaera neptunii* is similar to one end range of *Achomosphaera?* sp. A, but is larger, and thicker walled, with a more regular shape and better defined processes. These have a more uniform width and length with neater, and more consistent trifurcations and bifurcations. In addition, there are membranes linking adjacent processes, and these are generally restricted to the cingular area. Other species of *Achomosphaera* within this material have more numerous and much thinner processes. *Hystrichostrogylon membraniphorum* is also very similar with a variation in degree of separation between wall layers, over a variably large area, but this always includes the ventral area, forming a camocavate cyst. *Catastomocystis spinosa* also may appear similar but is fully circumcavate with an ellipsoidal pericyst outline and only short spines in gonal and intergonal positions.

Occurrence: Rebecca K. Bounds core (Kansas): Early Cenomanian - Middle Turonian. Blue Point (Arizona), Bunker Hill (Kansas), Pueblo (Colorado), Wahweap Wash (Utah): Late Cenomanian - Early Turonian.

Genus *Gonyaulacysta* Deflandre, 1964; emend. Sarjeant, 1966b; emend. Sarjeant, 1969; emend. Stover & Evitt, 1978; emend. Sarjeant, 1982b

Gonyaulacysta cassidata (Eisenack & Cookson, 1960) Sarjeant, 1966b

Plate 26, Figure 5

1960 Eisenack & Cookson (Australia: **Aptian - Cenomanian**) as *Gonyaulax cassidata*

1962b Cookson & Eisenack (Australia: **Aptian - Cenomanian**) as *Gonyaulax cassidata*

1964 Cookson & Hughes (Cambridgeshire, England: **Early Cenomanian**) as *Gonyaulax cassidata*

1966b Sarjeant (Fetcham Mill Borehole, Surrey, England: **Cenomanian**)

1967 Clarke & Verdier (Isle of Wight, England: **Early - Late Cenomanian**)

1969a Davey (Fetcham Mill Borehole, Surrey; Compton Bay, Isle of Wight, England; Escalles, France: **Cenomanian**)

1973 Davey & Verdier (France and Switzerland: **Late Albian - Early Cenomanian**)

1976 Norvick *in* Norvick & Burger (Bathurst Island, Australia: **Early Cenomanian - Early Turonian**)

1978 Bujak & Williams (Offshore South-eastern Canada: **earliest - latest Albian**)

1980 Morgan (Australia: **Late Aptian - latest Cenomanian**)

1981 Below (South-west Morocco: **Early Cenomanian**)

1982 Below (Morocco: **Early Cenomanian**)

1983 Foucher (Paris Basin, France: **Early - latest Cenomanian**)

1984 Below (Mazagan Plateau, Offshore North-west Africa: **earliest Cenomanian**)

1987 Habib & Drugg (Offshore USA, Western North Atlantic: **Cenomanian/Turonian**)

1988 Marshall & Batten (Lower Saxony Basin, North Germany: **Late Cenomanian**)

1990 Prössl (nr. Salzgitter, North-west Germany: **earliest Barremian - Late Cenomanian**)

1992 Costa & Davey (England and the North Sea: **Early Aptian - latest Cenomanian**)

1993 Williams *et al.* (N. Hemisphere: **Jurassic? - Cenomanian**)

Dimensions: Range of observed specimens: length of periphragm 50 (64) 78 μm, width of periphragm 42 (54) 71 μm, length of endophragm 31 (46) 58 μm, width of endophragm 40 (49) 65 μm, length of antapical pericoel 2 (3.1) 4 μm. 7 specimens measured.

Comparisons: This species is very similar to *Psaligonyaulax deflandrei* but is less obviously bicavate, with a large apical pericoel but a very small antapical pericoel. None of the specimens were preserved with particularly high or denticulate parasutural crests. In practice, it was not always easy to differentiate between these two species, and hence those specimens placed within *G. cassidata* are those with the length of their antapical pericoel less than 10% of the length of the periphragm (4 μm or less in length). Original descriptions do not describe or measure the pericoels and from original illustrations it is not possible to accurately determine the size of the antapical pericoels.

Gonyaulacysta helicoidea is similar but has a much smaller apical pericoel and is ornamented with intratabular tubercles.

Occurrence: Pueblo (Colorado), Wahweap Wash (Utah): Late Cenomanian. Blue Point (Arizona), Bunker Hill (Kansas): Early Turonian. Rebecca K. Bounds core (Kansas): Middle Turonian.

Genus *Hystrichostrogylon* Agelopoulos, 1964; emend. Stover & Evitt, 1978

Hystrichostrogylon membraniphorum Agelopoulos, 1964

Plate 8, Figures 7 & 8

1988 Masure (Bahamas: **Middle Cenomanian)**
1990 Prössl (nr. Salzgitter, North-west Germany: **Early Albian - Late Turonian)**
1994a Tocher & Jarvis (Fumichon, Normandy, France: **Middle Cenomanian)**

Dimensions: Range of observed specimens: length of endophragm 29 (41) 47 μm, width of endophragm 31 (38) 44 μm, maximum length of processes 11 (14) 19 μm, maximum height of wall separation 8 (14) 20 μm. 6 specimens measured.

Comparisons: This appears similar to species of *Spiniferites* and *Achomosphaera* but is camocavate (has a separation of the endophragm and periphragm over a substantial area of the cyst, particularly on the ventral side). Some specimens of *Achomosphaera* sp. A may appear similar but have wall separation over a much greater surface area of the cyst.

Occurrence: Rebecca K. Bounds core (Kansas): Late Cenomanian - Middle Turonian. Blue Point (Arizona), Pueblo (Colorado), Wahweap Wash (Utah): Late Cenomanian - Early Turonian. Bunker Hill (Kansas): Late Cenomanian.

Genus *Impagidinium* Stover & Evitt, 1978

Impagidinium delicatum (Davey, 1969a) *comb. nov.*

Plate 27, Figures 5 & 6

1969a Davey (Saskatchewan, Canada: **Cenomanian)** as *Gonyaulacysta delicata*
1975 Brideaux & McIntyre (District of Mackenzie, Canada: **Middle Albian)** as *Leptodinium? delicatum*

Dimensions: Range of observed specimens: length of cyst 48 (55) 69 µm, width of cyst 45 (54) 70 µm, width of muri 0.5 µm. 8 specimens measured.

Remarks: Species of *Leptodinium* and *Impagidinium* are segregated on the relative positions of their precingular and apical plates around the sulcal area. *Impagidinium* species have the A/1i (4'/6") boundary lower (i.e. closer to the cingulum) than or level with the 1u/ai (1'/s) boundary. *Leptodinium* species have the A/1i (4'/6") boundary higher than the 1u/ai (1'/s) boundary. One of the distinctive features of *I. delicatum* is that the A/1i (4'/6") boundary and the 1u/ai (1'/s) boundary are level at the top of the sulcus, the A and 1u (4' and 1') plates are of similar shape and of roughly equal length, and the 1i (6") paraplate is subtriangular. This paratabulation pattern does not agree with the generic description of *Leptodinium* but does agree with the generic description of *Impagidinium*. Consequently, I reject the transferal of *Gonyaulacysta delicata* to *Leptodinium?* by Sarjeant in Davey, Downie, Sarjeant & Williams (1969), and hereby transfer it to *Impagidinium*.

Comparisons: This species is distinguished in this material, by its thin wall and fine parasutural markings. *Impagidinium modicum* is similar but is thicker walled, with thicker parasutural markings.

Occurrence: Rebecca K. Bounds core (Kansas): Middle Turonian.

Imagidinium modicum (Brideaux & McIntyre, 1975) Jan du Chêne *et al.*, 1986a

Plate 27, Figures 2 & 3

1975 Brideaux & McIntyre (District of Mackenzie, Canada: **Middle Albian**) as *Leptodinium modicum*

1983 Singh (North-west Alberta, Canada: **Early Cenomanian**) as *Leptodinium modicum*

Dimensions: Range of observed specimens: length of cyst 32 (48) 56 µm, width of cyst 31 (45) 54 µm, maximum height of muri 1 (1.9) 3 µm, width of muri 1 (1.5) 2 µm. 11 specimens measured.

Comparisons: Although it was not possible to verify the paratabulation, the specimens found conform well with the original description. *Impagidinium delicatum* appears quite similar but is slightly larger and has much finer parasutural crests.

Occurrence: Rebecca K. Bounds core (Kansas): Late Cenomanian - Middle Turonian. Pueblo (Colorado), Bunker Hill (Kansas): Late Cenomanian - Early Turonian. Blue Point (Arizona), Wahweap Wash (Utah): Early Turonian.

Impagidinium sp. C

Plate 27, Figure 4

Diagnosis: Large, acavate, proximate cyst, with a subcircular outline. The autophragm is smooth with a few scattered granules, and low, smooth to tuberculate/ denticulate parasutural ridges. The archaeopyle is single plate precingular (type P).

Description: The outline of the cyst is subcircular, to slightly angular. The length and width of the cyst appear to be approximately equal, with the epicyst and hypocyst also of roughly equal length. The wall appears to be autophragm only, and is thick (1 µm), smooth and ornamented with a few, scattered granulae. The parasutures are well delineated by low, smooth to slightly denticulate or tuberculate ridges/septa of 1 to 1.5 μm thickness. The archaeopyle is precingular type P, plate 3". The operculum is free and measures 48 μm long by 41μm wide (1 specimen only). The species is confirmed as an *Impagidinium*, with a triangular 6" paraplate and equal sized 1' and 4' paraplates. The sulcus is well defined but the orientations available combined with folding do not allow the lower half of the sulcus to be seen. The paracingulum (5 μm wide) is offset by approximately three times its' width (15 μm), the ends also separated by almost three times the width (13μm across the sulcus). The paracingulum also seems to show faint cingular parasutures. There is no apical projection or horn.

Discussion: Only two specimens of this very distinctive species were found, and consequently the full paratabulation pattern was impossible to determine. Nevertheless, from the single ventral view, the paratabulation has been confirmed as S-type sexiform.

Dimensions: Range of observed specimens: length of cyst 90 & 98 μm, width of cyst 86 & 95 μm, respectively, width of muri 1 to 1.5 μm. 2 specimens measured.

Comparisons: The large size and smooth, thick wall easily distinguishes this species from all other species of *Impagidinium* within this material.

Occurrence: Rebecca K. Bounds core (Kansas): Middle Turonian.

Genus *Psaligonyaulax* Sarjeant, 1966b; emend. Sarjeant, 1982b

Psaligonyaulax deflandrei Sarjeant, 1966b; emend. Sarjeant, 1982b

Plate 26, Figures 2 & 3

1966b Sarjeant (Fetcham Mill Borehole, Surrey, England: **Cenomanian)**

1967 Clarke & Verdier (Isle of Wight, England: **Early - latest Cenomanian)** as *Gonyaulacysta extensa*

1970 Davey (Fetcham Mill Borehole, Surrey; Compton Bay, Isle of Wight, England; Escalles, France: **Cenomanian)**

1973 Davey & Verdier (France and Switzerland: **Late Albian - Early Cenomanian)**

1976 Norvick *in* Norvick & Burger (Bathurst Island, Australia: **Early Cenomanian - Early Turonian)**

1978 Bujak & Williams (Offshore South-eastern Canada: **earliest Cenomanian - latest Turonian)**

1980 Morgan (Australia: **Late Albian - latest Cenomanian)**

1983 Foucher (Paris Basin, France: **Early Cenomanian - Early Campanian)**

1988 Marshall & Batten (Lower Saxony Basin, North Germany: **Late Cenomanian)**

1990 Prössl (nr. Salzgitter, North-west Germany: **Late Albian - Late Turonian)**

1992 Costa & Davey (England and the North Sea: **Late Albian - latest Coniacian)**

1993 Williams *et al.* (N. Hemisphere: **Middle Albian - Santonian)**

Dimensions: Range of observed specimens: length of periphragm 52 (65) 90 µm, width of periphragm 38 (45) 54 µm, length of endophragm 30 (38) 50 µm, width of endophragm 33 (43) 54 µm, length of antapical pericoel 8 (11) 24 µm. 7 specimens measured.

Comparisons: None of the specimens were preserved with particularly high or denticulate parasutural crests. This species is very similar to *Gonyaulacysta cassidata* but is clearly bicavate, with large apical and antapical pericoels. In practice, it was not always easy to differentiate between these two species, and hence those specimens placed within *P. deflandrei* are those with the length of their antapical pericoel greater than 10% of the length of the periphragm (8 µm or more in length). The original descriptions of *G. cassidata* do not describe or measure the pericoels and from original illustrations it is not possible to accurately determine the maximum acceptable size for the antapical pericoels of this species.

Occurrence: Pueblo (Colorado): Late Cenomanian. Blue Point (Arizona): Early Turonian. Rebecca K. Bounds core (Kansas): Early Turonian - Middle Turonian.

Genus *Pterodinium* Eisenack, 1958a; emend. Yun, 1981; emend. Sarjeant, 1985a

Pterodinium cingulatum cingulatum (Wetzel, 1933b) Below, 1981a

Plate 27, Figure 8

1966a Davey & Williams (Fetcham Mill Borehole, Surrey, England: **Cenomanian**) as *Hystrichosphaera cingulata*

1967 Clarke & Verdier (Isle of Wight, England: **Early Cenomanian - Late Santonian**) as *Hystrichosphaera cingulata*

1969a Davey (Fetcham Mill Borehole, Surrey; Compton Bay, Isle of Wight, England; Escalles, France: **Cenomanian**) as *Hystrichosphaera cingulata cingulata*

1969a Davey (Fetcham Mill Borehole, Surrey; Compton Bay, Isle of Wight, England; Escalles, France: **mid - Late Cenomanian, Texas, USA: Late Cenomanian**) as *Hystrichosphaera crassimurata*

1971 Singh (North-west Alberta, Canada: **mid - Late Albian**) as *Spiniferites cingulatus*

1973 Davey & Verdier (France and Switzerland: **Late Albian - Early Cenomanian**) as *Spiniferites cingulatus*

1976 Norvick *in* Norvick & Burger (Bathurst Island, Australia: **Early - Late Cenomanian**) as *Spiniferites cingulatus*

1978 Bujak & Williams (Offshore South-eastern Canada: **Middle Albian - Early Palaeocene**) as *Spiniferites cingulatus*

1980 Morgan (Australia: **Late Neocomian - Cenomanian**) as *Spiniferites cingulatus*

1981 Below (South-west Morocco: **Hauterivian - Early Cenomanian**)

1983 Foucher (Paris Basin, France: **Early Cenomanian - Late Campanian**) as *Spiniferites cingulatus*

1983 Habib & Drugg (Blake-Bahama Basin, Western Atlantic: **Late Aptian - latest Vraconian**) as *Spiniferites cingulatus*

1983 Singh (North-west Alberta, Canada: **Early - Middle Cenomanian**) as *Spiniferites cingulatus*

1984 Below (Mazagan Plateau, Offshore North-west Africa: **Early Aptian - Early Cenomanian**)

1986 Ioannides (Bylot Island, Arctic Archipelago: **Santonian/Campanian - Early Palaeocene**) as *Spiniferites cingulatus*

1987 Firth (Georgia, USA: **Late Maastrichtian - Danian**)

1987 Habib & Drugg (Offshore USA, Western North Atlantic: **Middle Albian - Cenomanian/Turonian**) as *Spiniferites cingulatus*

1988 Mao Shaozhi & Norris (Kashi Area, Xinjiang Province, China: **Late Cretaceous**)

1988 Masure (Bahamas: **Early - Middle Cenomanian**)

1988 Marshall & Batten (Lower Saxony Basin, North Germany: **Late Cenomanian - Early Turonian**)

1990 Harker *et al.* (Interior Plains of Canada: **Late Santonian - Late Campanian**)

1993 Courtinat (Pueblo, Colorado, USA: **Late Cenomanian**)

Dimensions: Range of observed specimens: length of periphragm 51 (59) 68 µm, width of periphragm 51 (58) 65 µm, length of endophragm 37 (47) 55 µm, width of endophragm 33 (43) 50 µm, maximum height of crests 6 (10) 12 µm. 7 specimens measured.

Comparisons: This species of *Pterodinium* has very high parasutural septa which are longer around gonal spines and shorter in intergonal areas, forming a series of concavities around the perimeter. No other subspecies of *P. cingulatum* (for example *P. cingulatum granulatum* or *P. cingulatum reticulatum*) were observed. *Pterodinium? cornutum* is similar but has an apical horn and slightly lower septa, without the gonal spines to increase their height and form the concavities.

Occurrence: Rebecca K. Bounds core (Kansas): Early Cenomanian - Middle Turonian. Blue Point (Arizona): Late Cenomanian. Bunker Hill (Kansas), Pueblo (Colorado), Wahweap Wash (Utah): Late Cenomanian - Early Turonian.

Pterodinium? cornutum Cookson & Eisenack, 1962b

Plate 27, Figure 7

1962b Cookson & Eisenack (Australia: **Aptian - Albian**)

1970 Habib (Bahamas: **Albian/Cenomanian**)

1971 Singh (North-west Alberta, Canada: **Middle Albian**)

1981 Below (South-west Morocco: **Barremian - Aptian**)

1982 Below (Morocco: **Early Aptian - Early Cenomanian**)

1983 Singh (North-west Alberta, Canada: **Early - Middle Cenomanian**)

1984 Below (Mazagan Plateau, Offshore North-west Africa: **Early Aptian - earliest Cenomanian**)

1993 Courtinat (Pueblo, Colorado, USA: **Late Cenomanian**)

Dimensions: Range of observed specimens: length of periphragm 51 (55) 68 µm, width of periphragm 43 (49) 63 µm, length of endophragm 40 (45) 55 µm, width of endophragm 33 (39) 49 µm, maximum height of crests 4 (7) 10 µm, length of apical horn 5 (6) 9 µm. 7 specimens measured.

Comparisons: This species has a short apical horn and high parasutural septa. *Pterodinium cingulatum* has no apical horn, and has gonal spines which increase the height of the septa around the gonal areas, giving these septa an outline with a series of concavities. The septa of *P.? cornutum* have a more uniform length.

Occurrence: Rebecca K. Bounds core (Kansas): Early Cenomanian - Middle Turonian. Blue Point (Arizona), Bunker Hill (Kansas), Pueblo (Colorado), Wahweap Wash (Utah): Late Cenomanian - Early Turonian.

Genus *Spiniferites* Mantell, 1850; emend. Sarjeant, 1970

Spiniferites lenzii Below, 1982c

Plate 10, Figures 3 to 7

1982c Below (Morocco: **Hauterivian - Cenomanian)**

1984 Below (Mazagan Plateau, Offshore North-west Africa: **Early Aptian - Early Cenomanian)**

1992 Prössl (Colombia: **Middle Albian)** as *Gonyaulacysta* sp. and *Spiniferites* cf. *hyperacanthus*

> **Original Description:** Below, 1984, p. 34
> Central body spheroidal, subspheroidal to bitrapezoidal, two-layered and smooth. Solid, gonal processes are trifurcate and in second order bifurcate. Parasutural processes are numerous, bifurcate and in the second order also bifurcate. Gonal and parasutural processes reach ca. $^1/_3$ of the diameter of the central body and are of equal length. The parasutural processes are interconnected basally and in this way form low septa on the borders of the paratabulae. At first they taper rapidly toward the distal end to split at half length in two branches. These form an acute angle between them. The plane spread out between the processes is perpendicular to the paratabular border. The branches are again bifurcate in the second order. Gonal and parasutural processes reach ca. $^1/_3$ of the diameter of the central body and are of equal length. The archaeopyle is precingular, of type $P_{3''}$.
> **Original Remarks:** Particularly in the material from the Morrocan Hauterivian and Gargasian are frequently specimens which occupy an intermediary position between *Spiniferites lenzii* n.sp. and *Spiniferites multibrevis* stat. nov. ssp. *seghiris* n. ssp. (now *Spiniferites seghiris*). Still very short, parasutural processes, with the medial and terminal bifurcation typical for *Spiniferites lenzii*, developed from rudimentary septal outgrowths.
> **Original Measurements:** Holotype: length of central body 43 µm, width of central body 42 µm, length of processes 8-12 µm; other specimens: length of central body 39-44 µm, width of central body 38-43 µm, length of processes 8-15 µm.

Dimensions: Range of observed specimens: length of central body 37 (47) 62 µm, width of central body 34 (44) 54 µm, maximum length of processes 6 (9) 13 µm, maximum width of processes <1 (1) 2 µm. 18 specimens measured.

Remarks: This is a very distinctive species of *Spiniferites*, with its many, bifurcating intergonal processes, with bifurcate tips, proximally joined by parasutural crests. These processes are very numerous, even on one intergonal plate margin. Within this material, this species with distinctive processes also tends to have a large amount of morphological variability. As reported by Below (1982c) in his original remarks, a gradation exists with *Spiniferites seghiris* which has lower parasutural markings. These intermediate specimens have all been counted as *S. lenzii*, and in this material, they tend to also have fewer intergonal processes. Some specimens have the appearance of a *Spiniferites* with paratabulation made of 'lace', as the parasutural septa may also be perforate and interconnected with adjacent processes. Process lengths also tend to be shorter on many specimens than on those from the original population.

Comparisons: *Spiniferites twistringiensis* and *S. ramosus gracilis* may all appear very similar to many of the specimens but lack the very large number of bifurcating intergonal processes with bifid tips, and have much lower parasutural markings.

Occurrence: Rebecca K. Bounds core (Kansas): Early Cenomanian - Early Turonian. Blue Point (Arizona), Bunker Hill (Kansas), Pueblo (Colorado), Wahweap Wash (Utah): Late Cenomanian - Early Turonian.

Spiniferites porosus (Manum & Cookson, 1964) Harland, 1973

Plate 9, Figure 6

1964 Manum & Cookson (Arctic Canada: **'mid Cretaceous'**) as *Hystrichosphaera porosa*

1985 Williams & Bujak (World: **Early Turonian - mid Santonian)**

1986 Ioannides (Bylot Island, Arctic Archipelago: **Santonian/Campanian - Maastrichtian)**

Dimensions: Range of observed specimens: length of central body 61 (72) 80 µm, width of central body 58 (68) 79 µm, maximum length of processes 15 (21) 24 µm. 4 specimens measured.

Remarks: This is a distinctive species of *Spiniferites* with its large size, thick wall, and thick, distally expanded, perforated processes.

Occurrence: Pueblo (Colorado), Wahweap Wash (Utah): Late Cenomanian. Rebecca K. Bounds core (Kansas): Middle Turonian.

Spiniferites ramosus gracilis (Davey & Williams, 1966a) Lentin & Williams, 1973

Plate 9, Figure 2

1966a Davey & Williams (England: **Ypresian)** as *Hystrichosphaera ramosa* var. *gracilis*

1969a Davey (Fetcham Mill Borehole, Surrey; Compton Bay, Isle of Wight, England; Escalles, France: **Cenomanian)** as *Hystrichosphaera ramosa* var. *gracilis*

1971 Singh (North-west Alberta, Canada: **Middle Albian)** as *Hystrichosphaera ramosa* var. *gracilis*

1983 Singh (North-west Alberta, Canada: **Middle Cenomanian)**

1983 Foucher (Paris Basin, France: **Early Cenomanian - latest Campanian)**

1990 Harker *et al.* (Interior Plains of Canada: **earliest - Late Campanian)**

Dimensions: Range of observed specimens: length of central body 31 (43) 48 µm, width of central body 27 (38) 44 µm, maximum length of processes 11 (15) 18 µm, maximum width of processes <1 (1) 1.5 µm. 7 specimens measured.

Comparisons: This subspecies has many long, slender bifurcating intergonal processes and trifurcating gonal processes. In practice, *S. ramosus ramosus* has been differentiated from this subspecies by its small number of intergonal processes which along with the gonal processes, tend to be thicker and shorter.

Occurrence: Rebecca K. Bounds core (Kansas): Early Cenomanian - Middle Turonian. Blue Point (Arizona), Bunker Hill (Kansas), Pueblo (Colorado), Wahweap Wash (Utah): Late Cenomanian - Early Turonian.

Spiniferites ramosus granomembranaceous (Davey & Williams, 1966a)
Lentin & Williams, 1973
Plate 9, Figure 7

1966a Davey & Williams (Speeton, Yorkshire: **Barremian,** Fetcham Mill Borehole, Surrey: **Cenomanian,** England: **Ypresian)** as *Hystrichosphaera ramosa granomembranacea*
1980 Morgan (Australia: **earliest Aptian - latest Cenomanian)**
1983 Foucher (Paris Basin, France: **Early Cenomanian - Late Campanian)**
1987 Firth (Georgia, USA: **Early Maastrichtian - Danian)**
1990 Harker *et al.* (Interior Plains of Canada: **Early - Late Campanian)**
1990 Prössl (nr. Salzgitter, North-west Germany: **Early - Late Albian)**

Dimensions: Range of observed specimens: length of central body 43 (47) 52 µm, width of central body 35 (43) 52 µm, maximum length of processes 10 (14) 18 µm, maximum width of processes 9 (13) 17 µm. 8 specimens measured.

Remarks: This is a distinctive large, subspecies of *S. ramosus* with high parasutural membranes which often fuse adjacent processes, particularly in the polar areas, and with a granulate central body.

Occurrence: Rebecca K. Bounds core (Kansas): Early Cenomanian - Middle Turonian. Blue Point (Arizona): Late Cenomanian. Bunker Hill (Kansas), Pueblo (Colorado), Wahweap Wash (Utah): Late Cenomanian - Early Turonian.

Spiniferites ramosus ramosus (Ehrenberg, 1838) Mantell, 1854
Plate 9, Figure 1

1964 Cookson & Hughes (Cambridgeshire, England: **Late Albian - Early Cenomanian)** as *Hystrichosphaera ramosa*
1966a Davey & Williams (Speeton, Yorkshire: **Barremian,** Fetcham Mill Borehole, Surrey: **Cenomanian,** England: **Ypresian)** as *Hystrichosphaera ramosa ramosa*
1967 Clarke & Verdier (Isle of Wight, England: **Early Cenomanian - Late Santonian)** as *Hystrichosphaera ramosa ramosa*
1969a Davey (Fetcham Mill Borehole, Surrey; Compton Bay, Isle of Wight, England; Escalles, France; Saskatchewan, Canada; Texas, USA: **Cenomanian)** as *Hystrichosphaera ramosa ramosa*
1970 Habib (Bahamas: **Albian/Cenomanian)**

1971 Brideaux (Central Alberta, Canada: **Late Albian**) as *Hystrichosphaera ramosa*

1971 Singh (North-west Alberta, Canada: **mid - Late Albian**)

1973 Davey & Verdier (France and Switzerland: **Late Albian - Early Cenomanian**)

1976 Norvick *in* Norvick & Burger (Bathurst Island, Australia: **Early Cenomanian - Early Turonian**)

1978 Bujak & Williams (Offshore South-eastern Canada: **earliest Hauterivian - Early Palaeocene**)

1980 May (New Jersey, USA: **Late Campanian - Maastrichtian**)

1980 Morgan (Australia: **Late Neocomian - latest Cenomanian**)

1983 Foucher (Paris Basin, France: **Early Cenomanian - latest Campanian**)

1983 Habib & Drugg (Blake-Bahama Basin, Western Atlantic: **Late Valanginian - latest Vraconian**)

1983 Singh (North-west Alberta, Canada: **Early - Middle Cenomanian**)

1984 Below (Mazagan Plateau, Offshore North-west Africa: **Early Aptian - earliest Cenomanian**)

1986 Ioannides (Bylot Island, Arctic Archipelago: **Santonian/Campanian - Early Palaeocene**)

1987 Firth (Georgia, USA: **Early Maastrichtian - Danian**)

1987 Habib & Drugg (Offshore USA, Western North Atlantic: **Late Valanginian - Cenomanian/Turonian**)

1988 Masure (Bahamas: **Late Albian - Middle Cenomanian**)

1989 Habib & Milner (South Carolina & Georgia, USA: **Late Campanian - Late Maastrichtian**)

1990 Harker *et al.* (Interior Plains of Canada: **Late Santonian - Early Maastrichtian**)

1993 Courtinat (Pueblo, Colorado, USA: **Late Cenomanian**)

1994a Tocher & Jarvis (Fumichon, Normandy, France: **Early - Middle Cenomanian**)

Dimensions: Range of observed specimens: length of central body 32 (41) 47 μm, width of central body 27 (36) 41 μm, maximum length of processes 10 (12) 17 μm, maximum width of processes 2 (2.4) 3 μm. 7 specimens measured.

Comparisons: This species tends to have a very variable morphology, in terms of process numbers, lengths and widths, and consequently can sometimes be difficult to subspeciate. *Spiniferites ramosus gracilis* is differentiated in practice, by its larger number of intergonal processes, which along with its gonal processes, tend to be longer and thinner than those on *S. ramosus ramosus*. *Spiniferites ramosus granomembranaceous* is larger, has a granular central body and high parasutural membranes which fuse adjacent processes. *Spiniferites ramosus reticulatus* has a reticulate central body, *Spiniferites twistringiensis* has much shorter processes, and *Spiniferites wetzellii* has high parasutural flanges.

Occurrence: Rebecca K. Bounds core (Kansas): Early Cenomanian - Middle Turonian. Blue Point (Arizona), Bunker Hill (Kansas), Pueblo (Colorado), Wahweap Wash (Utah): Late Cenomanian - Early Turonian.

Spiniferites ramosus reticulatus (Davey & Williams, 1966a) Lentin & Williams, 1973

Plate 9, Figures 3 & 4

1966a Davey & Williams (Fetcham Mill Borehole, Surrey; England: **Cenomanian**) as *Hystrichosphaera ramosa reticulata*

1969a Davey (Saskatchewan, Canada: **Albian**, Fetcham Mill Borehole, Surrey; Compton Bay, Isle of Wight, England; Escalles, France: **Cenomanian**) as *Hystrichosphaera ramosa reticulata*

1973 Davey & Verdier (France and Switzerland: **Late Albian - Early Vraconian**)

1980 May (New Jersey, USA: **Late Campanian - Maastrichtian**)

1983 Foucher (Paris Basin, France: **Early Cenomanian - Late Campanian**)

1984 Below (Mazagan Plateau, Offshore North-west Africa: **mid - earliest Cenomanian**)

Dimensions: Range of observed specimens: length of central body 37 (41) 45 µm, width of central body 34 (37) 41 µm, maximum length of processes 15 (16) 17 µm, maximum width of processes 1 µm. 4 specimens measured.

Comparisons: This species is distinguished from all other species of *Spiniferites* within this material, by its reticulate central body.

Occurrence: Bunker Hill (Kansas): Late Cenomanian. Pueblo (Colorado): Late Cenomanian - Early Turonian. Wahweap Wash (Utah): Early Turonian.

Spiniferites tripus Singh, 1983

Plate 10, Figure 2

1983 Singh (North-west Alberta, Canada: **Early Cenomanian**)

Dimensions: Range of observed specimens: length of central body 31 (38) 43 µm, width of central body 24 (31) 36 µm, maximum length of processes 12 (14) 16 µm. 9 specimens measured.

Comparisons: This species possesses three gonal processes which are much larger than the rest, positioned around the antapical paraplate, and often partially fused by membranes. *Spiniferites ramosus ramosus* and *S. twistringiensis* are similar but lack this distinguishing characteristic. *Spiniferites ramosus granomembranaceous* is also similar, as it often has large linking membranes in the antapical region. However, this species is much larger and has a granulate central body.

Occurrence: Wahweap Wash (Utah): Late Cenomanian. Pueblo (Colorado): Late Cenomanian - Early Turonian. Bunker Hill (Kansas): Early Turonian. Rebecca K. Bounds core (Kansas): Middle Turonian.

Spiniferites twistringiensis (Maier, 1959) Fensome *et al.*, 1990

Plate 9, Figure 5

1966a Davey & Williams (Specton, Yorkshire: **Hauterivian - Barremian**, Fetcham Mill Borehole, Surrey: **Cenomanian**, England: **Ypresian**) as *Hystrichosphaera ramosa* var. *multibrevis*

1969 Davey (Saskatchewan, Canada: **Albian**, Fetcham Mill Borehole, Surrey; Compton Bay, Isle of Wight, England; Escalles, France: **Cenomanian**) as *Hystrichosphaera ramosa* var. *multibrevis*

1971 Singh (North-west Alberta, Canada: **mid - Late Albian**) as *Spiniferites ramosus multibrevis*

1980 May (New Jersey, USA: **Late Campanian - Maastrichtian**) as *Spiniferites ramosus multibrevis*

1982 Below (Morocco: **Albian - Vraconian**) as *Spiniferites multibrevis*

1983 Foucher (Paris Basin, France: **Early Cenomanian - Early Campanian** as *Spiniferites multibrevis*

1983 Singh (North-west Alberta, Canada: **Early - Middle Cenomanian**) as *Spiniferites ramosus multibrevis*

1984 Below (Mazagan Plateau, Offshore North-west Africa: **Early Aptian - earliest Cenomanian**) as *Spiniferites multibrevis*

1987 Firth (Georgia, USA: **Early Maastrichtian - Danian**) as *Spiniferites ramosus multibrevis*

1988 Masure (Bahamas: **Late Albian - Middle Cenomanian**) as *Spiniferites multibrevis*

1989 Habib & Milner (South Carolina & Georgia, USA: **Late Campanian - Late Maastrichtian**) as *Spiniferites multibrevis*

1990 Harker *et al.* (Interior Plains of Canada: **earliest - Late Campanian**) as *Spiniferites ramosus* var. *multibrevis*

1993 Courtinat (Pueblo, Colorado, USA: **Late Cenomanian**) as *Spiniferites multibrevis*

1994a Tocher & Jarvis (Fumichon, Normandy, France: **Early - Middle Cenomanian**)

Dimensions: Range of observed specimens: length of central body 36 (42) 55 µm, width of central body 30 (38) 43 µm, maximum length of processes 4 (7) 9 µm, maximum width of processes 1 (1.8) 3 µm. 9 specimens measured.

Comparisons: This species is characterised by its short gonal and intergonal processes. All other species of *Spiniferites* within this material have longer processes, with the exception of some specimens counted as *S. lenzii* which have many more intergonal processes, with higher parasutural crests. *Spiniferites tripus* has three, much longer and wider processes on the antapex.

Occurrence: Rebecca K. Bounds core (Kansas): Early Cenomanian - Middle Turonian. Blue Point (Arizona), Bunker Hill (Kansas), Pueblo (Colorado), Wahweap Wash (Utah): Late Cenomanian - Early Turonian.

Spiniferites wetzelii (Deflandre, 1937b) Sarjeant, 1970

Plate 10, Figure 1

1978 Bujak & Williams (Offshore South-eastern Canada: **earliest - latest Campanian**)

1980 Morgan (Australia: **mid Aptian - Middle Cenomanian**)

1986 Ioannides (Bylot Island, Arctic Archipelago: **Santonian/Campanian - Maastrichtian?**)

1991 Kirsch (Germany: **Campanian - Maastrichtian**)

Dimensions: Range of observed specimens: length of periphragm 65 (70) 82 µm, width of periphragm 57 (64) 71 µm, length of endophragm 36 (45) 61 µm, width of endophragm 36 (40) 47 µm. 7 specimens measured.

Comparisons: This species is easily distinguished by high parasutural membranes extending almost entirely around the central body, joining gonal and intergonal processes. *Spiniferites ramosus granomembranaceous* is similar but is larger and only has occasional process linkage around a granulate central body. In some instances, *Dinopterygium cladoides* may appear similar but lacks the inner processes, with the trifurcate and bifurcate tips characteristic of the genus *Spiniferites*.

Occurrence: Rebecca K. Bounds core (Kansas): Middle Cenomanian - Middle Turonian. Blue Point (Arizona): Late Cenomanian. Pueblo (Colorado), Wahweap Wash (Utah): Late Cenomanian - Early Turonian. Bunker Hill (Kansas): Early Turonian.

Subfamily uncertain

Genus *Callaiosphaeridium* Davey & Williams, 1966b; emend. Duxbury, 1980; emend. Below, 1981a

Callaiosphaeridium asymmetricum (Deflandre & Courteville, 1939) Davey & Williams, 1966b

Plate 2, Figure 7

1966b Davey & Williams (Speeton, Yorkshire: **Hauterivian, Early-mid Barremian**, Fetcham Mill Borehole, Surrey, England: **Cenomanian**)

1967 Clarke & Verdier (Isle of Wight, England: **Early Cenomanian - mid Santonian**) as *Hexasphaera asymmetricum*

1967 Warren (California, USA: **Hauterivian - Barremian / Aptian**)

1969a Davey (Fetcham Mill Borehole, Surrey, England: **Albian - Turonian**, Compton Bay, Isle of Wight, England; Escalles, France: **Cenomanian**)

1971 Brideaux (Central Alberta, Canada: **Late Albian**)

1973 Davey & Verdier (France and Switzerland: **Late Albian - Early Cenomanian**)

1976 Norvick *in* Norvick & Burger (Bathurst Island, Australia: **Early - Late Cenomanian**)

1978 Bujak & Williams (Offshore South-eastern Canada: **earliest Hauterivian - latest Coniacian**)

1980 Morgan (Australia: **earliest Aptian - latest Cenomanian**)

1981 Below (South-west Morocco: **Aptian**)

1982 Below (Morocco: **mid Aptian**)

1982 Nichols, Jacobson & Tschudy (Wyoming & Montana, USA: **Early Coniacian - Late Santonian**)

1983 Foucher (Paris Basin, France: **Early Cenomanian - Early Campanian**)

1983 Habib & Drugg (Blake-Bahama Basin, Western Atlantic: **latest Hauterivian - Early Albian**)

1987 Habib & Drugg (Offshore USA, Western North Atlantic: **Early Hauterivian - Late Coniacian/Santonian**)

1988 Marshall & Batten (Lower Saxony Basin, North Germany: **Late Cenomanian - Early Turonian**)

1988 Masure (Bahamas: **Vraconian - Middle Cenomanian)**
1989 Habib & Milner (South Carolina & Georgia, USA: **Late Campanian)**
1990 Prössl (nr. Salzgitter, North-west Germany: **Early Hauterivian - Late Turonian)**
1992 Costa & Davey (England and the North Sea: **Early Hauterivian - Early Campanian)**
1993 Nøhr-Hansen (North-east Greenland: **?Late Barremian - Late Albian)**
1994a Tocher & Jarvis (Fumichon, Normandy, France: **Early - Middle Cenomanian)**
1996 Stover *et al.* (World wide: **middle Hauterivian - Early Campanian)**

Dimensions: Range of observed specimens: maximum width of central body 40 (47) 54 µm, maximum length of processes 12 (18) 25 µm. 8 specimens measured.
Comparisons: This species is easily distinguishable from other species in the material, by its six, radiating, large and tubular, cingular processes. The remainder of the processes are thin and solid and linked by low parasutural ridges. In all cases this cyst was seen in polar view.
Occurrence: Bunker Hill (Kansas), Pueblo (Colorado), Wahweap Wash (Utah): Late Cenomanian. Blue Point (Arizona): Late Cenomanian - Early Turonian.

Genus *Cometodinium* Deflandre & Courteville, 1939; emend. Monteil, 1991

Cometodinium? whitei (Deflandre & Courteville, 1939) Stover & Evitt, 1978

Plate 16, Figure 8

1967 Clarke & Verdier (Isle of Wight, England: **Early Cenomanian - Late Santonian)** as *Baltisphaeridium whitei*
1971 Singh (North-west Alberta, Canada: **mid - Late Albian)** as *Baltisphaeridium whitei*
1973 Davey & Verdier (France and Switzerland: **Late Albian)** as *Baltisphaeridium whitei*
1978 Bujak & Williams (Offshore South-eastern Canada: **earliest Cenomanian - latest Campanian)** as *Impletosphaeridium whitei*
1982 Below (Morocco: **Late Hauterivian - Vraconian)**
1983 Foucher (Paris Basin, France: **Early Cenomanian - Late Campanian)** as *Baltisphaeridium whitei*
1983 Habib & Drugg (Blake-Bahama Basin, Western Atlantic: **Tithonian - Early Aptian)**
1983 Singh (North-west Alberta, Canada: **Early - Middle Cenomanian)**
1984 Below (Mazagan Plateau, Offshore North-west Africa: **Early Aptian - earliest Cenomanian)**
1987 Habib & Drugg (Offshore USA, Western North Atlantic: **Late Berriasian - mid Barremian)**
1988 Masure (Bahamas: **Late Albian - Middle Cenomanian)**
1990 Harker *et al.* (Interior Plains of Canada: **Early - Late Campanian)**
1990 Prössl (nr. Salzgitter, North-west Germany: **Early Hauterivian - Late Turonian)**
1991 Kirsch (Germany: **Early Campanian - Maastrichtian)**

Dimensions: Range of observed specimens: maximum diameter of cyst 40 (46) 53 μm, maximum diameter of endophragm 25 (33) 40 μm. 7 specimens measured.

Comparisons: This is a distinctive, small cyst, with a differentiated autophragm which forms a dense cover of fine hairs. *Exochosphaeridium arnace* is very similar but is larger and has a precingular archaeopyle.

Occurrence: Rebecca K. Bounds core (Kansas): Early Cenomanian - Middle Turonian. Blue Point (Arizona), Bunker Hill (Kansas), Pueblo (Colorado), Wahweap Wash (Utah): Late Cenomanian - Early Turonian.

Genus *Coronifera* Cookson & Eisenack, 1958; emend. Davey, 1974; emend. May, 1980; emend. Mao Shaozhi & Norris, 1988

Coronifera oceanica Cookson & Eisenack, 1958; emend. May, 1980

Plate 3, Figure 1

1958 Cookson & Eisenack (Australia: **Albian**)
1964 Cookson & Hughes (Cambridgeshire, England: **Late Albian**)
1967 Clarke & Verdier (Isle of Wight, England: **Early Cenomanian - Early Coniacian**)
1969 Cookson & Eisenack (Balcatta, nr. Perth, Australia: **Albian/Cenomanian**)
1969a Davey (Saskatchewan, Canada: **Albian**, Fetcham Mill Borehole, Surrey, England: **Albian - Cenomanian**, Compton Bay, Isle of Wight, England; Escalles, France: **Cenomanian**)
1973 Davey & Verdier (France and Switzerland: **Late Albian - Early Cenomanian**)
1976 Norvick *in* Norvick & Burger (Bathurst Island, Australia: **Early Cenomanian - Early Turonian**
1978 Bujak & Williams (Offshore South-eastern Canada: **earliest Berriasian - latest Coniacian**)
1980 May (New Jersey, USA: **Late Campanian - Maastrichtian**)
1980 Morgan (Australia: **earliest Aptian - latest Cenomanian**)
1982 Below (Morocco: **Late Hauterivian - Early Cenomanian**)
1983 Foucher (Paris Basin, France: **Early Cenomanian - Late Campanian**)
1983 Habib & Drugg (Blake-Bahama Basin, Western Atlantic: **Late Barremian - latest Vraconian**)
1983 Singh (North-west Alberta, Canada: **Early Cenomanian**)
1984 Below (Mazagan Plateau, Offshore North-west Africa: **Early Aptian - Early Cenomanian**)
1986 Ioannides (Bylot Island, Arctic Archipelago: **Santonian/Campanian - Maastrichtian?**)
1987 Habib & Drugg (Offshore USA, Western North Atlantic: **Early Barremian - Early Cenomanian**)
1988 Masure (Bahamas: **Late Albian - Middle Cenomanian**)
1989 Habib & Milner (South Carolina & Georgia, USA: **Late Campanian**)
1990 Prössl (nr. Salzgitter, North-west Germany: **Late Hauterivian - Late Turonian**)
1993 Courtinat (Pueblo, Colorado, USA: **Late Cenomanian**)
1993 Williams *et al.* (N. Hemisphere: **Hauterivian - Campanian/Maastrichtian boundary**)

1993 Nøhr-Hansen (North-east Greenland: **Early Barremian - Middle Albian)**

1994a Tocher & Jarvis (Fumichon, Normandy, France: **Early - Middle Cenomanian)**

1996 Stover *et al.* (World wide **middle Hauterivian - Early Maastrichtian)**

Dimensions: Range of observed specimens: length of endophragm 29 (40) 49 μm, width of endophragm 31 (39) 45 μm, maximum length of processes 11 (13) 16 μm, length of antapical horn 9 (12) 15 μm, width of antapical horn 9 (12) 15 μm. 7 specimens measured.

Comparisons: *Coronifera oceanica* is fairly distinctive with its dense cover of flexuous, simple, bifurcate and trifurcate processes and its distally flaring and open antapical process. *Coronifera striolata* is similar but has thicker and more rigid processes, and a striate central body. *Florentinia resex* is also very similar but has less processes which are only simple, and the antapical process narrows and is closed distally. *Downiesphaeridium multispinosum* is similar but is smaller and does not have the large, tubular, antapical process. *Systematophora* sp. A is also superficially similar but has complex, annular processes.

Occurrence: Rebecca K. Bounds core (Kansas): Early Cenomanian - Middle Turonian. Blue Point (Arizona), Bunker Hill (Kansas), Pueblo (Colorado), Wahweap Wash (Utah): Late Cenomanian - Early Turonian.

Coronifera striolata (Deflandre, 1937b) Stover & Evitt, 1978

Plate 3, Figures 2 & 3

1958 Cookson & Eisenack (Australia: **Albian)** as *Hystrichosphaeridium striolatum*

1967 Clarke & Verdier (Isle of Wight, England: **Early Cenomanian - Late Campanian)** as *Baltisphaeridium striolatum*

1973 Davey & Verdier (France and Switzerland: **Early Vraconian)** as *Exochosphaeridium striolatum*

1978 Bujak & Williams (Offshore South-eastern Canada: **earliest Santonian - latest Campanian)** as *Exochosphaeridium striolatum*

1980 Morgan (Australia: **Late Neocomian - Middle Cenomanian)** as *Exochosphaeridium striolatum*

1983 Foucher (Paris Basin, France: **Early Cenomanian - Late Campanian)** as *Exochosphaeridium striolatum*

1986 Ioannides (Bylot Island, Arctic Archipelago: **Santonian/Campanian - Maastrichtian)** as *Exochosphaeridium striolatum*

1988 Masure (Bahamas: **Vraconian - Middle Cenomanian)**

1990 Prössl (nr. Salzgitter, North-west Germany: **Early Albian - Late Cenomanian)**

1991 Kirsch (Germany: **Late Santonian - Maastrichtian)**

1992 Costa & Davey (England and the North Sea: **Late Albian - Early Campanian)**

Dimensions: Range of observed specimens: length of endophragm 39 (42) 47 µm, width of endophragm 39 (41) 45 µm, maximum length of processes 11 (12) 14 µm, length of antapical horn 10 (13) 15 µm, width of antapical horn 10 (12) 14 µm. 5 specimens measured.

Comparisons: *Coronifera striolata* has a striate central body, and many processes with acuminate to bifid tips, connected at their bases by low sutures. *Coronifera oceanica* is similar but does not have the distinctive striate central body.

Occurrence: Blue Point (Arizona), Rebecca K. Bounds core (Kansas): Late Cenomanian. Wahweap Wash (Utah): Early Turonian.

Genus *Hystrichodinium* Deflandre, 1935; emend. Sarjeant, 1966b; emend. Clarke & Verdier, 1967

Hystrichodinium pulchrum Deflandre, 1935

Plate 23, Figures 5 & 6

1964 Manum & Cookson (Arctic Canada: **'mid Cretaceous'**)
1967 Clarke & Verdier (Isle of Wight, England: **Early Cenomanian - Late Santonian**)
1973 Davey & Verdier (France and Switzerland: **Late Albian - Early Cenomanian**)
1978 Bujak & Williams (Offshore South-eastern Canada: **Portlandian - mid Maastrichtian**)
1980 Morgan (Australia: **Late Neocomian - Cenomanian**)
1983 Foucher (Paris Basin, France: **Early Cenomanian - Late Campanian**)
1984 Below (Mazagan Plateau, Offshore North-west Africa: **mid Aptian - earliest Cenomanian**)
1986 Ioannides (Bylot Island, Arctic Archipelago: **Santonian/Campanian**)
1987 Habib & Drugg (Offshore USA, Western North Atlantic: **Late Berriasian - Cenomanian/Turonian**)
1988 Marshall & Batten (Lower Saxony Basin, North Germany: **Late Cenomanian - Early Turonian**)
1989 Habib & Milner (South Carolina & Georgia, USA: **Late Campanian**)
1990 Harker *et al.* (Interior Plains of Canada: **Early - Late Campanian**)
1990 Prössl (nr. Salzgitter, North-west Germany: **Early Hauterivian - Late Turonian**)
1991 Kirsch (Germany: **Turonian - Early Maastrichtian**)
1992 Costa & Davey (England and the North Sea: **Jurassic - Late Maastrichtian**)
1992 Mohr & Gee (Kerguelan Plateau, Southern Indian Ocean: **Late Cenomanian - Late Coniacian**)
1993 Nøhr-Hansen (North-east Greenland: **Middle Albian**)
1994a Tocher & Jarvis (Fumichon, Normandy, France: **Middle Cenomanian**)

Dimensions: Range of observed specimens: length of endophragm 43 (52) 64 µm, width of endophragm 38 (50) 62 µm, maximum length of processes 14 (20) 24 µm. 7 specimens measured.

Comparisons: This species is very distinctive, with its long, thin parasutural spines and clearly defined, prominent paracingulum and precingular archaeopyle. *Xiphophoridium alatum* appears similar but has high parasutural crests which extend into parasutural spines.

Occurrence: Rebecca K. Bounds core (Kansas): Late Cenomanian - Middle Turonian. Blue Point (Arizona), Bunker Hill (Kansas), Pueblo (Colorado), Wahweap Wash (Utah): Late Cenomanian - Early Turonian.

Genus *Kiokansium* Stover & Evitt, 1978; emend. Duxbury, 1983

Kiokansium unituberculatum (Tasch, 1964) Stover & Evitt, 1978

Plate 3, Figure 4

1962b Cookson & Eisenack (Australia: **Albian - Cenomanian**) as *Hystrichosphaeridium recurvatum polypes*

1964 Cookson & Hughes (Cambridgeshire, England: **Late Albian - Early Cenomanian**) as *Hystrichosphaeridium recurvatum polypes*

1964 Tasch (Clark County, Kansas, USA: **Albian**) as *Hystrichosphaeridium unituberculatum*

1969a Davey (Fetcham Mill Borehole, Surrey; Compton Bay, Isle of Wight, England; Escalles, France; Saskatchewan, Canada; Texas, USA: **mid - Late Cenomanian**) as *Cleistosphaeridium polypes*

1971 Singh (North-west Alberta, Canada: **mid - Late Albian**) as *Bacchidinium polypes*

1975 Brideaux & McIntyre (District of Mackenzie, Canada: **Early Aptian - Middle Albian**) as *Cleistosphaeridium polypes*

1976 Norvick *in* Norvick & Burger (Bathurst Island, Australia: **Early Cenomanian - Early Turonian**) as *Cleistosphaeridium polypes*

1978 Bujak & Williams (Offshore South-eastern Canada: **mid Barremian - latest Cenomanian**) as *Cleistosphaeridium polypes*

1980 Morgan (Australia: **Late Neocomian - latest Cenomanian**) as *Cleistosphaeridium polypes*

1982 Below (Morocco: **Late Hauterivian - Albian**) as *Kiokansium polypes*

1982 Nichols, Jacobson & Tschudy (Wyoming & Montana, USA: **Early - Late Cenomanian**) as *Cleistosphaeridium polypes*

1983 Habib & Drugg (Blake-Bahama Basin, Western Atlantic: **latest Berriasian - latest Vraconian**) as *Cleistosphaeridium polypes*

1983 Singh (North-west Alberta, Canada: **Early - Middle Cenomanian**) as *Bacchidinium polypes*

1984 Below (Mazagan Plateau, Offshore North-west Africa: **mid Aptian - Late Albian**) as *Kiokansium polypes*

1987 Habib & Drugg (Offshore USA, Western North Atlantic: **Early Valanginian - Cenomanian/Turonian**) as *Bacchidinium polypes*

1988 Jarvis *et al.* (Dover, Kent, England: **Late Cenomanian**) as *Kiokansium polypes*

1988 Mao Shaozhi & Norris (Kashi Area, Xinjiang Province, China: **Late Cretaceous**)

1990 Prössl (nr. Salzgitter, North-west Germany: **Late Hauterivian - latest Albian**) as *Bacchidinium polypes*

1992 Costa & Davey (England and the North Sea: **Late Hauterivian - latest Cenomanian**)

1992 Mohr & Gee (Kerguelan Plateau, Southern Indian Ocean: **Late Cenomanian - Late Turonian**)

1993 Nøhr-Hansen (North-east Greenland: **Early Barremian - Late Albian/ Early Cenomanian?**) as *Kiokansium polypes*

1994a Tocher & Jarvis (Fumichon, Normandy, France: **Early - Middle Cenomanian**)

Dimensions: Range of observed specimens: length of endophragm 26 (40) 55 μm, width of endophragm 31 (37) 48 μm, maximum length of processes 6 (11) 16 μm, maximum width of processes <1 μm. 7 specimens measured.

Comparisons: This is a distinctive species of skolochorate cyst, with a spherical central body, a two-plate precingular archaeopyle, and many long, thin, solid processes which terminate with a few short spines. *Kiokansium williamsii* is similar but has a prolate central body with shorter processes. Species of *Hystrichosphaeridium* and *Oligosphaeridium* appear similar but have fewer, wider processes and an apical archaeopyle. *Surculosphaeridium? longifurcatum* has thin solid processes, which branch medially, and an apical archaeopyle.

Occurrence: Rebecca K. Bounds core (Kansas): Early Cenomanian. Blue Point (Arizona), Wahweap Wash (Utah): Late Cenomanian. Pueblo (Colorado): Late Cenomanian - Early Turonian.

Kiokansium williamsii Singh, 1983

Plate 3, Figure 7

1983 Singh (North-west Alberta, Canada: **Middle Cenomanian**)

1988 Masure (Bahamas: **Late Albian - Vraconian**)

1990 Prössl (nr. Salzgitter, North-west Germany: **mid Barremian - Early Albian**)

Dimensions: Range of observed specimens: length of endophragm 46 (57) 65 μm, width of endophragm 32 (36) 41 μm, maximum length of processes 9 (12) 16 μm, maximum width of processes <1 μm. 7 specimens measured.

Comparisons: This is a distinctive species, with a prolate central body, many thin processes which terminate with spines, and a two-plate precingular archaeopyle. *Kiokansium unituberculatum* is similar but has a spherical central body and longer processes.

Occurrence: Rebecca K. Bounds core (Kansas): Early Cenomanian - Middle Turonian. Blue Point (Arizona): Late Cenomanian. Wahweap Wash (Utah): Early Turonian.

Genus *Pervosphaeridium* Yun, 1981

Pervosphaeridium brevispinum (Norvick *in* Norvick & Burger, 1976) Below, 1982c

Plate 12, Figure 1

1976 Norvick *in* Norvick & Burger (Bathurst Island, Australia: **Early Cenomanian - Early Turonian**) as *Exochosphaeridium brevispinum*

Dimensions: Range of observed specimens: length of central body 73 & 75 µm, width of central body 73 & 66 µm, respectively, maximum length of processes 4 µm. 2 specimens measured.
Comparisons: This species is distinguished by its extremely short processes. Only two specimens were found, in the Rebecca Bounds Core and the Pueblo section. It is possible that these specimens may form part of the population of *P. truncatum* but with very short processes.
Occurrence: Rebecca K. Bounds core (Kansas): Early Cenomanian. Pueblo (Colorado): Late Cenomanian.

Pervosphaeridium pseudhystrichodinium (Deflandre, 1937b) Yun, 1981

Plate 12, Figures 2 & 5

1967 Clarke & Verdier (Isle of Wight, England: **Early Cenomanian - Late Santonian**) as *Baltisphaeridium pseudhystrichodinium*

1969a Davey (Fetcham Mill Borehole, Surrey, England: **Cenomanian - Turonian**, Compton Bay, Isle of Wight, England; Escalles, France: **Cenomanian**) as *Exochosphaeridium pseudhystrichodinium*

1970 Habib (Bahamas: **Albian/Cenomanian**) as *Baltisphaeridium pseudhystrichodinium*

1973 Davey & Verdier (France and Switzerland: **Early Vraconian**) as *Exochosphaeridium pseudhystrichodinium*

1976 Norvick *in* Norvick & Burger (Bathurst Island, Australia: **Early Cenomanian - Early Turonian**) as *Exochosphaeridium pseudhystrichodinium*

1983 Foucher (Paris Basin, France: **Early Cenomanian - Late Campanian**) as *Exochosphaeridium pseudhystrichodinium*

1983 Singh (North-west Alberta, Canada: **Middle Cenomanian**) as *Exochosphaeridium pseudhystrichodinium*

1984 Below (Mazagan Plateau, Offshore North-west Africa: **Late Albian - earliest Cenomanian**)

1988 Marshall & Batten (Lower Saxony Basin, North Germany: **Late Cenomanian - Early Turonian**)

1990 Prössl (nr. Salzgitter, North-west Germany: **Late Albian - Late Turonian**)

1991 Kirsch (Germany: **Coniacian - mid Campanian**)

1992 Mohr & Gee (Kerguelan Plateau, Southern Indian Ocean: **Late Cenomanian - Late Coniacian**)

1993 Courtinat (Pueblo, Colorado, USA: **Late Cenomanian**)

1994a Tocher & Jarvis (Fumichon, Normandy, France: **Middle Cenomanian**)

Dimensions: Range of observed specimens: length of central body 40 (50) 55 µm, width of central body 44 (47) 54 µm, maximum length of processes 11 (14) 18 µm. 6 specimens measured.

Comparisons: This species is recognised by its numerous, long, slender processes with distally expanded, truncate tips. Occasionally some of the processes have pointed tips. *Pervosphaeridium truncatum* also possesses processes with distally expanded, truncate tips, but these are generally shorter, more sparsely distributed and many of the processes have simple truncate or acuminate tips. *Exochosphaeridium phragmites* only has a one-plate precingular archaeopyle, and the processes are thinner and acicular to acuminate. *Exochosphaeridium bifidum* is very similar but also only has a one-plate precingular archaeopyle and the processes have bifurcate and capitate tips.

Occurrence: Rebecca K. Bounds core (Kansas): Early Cenomanian - Late Cenomanian. Blue Point (Arizona), Pueblo (Colorado), Wahweap Wash (Utah): Late Cenomanian.

Pervosphaeridium truncatum (Davey, 1969a) Below, 1982c; emend. Masure, 1988b; emend. Harker & Sarjeant *in* Harker *et al.*, 1990

Plate 12, Figures 6 & 7

1969a Davey (Fetcham Mill, Surrey, England: **Albian - Turonian**, Compton Bay, Isle of Wight, England; Escalles, France; Texas, USA: **Cenomanian**) as *Exochosphaeridium striolatum* var. *truncatum*

1973 Davey & Verdier (France and Switzerland: **Late Albian - Early Cenomanian**) as *Exochosphaeridium striolatum truncatum*

1976 Norvick *in* Norvick & Burger (Bathurst Island, Australia: **Early Cenomanian - Early Turonian**) as *Exochosphaeridium cenomaniense*

1982 Below (Morocco: **Late Hauterivian - Vraconian**)

1984 Below (Mazagan Plateau, Offshore North-west Africa: **Early Aptian - Early Cenomanian**)

1988 Masure (Bahamas: **Late Albian - Middle Cenomanian**)

1988 Marshall & Batten (Lower Saxony Basin, North Germany: **Late Cenomanian - Early Turonian**)

1990 Harker *et al.* (Interior Plains of Canada: **Late Santonian - Late Campanian**)

1990 Prössl (nr. Salzgitter, North-west Germany: **Late Albian - Middle Turonian**) and (**Late Aptian - Late Turonian**)

1991 Kirsch (Germany: **?Campanian - Maastrichtian**)

1992 Costa & Davey (England and the North Sea: **Late Albian - Early Coniacian**)

1993 Courtinat (Pueblo, Colorado, USA: **Late Cenomanian**)

1994a Tocher & Jarvis (Fumichon, Normandy, France: **Middle Cenomanian**)

Original diagnosis: Davey, 1969, p. 164-165: *Exochosphaeridium striolatum* ssp. *truncatum*
A variety of *E. striolatum* possessing subspherical to ovoidal shell; shell wall fibrous or lightly pitted. Processes numerous, typically fibrous and blunted distally, slender or subtriangular, rarely branched. Apical process large, often foliate. Precingular archaeopyle, commonly present, formed by loss of two plate areas, rarely one.

Dimensions: Diameter of central body 34 (56.1) 81 µm, maximum length of processes 6 (17.8) 27 µm.

Original descripition: Davey, 1969, p. 165: *Exochosphaeridium striolatum* ssp. *truncatum*
The shell possesses a moderately thick wall (c. 1 µm) but it is quite often distorted, especially when an archaeopyle is developed. The shell surface (periphragm) is typically fibrous; the fibres pass down the length of the processes onto the shell surface and, there, join up with similar fibres from adjacent processes. Some specimens are less conspicuously fibrous, the fibres being apparent near the bases of the processes and only extending a little way onto the shell surface. The remainder of the shell surface in these forms is lightly pitted. The processes may be fairly slender to subtriangular and are occasionally joined proximally. A small number of processes are subdivided medially. The processes are typically truncated distally but may be slightly bulbous. Process alignment was not observed. The apical process is larger than the other processes and often foliate; the endophragm occasionally forms a small apical bulge beneath it. The archaeopyle is typically formed by the removal of two precingular plates, as is apparent by its shape. Rarely only one plate is lost. Detached opercula consisting of two precingular plates have been located.

Emended diagnosis: Masure, 1988, p. 129
Proximochorate, two-layered dinoflagellate cyst with subspheroidal central body and fibrous, lightly pitted periphragm. Processes intratabular, hollow, fibrous with broad bases, blunted distally, slender, some joined proximally. Apical and antapical processes well developed. Gonyaulacoid paratabulation processes represent 1-?2 preapicals, 4 apicals, 6 precingulars, 6 cingulars, X sulcals, 5-6 postcingulars, ?1 posterior intercalary, 1 antapical. Precingular archeopyle, type 2P 3-4.
Emended description: Masure, 1988, p. 129
The processes are intratabular, with one or more than one for each paraplate. The processes of the post-cingular paraplate (III / IV) may form a penitabular complex, with their broad bases joined proximally. The preapical process is distinctive; the antapical Y is well developed.

Emended diagnosis: Harker, Sarjeant and Caldwell, 1990, p. 73-74
Proximochorate cyst, with radius of endocoel: radius overall within the range 0.6-0.8. Ambitus spheroidal to ovoidal. Periphragm composed of fibres producing a meshwork that covers the shagreenate endophragm; total phragma thickness around 1-1.5 µm. Numerous short, nontabular processes arise at the confluence of several fibres (a feature best seen under scanning electron microscopy: see Pl. 3, Fig. 12). Processes slender, tapering to sub-triangular; blunted; bulbous, branched or recurved distally; often connected proximally to adjacent processes by low fibrous crests. Apical process usually large and foliate, arising from a small apical bulge. Cingulum sometimes indicated by a parallel alignment of processes about the equatorial region (Pl. 3, Fig. 11). Archaeopyle adjacent and anterior to the cingulum on the dorsal surface and formed by loss of two precingular paraplates (Pl. 3, Fig. 10).

Affinities: Masure, 1988, p. 129: *Pervosphaeridium truncatum* differs from other species of the genus in having some processes joined proximally. The archeopyle formula of the genus *Pervosphaeridium* is 2P (Yun, 1981). Below (1981, p. 60) specified that the archeopyle of *Pervosphaeridium paucispinum* was 2P 3-4. *Pervosphaeridium truncatum* and *P. paucispinum* appear to have 2P 3-4 archeopyle formula.

Pervosphaeridium cenomaniense (Norvick *in* Norvick & Burger, 1976) Below, 1982c
Original diagnosis: Norvick, 1976, p.52-53: *Exochosphaeridium cenomaniense*
Cyst chorate. Central body prolate or spherical. Processes tapering, solid or fibrous, medium to long. Processes are striate proximally, pointed or minutely capitate distally. Periphragm fibrous, coarsely and irregularly reticulate. Process arrangement random, at least three per plate area. Apical process distinct, often foliate. Archaeopyle precingular, composed of either one or two discrete plates.
Original Description: Norvick, 1976, p. 53: *Exochosphaeridium cenomaniense*
Chorate cyst with a spherical to prolate central body and medium to long tapering processes. The processes reach 18 µm in length, with a solid or fibrous structure and pointed or minutely capitate distal extremities. The process bases are up to 5 µm broad and, where coarsely fibrous, are sometimes perforate proximally. Fibrils radiate over the periphragm from the process bases and

> anastomose into a coarse and completely irregular periphragmic net-work. Fibrils are 0.5 μm to 1μm thick and lumina up to 1 μm in diameter. The processes are arranged randomly, three or more per plate area. No trace of cingular alignment could be identified, in the population studied., but the apical process is usually longer than the others and it is often distally foliate. The archaeopyle may be formed by the loss of one or two reflected precingular plate areas. The wall is 1-1.5 μm thick. Dimensions: Overall diameter ranges between 51 and 97 μm (average 74 μm for 24 specimens). Holotype overall diameter 73 μm, diameter of central body 60 μm, process length 7 - 12 μm.

Dimensions: Range of observed specimens: length of central body 52 (60) 68 μm, width of central body 48 (58) 68 μm, maximum length of processes 9 (11) 15 μm. 12 specimens measured.

Remarks: The original description of *P. truncatum* states that "The processes may be fairly slender to subtriangular and are occasionally joined proximally. A small number of processes are subdivided medially. The processes are typically truncated distally but may be slightly bulbous." The original description of *P. cenomaniense* includes " The processes reach 18 μm in length, with a solid or fibrous structure and pointed or minutely capitate distal extremities." Minutely capitate suggests slightly expanded, truncate tips.

Close examination of recently taken photographs of the holotype of *P. truncatum* show several of the shorter processes have acuminate tips. Close examination of the plate of the paratype of *P. cenomaniense* shows numerous truncate tips, many of which are slightly truncate or bulbous.

The population within the material from the Western Interior Basin, showed a variation in process tip which covered both of the descriptions of *P. cenomaniense* and *P. truncatum*, not just between specimens but also on individual specimens. These included specimens that possessed acuminate, truncate and distally expanded truncate tips.

Norvick (*in* Norvick & Burger, 1976) also suggests that "*E. striolatum* var. *truncatum* (Davey, 1969a) has distally truncate processes, which resemble some of the Bathurst Island specimens. However, Davey's illustrations show a form with fewer and longer processes than those under study". The lengths of the processes on Norvicks' specimens, however, are included within the size range quoted for Davey's original population. In addition, there appears to be a greater number of processes on the Davey holotype than on the Norvick holotype, which is the converse of Norvicks' comparative suggestions.

The population under study shows variation in both the number of processes per specimen and in the lengths of processes both between specimens and on individuals.

In conclusion, therefore, I suggest that *P. cenomaniense* and *P. truncatum* are synonymous for three reasons: (1) Previously suggested differences between the type populations in terms of process number per specimen are not borne out by examination of the respective holotypes; (2) previously suggested differences in process lengths from one species population are included within the range of lengths from the other population; and (3) the type material of both species includes truncate and acuminate tips, and my own populations carry both types of process tip and cannot be satisfactorily split on that or any other criteria. Since the holotype of *P. truncatum* was described first, I suggest that this species take priority.

Comparisons: *Pervosphaeridium pseudhystrichodinium* is similar, but possesses more numerous processes, which are longer and thinner and terminate with distally expanded, truncate tips.

Pervosphaeridium brevispinum has much shorter processes. *Pervosphaeridium* sp. A also has more numerous processes, which are thinner walled, with many adjacent processes that are fused together. *Exochosphaeridium phragmites* only has a one-plate precingular archaeopyle, and has more numerous processes, which are thinner walled, and are acicular to acuminate.

Occurrence: Rebecca K. Bounds core (Kansas): Early Cenomanian - Middle Turonian. Blue Point (Arizona), Bunker Hill (Kansas), Pueblo (Colorado), Wahweap Wash (Utah): Late Cenomanian - Early Turonian.

Pervosphaeridium sp. A

Plate 11, Figures 1 to 3

Diagnosis: Skolochorate, apiculocavate cyst. The central body is subspherical and punctate to reticulate, and sometimes striate. The numerous processes are thin-walled, simple, hollow and acuminate and are often fused into compound and complex processes. The archaeopyle is two-plate precingular, operculum free.

Description: The periphragm forms a perforate to reticulate and striate surface over the central body and is thinner than the endophragm. Consequently the processes are characteristically thinner than the central body. The processes are gradually tapering, faintly striate and sometimes faintly reticulate. Often they are connected at their bases, by low ridges, which in many cases are expanded to form medial or distal flanges, which fuse two or more adjacent processes to form compound and complex processes. The process terminations are acuminate to slightly capitate, bifurcate or truncate. The apex is sometimes surmounted by a shorter, wider, blunter apical projection of the periphragm. The archaeopyle is type 2P (presumably plates 3" and 4"), with the principle archeopyle suture having a characteristic flat base along the paracingulum and downward pointing angulation along the apical paraplates. Sometimes only one of the paraplates of the operculum is lost though the principle archaeopyle suture can still be traced around the second paraplate. No other features indicate the paracingulum, parasulcus or paratabulation.

Dimensions: Range of observed specimens: length of periphragm 65 (76) 84 μm, width of periphragm 69 (76) 85 μm, length of endophragm 47 (57) 64 μm, width of endophragm 50 (58) 65 μm, maximum length of processes 14 (16) 19 μm. 12 specimens measured.

Comparisons: This species differs from others in this material in its possession of thin-walled, complex processes. *Exochosphaeridium phragmites* appears very similar to this species but only has narrow, solid, simple or occasionally compound processes, and a single-plate precingular archaeopyle. *Pervosphaeridium truncatum* and *P. pseudhystrichodinium* also only have simple or occasionally compound processes, with a periphragm which is thicker than the endophragm, giving thicker walled processes. *Pervosphaeridium morgenrothii* may seem similar but only has compound processes (appearing to be medially to distally bifurcate), which seem to be longer in comparison with the diameter of the central body. *Florentinia tenera* may also seem similar with thinner-walled simple and complex processes, but has a smooth wall and single-plate precingular archaeopyle.

Occurrence: Rebecca K. Bounds core (Kansas): Middle Turonian.

Genus *Stephodinium* Deflandre, 1936a; emend. Davey, 1970

Stephodinium coronatum Deflandre, 1936a

Plate 25, Figures 4 & 5

1967 Clarke & Verdier (Isle of Wight, England: **Early - Late Cenomanian)**

1970 Davey (Fetcham Mill Borehole, Surrey, England: **Albian - Cenomanian,** Compton Bay, Isle of Wight, England; Escalles, France: **Cenomanian)**

1973 Davey & Verdier (France and Switzerland: **Late Albian)**

1978 Bujak & Williams (Offshore South-eastern Canada: **Late Albian - mid Santonian)**

1980 Morgan (Australia: **earliest Albian - Middle Cenomanian)**

1983 Foucher (Paris Basin, France: **Early Cenomanian - Late Santonian)**

1983 Singh (North-west Alberta, Canada: **Early Cenomanian)**

1986 Ioannides (Bylot Island, Arctic Archipelago: **Santonian/Campanian)**

1988 Marshall & Batten (Lower Saxony Basin, North Germany: **Late Cenomanian)**

1990 Prössl (nr. Salzgitter, North-west Germany: **Late Aptian - Late Cenomanian)**

1992 Costa & Davey (England and the North Sea: **Middle Albian - latest Turonian)**

1993 Williams *et al.* (N. Hemisphere: **Middle Albian - Turonian)**

Dimensions: Range of observed specimens: length of periphragm 27 & 38 μm (2 specimens only), width of periphragm 51 (60) 66 μm, length of endophragm 43 & 44 μm (2 specimens only), width of endophragm 28 (42) 47 μm. 4 specimens measured.

Comparisons: This is a distinctive species of pterocavate cyst with an equatorial pericoel (the wall layers are appressed on both polar surfaces), a precingular archaeopyle and parasutural ridges. Species of *Disphaeria* may appear similar to *S. coronatum* in polar view, but are camocavate and the wall layers are only appressed on the dorsal surface.

Occurrence: Blue Point (Arizona), Pueblo (Colorado): Late Cenomanian. Rebecca K. Bounds core (Kansas): Middle Turonian.

Genus *Surculosphaeridium* Davey, Downie, Sarjeant & Williams, 1966; emend. Davey, 1982b

Surculosphaeridium? *longifurcatum* (Firtion, 1952) Davey, Downie, Sarjeant & Williams, 1966

Plate 1, Figure 5

1966 Davey *et al.* (Fetcham Mill Borehole, Surrey, England: **Cenomanian)**

1969a Davey (Fetcham Mill Borehole, Surrey; Compton Bay, Isle of Wight, England; Escalles, France; Texas, USA: **Cenomanian)**

1973 Davey & Verdier (France and Switzerland: **Late Albian - Early Cenomanian)**

1978 Bujak & Williams (Offshore South-eastern Canada: **earliest Hauterivian - mid Santonian)**

1983 Foucher (Paris Basin, France: **Early Cenomanian - Early Campanian)**
1986 Ioannides (Bylot Island, Arctic Archipelago: **Santonian/Campanian)**
1988 Jarvis *et al.* (Dover, Kent, England: **Late Cenomanian)**
1990 Prössl (nr. Salzgitter, North-west Germany: **Late Barremian - Early Cenomanian)**
1991 Kirsch (Germany: **?Turonian - Campanian)**
1992 Costa & Davey (England and the North Sea: **Late Aptian - Early Santonian)**
1993 Williams *et al.* (N. Hemisphere: **Early Albian - Early Campanian)**
1994a Tocher & Jarvis (Fumichon, Normandy, France: **Early - Middle Cenomanian)**

Dimensions: Range of observed specimens: length of central body 31 (34) 37 µm, width of central body 35 (38) 40 µm, maximum length of processes 14 (21) 25 µm. 7 specimens measured.
Comparisons: This is a distinctive species of skolochorate cyst with thin, solid, proximally-medially-and-distally, irregularly branching processes. *Oligosphaeridium dividuum* has much broader, tubular, dividing processes. *Hystrichosphaeridium recurvatum* may appear similar, but has narrow tubular processes which distally terminate with regular aculei.
Occurrence: Rebecca K. Bounds core (Kansas): Middle Cenomanian - Middle Turonian. Blue Point (Arizona), Pueblo (Colorado), Wahweap Wash (Utah): Late Cenomanian - Early Turonian. Bunker Hill (Kansas): Early Turonian.

Family **Areoligeraceae** Evitt, 1963

Genus *Adnatosphaeridium* Williams & Downie, 1966; emend. Stancliffe & Sarjeant, 1990

Adnatosphaeridium tutulosum (Cookson & Eisenack, 1960a) Morgan, 1980

Plate 24, Figure 6

1960a Cookson & Eisenack (Perth & Carnarvon Basins, Australia: **Cenomanian?)** as *Cannosphaeropsis tutulosum*
1980 Morgan (Australia: **Late Albian - Middle Cenomanian)** as *Cannosphaeropsis tutulosa*
1988 Marshall & Batten (Lower Saxony Basin, North Germany: **Late Cenomanian - Early Turonian)**

Dimensions: Range of observed specimens: length of ectophragm 37 (47) 57 µm, width of ectophragm 46 (50) 60 µm, length of autophragm 17 (25) 28 µm, width of autophragm 24 (27) 31 µm, maximum length of processes 11 (13) 18 µm. 7 specimens measured.
Comparisons: This species is easily distinguished by its numerous rigid processes, linked by distal trabeculae. *Nematosphaeropsis densiradiata* is very similar, but has a precingular archaeopyle (type P) instead of an apical one (type 4A).
Occurrence: Bunker Hill (Kansas), Pueblo (Colorado), Rebecca K. Bounds core (Kansas): Late Cenomanian.

Genus *Canningia* Cookson & Eisenack, 1960b; emend. Cookson & Eisenack, 1961a; emend. Dörhofer & Davies, 1980; emend. Below, 1981a; emend. Helby, 1987

Canningia reticulata Cookson & Eisenack, 1960b; emend. Below, 1981a; emend. Helby, 1987

Plate 21, Figures 1 & 2

1967 Clarke & Verdier (Isle of Wight, England: **Early Cenomanian**)

1978 Bujak & Williams (Offshore South-eastern Canada: **earliest Cenomanian - latest Campanian**)

1982 Nichols, Jacobson & Tschudy (Wyoming & Montana, USA: **Albian**)

1988 Mao Shaozhi & Norris (Kashi Area, Xinjiang Province, China: **Late Cretaceous**)

1989 Aurisano (New Jersey & Delaware, USA: **Cenomanian - Late Santonian**)

1993 Nøhr-Hansen (North-east Greenland: **Late Aptian**)

Original description: Cookson and Eisenack, 1960b, p. 251
Shell with straight or rounded sides; apical projection not prominent, basal indentation clearly marked; a 'girdle' is usually present slightly above the equator. Shell-membrane densely and irregular reticulate, the reticulum low, small-meshed and thick-walled.

Emended diagnosis: Below, 1981, p. 32
Two-layered cyst. The smooth endophragm forms the sphaeroidal, lenticular inner body. Periphragm smooth, forming the, in outline, sphaeriodal to pentagonal outer body. ?Endophragmal, spongious, matted lattice structure fills pericoel. Paratabulation weakly indicated, seemingly gonyaulacoidal. Paracingulum spiral, indented into outer body, parasulcus just as thick, undifferentiated dent recognisable. Archaeopyle apical, Type "Aa", operculum enlarged.

Emended description: Helby, 1987, p. 322
Cyst lenticular with obtuse, low apical horn, 2 low rounded antapical horns, with that on the left larger and much further from the paracingulum. Ectophragm usually protrusive at the paracingulum. Autophragm and ectophragm relatively close to each other, and ectocoel wider below horns and paracingulum than elsewhere.
Supporting structures within the ectocoel varying in length and distribution and longest and most closely packed in parasutural areas (up to 6 µm long). Ectophragm finely reticulate to rugoreticulate, although some specimens may have granulate or smooth areas. Paratabulation indicated by principal and accessory archeopyle sutures. However, on some specimens paraplate boundaries marked by low external ridges underlain by longer ectophragm supports. Paratabulation formula 4', 6", 6c, 6''' ,1 p, 1'''' . Archeopyle apical, type [tA], principal archeopyle suture zigzag with offset parasulcal notch and operculum free. Parasulcus often marked by a reduction in the extent, or even absence, of ectocoel development and characteristically sinuous. Paracingulum indicated laterally by equatorial protrusion of wall layers and transversely by slight parasutural ridges. Paracingulum markedly offset adjacent to the parasulcus.

Dimensions: Range of observed specimens: length of periphragm with no apex 48 (61) 77 µm, length of periphragm with apex 75 (80) 85 µm (4 specimens), width of periphragm 65 (76) 90 µm, length of endophragm with no apex 45 (54) 66 µm, length of endophragm with apex 57 (67) 74 µm (4 specimens), width of endophragm 62 (73) 87 µm, maximum separation of wall layers 3 (4.3) 6 µm. 7 specimens measured.

Comparisons: This is one of a number of very similar species, which are only subtly different, and as with many areoligeracaean cysts, seems to form a gradation. *Canningia reticulata* has a low and comparatively fine meshed reticulum. *Canningia* sp. A also has a fine meshed reticulum but this is closely appressed to the endophragm with no wall layer separation. *Canningia* sp. B also appears similar but has a smooth to punctate periphragm which is irregularly thickened and folded over the endophragm. *Cyclonephelium chabaca* is very similar but has a higher reticulum, far more obviously supported by more numerous, discrete, thicker, stronger and longer pillars, with more obvious evidence of paratabulation and sometimes areas of reduced ornamentation over the mid-dorsal and mid-ventral regions, typical of the genus *Cyclonephelium*. *Canningia senonica* is also very similar and also has a much higher and coarser reticulum, which is far more irregular than that of *C. reticulata* and is supported by thin and irregular processes, giving the cyst a 'messy' appearance. *Canningia scabrosa* appears similar but has little or no reticulum.

Senoniasphaera microreticulata also has a fine meshed reticulum but always forms a characteristic cingulum. *Valensiella reticulata* is much smaller and more sub-spherical than *C. reticulata*.

Occurrence: Rebecca K. Bounds core (Kansas): Early Cenomanian - Early Turonian. Blue Point (Arizona), Bunker Hill (Kansas), Wahweap Wash (Utah): Late Cenomanian - Early Turonian. Pueblo (Colorado): Early Turonian.

Canningia scabrosa Cookson & Eisenack, 1970a

Plate 20, Figures 4 to 6

1970 Cookson & Eisenack (Eucla Basin, Western Australia: **Albian - Cenomanian)**

> **Original description:** Cookson and Eisenack, 1970, p.146
> Shell rather flat, almost circular to slightly angular in outline, with a slight apical prominence and with, as in the holotype, or without a slight antapical concavity bounded by blunt or pointed outgrowths.
> In one example (from 1486-1523 ft) a girdle is clearly evident on the ventral surface. The shell opens by the removal of a considerable portion of the epitheca.
> The ornamentation consists of densely arranged, irregularly outlined thickenings, some of which narrow to short, hair-like appendages (Pl. 13, fig. 4).
> **Dimensions:** Holotype: c. 102 μm long, 90 μm broad. Range in breadth: c. 78-94 μm.

Dimensions: Range of observed specimens: length of endophragm with no apex 45 (60) 70 μm, length of endophragm with apex 67 (81) 96 μm (4 specimens), width of endophragm 55 (78) 97 μm, maximum height of ornamentation 1.5 (4) 6 μm. 9 specimens measured.

Comparisons: This species is distinguished by its low, dense and irregular ornamentation of processes and hairs, which mesh together to a small extent, and which give the cyst a 'scabby' appearance. *Canningia senonica* is similar but has much higher ornamentation with a better defined, though loose, reticulum. A gradation exists between this species and *Cyclonephelium brevispinatum* which is very similar but has discrete, short and irregular processes instead of a continuous cover. Specimens developing any meshing or amalgamation of ornamentation were placed in *C. scabrosa*.

Downiesphaeridium? sp. A is smaller and thinner walled, and has a dense covering of fine, acicular hairs.

Occurrence: Rebecca K. Bounds core (Kansas): Early Cenomanian - Middle Turonian. Blue Point (Arizona): Late Cenomanian. Pueblo (Colorado): Late Cenomanian - Early Turonian.

Canningia senonica Clarke & Verdier, 1967

Plate 20, Figures 1 to 3

1967 Clarke & Verdier (Isle of Wight, England: **mid Santonian**)
1978 Bujak & Williams (Offshore South-eastern Canada: **earliest Coniacian - latest Santonian**)
1983 Foucher (Paris Basin, France: **Late Santonian - earliest Campanian**)

> **Original diagnosis:** Clarke and Verdier, 1967, p. 21
> A species of *Canningia* with a small apical and frequently two small antapical protrusions. The sculpture consists of a fine, irregular reticulum.
> **Original description:** Clarke and Verdier, 1967, p. 21
> Shape of body rounded with small apical and sometimes antapical protrusions. The apical archaeopyle is well displayed on most specimens which are incomplete having lost their apical part. Sculpture of thin irregular processes up to 12 µm long which join distally to form an incomplete and irregular reticulum; the sculpture completely covers the body.
> Dimensions: Range: overall length 60-85 µm, overall breadth 50-70 µm, process length 6-12 µm.

Dimensions: Range of observed specimens: length of periphragm 56 (68) 95 µm, width of periphragm 63 (78) 105 µm, length of endophragm 51 (62) 81 µm, width of endophragm 56 (73) 96 µm, maximum separation of wall layers 5 (7) 10 µm. 7 specimens measured.

Comparisons: The cyst has a dense covering of long, irregular processes, which form a loose and irregular, high reticulum. *Cyclonephelium chabaca* also has a high reticulum, but this is far more regularly meshed and supported by numerous, very obvious, rigid pillars. *Canningia reticulata* has a much finer and more regular reticulum, which is appressed closer to the endophragm. *Canningia scabrosa* is similar but has shorter and denser ornamentation which only forms a slight reticulum by meshing close to the surface of the endophragm.

Occurrence: Rebecca K. Bounds core (Kansas): Middle Turonian.

Canningia sp. A

Plate 21, Figures 3 & 4

Description: The cyst is proximate, with a subcircular to lenticular outline. The two wall layers are closely appressed, with a fine and dense reticulation over the surface of the periphragm. The archaeopyle is apical, type 4A, and the operculum is often free.

Diagnosis: The outline of the cyst is often rounded but sometimes displays an indented antapex between rounded antapical horns. The periphragm is finely and densely reticulate and is completely appressed over the entire endophragm with little, or more often, no folding or thickening. The principle archaeopyle suture is zig-zag, and displays an offset sulcal notch, sometimes with accessory archaeopyle sutures. No other indication of paratabulation can be seen.

Dimensions: Range of observed specimens: length of endophragm with no apex 41 (56) 78 µm, length of endophragm with apex 56 (75) 105 µm (9 specimens), width of endophragm 49 (69) 91 µm. 18 specimens measured.

Comparisons: This species is very similar to *C. reticulata* which also has a fine meshed reticulum but this is clearly separated from the endophragm, particularly in apical, postcingular and antapical areas. A gradation seems to exist with *Canningia* sp. B, which also appears similar but has a smooth to punctate periphragm which is irregularly thickened and folded over the endophragm. Intermediate forms show a poor development of the reticulum and small amounts of folding and thickening of the periphragm. Only those forms with a well developed reticulum and almost no folding have been placed in *Canningia* sp. A.

Occurrence: Pueblo (Colorado): Late Cenomanian. Blue Point (Arizona): Late Cenomanian - Early Turonian. Rebecca K. Bounds core (Kansas): Early Turonian - Middle Turonian.

Canningia sp. B

Plate 21, Figures 5 & 6

Description: The cyst is proximate, with a subcircular to lenticular outline. The outer wall layer is smooth to punctate and irregularly thickened and folded over the endophragm. The archaeopyle is apical, type 4A, and often operculum free.

Diagnosis: The outline of the cyst is often rounded but sometimes displays an indented antapex between rounded antapical horns. The surface of the periphragm is smooth to punctate, and in places displays a very poorly developed reticulum. The periphragm is lightly and finely folded over the endophragm and irregularly thickened, giving the surface of the cyst the appearance of a very coarse, uneven reticulum under low magnification. Only small scale separation of wall layers occurs (up to 3 µm). The principle archaeopyle suture is zig-zag, and displays an offset sulcal notch, sometimes with accessory archaeopyle sutures. No other indication of paratabulation can be seen.

Dimensions: Range of observed specimens: length of endophragm with no apex 37 (60) 74 µm, length of endophragm with apex 47 (70) 85 µm (4 specimens), width of endophragm 46 (65) 89 µm, maximum height of ornamentation 1 (1.7) 3 µm. 15 specimens measured.

Comparisons: *Canningia reticulata* is very similar but has a fine meshed reticulum which, though separated from the endophragm, is not folded or thickened. A gradation seems to occur with *Canningia* sp. A, which also appears similar but it has a finely and densely reticulate periphragm which is closely appressed over the entire surface of the endophragm. Intermediate forms show a poor development of the reticulum and small amounts of folding and thickening of the periphragm. Only those forms with a well developed reticulum and almost no folding have been placed in *Canningia* sp. A. *Canningia senonica* may also appear similar but has a high, irregular and coarse reticulum, supported by thin and irregular processes.

Occurrence: Blue Point (Arizona), Pueblo (Colorado), Wahweap Wash (Utah): Late Cenomanian - Early Turonian. Rebecca K. Bounds core (Kansas): Early Turonian - Middle Turonian.

Genus *Canninginopsis* Cookson & Eisenack, 1962; emend. Marshall, 1990

Canninginopsis colliveri (Cookson & Eisenack, 1960b) Backhouse, 1988

Plate 19, Figure 6

1960b Cookson & Eisenack (nr. Broome, North-west Australia: **Aptian**) as *Canningia colliveri*

1967 Clarke & Verdier (Isle of Wight, England: **Early Cenomanian - mid Santonian**) as *Canningia colliveri*

1971 Singh (North-west Alberta, Canada: **middle - Late Albian**) as *Canningia colliveri*

1973 Davey & Verdier (France and Switzerland: **Late Albian - Early Cenomanian**) as *Canningia colliveri*

1978 Bujak & Williams (Offshore South-eastern Canada: **earliest Berriasian - latest Turonian**) as *Canningia colliveri*

1979 May (North Slope, Alaska, USA: **Middle Albian**) as *Canningia colliveri*

1980 Morgan (Australia: **Late Neocomian - Middle Cenomanian**) as *Canningia colliveri*

1981 Below (South-west Morocco: **Hauterivian - Aptian**) as *Canningia colliveri*

1982 Below (Morocco: **Late Hauterivian - Early Cenomanian**) as *Canningia colliveri*

1988 Jarvis *et al.* (Dover, Kent, England: **Late Cenomanian - Early Turonian**) as *Canningia colliveri*

1988 Mao Shaozhi & Norris (Kashi Area, Xinjiang Province, China: **Late Cretaceous**) as *Canningia colliveri*

1989 Habib & Milner (South Carolina & Georgia, USA: **Campanian**)

1994a Tocher & Jarvis (Fumichon, Normandy, France: **Middle Cenomanian**)

Dimensions: Range of observed specimens: length of endophragm with no apex 42 (61) 74 μm, length of endophragm with apex 88 μm (1 specimen), width of endophragm 53 (70) 84 μm. 7 specimens measured.

Comparisons: Placed in the genus *Canninginopsis* due to its single wall layer and infrequent evidence of paratabulation, this species is distinguishable by its lenticular shape and finely granulate to echinate ornamentation. A gradation exists with *Cyclonephelium brevispinatum*, which is similar in having low ornamentation, but has short truncate to echinate processes. Any specimens displaying truncate ornamentation were placed in *C. brevispinatum*. *Cyclonephelium paucimarginatum* is also similar but has a less lenticular and more sub-rounded shape, and larger granulae/vermiculae, which fuse to form short ridges, immediately around the mid-dorsal and mid-ventral areas.

Occurrence: Rebecca K. Bounds core (Kansas): Early Cenomanian - Middle Turonian. Blue Point (Arizona), Bunker Hill (Kansas), Pueblo (Colorado), Wahweap Wash (Utah): Late Cenomanian - Early Turonian.

Genus *Circulodinium* Alberti, 1961

Circulodinium distinctum (Deflandre & Cookson, 1955) Jansonius, 1986

Plate 18, Figure 2

1955 Deflandre & Cookson (Australia: **Senonian**) as *Cyclonephelium distinctum*

1962b Cookson & Eisenack (Australia: **Albian - mid Senonian**) as *Cyclonephelium distinctum*

1964 Manum & Cookson (Arctic Canada: **'mid Cretaceous'**) as *Cyclonephelium distinctum*

1967 Clarke & Verdier (Isle of Wight, England: **Early Cenomanian - Late Campanian**) as *Cyclonephelium distinctum*

1969a Davey (Fetcham Mill Borehole, Surrey; Compton Bay, Isle of Wight, England; Escalles, France; Saskatchewan, Canada: **Cenomanian**) as *Cyclonephelium distinctum*

1971 Singh (North-west Alberta, Canada: **mid - Late Albian**) as *Cyclonephelium distinctum*

1973 Davey & Verdier (France and Switzerland: **Late Albian - Early Cenomanian**) as *Cyclonephelium distinctum*

1976 Norvick *in* Norvick & Burger (Bathurst Island, Australia: **Early Cenomanian - Early Turonian**) as *Cyclonephelium distinctum*

1978 Bujak & Williams (Offshore South-eastern Canada: **earliest Berriasian - latest Maastrichtian**) as *Cyclonephelium distinctum*

1980 Morgan (Australia: **Late Neocomian - Cenomanian**) as *Cyclonephelium distinctum*

1981 Below (South-west Morocco: **Hauterivian - Vraconian**) as *Cyclonephelium distinctum*

1983 Foucher (Paris Basin, France: **Early Cenomanian - Early Coniacian**) as *Cyclonephelium distinctum*

1983 Habib & Drugg (Blake-Bahama Basin, Western Atlantic: **Late Berriasian - Late Albian**) as *Cyclonephelium distinctum*

1983 Singh (North-west Alberta, Canada: **Early - Middle Cenomanian**) as *Cyclonephelium distinctum*

1984 Below (Mazagan Plateau, Offshore North-west Africa: **Early Aptian - Early Cenomanian**) as *Cyclonephelium distinctum*

1986 Ioannides (Bylot Island, Arctic Archipelago: **Santonian/Campanian - Maastrichtian**) as *Cyclonephelium distinctum*

1987 Firth (Georgia, USA: **Late Maastrichtian**) as *Cyclonephelium distinctum*

1987 Habib & Drugg (Offshore USA, Western North Atlantic: **Late Berriasian - Middle Albian**) as *Cyclonephelium distinctum*

1988 Jarvis *et al.* (Dover, Kent, England: **Late Cenomanian - Early Turonian**) as *Cyclonephelium distinctum*

1988 Mao Shaozhi & Norris (Kashi Area, Xinjiang Province, China: **Late Cretaceous**) as *Cyclonephelium distinctum*

1988 Marshall & Batten (Lower Saxony Basin, North Germany: **Late Cenomanian - Early Turonian**) as *Cyclonephelium distinctum*

1988 Masure (Bahamas: **Late Albian - Middle Cenomanian**) as *Cyclonephelium distinctum*

1989 Habib & Milner (South Carolina & Georgia, USA: **Campanian)**
1990 Harker *et al.* (Interior Plains of Canada: **Early - Late Campanian)**
1990 Prössl (nr. Salzgitter, North-west Germany: **Early Hauterivian - Late Turonian)** as *Cyclonephelium distinctum*
1991 Kirsch (Germany: **Turonian - Maastrichtian)**
1993 Courtinat (Pueblo, Colorado, USA: **Late Cenomanian)**
1993 Nøhr-Hansen (North-east Greenland: **Early Barremian - Late Albian/ Early Cenomanian?)**
1993 Williams *et al.* (N. Hemisphere: **Jurassic - Late Maastrichtian)**
1994a Tocher & Jarvis (Fumichon, Normandy, France: **Early - Middle Cenomanian)**
1996 Stover *et al.* (World wide: **Upper Jurassic - Paleocene)**

Dimensions: Range of observed specimens: length of endophragm with no apex 41 (50) 63 µm, length of endophragm with apex 58 (65) 71 µm (5 specimens), width of endophragm 46 (59) 77 µm, maximum height of ornamentation 5 (7) 8 µm. 8 specimens measured.

Comparisons: The ornamentation of *C. distinctum* consists of a variable number of solid processes of variable length, with variable distal extremities, including acuminations, expansions, bifurcations and capitations. It is similar to many other species of Areoligeracaean cysts. *Tenua hystrix* has a more even cover of many more processes, of even length, even width, and with capitate to bifurcate tips. *Cyclonephelium brevispinatum* has very short and irregular processes. *Cyclonephelium vannophorum* also has shorter processes, which are infundibular (terminate in a distinctive fan-shape) and may occasionally form small sections of trabeculum. *Cyclonephelium hughesii* has thicker processes of an even length and even width with distally expanded and indented tips. *Heterosphaeridium? heteracanthum* generally has longer processes with extremities which are as variable as on *C. distinctum*, but the processes are connected proximally by surface ridges. *Downiesphaeridinium* sp. A has an even cover of processes, which are much thinner and have acuminate tips.

Occurrence: Rebecca K. Bounds core (Kansas): Early Cenomanian - Middle Turonian. Blue Point (Arizona), Bunker Hill (Kansas), Pueblo (Colorado), Wahweap Wash (Utah): Late Cenomanian - Early Turonian.

Genus *Cyclonephelium* Deflandre & Cookson, 1955; emend. Williams & Downie, 1966; emend. Ioannides *et al.*, 1977; emend. Sarjeant & Stover, 1978; emend. Stover & Evitt, 1978; emend. Dörhofer & Davies, 1980

Cyclonephelium brevispinatum (Millioud, 1969) Below, 1981a

Plate 19, Figures 3 & 4

1981 Below (South-west Morocco: **Hauterivian - Early Cenomanian)**
1984 Below (Mazagan Plateau, Offshore North-west Africa: **Early Aptian - Early Cenomanian)**
1990 Prössl (nr. Salzgitter, North-west Germany: **Early Hauterivian - latest Barremian)**
1993 Courtinat (Pueblo, Colorado, USA: **Late Cenomanian)**

Dimensions: Range of observed specimens: length of endophragm with no apex 47 (59) 68 µm, length of endophragm with apex 67 µm (1 specimen), width of endophragm 60 (72) 86 µm, maximum height of ornamentation 1 (2) 3 µm. 8 specimens measured.

Comparisons: *Cyclonephelium brevispinatum* has discrete, short, irregular, truncate to echinate processes. It seems to occupy an intermediate position between a number of potentially related Areoligeracaean cysts. A gradation exists with *Canninginopsis colliveri*, which also has low ornamentation, but of granules and cones, and occasionally shows some paratabulation. Any specimens displaying truncate ornamentation were placed in *C. brevispinatum*.

A gradation also exists between this species and *Canningia scabrosa* which is distinguished by its low, dense and irregular ornamentation of processes and hairs, which mesh together to a small extent, and which give the cyst a 'scabby' appearance. Any specimens displaying meshing or amalgamation of ornamentation were placed in *C. scabrosa*.

Cyclonephelium paucimarginatum is also similar but always has a sub-rounded shape, with larger granulae/vermiculae which join to form short ridges immediately around the mid-dorsal and mid-ventral areas. *Cyclonephelium vannophorum* has infundibular processes (terminate in a distinctive fan-shape), particularly in apical and antapical areas, which may occasionally form small sections of trabeculum. *Circulodinium distinctum* has a variable number of solid processes of greater length, with variable distal extremities, including acuminations, expansions, bifurcations and capitations.

Occurrence: Rebecca K. Bounds core (Kansas): Early Cenomanian - Middle Turonian. Blue Point (Arizona), Bunker Hill (Kansas), Pueblo (Colorado), Wahweap Wash (Utah): Late Cenomanian - Early Turonian.

Cyclonephelium chabaca Below, 1981a

Plate 19, Figures 1 & 2

1981 Below (South-west Morocco: **Aptian - Early Cenomanian**)
1982 Below (Morocco: **Vraconian - Early Cenomanian**)
1984 Below (Mazagan Plateau, Offshore North-west Africa: **Albian - Early Cenomanian**)
1988 Masure (Bahamas: **Vraconian - Middle Cenomanian**)

Dimensions: Range of observed specimens: length of periphragm 45 (64) 81 µm, width of periphragm 57 (77) 90 µm, length of endophragm 41 (58) 72 µm, width of endophragm 56 (73) 85 µm, maximum height of reticulum 3 (5) 7 µm. 8 specimens measured.

Comparisons: *Cyclonephelium chabaca* has a high, regularly meshed reticulum clearly supported by numerous, discrete, rigid pillars, with some evidence of paratabulation and sometimes reduced ornamentation over the mid-dorsal and mid-ventral areas, typical of the genus *Cyclonephelium*. *Canningia senonica* is very similar in possessing a high, and comparatively coarse reticulum. However, this is far more irregular than that of *C. chabaca* and is supported by thin and irregular processes, giving the cyst a 'messy' appearance. *Canningia reticulata* has a finer reticulum, which is less obviously supported by pillars, and is more closely appressed to the endophragm. *Canningia scabrosa* appears similar but has little or no reticulum. *Cyclonephelium vannophorum* may also appear similar, and may be closely related, but has discrete, infundibular processes around its periphery, which may occasionally form small sections of trabeculum, very similar to that of *C. chabaca.*

Occurrence: Rebecca K. Bounds core (Kansas): Early Cenomanian - Middle Turonian. Blue Point (Arizona), Bunker Hill (Kansas), Pueblo (Colorado): Late Cenomanian - Early Turonian. Wahweap Wash (Utah): Early Turonian.

Cyclonephelium compactum Deflandre & Cookson, 1955

Plate 17, Figure 2

1962b	Cookson & Eisenack (Australia: **Aptian - Cenomanian**)
1976	Norvick *in* Norvick & Burger (Bathurst Island, Australia: **Early Cenomanian - Early Turonian**)
1980	Morgan (Australia: **earliest Aptian - latest Cenomanian**)
1984	Below (Mazagan Plateau, Offshore North-west Africa: **Late Albian**)
1988	Masure (Bahamas: **Vraconian - Middle Cenomanian**)
1988	Marshall & Batten (Lower Saxony Basin, North Germany: **Late Cenomanian - Early Turonian**)
1990	Prössl (nr. Salzgitter, North-west Germany: **Late Aptian - Late Turonian**)
1994a	Tocher & Jarvis (Fumichon, Normandy, France: **Middle Cenomanian**)

Dimensions: Range of observed specimens: length of endophragm with no apex 38 (53) 66 µm, length of endophragm with apex 69 µm (2 specimens), width of endophragm 62 (67) 72 µm, maximum height of processes 10 (12) 15 µm. 7 specimens measured.

Comparisons: *Cyclonephelium compactum* has a number of broad, distally expanded processes around its periphery, which are often proximally linked. The maximum length of these processes is normally approximately $^1/_6$ of the width of the central body. Often, adjacent processes may be joined by membranes which, when commonly developed, form a gradation with *C. membraniphorum*. Those specimens with more-or-less continuous membranes around the margin of the central body, have been placed in *C. membraniphorum.*

Heterosphaeridium difficile is very similar but has strongly developed ridges which join the bases of adjacent processes, which are longer in proportion to the size of the central body (their maximum length averages at 23 µm and is normally approximately $^1/_3$ of the width of the central body). *Cyclonephelium uncinatum* is also very similar, but the processes are generally narrower, have a more constant width, and have a trabeculum which joins the distal ends to form a series of 'loops' around the perimeter of the cyst. *Circulodinium distinctum* has much narrower processes which are of variable length, with variable distal extremities, including acuminations, expansions, bifurcations and capitations. Some specimens of *C. compactum* with short processes appear similar to *Pseudoceratium eisenackii*, which is ornamented with a series of low irregular crests joining short capitate processes.

Occurrence: Rebecca K. Bounds core (Kansas): Late Cenomanian - Middle Turonian. Blue Point (Arizona), Bunker Hill (Kansas), Pueblo (Colorado), Wahweap Wash (Utah): Late Cenomanian - Early Turonian.

Cyclonephelium membraniphorum Cookson & Eisenack, 1962b

Plate 17, Figures 3 & 4

1962b Cookson & Eisenack (Australia: **Albian - Cenomanian)**
1964 Cookson & Hughes (Cambridgeshire, England: **Early Cenomanian)**
1967 Clarke & Verdier (Isle of Wight, England: **Early Turonian - Early Coniacian)**
1969a Davey (Fetcham Mill Borehole, Surrey; Compton Bay, Isle of Wight, England; Escalles, France: **Cenomanian)**
1973 Davey & Verdier (France and Switzerland: **Early - Late Vraconian)**
1976 Norvick *in* Norvick & Burger (Bathurst Island, Australia: **Early Cenomanian - Early Turonian)**
1978 Bujak & Williams (Offshore South-eastern Canada: **earliest Albian - latest Cenomanian)**
1979 May (North Slope, Alaska, USA: **Middle Albian)**
1980 Morgan (Australia: **earliest Vraconian - latest Cenomanian)**
1983 Foucher (Paris Basin, France: **Early Cenomanian - Early Santonian)**
1986 Ioannides (Bylot Island, Arctic Archipelago: **Santonian/Campanian)**
1988 Jarvis *et al.* (Dover, Kent, England: **Late Cenomanian - Early Turonian)**
1988 Marshall & Batten (Lower Saxony Basin, North Germany: **Late Cenomanian - Early Turonian)**
1990 Harker *et al.* (Interior Plains of Canada: **Early - Late Campanian)**
1990 Prössl (nr. Salzgitter, North-west Germany: **Late Albian - Late Turonian)**
1992 Costa & Davey (England and the North Sea: **earliest Cenomanian - latest Turonian)** as *Maghrebinia membraniphora*
1993 Courtinat (Pueblo, Colorado, USA: **Late Cenomanian)** as *Maghrebinia membraniphora*
1994a Tocher & Jarvis (Fumichon, Normandy, France: **Early - Middle Cenomanian)**

Dimensions: Range of observed specimens: length of endophragm with no apex 43 (48) 59 μm, length of endophragm with apex 63 (68) 77 μm (3 specimens), width of endophragm 55 (62) 70 μm, maximum height of membrane 9 (12) 15 μm. 7 specimens measured.

Comparisons: *Cyclonephelium membraniphorum* is ornamented with a series of high, fibrous, peripheral crests, which form box-like structures around the outer edge of the cyst. A complete gradation exists between *C. compactum* and *C. membraniphorum* which has been noted by a number of authors (Norvick *in* Norvick & Burger, 1976; Morgan, 1980; Marshall & Batten, 1988). Those specimens with more-or-less continuous membranes around the margin of the central body, have been placed in *C. membraniphorum. Dinopterygium cladoides* appears similar but possesses higher, parasutural membranes, supported by gonal spines, and does not have an apical archaeopyle.

Occurrence: Rebecca K. Bounds core (Kansas): Late Cenomanian - Middle Turonian. Blue Point (Arizona), Bunker Hill (Kansas), Pueblo (Colorado): Late Cenomanian - Early Turonian. Wahweap Wash (Utah): Late Cenomanian.

Cyclonephelium paucimarginatum Cookson & Eisenack, 1962b

Plate 19, Figure 7

1962b Cookson & Eisenack (Australia: ?**Late Albian - Cenomanian**)

1980 Morgan (Australia: **earliest Vraconian - Middle Cenomanian**)

1981 Below (South-west Morocco: **Albian**)

1982 Below (Morocco: **earliest Albian - Early Cenomanian**)

1984 Below (Mazagan Plateau, Offshore North-west Africa: **Early Aptian - earliest Cenomanian**)

Dimensions: Range of observed specimens: length of endophragm with no apex 46 (58) 65 μm, length of endophragm with apex 63 (78) 88 μm (5 specimens), width of endophragm 64 (73) 86 μm. 7 specimens measured.

Comparisons: This species has a sub-rounded shape and is ornamented with large granulae and vermiculae, which fuse to form short, wavy ridges, immediately around the mid-dorsal and mid-ventral areas, in a concentric ring. *Cyclonephelium brevispinatum* and *Canninginopsis colliveri* appear similar, with low ornamentation, but often may have a more lenticular shape and do not have the concentric ring of coalesced ornamentation.

Occurrence: Rebecca K. Bounds core (Kansas): Middle Cenomanian - Middle Turonian. Wahweap Wash (Utah): Early Turonian.

Cyclonephelium uncinatum (Norvick *in* Norvick & Burger, 1976) Stover & Evitt, 1978

Plate 17, Figures 5 & 6

1976 Norvick *in* Norvick & Burger (Bathurst Island, Australia: **Early - Late Cenomanian**) as *Adnatosphaeridium uncinatum*

Dimensions: Range of observed specimens: length of endophragm with no apex 48 (56) 65 μm, length of endophragm with apex 66 & 76 μm (2 specimens), width of endophragm 56 (63) 70 μm, maximum height of processes 7 (11) 15 μm. 9 specimens measured.

Comparisons: This distinctive species is ornamented with numerous short processes, which divide distally into narrow aculei, which recurve and join with those from adjacent processes, forming an incomplete trabeculum and giving the cyst the appearance of a series of simple loops, standing out from the body wall. *Cyclonephelium compactum* may appear similar but, in almost all cases, any membranes fusing adjacent processes, join them either at their bases, or along their entire lengths.

Occurrence: Blue Point (Arizona), Bunker Hill (Kansas), Pueblo (Colorado), Wahweap Wash (Utah): Late Cenomanian - Early Turonian. Rebecca K. Bounds core (Kansas): Early Turonian.

Cyclonephelium vannophorum Davey, 1969a

Plate 19, Figure 5

1969a Davey (Compton Bay, Isle of Wight, England: **Early Cenomanian**)

1973 Davey & Verdier (France and Switzerland: **Late Vraconian**)

1976 Norvick *in* Norvick & Burger (Bathurst Island, Australia: **Late Cenomanian - Early Turonian)**

1978 Bujak & Williams (Offshore South-eastern Canada: **earliest Hauterivian - latest Coniacian)**

1981 Below (South-west Morocco: **Aptian - Early Cenomanian)**

1982 Below (Morocco: **Albian - Early Cenomanian)**

1983 Singh (North-west Alberta, Canada: **Early - Middle Cenomanian)**

1984 Below (Mazagan Plateau, Offshore North-west Africa: **Late Albian - Early Cenomanian)**

1988 Marshall & Batten (Lower Saxony Basin, North Germany: **Early Turonian)**

1990 Prössl (nr. Salzgitter, North-west Germany: **Early - latest Albian)**

Dimensions: Range of observed specimens: length of endophragm with no apex 49 (60) 70 μm, length of endophragm with apex 71 μm (2 specimens), width of endophragm 65 (73) 85 μm, maximum height of processes 5 (7) 8 μm. 7 specimens measured.

Comparisons: *Cyclonephelium vannophorum* is ornamented with numerous short, irregular processes. Along its circumference, and particularly around the apical and antapical horns, the processes are longer and widen rapidly at their distal ends producing a distinctive fan-shape. These sometimes bifurcate, and may occasionally join to form small sections of trabeculum. *Cyclonephelium brevispinatum* is very similar but does not possess these distinctive infundibular processes. *Cyclonephelium chabaca* is also similar but is mostly covered by a reticulum, supported by its numerous processes. *Circulodinium distinctum* has a variable number of processes of greater length, with variable distal extremities. *Circulodinium attadalicum* is very similar but has a more polygonal outline and always has a definable paracingulum. *Tenua hystrix* has a more continuous cover of processes with even lengths and widths, and with capitate to bifurcate tips.

Occurrence: Rebecca K. Bounds core (Kansas): Early Cenomanian - Middle Turonian. Blue Point (Arizona), Bunker Hill (Kansas), Pueblo (Colorado), Wahweap Wash (Utah): Late Cenomanian - Early Turonian.

Genus *Senoniasphaera* Clarke & Verdier, 1967

Senoniasphaera microreticulata Brideaux & McIntyre, 1975

Plate 22, Figure 1

1975 Brideaux & McIntyre (District of Mackenzie, Canada: **Middle Albian)**

1978 Bujak & Williams (Offshore South-eastern Canada: **earliest - latest Albian)**

1988 Jarvis *et al.* (Dover, Kent, England: **Early Turonian)**

1993 Nøhr-Hansen (North-east Greenland: **Late Aptian - Early Albian)**

Dimensions: Range of observed specimens: length of periphragm (including apex) 70 (83) 95 μm (7 specimens), width of periphragm 60 (74) 86 μm, length of endophragm (including apex) 66 (76) 88 μm (7 specimens), width of endophragm 58 (71) 84 μm. 10 specimens measured.

Comparisons: This species has a very fine meshed reticulum, which may be folded over the endophragm to reflect paratabulation, and always displays a characteristic paracingulum. *Senoniasphaera rotundata* also has a prominent paracingulum with a much coarser reticulum and short, perforate pillars connecting the periphragm to the endophragm. *Canningia reticulata* is also similar with a low, fine meshed reticulum, but does not show paratabulation or have the prominent paracingulum.

Occurrence: Rebecca K. Bounds core (Kansas): Middle Cenomanian.

Genus *Tenua* Eisenack, 1958a; emend. Sarjeant, 1968; emend. Pocock, 1972; emend. Sarjeant, 1985a

Tenua hystrix Eisenack, 1958a

Plate 18, Figure 1

1975	Brideaux & McIntyre (District of Mackenzie, Canada: **mid Aptian - Late Albian)**
1978	Bujak & Williams (Offshore South-eastern Canada: **Portlandian - latest Barremian)**
1980	Morgan (Australia: **Late Neocomian - latest Cenomanian)**
1981	Below (South-west Morocco: **Barremian - Albian)** as *Cyclonephelium hystrix*
1982	Below (Morocco: **Early Aptian - Albian)** as *Cyclonephelium hystrix*
1984	Below (Mazagan Plateau, Offshore North-west Africa: **Early Aptian - Early Cenomanian)** as *Cyclonephelium hystrix*
1988	Mao Shaozhi & Norris (Kashi Area, Xinjiang Province, China: **Late Cretaceous)** as *Cyclonephelium hystrix*
1988	Masure (Bahamas: **Vraconian - Middle Cenomanian)** as *Cyclonephelium hystrix*
1990	Prössl (nr. Salzgitter, North-west Germany: **Early Hauterivian - Early Albian)**
1992	Costa & Davey (England and the North Sea: **Jurassic - Late Maastrichtian)**
1993	Courtinat (Pueblo, Colorado, USA: **Late Cenomanian)**

Dimensions: Range of observed specimens: length of central body (no apex) 43 (52) 63 μm, length of central body (including apex) 60 & 63 μm (2 specimens), width of central body 44 (63) 79 μm, maximum length of processes 3 (4.1) 5 μm, maximum width of processes <1 μm. 7 specimens measured.

Remarks: *Tenua hystrix* has a dense cover of processes, of thin but even width, even length, and with capitate to bifurcate tips. Sometimes the processes may show some degree of parasutural alignment. Sometimes mid-ventral and mid-dorsal ornamentation may be reduced, as with species of the genus *Cyclonephelium*.

Comparisons: This species is similar to many other species of Areoligeracacean cysts. *Circulodinium distinctum* is very similar but has ornamentation that consists of a variable number of thicker, solid processes of variable length, with variable distal extremities, including acuminations, expansions, bifurcations and capitations. *Heterosphaeridium? heteracanthum* generally has longer processes with equally variable extremities, but the processes are connected proximally by surface ridges. *Cyclonephelium brevispinatum* has very short, irregular processes. *Cyclonephelium vannophorum* also has shorter processes, which are infundibular (terminate in a distinctive fan-shape) and may occasionally form small sections of trabeculum. *Cyclonephelium hughesii* has much thicker processes of an even length and even width with distally expanded and indented tips.

Other species of cyst also appear similar. *Downiesphaeridium* sp. A also has an even cover of processes, which are much thinner and have acuminate tips.

Occurrence: Rebecca K. Bounds core (Kansas): Early Cenomanian - Middle Turonian. Blue Point (Arizona), Bunker Hill (Kansas), Pueblo (Colorado), Wahweap Wash (Utah): Late Cenomanian - Early Turonian.

Suborder **Ceratiineae** Fensome *et al.*, 1993
Family **Ceratiaceae** Willey & Hickson, 1909

Genus *Nyktericysta* Bint, 1986

Nyktericysta sp. A

Plate 30, Figures 2 & 3

1986 Bint (Kansas, USA: **early Late Albian**) as *Nyktericysta* sp. A

Original Description: Bint, 1986, pp. 154-156: *Nyktericysta* sp. A
Intermediate-sized, dorso-ventrally compressed cysts with tapering, rounded apical and two antapical horns, and two broad, blunt lateral horns from which arise short, rounded postcingular extensions. Smaller precingular extensions may or may not also arise from each lateral horn. Left lateral horn may be slightly larger in overall size than right; on some specimens lateral horns may be reduced to low, rounded bulges. Left antapical horn is larger than right.

Cysts two-layered, cornucavate. Endocyst produced into five prominent horns; apical and two antapical horns are tapering and rounded, lateral horns are blunt and may have a rounded postcingular extension. Periphragm separated from endophragm at all five horns, and sometimes the cavation extends beyond the horns to the extent that some specimens are almost circumcavate with the two walls in contact (in dorso-ventral view) only in the vicinity of the archaeopyle suture. The periphragm may enclose one or two pericoels at the lateral horns. When there are two pericoels, they correspond to separate, short, rounded pre- and postcingular extensions, the latter being longer. Alternatively, the pre- and postcingular cavations may be connected producing a single lateral pericoel, which in addition usually has a short, rounded, posterior extension, but does not have a precingular extension. Endophragm smooth, periphragm very finely perforate with perforations typically 0.1 μm or less in diameter, rarely ranging up to 0.2 μm. Both walls are very thin.

Paratabulation not expressed. Cingulum may be indicated by indentation of the lateral horns and faint to distinct transverse lines; sulcus not indicated. Archaeopyle apical, suture weakly angular and incomplete. Operculum adnate, probably ventrally, but often broken away.

Size: Length of complete specimen 86-94 μm, 4 measurements; length of one specimen with operculum broken away 70μm; width 66 - 76 μm; 5 specimens measured. Approximate lengths of horns: apical 23 - 30 μm, precingular 2 - 4 μm, postcingular 3 - 7 μm, left antapical 16 - 28 μm, right antapical 9 - 16 μm.

Remarks: The precingular extensions on the lateral horns of *Nyktericysta* sp. A tend to be small or apparently absent in contrast to the concept of the genus *Nyktericysta*. However, the wall ultrastructure and the shape of the endocyst demonstrate the affinity of *N.* sp. A with the other species of *Nyktericysta* described here. The inconspicuous precingular extensions can then be explained by reduction in length of the precingular extension relative to the postcingular extension, and oftentimes in addition by connection of the two extensions to produce a single lateral pericoel.

The species is not named because it occurs in just one sample, is rare, and is generally not well preserved.

Remarks: The specimens found within the Rebecca Bounds Core and Wahweap Wash sections match the description of *Nyktericysta* sp. A from Bint, 1986. The specimens within this material are also generally not well preserved, owing to their very thin and fragile walls. In comparison, however, the overall outline seems more varied, as it is also common for the lateral horns to be very reduced or even absent, and for the antapical horns to also be very reduced.

Dimensions: Range of observed specimens: length of periphragm 57 (74) 93 µm, width of periphragm 43 (58) 73 µm, length of endophragm 44 (58) 66 µm, width of endophragm 41 (53) 68 µm, length of apical horn 6 (19) 33 µm, length of left antapical horn 4 (12) 22 µm, length of right antapical horn 2 (11) 20 µm, length of left lateral horn 0 (4) 15 µm, length of right lateral horn 0 (6) 22 µm. 16 specimens measured.

Comparisons: The genus *Nyktericysta* differs from *Muderongia* in having an endocyst which parallels the pericyst in forming prominent horns; in having an adnate operculum; and in having precingular extensions on the lateral horns. Both *Muderongia asymmetrica* and *Nyktericysta* sp. A have attributes which could place them in either *Muderongia* or *Nyktericysta. Muderongia asymmetrica* is very similar to *Nyktericysta* sp. A, with an endophragm which sometimes protrudes into the horns, and with a very similar shape to those specimens of *Nyktericysta* sp. A which do form longer horns. *Nyktericysta* sp. A has an endophragm which does not form horns which are as prominent as the generic description of *Nyktericysta* would suggest, and does not always show precingular extensions on the lateral horns. However, in comparison to *Nyktericysta* sp. A, *M. asymmetrica* has a thicker periphragm and a thinner endophragm, and little variation in shape is recorded in the original and emended descriptions. It is possible that these two species are closely related.

Nyktericysta pentagonum is also similar but has an endophragm with sharply pointed horns.

Occurrence: Rebecca K. Bounds core (Kansas): Early Cenomanian. Wahweap Wash (Utah): Early Turonian.

Genus *Odontochitina* Deflandre, 1935; emend. Davey, 1970; emend. Bint, 1986

Odontochitina costata Alberti, 1961; emend. Clarke & Verdier, 1967

Plate 31, Figure 3

1962b Cookson & Eisenack (Australia: **Albian - Cenomanian**) as *Odontochitina striatoperforata*

1964 Cookson & Hughes (Cambridgeshire, England: **Late Albian - Early Cenomanian**)

1964 Manum & Cookson (Arctic Canada: **'mid Cretaceous'**) as *Odontochitina striatoperforata*

1967 Clarke & Verdier (Isle of Wight, England: **Early Cenomanian - Late Campanian**)

1970 Davey (Saskatchewan, Canada: **Late Albian - Early Cenomanian**, Fetcham Mill Borehole, Surrey; Compton Bay, Isle of Wight, England; Escalles, France: **Cenomanian**)
1971 Singh (North-west Alberta, Canada: **mid - Late Albian**)
1973 Davey & Verdier (France and Switzerland: **Early Vraconian - Early Cenomanian**)
1976 Norvick *in* Norvick & Burger (Bathurst Island, Australia: **Early Cenomanian - Early Turonian**)
1978 Bujak & Williams (Offshore South-eastern Canada: **Late Albian - latest Campanian**)
1979 May (North Slope, Alaska, USA: **Early Cenomanian?**)
1980 May (New Jersey, USA: **Late Campanian**)
1980 Morgan (Australia: **earliest Aptian - Middle Cenomanian**)
1983 Foucher (Paris Basin, France: **Early Cenomanian - Early Campanian**)
1983 Singh (North-west Alberta, Canada: **Early - Middle Cenomanian**)
1985 Williams & Bujak (World: **Late Albian - Late Campanian**)
1986 Ioannides (Bylot Island, Arctic Archipelago: **Santonian/Campanian - Maastrichtian**)
1988 Jarvis *et al.* (Dover, Kent, England: **Late Cenomanian - Early Turonian**)
1988 Masure (Bahamas: **Late Albian - Middle Cenomanian**)
1988 Marshall & Batten (Lower Saxony Basin, North Germany: **Late Cenomanian - Early Turonian**)
1989 Habib & Milner (South Carolina & Georgia, USA: **Late Campanian**)
1990 Harker *et al.* (Interior Plains of Canada: **Early - Late Campanian**)
1990 Prössl (nr. Salzgitter, North-west Germany: **Late Aptian - Late Turonian**)
1991 Kirsch (Germany: **Late Santonian - Late Campanian**)
1992 Costa & Davey (England and the North Sea: **Middle Albian - Early Maastrichtian**)
1993 Courtinat (Pueblo, Colorado, USA: **Late Cenomanian**)
1993 Nøhr-Hansen (North-east Greenland: **Late Albian**)
1993 Williams *et al.* (N. Hemisphere: **Late Albian/Cenomanian boundary - Late Campanian**)
1994a Tocher & Jarvis (Fumichon, Normandy, France: **Early - Middle Cenomanian**)

Dimensions: Range of observed specimens: length of periphragm 102 (154) 196 µm, width of periphragm 35 (53) 73 µm, length of endophragm 37 (52) 66 µm, width of endophragm 35 (53) 73 µm, length of antapical horn 63 (104) 124 µm, maximum width of antapical horn at proximal end 16 (27) 40 µm, length of lateral horn 52 (102) 149 µm, maximum width of lateral horn at proximal end 11 (17) 21 µm. 5 specimens measured.

Comparisons: *Odontochitina operculata* is very similar but lacks the costae or lines of perforations along the horns.

Occurrence: Rebecca K. Bounds core (Kansas): Early Cenomanian - Middle Turonian. Blue Point (Arizona), Bunker Hill (Kansas), Pueblo (Colorado), Wahweap Wash (Utah): Late Cenomanian - Early Turonian.

Odontochitina operculata (Wetzel, 1933a) Deflandre & Cookson, 1955

Plate 31, Figure 1

1964 Cookson & Hughes (Cambridgeshire, England: **Late Albian - Early Cenomanian)**

1966c Sarjeant (Fetcham Mill Borehole, Surrey, England: **Cenomanian)**

1967 Clarke & Verdier (Isle of Wight, England: **Early Cenomanian - Late Campanian)**

1970 Davey (Fetcham Mill Borehole, Surrey; Compton Bay, Isle of Wight, England; Escalles, France; Saskatchewan, Canada; Texas, USA: **Cenomanian)**

1971 Brideaux (Central Alberta, Canada: **mid - Late Albian)**

1971 Singh (North-west Alberta, Canada: **mid - Late Albian)**

1973 Davey & Verdier (France and Switzerland: **Late Albian - Early Cenomanian)**

1975 Brideaux & McIntyre (District of Mackenzie, Canada: **Aptian - Middle Albian)**

1976 Norvick *in* Norvick & Burger (Bathurst Island, Australia: **Early Cenomanian - Early Turonian)**

1978 Bujak & Williams (Offshore South-eastern Canada: **earliest Barremian - latest Campanian)**

1979 May (North Slope, Alaska, USA: **Middle Albian)**

1980 Morgan (Australia: **earliest Aptian - latest Cenomanian)**

1981 Below (South-west Morocco: **Barremian - Early Cenomanian)**

1982 Below (Morocco: **Late Hauterivian - Early Cenomanian)**

1983 Foucher (Paris Basin, France: **Early Cenomanian - Late Campanian)**

1983 Habib & Drugg (Blake-Bahama Basin, Western Atlantic: **latest Hauterivian - latest Vraconian)**

1983 Singh (North-west Alberta, Canada: **Middle Cenomanian)**

1984 Below (Mazagan Plateau, Offshore North-west Africa: **Early Aptian - Early Cenomanian)**

1986 Bint (Kansas, USA: **Middle Albian - Late Cenomanian)**

1986 Ioannides (Bylot Island, Arctic Archipelago: **Santonian/Campanian - Maastrichtian?)**

1987 Habib & Drugg (Offshore USA, Western North Atlantic: **Late Hauterivian - Cenomanian/Turonian)**

1988 Jarvis *et al.* (Dover, Kent, England: **Late Cenomanian - Early Turonian)**

1988 Mao Shaozhi & Norris (Kashi Area, Xinjiang Province, China: **Late Cretaceous)**

1988 Masure (Bahamas: **Late Albian - Middle Cenomanian)**

1988 Marshall & Batten (Lower Saxony Basin, North Germany: **Late Cenomanian - Early Turonian)**

1989 Habib & Milner (South Carolina & Georgia, USA: **Campanian)**

1990 Harker *et al.* (Interior Plains of Canada: **Late Santonian - Early Maastrichtian)**

1990 Prössl (nr. Salzgitter, North-west Germany: **Early Hauterivian - Late Turonian)**

1991 Kirsch (Germany: **Coniacian - Campanian)**

1992 Costa & Davey (England and the North Sea: **Early Barremian - Early Maastrichtian)**

1993 Courtinat (Pueblo, Colorado, USA: **Late Cenomanian)**

1993 Nøhr-Hansen (North-east Greenland: **Late Barremian - Late Albian/ Early Cenomanian?)**

1993 Williams *et al.* (N. Hemisphere: **Hauterivian - Early Maastrichtian)**

1994a Tocher & Jarvis (Fumichon, Normandy, France: **Early - Middle Cenomanian)**
1996 Stover *et al.* (World wide: **Late Hauterivian - Early Maastrichtian)**

Dimensions: Range of observed specimens: length of periphragm 117 (164) 227 µm, width of periphragm 45 (55) 65 µm, length of endophragm 46 (51) 60 µm, width of endophragm 45 (55) 65 µm, length of antapical horn 57 (113) 177 µm, maximum width of antapical horn at proximal end 18 (24) 31 µm, length of lateral horn 43 (70) 106 µm, maximum width of lateral horn at proximal end 10 (15) 20 µm. 5 specimens measured.

Comparisons: *Odontochitina costata* is very similar but is ornamented with costae and/or rows of perforations/claustra. *Odontochitina rhakodes* has blunted horns. *Odontochitina* sp. A has a much thinner and very readily folded wall, with wider horns.

Occurrence: Rebecca K. Bounds core (Kansas): Early Cenomanian - Middle Turonian. Blue Point (Arizona), Bunker Hill (Kansas), Pueblo (Colorado), Wahweap Wash (Utah): Late Cenomanian - Early Turonian.

Odontochitina rhakodes Bint, 1986

Plate 31, Figure 2

1986 Bint (Kansas, USA: **middle Albian - Early Cenomanian)**

Dimensions: Range of observed specimens: length of periphragm 66 (78) 109 µm, width of periphragm 52 (66) 83 µm, length of endophragm 40 (54) 81 µm, width of endophragm 44 (55) 83 µm, length of antapical horn 20 (24) 26 µm, maximum width of antapical horn at proximal end 22 (28) 36 µm. 6 specimens measured.

Comparisons: *Odontochitina rhakodes* has blunted horns which terminate with irregular, perforate margins. Both *O. costata* and *O. operculata* have acuminate horns with pointed tips. *Xenascus plotei* is very similar and may be related, but possesses a few, irregularly placed spines, on the central body and at the bases of the horns.

Occurrence: Blue Point (Arizona), Wahweap Wash (Utah): Late Cenomanian - Early Turonian. Pueblo (Colorado): Late Cenomanian. Rebecca K. Bounds core (Kansas): Early Turonian - Middle Turonian.

Odontochitina sp. A

Plate 30, Figure 1

1993 Nøhr-Hansen (North-east Greenland: **Upper Albian)** as Dinoflagellate cyst 2

Diagnosis: Large, ceratioid, cornucavate cyst, with thin, membranous walls and a single apical, postcingular and antapical horn. The apical and antapical horns are long and distally expanded. The archaeopyle is apical, type (tA), operculum free.

Description: Only one complete specimen and a further two apical operculae were found. The endophragm is rhomboidal in shape, and appressed to the periphragm except at the base of the three horns. The wall layers are thin, membranous and psilate to sparsely and finely granulate. The primary suture of the apical archaeopyle does not seem to be angular and no other parasutural features are visible. The postcingular horn on the single full specimen is comparatively short and distally pointed. Both the apical horns and the antapical horn are long and distally wide with truncate to rounded terminations. The apical horns are constricted at their bases where connected to the endophragm, but rapidly expand and then gradually contract distally. They also appear to be striate, but only due to longitudinal folding.

Dimensions: Size of one complete observed specimen: length of periphragm including apex 202 µm, width of periphragm 67 µm, length of endophragm including apex 63 µm, width of endophragm 67 µm, length of antapical horn 102 µm, maximum width of antapical horn at proximal end 25 µm, length of lateral horn 18 µm, maximum width of lateral horn at proximal end 21 µm, length of apical horn 37 µm, maximum width of apical horn at proximal end 23 µm, length of complete apex 59 µm, maximum width of complete apex at proximal end 46 µm.

Additional apex specimen: length of apical horn 92 µm, maximum width of apical horn at proximal end 47 µm, length of complete apex 115 µm, maximum width of complete apex at proximal end 29 µm.

Comparisons: This species differs from all other species of *Odontochitina* in having membranous, thinner walls which are more easily folded; a less definable and rigid shape; and long horns with wide, expanded and rounded terminations. The species appears very similar (in size and morphology) to both the illustration (Plate 30, Fig. 1) and description of Dinoflagellate cyst 2 of Nøhr-Hansen (1993).

Occurrence: Rebecca K. Bounds core (Kansas): Early Cenomanian.

Genus *Pseudoceratium* Gocht, 1957; emend. Dörhofer & Davies, 1980; emend. Bint, 1986; emend. Helby, 1987

Pseudoceratium eisenackii (Davey, 1969a) Bint, 1986

Plate 30, Figures 4 to 6

1969a Davey (Saskatchewan, Canada: **Albian)** as *Cyclonephelium eisenacki*

1971 Brideaux (Central Alberta, Canada: **mid - Late Albian)** as *Cyclonephelium eisenackii*

1978 Bujak & Williams (Offshore South-eastern Canada: **Late Aptian - latest Cenomanian)** as *Cyclonephelium eisenackii*

1980 Morgan (Australia: **mid Aptian - latest Cenomanian)** as *Cyclonephelium eisenackii*

1981 Below (South-west Morocco: **Barremian - Early Cenomanian)** as *Aptea eisenackii*

1982 Below (Morocco: **Barremian - Early Cenomanian)** as *Aptea eisenackii*

1984 Below (Mazagan Plateau, Offshore North-west Africa: **Early Aptian - earliest Cenomanian)** as *Aptea eisenackii*

1986 Bint (Kansas, USA: **middle and Late Albian)**

1990 Prössl (nr. Salzgitter, North-west Germany: **Late Aptian - latest Albian)**

1993 Nøhr-Hansen (North-east Greenland: **Early Aptian - Middle Albian)**

Dimensions: Range of observed specimens: length of endophragm with no apex 51 (57) 61 μm, length of endophragm with apex 68 (70) 72 μm (3 specimens), width of endophragm 62 (69) 74 μm, maximum height of ornamentation 1 (2.8) 4 μm. 8 specimens measured.

Comparisons: This species is ornamented with a complex network of low crests and short capitate processes, surrounding a mid-dorsal and mid-ventral area of reduced or no ornamentation. *Cyclonephelium compactum* is ornamented with a number of broad, distally expanded processes around its periphery, which are often proximally linked, and some specimens with short processes appear similar to *P. eisenackii*.

Occurrence: Rebecca K. Bounds core (Kansas): Early Cenomanian - Middle Turonian. Blue Point (Arizona), Bunker Hill (Kansas), Pueblo (Colorado), Wahweap Wash (Utah): Late Cenomanian - Early Turonian.

Genus *Xenascus* Cookson & Eisenack, 1969; emend. Yun, 1981; emend. Stover & Helby, 1987

Xenascus australensis Cookson & Eisenack, 1969

Plate 32, Figures 2 to 4

1969 Cookson & Eisenack (Balcatta, nr. Perth, Australia: **Albian/Cenomanian)**

1990 Prössl (nr. Salzgitter, North-west Germany: **Late Turonian)**

Dimensions: Range of observed specimens: length of periphragm (no apex) 48 (64) 75 μm, length of periphragm including apex 115 μm (1 specimen), width of periphragm 51 (69) 89 μm, length of endophragm (no apex) 27 (43) 58 μm, length of endophragm including apex 50 μm (1 specimen), width of endophragm 34 (48) 59 μm, length of antapical horn 9 (22) 33 μm, maximum width of antapical horn at proximal end 16 (25) 35 μm, length of lateral horn 9 (15) 25 μm, maximum width of lateral horn at proximal end 13 (31) 55 μm. 8 specimens measured.

Comparisons: *Xenascus australensis* has a comparatively short antapical horn, with a straight or gently rounded distal end. This species differs from *Xenascus perforatus* and *Xenascus plotei* in having horns without perforations. *Xenascus ceratioides* is very similar but has a longer, thinner, tapered antapical horn with a thinner, truncate end. *Xenascus gochtii* has longer processes and a wide antapical pericoel which stretches from lateral horns on both sides, down to the antapical horn.

Occurrence: Rebecca K. Bounds core (Kansas): Late Cenomanian - Middle Turonian. Bunker Hill (Kansas): Late Cenomanian. Blue Point (Arizona), Pueblo (Colorado), Wahweap Wash (Utah): Late Cenomanian - Early Turonian.

Xenascus perforatus (Vozzhennikova, 1967) Yun, 1981

Plate 32, Figure 1

1981 Below (South-west Morocco: **Early Cenomanian)**

1982 Below (Morocco: **Early Cenomanian)**

1990 Prössl (nr. Salzgitter, North-west Germany: **Late Turonian**)

Dimensions: Range of observed specimens: length of periphragm (no apex) 81 (95) 113 μm, width of periphragm 59 (71) 79 μm, length of endophragm (no apex) 46 (50) 54 μm, width of endophragm 41 (50) 63 μm, length of antapical horn 28 (43) 55 μm, maximum width of antapical horn at proximal end 15 (23) 29 μm, length of lateral horn 15 (40) 57 μm, maximum width of lateral horn at proximal end 10 (13) 17 μm. 7 specimens measured.

Comparisons: This species of *Xenascus* has long, tapering horns which are distally perforate. *Xenascus plotei* has shorter and distally rounded apical and antapical horns which are distally perforate. *Xenascus australensis* also has shorter, often distally rounded horns, but without perforations.

Occurrence: Blue Point (Arizona), Wahweap Wash (Utah): Late Cenomanian - Early Turonian. Pueblo (Colorado): Early Turonian.

Xenascus plotei Below, 1981a

Plate 32, Figures 5 & 6

1981 Below (South-west Morocco: **Barremian - Early Cenomanian**)
1982 Below (Morocco: **earliest Albian - Early Cenomanian**)
1984 Below (Mazagan Plateau, Offshore North-west Africa: **Late Albian - earliest Cenomanian**)
1986 Bint (Kansas, USA: **early Late Albian**)
1988 Masure (Bahamas: **Late Albian - Middle Cenomanian**)

Dimensions: Range of observed specimens: length of periphragm (no apex) 51 (75) 90 μm, width of periphragm 46 (71) 85 μm, length of endophragm (no apex) 36 (49) 62 μm, width of endophragm 46 (54) 66 μm, length of antapical horn 15 (25) 36 μm, maximum width of antapical horn at proximal end 14 (23) 31 μm, length of apical horn 22 & 31 μm (2 specimens), maximum width of apical horn at proximal end 30 & 17 μm (2 specimens), length of apex 52 & 60 μm (2 specimens), maximum width of apex 43 & 42 μm, respectively (2 specimens). 10 specimens measured.

Comparisons: *Xenascus plotei* has short, distally rounded, blunted horns which terminate with irregular, perforate margins. *Odontochitina rhakodes* is very similar and may be related, but does not have any spines on the central body or at the bases of the horns. *Xenascus perforatus* has longer, tapering, perforate horns, with regular distal terminations. *Xenascus australensis* has distally rounded and blunted horns but no perforations.

Occurrence: Bunker Hill (Kansas): Late Cenomanian. Blue Point (Arizona), Wahweap Wash (Utah): Late Cenomanian - Early Turonian. Rebecca K. Bounds core (Kansas): Middle Turonian.

Suborder **Goniodomineae** Fensome *et al.*, 1993

Family **Goniodomaceae** Lindemann, 1928

Subfamily **Pyrodinioideae** Fensome *et al.*, 1993

Genus *Dinopterygium* Deflandre, 1935; emend. Stover & Evitt, 1978

Dinopterygium cladoides Deflandre, 1935

Plate 23, Figures 1 & 2

1960a Cookson & Eisenack (Perth & Carnarvon Basins, Australia: **Campanian - Santonian**) as *Toolongia medusoides*

1967 Clarke & Verdier (Isle of Wight, England: **Early Cenomanian - Late Santonian**)

1973 Davey & Verdier (France and Switzerland: **Late Albian - Early Cenomanian**)

1978 Bujak & Williams (Offshore South-eastern Canada: **earliest Cenomanian - mid Santonian**)

1983 Foucher (Paris Basin, France: **Early Cenomanian - Early Campanian**)

1987 Habib & Drugg (Offshore USA, Western North Atlantic: **Late Albian - Late Coniacian/Santonian**)

1988 Masure (Bahamas: **Late Albian - Middle Cenomanian**)

1988 Marshall & Batten (Lower Saxony Basin, North Germany: **Late Cenomanian - Early Turonian**)

1990 Prössl (nr. Salzgitter, North-west Germany: **Middle Albian - Late Turonian**)

1992 Costa & Davey (England and the North Sea: **? - Late Maastrichtian**)

Dimensions: Range of observed specimens: length of periphragm 79 (86) 97 µm, width of periphragm 63 (72) 85 µm, length of endophragm 48 (55) 60 µm, width of endophragm 42 (53) 63 µm, maximum height of crests 7 (13) 16 µm, length of antapical spine (4 specimens) 16 (23) 29 µm. 7 specimens measured.

Comparisons: This species is very distinctive, with its high parasutural membranes and gonal spines. With a well developed and regular ornamentation of membranes, *Cyclonephelium membraniphorum* may appear similar but it has an apical archaeopyle and reduced ornamentation in the mid-dorsal and mid-ventral areas. *Xiphophoridium alatum* is also similar but has intergonal spines projecting from its parasutural membranes.

Occurrence: Rebecca K. Bounds core (Kansas): Middle Cenomanian - Middle Turonian. Blue Point (Arizona), Bunker Hill (Kansas), Pueblo (Colorado), Wahweap Wash (Utah): Late Cenomanian - Early Turonian.

Dinopterygium reticulatum Singh, 1983

Plate 22, Figure 2

1983 Singh (North-west Alberta, Canada: **Early Cenomanian**)

Dimensions: Range of observed specimens: length of periphragm 41 (47) 56 µm, width of periphragm 39 (52) 61 µm, length of endophragm 35 (45) 62 µm, width of endophragm 39 (49) 54 µm, maximum height of crests 3 (5) 8 µm. 7 specimens measured.

Comparisons: This is a distinctive species of cyst with a coarsely reticulate periphragm, loosely folded over a subcircular to subpentagonal endophragm, and sometimes forming well-defined parasutural

crests. The endophragm displays prominent parasutural and paracingular thickenings and accessory archaeopyle sutures are commonly visible on the smaller epicyst. *Dinopterygium cladoides* is similar but also larger with higher parasutural crests and with no reticulate ornamentation. *Senoniasphaera microreticulata* is similar but has a much finer reticulum which is fairly evenly distributed across the surface of the periphragm. *Senoniasphaera rotundata* appears very similar but is larger with the outer membrane attached to the inner body by short perforated pillars giving the appearance of a reticulum.
Occurrence: Rebecca K. Bounds core (Kansas): Early Cenomanian.

Genus *Hystrichosphaeridium* Deflandre, 1937b; emend. Davey & Williams, 1966b

Hystrichosphaeridium bowerbankii Davey & Williams, 1966b

Plate 1, Figures 1 & 2

1966b Davey & Williams (Fetcham Mill Borehole, Surrey; England: **Cenomanian)**
1969a Davey (Fetcham Mill Borehole, Surrey, England: **Albian - Turonian**, Compton Bay, Isle of Wight; Escalles, France: **Cenomanian)**
1973 Davey & Verdier (France and Switzerland: **Early Vraconian - Early Cenomanian)**
1978 Bujak & Williams (Offshore South-eastern Canada: **earliest Albian - mid Campanian)**
1984 Below (Mazagan Plateau, Offshore North-west Africa: **Late Albian - Early Cenomanian)**
1988 Masure (Bahamas: **Vraconian - Early Cenomanian)**
1990 Prössl (nr. Salzgitter, North-west Germany: **mid Barremian - Late Turonian)**
1994a Tocher & Jarvis (Fumichon, Normandy, France: **Early - Middle Cenomanian)**

Dimensions: Range of observed specimens: length of endophragm 35 (39) 48 µm, width of endophragm 27 (32) 45 µm, maximum length of processes 14 (18) 21 µm, maximum width of processes 1 (1.9) 3 µm. 7 specimens measured.
Comparisons: This species has a slightly prolate central body, and is ornamented with thin tubular processes, which show prominent circular basal wrinkles, and terminate with a number of short spines. The processes may expand to a small degree, both proximally and distally. *Hystrichosphaeridium recurvatum* is extremely similar, but is slightly larger, has a spherical to oblate central body, and has straighter processes. *Oligosphaeridium prolixospinosum* is also similar with a prolate central body, but has fewer processes which have filiform/spinose terminations.
Occurrence: Rebecca K. Bounds core (Kansas): Middle Cenomanian. Blue Point (Arizona), Bunker Hill (Kansas), Pueblo (Colorado), Wahweap Wash (Utah): Late Cenomanian.

Hystrichosphaeridium recurvatum (White, 1842) Lejeune-Carpentier, 1940

Plate 1, Figures 3 & 4

1973 Davey & Verdier (France and Switzerland: **Early Vraconian - Early Cenomanian)**
1978 Bujak & Williams (Offshore South-eastern Canada: **Late Valanginian - mid Campanian)**
1983 Foucher (Paris Basin, France: **Early Cenomanian - Late Campanian)**

1988 Jarvis *et al.* (Dover, Kent, England: **Late Cenomanian - Early Turonian**) as *Hystrichosphaeridium palmatum*

1988 Marshall & Batten (Lower Saxony Basin, North Germany: **Late Cenomanian - Early Turonian**) as *Hystrichosphaeridium palmatum*

1989 Habib & Milner (South Carolina & Georgia, USA: **Campanian - Late Maastrichtian**) as *Hystrichosphaeridium palmatum*

1990 Prössl (nr. Salzgitter, North-west Germany: **Early Hauterivian - Late Turonian**) as *Hystrichosphaeridium palmatum*

1993 Courtinat (Pueblo, Colorado, USA: **Late Cenomanian**)

Dimensions: Range of observed specimens: length of endophragm 25 (32) 40 µm, width of endophragm 30 (37) 46 µm, maximum length of processes 12 (21) 31 µm, maximum width of processes 1 (2.1) 4 µm. 8 specimens measured.

Comparisons: *Hystrichosphaeridium bowerbankii* is extremely similar but is slightly smaller, has a slightly prolate central body, and with processes that have a less even width along their lengths. In practice, it is often difficult to tell these species apart. *Oligosphaeridium complex* is also similar but has less processes (has no paracingular processes) and a greater variation in process terminations. *Surculosphaeridium? longifurcatum* may also appear similar but has solid, medially and distally dividing processes.

Occurrence: Blue Point (Arizona), Bunker Hill (Kansas), Pueblo (Colorado), Wahweap Wash (Utah): Late Cenomanian - Early Turonian. Rebecca K. Bounds core (Kansas): Early Turonian - Middle Turonian.

Suborder uncertain

Genus *Atopodinium* Drugg, 1978; emend. Masure, 1991

Atopodinium haromense Thomas & Cox, 1988

Plate 25, Figure 1

1978 Davey (Offshore South-western Africa: **Turonian - lower Maastrichtian**) as *?Maduradinium* sp. A

1988 Masure (Bahamas: **Vraconian - Middle Cenomanian**) as *Maghrebinia breviornata*

1993 Nøhr-Hansen (North-east Greenland: **Late Barremian - Early Aptian**)

Dimensions: Range of observed specimens: length of cyst 65 (73) 79 µm, width of cyst 63 (68) 84 µm. 7 specimens measured.

Comparisons: This acavate cyst species is easily distinguishable from all others in the material, by its distinctive subspheroidal to subpolygonal shape, unevenly distributed ornamentation of granulae and gemmae, and strong parasutural folding.

Occurrence: Rebecca K. Bounds core (Kansas): Late Cenomanian - Middle Turonian. Blue Point (Arizona), Bunker Hill (Kansas), Pueblo (Colorado), Wahweap Wash (Utah): Late Cenomanian - Early Turonian.

Genus *Batiacasphaera* Drugg, 1970; emend. Morgan, 1975; emend. Dörhofer & Davies, 1980

Batiacasphaera euteiches (Davey, 1969a) Davey, 1979d

Plate 14, Figure 8

1969a Davey (Escalles, France: **Cenomanian**) as *Chytroeisphaeridia euteiches*
1988 Jarvis *et al.* (Dover, Kent, England: **Late Cenomanian - Early Turonian**)

Dimensions: Range of observed specimens: length of cyst 36 (39) 41 μm, width of cyst 41 (43) 45 μm. 3 specimens measured.
Comparisons: This species is distinguished by its thick and evenly covered, densely granular wall. *Batiacasphaera granulosa* is also granular but has a thinner wall, and a sparse but even covering of granulae.
Occurrence: Rebecca K. Bounds core (Kansas): Early Cenomanian - Middle Turonian.

Batiacasphaera granulosa (Cookson & Eisenack, 1974) Jansonius, 1989

Plate 14, Figure 7

1983 Singh (North-west Alberta, Canada: **Early Cenomanian**) as *Fromea granulosa*
1988 Jarvis *et al.* (Dover, Kent, England: **Late Cenomanian**) as *Fromea granulosa*

Dimensions: Range of observed specimens: length of cyst without apex 30 (39) 49 μm, width of cyst 35 (40) 47 μm. 9 specimens measured. Length of cyst with apex 37 & 48 μm. 2 specimens measured.
Comparisons: Distinguishable by its moderate but even covering of fine granulae, this species differs from *B. euteiches* which has a much denser, continuous cover of granulae. *Canninginopsis colliveri* is similarly ornamented but is much larger and often lenticular with antapical protuberances.
Occurrence: Rebecca K. Bounds core (Kansas): Early Cenomanian - Middle Turonian. Blue Point (Arizona), Bunker Hill (Kansas), Pueblo (Colorado), Wahweap Wash (Utah): Late Cenomanian - Early Turonian.

Batiacasphaera sp. A

Plate 14, Figures 1 to 4

Description: The cyst is subspherical to ovoidal. The ornamentation is a uniform, dense covering of very short (commonly 1 μm long), fine hairs. The archaeopyle is apical, type 4A, with accessory archaeopyle sutures often present and a sulcal notch sometimes visible. No other features of paratabulation are visible.

Dimensions: Range of observed specimens: length of cyst 36 (46) 57 µm, width of cyst 36 (47) 65 µm, maximum height of ornamentation 1 µm on almost all specimens, occasionally reaching 1.5 to 2 µm. 26 specimens measured.

Comparisons: The ornamentation of dense, fine hairs easily differentiates this species from other species of *Batiacasphaera*. *Downiesphaeridium* sp. B may appear similar, but is larger, with longer ornamentation.

Occurrence: Rebecca K. Bounds core (Kansas): Early Cenomanian - Middle Turonian. Bunker Hill (Kansas), Pueblo (Colorado), Wahweap Wash (Utah): Late Cenomanian - Early Turonian. Blue Point (Arizona): Late Cenomanian.

Genus *Chlamydophorella* Cookson & Eisenack, 1958; emend. Duxbury, 1983

Chlamydophorella discreta Clarke & Verdier, 1967

Plate 13, Figure 5

1967 Clarke & Verdier (Isle of Wight, England: **Early Cenomanian - Late Santonian)**
1978 Bujak & Williams (Offshore South-eastern Canada: **earliest Coniacian - latest Santonian)**
1978 Davey (Offshore SW Africa: **Turonian - Maastrichtian)**
1981 Below (South-west Morocco: **Barremian - Albian)**
1983 Foucher (Paris Basin, France: **Early Cenomanian - Early Campanian)**
1984 Below (Mazagan Plateau, Offshore North-west Africa: **Late Aptian - earliest Cenomanian)**
1986 Ioannides (Bylot Island, Arctic Archipelago: **Santonian/Campanian)**
1988 Masure (Bahamas: **Vraconian - Middle Cenomanian)**

Dimensions: Range of observed specimens: length of endophragm 27 (37) 50 µm, width of endophragm 29 (38) 50 µm, maximum height of ornamentation 1 (1.1) 2 µm. 7 specimens measured.

Comparisons: *Chlamydophorella discreta* is a distinctive, small cyst, with a dense, continuous covering of very short (1-2 µm), flat-topped pillars, supporting a thin ectophragm. *Chlamydophorella nyei* is similar but larger, with longer processes. *Histiocysta palla* is also similar in appearance and size. However, the ornamentation consists of a low reticulum which also displays paratabulation.

Occurrence: Rebecca K. Bounds core (Kansas): Early Cenomanian - Middle Turonian. Bunker Hill (Kansas), Pueblo (Colorado): Late Cenomanian - Early Turonian. Blue Point (Arizona), Wahweap Wash (Utah): Early Turonian.

Chlamydophorella nyei Cookson & Eisenack, 1958

Plate 13, Figures 7 & 10

1958 Cookson & Eisenack (Australia: **Aptian - Turonian)**
1964 Cookson & Hughes (Cambridgeshire, England: **Late Albian - Early Cenomanian)**

1964 Manum & Cookson (Arctic Canada: **'mid Cretaceous'**)
1970 Davey (Saskatchewan, Canada: **Late Albian - Cenomanian**)
1971 Brideaux (Central Alberta, Canada: **mid - Late Albian**)
1971 Singh (North-west Alberta, Canada: **mid - Late Albian**)
1976 Norvick *in* Norvick & Burger (Bathurst Island, Australia: **Early Cenomanian - Early Turonian**)
1978 Bujak & Williams (Offshore South-eastern Canada: **Middle Cenomanian - mid Campanian**)
1979 May & Stein (Alaska, USA: **mid - Late Albian**)
1980 Morgan (Australia: **Late Neocomian - latest Cenomanian**)
1981 Below (South-west Morocco: **Barremian - Early Cenomanian**)
1983 Habib & Drugg (Blake-Bahama Basin, Western Atlantic: **Late Barremian - latest Vraconian**)
1983 Singh (North-west Alberta, Canada: **Early - Middle Cenomanian**)
1984 Below (Mazagan Plateau, Offshore North-west Africa: **mid Aptian - Early Cenomanian**)
1986 Ioannides (Bylot Island, Arctic Archipelago: **Santonian/Campanian**)
1987 Habib & Drugg (Offshore USA, Western North Atlantic: **mid Hauterivian - Cenomanian/Turonian**)
1988 Masure (Bahamas: **Late Albian - Middle Cenomanian**)
1989 Habib & Milner (South Carolina & Georgia, USA: **Campanian**)
1990 Harker *et al.* (Interior Plains of Canada: **earliest - Late Campanian**)
1990 Prössl (nr. Salzgitter, North-west Germany: **Early Hauterivian - Late Turonian**)
1992 Mohr & Gee (Kerguelan Plateau, Southern Indian Ocean: **Early Turonian - Late Coniacian**)
1993 Nøhr-Hansen (North-east Greenland: **Early Barremian - Late Albian**)
1996 Stover *et al.* (World wide: **Early Barremian - Early Albian**)

Dimensions: Range of observed specimens: length of periphragm 37 (48) 54 μm, width of periphragm 38 (47) 54 μm, length of endophragm 34 (38) 44 μm, width of endophragm 35 (40) 44 μm, maximum height of ornamentation 3 (5) 7 μm, maximum thickness of processes <0.5 μm, length of apical horn 6 (8) 10 μm (from 5 specimens possessing an apical horn). 8 specimens measured.

Comparisons: A gradation was noted with *C. discreta* which is similar but has dense and continual cover of much shorter, processes, supporting an ectophragm closely appressed to the endophragm. Intermediate forms also possessed a shorter, finer and denser covering of processes than on the holotype of *C. nyei*. However, while specimens possessed processes which were not so dense as to provide a continuous cover and were more than 2 μm high, then they were placed in *C. nyei*. A gradation was noted between *C. nyei* and *Dapsilidinium ambiguum*, which is also very similar but is perhaps slightly smaller, with fewer, shorter, and slightly thicker processes. In practice, in many cases, it was not possible to satisfactorily differentiate between these two species, and they were logged as a complex. Where these species were separated, they were divided on the thickness and number of processes. Other species of *Dapsilidinium* are also similar, but they tend to have longer, and often thicker processes, which do not form an ectophragm at their distal extremities.

Occurrence: Rebecca K. Bounds core (Kansas): Early Cenomanian - Middle Turonian. Wahweap Wash (Utah): Late Cenomanian. Blue Point (Arizona), Bunker Hill (Kansas), Pueblo (Colorado): Late Cenomanian - Early Turonian. Logged as a complex of *Chlamydophorella nyei* and *Dapsilidinium ambiguum.*

Genus *Dapsilidinium* Bujak, Downie, Eaton & Williams, 1980

Dapsilidinium ambiguum (Deflandre, 1937b) Wheeler & Sarjeant, 1990

Plate 13, Figures 8 & 9

1937 Deflandre, (France: **Cretaceous**) as *Micrhystridium ambiguum*

1960a Cookson & Eisenack (Perth & Carnarvon Basins, Australia: **Albian - Cenomanian**) as *Hystrichosphaeridium ancoriferum*

1964 Cookson & Hughes (Cambridgeshire, England: **Late Albian - Early Cenomanian**) as *Hystrichosphaeridium ancoriferum*

1966 Davey *et al.* (Fetcham Mill Borehole, Surrey, England: **Cenomanian**) as *Cleistosphaeridium ancoriferum*

1967 Clarke & Verdier (Isle of Wight, England: **Early - latest Cenomanian**) as *Hystrichosphaeridium huguoniotii*

1969 Cookson & Eisenack (Balcatta, nr. Perth, Australia: **Albian/Cenomanian**) as *Cleistosphaeridium ancoriferum*

1969a Davey (Fetcham Mill Borehole, Surrey, England: **Albian - Cenomanian**, Compton Bay, Isle of Wight, England: Escalles, France: **Cenomanian**, Texas, USA: **Late Cenomanian**) as *Cleistosphaeridium huguonioti*

1970 Habib (Bahamas: **Albian/Cenomanian**) as *Cleistosphaeridium huguoniotii*

1973 Davey & Verdier (France and Switzerland: **Late Albian - Early Cenomanian**) as *Cleistosphaeridium huguoniotii*

1976 Norvick *in* Norvick & Burger (Bathurst Island, Australia: **Early - latest Cenomanian**) as *Cleistosphaeridium ancoriferum*

1978 Bujak & Williams (Offshore South-eastern Canada: **earliest Albian - Middle Turonian**) as *Cleistosphaeridium huguoniotii*

1979 May & Stein (Alaska: **mid -Late Albian**) as *Cleistosphaeridium huguoniotii*

1980 Morgan (Australia: **mid Aptian - latest Cenomanian**) as *Cleistosphaeridium ancoriferum*

1983 Foucher (Paris Basin, France: **Early Cenomanian - Early Coniacian**) as *Cleistosphaeridium huguoniotii*

1984 Below (Mazagan Plateau, Offshore North-west Africa: **Late Aptian**) as *Cleistosphaeridium huguoniotii*

1988 Marshall & Batten (Lower Saxony Basin, North Germany: **Late Cenomanian - Early Turonian**) as *Cleistosphaeridium huguoniotii*

1989 Aurisano (New Jersey & Delaware, USA: **Cenomanian**) as *Cleistosphaeridium ancoriferum*

1990 Prössl (nr. Salzgitter, North-west Germany: **mid Barremian - Late Turonian**) as *Chlamydophorella ambigua*

1992 Costa & Davey (England and the North Sea: **Early Cretaceous - Late Cenomanian**) as *Cleistosphaeridium huguoniotii*

1992 Mohr & Gee (Kerguelan Plateau, Southern Indian Ocean: **Late Cenomanian - Early Coniacian**)

1993 Courtinat (Pueblo, Colorado, USA: **Late Cenomanian**) as *Cleistosphaeridium huguoniotii* and *Cleistosphaeridium ancoriferum*

1993 Nøhr-Hansen (North-east Greenland: **Early Barremian - Late Albian**) as *Cleistosphaeridium huguoniotii*

Dimensions: Range of observed specimens: length of endophragm 27 (35) 48 μm, width of endophragm 30 (36) 42 μm, maximum height of processes 4 (6) 7 μm, maximum width of processes <1 (1) 1.5 μm. 7 specimens measured.

Comparisons: A gradation was noted between *D. ambiguum* and *Chlamydophorella nyei*, which is also very similar but is perhaps slightly larger, with more numerous and slightly thinner processes. In practice, in many cases, it was not possible to satisfactorily differentiate between these two species, and they were logged as a complex. Where it was possible to differentiate between them, the splitting was achieved using the relative number and thickness of the processes. Other species of *Dapsilidinium* are also similar, but they tend to have much longer, and often wider processes, which do not form an ectophragm at their distal extremities.

Occurrence: Rebecca K. Bounds core (Kansas): Early Cenomanian - Middle Turonian. Wahweap Wash (Utah): Late Cenomanian. Blue Point (Arizona), Bunker Hill (Kansas), Pueblo (Colorado): Late Cenomanian - Early Turonian. Logged as a complex of *Chlamydophorella nyei* and *Dapsilidinium ambiguum*.

Dapsilidinium laminaspinosum (Davey & Williams, 1966b) Lentin & Williams, 1981

Plate 15, Figures 4 & 5

1966b Davey & Williams (Fetcham Mill Borehole, Surrey, England: **Cenomanian**) as *Polysphaeridium laminaspinosum*

1969a Davey (Fetcham Mill Borehole, Surrey; Compton Bay, Isle of Wight, England; Escalles, France: **Cenomanian**) as *Polysphaeridium laminaspinosum*

1973 Davey & Verdier (France and Switzerland: **Late Albian - Early Cenomanian**) as *Polysphaeridium laminaspinosum*

1975 Brideaux & McIntyre (District of Mackenzie, Canada: **Early Aptian - Middle Albian**) as *Polysphaeridium laminaspinosum*

1978 Bujak & Williams (Offshore South-eastern Canada: **earliest Albian - latest Cenomanian**) as *Polysphaeridium laminaspinosum*

1988 Masure (Bahamas: **Vraconian - Early Cenomanian**)

1988 Marshall & Batten (Lower Saxony Basin, North Germany: **Late Cenomanian - Early Turonian)**

1990 Prössl (nr. Salzgitter, North-west Germany: **middle Barremian - Late Turonian)**

1994 Tocher & Jarvis (Fumichon, Normandy, France: **Early - Middle Cenomanian)**

Dimensions: Range of observed specimens: length of endophragm 26 (32) 44 μm, width of endophragm 26 (30) 37 μm, maximum height of processes 8 (11) 13 μm, maximum width of processes 1 (2.1) 3 μm. 7 specimens measured.

Comparisons: This species has numerous broad, tubular, distally expanded processes with entire and often serrated margins, which often appear wide, flattened and blade-like due to preservation. *Dapsilidinium marinum* has very similar processes, with expanded, entire and serrate tips, but they are much shorter (only $^1/_5$ of the diameter of the central body) and generally narrower (1 μm wide). *Dapsilidinium multispinosum* has many more, thinner processes which terminate with a few short spines. *Dapsilidinium? pumilum* is smaller, and the processes have recurved, though entire terminations.

Occurrence: Rebecca K. Bounds core (Kansas): Early Cenomanian - Middle Turonian. Blue Point (Arizona), Bunker Hill (Kansas), Pueblo (Colorado), Wahweap Wash (Utah): Late Cenomanian - Early Turonian.

Dapsilidinium marinum Singh, 1983

Plate 15, Figures 1 to 3

1983 Singh (North-west Alberta, Canada: **Early - Middle Cenomanian)**

Dimensions: Range of observed specimens: length of endophragm 27 (31) 36 μm, width of endophragm 27 (33) 37 μm, maximum height of processes 5 (6) 7 μm, maximum width of processes 1 μm. 6 specimens measured.

Comparisons: This species has numerous tubular, distally expanded processes with entire and often serrated margins. The most noticeable feature of this species is the length of the processes, which are comparatively short (only $^1/_5$ of the diameter of the central body), and hence are much shorter in comparison to the size of the central body, than many other species of *Dapsilidinium*. *Dapsilidinium laminaspinosum* has very similar processes, with expanded, entire and serrate tips, but they are wider and much longer in comparison (approximately $^1/_3$ of the diameter of the central body), and often appear flattened and blade-like. *Dapsilidinium multispinosum* has many more, thinner processes which are much longer and terminate with a few short spines. *Dapsilidinium? pumilum* is smaller, with fewer processes which have recurved, though entire terminations. *Dapsilidinium ambiguum* also has short processes, which have bifurcate tips and are sometimes connected by a distal ectophragm (depending on preservation).

Occurrence: Rebecca K. Bounds core (Kansas): Early Cenomanian - Middle Cenomanian. Wahweap Wash (Utah): Late Cenomanian.

Dapsilidinium multispinosum (Davey, 1974) Bujak, Downie, Eaton & Williams, 1980

Plate 16, Figure 9

1990 Prössl (nr. Salzgitter, North-west Germany: **Early Hauterivian - Late Barremian)**

1994 Tocher & Jarvis (Fumichon, Normandy, France: **Middle Cenomanian)**

Dimensions: Range of observed specimens: length of endophragm 25 (32) 45 µm, width of endophragm 23 (33) 39 µm, maximum height of processes 6 (10) 15 µm, maximum width of processes 0.5 (0.6) 1 µm. 11 specimens measured.

Comparisons: This species is distinguished from other species of *Dapsilidinium* within this material, by its larger number of processes. These are narrow, tubular and terminate with a few short spines. *Dapsilidinium laminaspinosum* has fewer processes with entire margins. *Dapsilidinium marinum* has fewer, shorter processes with entire margins. *Dapsilidinium? pumilum* is much smaller with far fewer processes which terminate with entire, recurved tips. *Kiokansium unituberculatum* is very similar but has a precingular archaeopyle (2P) instead of an apical one, and has fewer processes, which are solid, and not tubular/hollow.

Occurrence: Rebecca K. Bounds core (Kansas): Early Cenomanian. Blue Point (Arizona), Pueblo (Colorado): Late Cenomanian. Bunker Hill (Kansas), Wahweap Wash (Utah): Late Cenomanian - Early Turonian.

Dapsilidinium? pumilum (Davey & Williams, 1966b) Lentin & Williams, 1981

Plate 15, Figures 6 & 7

1966b Davey & Williams (Fetcham Mill Borehole, Surrey, England: **Cenomanian)** as *Polysphaeridium pumilum*

1969a Davey (Fetcham Mill Borehole, Surrey, England: **Cenomanian)** as *Polysphaeridium pumilum*

1973 Davey & Verdier (France and Switzerland: **Early - Late Vraconian)** as *Polysphaeridium pumilum*

1983 Foucher (Paris Basin, France: **Early Cenomanian - Early Campanian)** as *Polysphaeridium pumilum*

1987 Firth (Georgia, USA: **Early-Late Maastrichtian)** as *Polysphaeridium? pumilum*

1988 Marshall & Batten (Lower Saxony Basin, North Germany: **Late Cenomanian - Early Turonian)**

1993 Courtinat (Pueblo, Colorado, USA: **Late Cenomanian)**

1994 Tocher & Jarvis (Fumichon, Normandy, France: **Middle Cenomanian)**

Dimensions: Range of observed specimens: length of endophragm 20 (24) 26 µm, width of endophragm 20 (25) 28 µm, maximum height of processes 8 (11) 15 µm. 8 specimens measured.

Comparisons: *Dapsilidinium? pumilum* is distinguished by its smaller size and its fewer process with terminations which are entire, slightly denticulate and recurved. Other species of *Dapsilidinium* are larger, except for *Dapsilidinium ambiguum* which has much shorter processes with bifurcate tips.

Occurrence: Rebecca K. Bounds core (Kansas): Early Cenomanian - Middle Turonian. Pueblo (Colorado): Late Cenomanian. Blue Point (Arizona), Bunker Hill (Kansas), Wahweap Wash (Utah): Late Cenomanian - Early Turonian.

Genus *Disphaeria* Cookson & Eisenack, 1960a; emend. Norvick, 1973

Fensome *et al.* (1993) considers *Disphaeria* to be an acritarch genus despite an emended diagnosis (Norvick *in* Norvick & Burger, 1976) which describes a single plate precingular archaeopyle. The archaeopyle on many specimens within this material is not easily discernible but nevertheless, some specimens show a clear one-plate precingular archaeopyle.

Disphaeria macropyla Cookson & Eisenack, 1960a;
emend. Norvick *in* Norvick & Burger, 1976

Plate 25, Figures 2 & 3

1960a Cookson & Eisenack (Perth & Carnarvon Basins, Australia: **Turonian)**
1976 Norvick *in* Norvick & Burger (Bathurst Island, Australia: **Late Cenomanian)**
1980 Morgan (Australia: **earliest Vraconian - latest Cenomanian)**

Dimensions: Range of observed specimens: length of periphragm 44 (55) 74 μm, width of periphragm 37 (54) 80 μm, length of endophragm 24 (35) 46 μm, width of endophragm 19 (34) 57 μm. 12 specimens measured.

Comparisons: This species appears similar to large leiospheres but is obviously double-walled. *Disphaeria hypoflata* is differentiated from *D. macropyla* by the prescence of incomplete, parasutural lines on the surface of the periphragm. *Disphaeria munda* can be distinguished from *D. macropyla* by the presence of five, large, hollow, distally flaring, intratabular processes which connect the endophragm to the periphragm.

Occurrence: Rebecca K. Bounds core (Kansas): Late Cenomanian - Middle Turonian. Pueblo (Colorado): Late Cenomanian. Blue Point (Arizona), Wahweap Wash (Utah): Early Turonian.

Genus *Dorocysta* Davey, 1970

Dorocysta litotes Davey, 1970

Plate 39, Figure 10

1970 Davey (Compton Bay, Isle of Wight, England: **Early Cenomanian**, Escalles, France: **Cenomanian)**
1986 Ioannides (Bylot Island, Arctic Archipelago: **Santonian/Campanian)**
1990 Prössl (nr. Salzgitter, North-west Germany: **mid - Late Cenomanian)**
1993 Nøhr-Hansen (North-east Greenland: **Late Albian - Early Cenomanian?)**

Dimensions: Range of observed specimens: length of endophragm 22 (26) 29 μm, width of endophragm 19 (23) 25 μm, length of processes 12 (14) 16 μm. 7 specimens measured.

Remarks: This species is extremely distinctive. The cyst is small, projecting four apical and five antapical processes. These are often medially bifurcate, and sometimes terminate with small bifurcations.

Occurrence: Rebecca K. Bounds core (Kansas): Late Cenomanian -Middle Turonian. Blue Point (Arizona): Late Cenomanian - Early Turonian. Pueblo (Colorado): Late Cenomanian. Bunker Hill (Kansas): Early Turonian.

Genus *Downiesphaeridium* Islam, 1993

Downiesphaeridium armatum (Deflandre, 1937b) Islam, 1993

Plate 16, Figure 3

1937 Deflandre (France: **Cenomanian**) as *Hystrichosphaeridium armatum*

1967 Clarke & Verdier (Isle of Wight, England: **Early Cenomanian - Late Campanian**) as *Baltisphaeridium armatum*

1969 Davey (Fetcham Mill, Surrey; Compton Bay, Isle of Wight, England; Escalles, Northern France: **Cenomanian**) as *Cleistosphaeridium armatum*

1973 Davey & Verdier (France and Switzerland: **Late Albian - Early Cenomanian**) as *Cleistosphaeridium armatum*

1980 Morgan (Australia: **earliest - latest Cenomanian**) as *Cleistosphaeridium armatum*

1983 Foucher (Paris Basin, France: **Early Cenomanian - Late Campanian**) as *Cleistosphaeridium armatum*

1988 Jarvis *et al.* (Dover, Kent, England: **Late Cenomanian**) as *Cleistosphaeridium armatum*

1988 Marshall & Batten (Lower Saxony Basin, North Germany: **Late Cenomanian - Early Turonian**) as *Cleistosphaeridium armatum*

1990 Harker *et al.* (Interior Plains of Canada: **Early - Late Campanian**) as *Cleistosphaeridium armatum*

1990 Prössl (nr. Salzgitter, North-west Germany: **Late Turonian**) as *Cleistosphaeridium armatum*

1994 Tocher & Jarvis (Fumichon, Normandy, France: **Early - Middle Cenomanian**) as *Cleistosphaeridium armatum*

Dimensions: Range of observed specimens: length of endophragm 30 (34) 42 μm, width of endophragm 30 (35) 40 μm, length of processes 8 (10) 11 μm, width of processes at their bases 1 (1.4) 1.5 μm. 8 specimens measured.

Comparisons: This species is distinguished by its numerous, broad based, gradually tapering, hollow, acuminate processes, some of which bear a number of tiny, stiff spines. *Operculodinium* sp. A appears identical but is slightly smaller and has a single plate precingular archaeopyle instead of an apical one. It is a possibility that *Operculodinium* sp. A may even be the same species but excysting with a different archaeopyle. *Dapsilidinium multispinosum* is also similar but has much thinner, acicular processes which occasionally bifurcate. *Prolixosphaeridium conulum* is similar but has a prolate central body.

Occurrence: Rebecca K. Bounds core (Kansas): Late Cenomanian - Middle Turonian. Blue Point (Arizona): Late Cenomanian. Bunker Hill (Kansas), Pueblo (Colorado): Late Cenomanian - Early Turonian. Wahweap Wash (Utah): Early Turonian.

Downiesphaeridium multispinosum (Singh, 1964) Islam, 1993

Plate 16, Figure 7

1964 Singh (Central Alberta, Canada: **mid - Late Albian**) as *Baltisphaeridium multispinosum*

1969 Davey (Saskatchewan, Canada: **Late Albian - Early Cenomanian**) as *Cleistosphaeridium? aciculare*

1971 Brideaux (Central Alberta, Canada: **mid - Late Albian**) as *Cleistosphaeridium multispinosum*

1971 Singh (North-west Alberta, Canada: **mid - Late Albian**) as *Baltisphaeridium multispinosum*

1975 Brideaux & McIntyre (District of Mackenzie, Canada: **Middle Albian**) as *Cleistosphaeridium? aciculare*

1975 Brideaux & McIntyre (District of Mackenzie, Canada: **Early Aptian - Middle Albian**) as *Cleistosphaeridium multispinosum*

1979 May (North Slope, Alaska, USA: **Middle Albian - Early Cenomanian?**) as *Cleistosphaeridium multispinosum*

1979 May & Stein (Alaska: **Middle Albian - Early Cenomanian**) as *Cleistosphaeridium multispinosum*

1982 Nichols, Jacobson & Tschudy (Wyoming & Montana, USA: **Albian**) as *Cleistosphaeridium multispinosum*

1983 Singh (North-west Alberta, Canada: **Early - Middle Cenomanian**) as *Cleistosphaeridium multispinosum*

1984 Below (Mazagan Plateau, Offshore North-west Africa: **Late Albian**) as *Cleistosphaeridium multispinosum*

1986 Ioannides (Bylot Island, Arctic Archipelago: **Santonian/Campanian - Maastrichtian?**) as *Cleistosphaeridium? aciculare*

1988 Jarvis *et al.* (Dover, Kent, England: **Late Cenomanian**) as *Cleistosphaeridium? aciculare*

1990 Harker *et al.* (Interior Plains of Canada: **late Santonian - early Maastrichtian**) as *Cleistosphaeridium? aciculare*

1990 Prössl (nr. Salzgitter, North-west Germany: **Late Hauterivian - Late Cenomanian**) as *Cleistosphaeridium aciculare*

1990 Prössl (nr. Salzgitter, North-west Germany: **Late Albian - Late Cenomanian**) as *Cleistosphaeridium? multispinosum*

1993 Courtinat (Pueblo, Colorado, USA: **Late Cenomanian**) as *Cleistosphaeridium multispinosum*

1993 Nøhr-Hansen (North-east Greenland: **Early Barremian - Late Albian)** as *Cleistosphaeridium? aciculare/Cleistosphaeridium? multispinosum* complex

Original description: Singh, 1964, p. 141-142: *Baltisphaeridium multispinosum*
Vesicle circular, thin-walled; length of processes about $^1/_4$ of the diameter of the body, unbranched, thin, tapering and closed at the outer end, broadening slightly towards the base; some processes bifurcating at the tips.
Size range: Total diameter of the specimens 62-74 μm, holotype 62 μm. Diameter of the vesicle 40-50 μm, holotype 41 μm. Length of processes 10-15 μm. Width of the processes 0.5-1 μm, holotype 1 μm.

Supplemental description: Brideaux, 1971, p. 94: *Cleistosphaeridium multispinosum*
Dinoflagellate cyst ; outline ovoid, elongate in the longitudinal axis or nearly circular. Orientation in the absence of archeopyle formation uncertain; no cingulum or sulcus structure noted. Cyst ornamented with numerous, closely spaced, parallel-sided, thin fimbriate processes, closed apically and rounded, sometimes slightly bifid; processes 3-16 μm long, not outlining any discernible pattern or reflected tabulation. Specimens having exactly similar morphology but possessing an apical archeopyle with zig-zag margin have been noted rarely.
Dimensions: Maximum diameter on 37 measured specimens, 24-59 μm; minimum diameter on 24 measured specimens, 18-59 μm. Total of 50 specimens recorded, many more observed.
Affinities: Brideaux, 1971, p. 94: *Cleistosphaeridium multispinosum*
Specimens illustrated by Singh (1964) are identical in morphology with forms encountered here. The form called *?C. aciculare* by Davey (1969) is likely a partial synonym, the processes and other morphology (Pl. 6, fig. 11) being consistent with the material recorded from Alberta. The writer has had the opportunity of examining material from the samples studied by Davey (1969) but has only been able to locate a few specimens for comparison. Hence the two species are only tentatively synonymized.

Original diagnosis: Davey, 1969, p. 158: *Cleistosphaeridium? aciculare*
Shell spherical to subspherical; shell wall of moderate thickness, densely granular. Processes numerous, finely to broadly acuminate, slightly flexuous, less than one-third of shell diameter in length.
Dimensions: diameter of central body 32 (43) 54 μm, maximum length of processes 8 (13.9) 21 μm.
Original descrption: Davey, 1969, p. 158: *Cleistosphaeridium? aciculare*
The processes may be finely or broadly acuminate but on each individual their width is constant. On individuals bearing fine processes these are more densely packed than in individuals with broad processes. All intergradations exist between the fine and the broad processed forms. The processes are always pointed distally and occasionally bear small subsidiary spines near their extremities. An archaeopyle has never been observed.

Dimensions: Range of observed specimens: length of endophragm 28 (32) 37 μm, width of endophragm 27 (32) 38 μm, length of processes 9 (11) 13 μm. 7 specimens measured.

Remarks: Singh (1964), in the original description of *D. multispinosum* recorded a width of process of 0.5 to 1 μm. Davey (1969), in the original description of *D. aciculare* states that "The processes may be finely or broadly acuminate but on each individual their width is constant. On individuals bearing fine processes these are more densely packed than in individuals with broad processes. All intergradations exist between the fine and the broad processed forms." Brideaux (1971) suggested that *Cleistosphaeridium?* (now *Downiesphaeridium*) *aciculare* was a partial synonym of *Cleistosphaeridium* (originally *Baltisphaeridium?* and now *Downiesphaeridium*) *multispinosum*, since he had only been able to locate a few specimens of *D. aciculare* from the type material for comparison. It seems that it is only the slight difference in process width and density which separates the species, based on pictures of the holotypes. Within my own material from the Western Interior Basin, and within other material from the Anglo-Paris Basin, a complete gradation can be seen in process width and density which still conforms with both species descriptions.

After considering the original species descriptions and illustrations, and recently taken photographs of the Davey holotype, and from the large populations seen in material from both the Anglo-Paris Basin and the Western Interior Basin, I see no rational reason for trying to differentiate between these two synonymous species. Consequently, all specimens have been logged as the senior *D. multispinosum*. Nøhr-Hansen (1993) made no attempt to differentiate between the two species and logged them as a complex.

Comparisons: A number of small skolochorate cysts may appear similar. *Downiesphaeridium armatum* and *Operculodinium* sp. A have much wider processes, which taper gradually. *Impletosphaeridium clavulum* and *Protoellipsodinium spinosum* have solid processes with capitate tips. *Heterosphaeridium multifurcatum* has solid processes with bifurcate tips. *Dapsilidinium multispinosum* has tubular processes which terminate with small spines. *Prolixosphaeridium parvispinum* has a prolate central body. *Cometodinium? whitei* has a differentiated autophragm which forms a dense aura of fine hairs. *Coronifera oceanica* and *Florentinia resex* are larger and have distinctive, wider antapical processes.

Occurrence: Rebecca K. Bounds core (Kansas): Early Cenomanian - Middle Turonian. Blue Point (Arizona), Bunker Hill (Kansas), Pueblo (Colorado), Wahweap Wash (Utah): Late Cenomanian - Early Turonian.

Downiesphaeridium? sp. A

Plate 16, Figures 10 to 12

Diagnosis: Spherical to subspherical skolochorate cyst, ornamented with a dense covering of nontabular, short, fine acicular hairs, of even length and fine width, which are always recurved. Archaeopyle is apical type (tA). No paratabulation is discernible.

Description: The central body is quite large compared to other species of the same genus, and the processes are very short in comparison, averaging around 10 to 15% of the diameter of the central body. These hairs have a uniform thickness (approximately 0.1 μm) with acicular or occasionally very finely capitate terminations. The processes are always noticably recurved, perhaps due to their fine width. The periphragm has a psilate to slightly granulate wall in between processes. The archaeopyle is often poorly developed but is of type (tA)a, with the operculum always in place. This species of cyst occurs most often in very organic rich sediments, particularly in the Bunker Hill section, and consequently most specimens have a certain amount of structureless organic matter adhered to their processes.

Dimensions: Range of observed specimens: length of endophragm 32 (42) 53 μm, width of endophragm 41 (48) 59 μm, length of processes 4 (6) 7 μm. Maximum length of processes as a percentage of average cyst diameter 9 (13) 16 %. 18 specimens measured.

Comparisons: *Downiesphaeridium multispinosum* is very similar but has a smaller central body and longer, less flexuous processes in comparison, which can also be wider. *Batiacasphaera* sp. A also appears similar but has a much shorter (1 μm) and denser covering of finer hairs.
Occurrence: Rebecca K. Bounds core (Kansas): Late Cenomanian. Bunker Hill (Kansas), Pueblo (Colorado): Late Cenomanian - Early Turonian.

Genus *Ellipsodinium* Clarke & Verdier, 1967

Ellipsodinium rugulosum Clarke & Verdier, 1967

Plate 25, Figure 6

1967 Clarke & Verdier (Isle of Wight, England: **Early Cenomanian - Early Santonian)**
1969a Davey (Compton Bay, Isle of Wight; Fetcham Mill Borehole, England; Escalles, France: **Cenomanian)**
1973 Davey & Verdier (France and Switzerland: **Late Albian - Early Cenomanian)**
1983 Foucher (Paris Basin, France: **Early Cenomanian - mid Santonian)**
1988 Marshall & Batten (Lower Saxony Basin, North Germany: **Late Cenomanian - Early Turonian)**
1989 Habib & Milner (South Carolina & Georgia, USA: **Late Campanian)**
1990 Prössl (nr. Salzgitter, North-west Germany: **Early Albian - Middle Turonian)**
1992 Costa & Davey (England and the North Sea: **Late Albian - Early Santonian)**
1994a Tocher & Jarvis (Fumichon, Normandy, France: **Early - Middle Cenomanian)**

Dimensions: Range of observed specimens: length of cyst 46 (52) 61 μm, width of cyst 35 (41) 48 μm. 4 specimens measured.
Remarks: Only four specimens were found from the Rebecca K. Bounds core and from Pueblo. This species is extremely distinctive with its longitudinal ridges, clearly defined paracingulum and precingular archaeopyle.
Occurrence: Pueblo (Colorado): Late Cenomanian. Rebecca K. Bounds core (Kansas): Early Turonian.

Genus *Exochosphaeridium* Davey, Downie, Sarjeant & Williams, 1966

Exochosphaeridium arnace Davey & Verdier, 1973

Plate 11, Figure 4

1973 Davey & Verdier (France and Switzerland: **Early Vraconian - Early Cenomanian)**
1983 Foucher (Paris Basin, France: **Early Cenomanian - Late Santonian)**
1988 Marshall & Batten (Lower Saxony Basin, North Germany: **Late Cenomanian)**
1990 Prössl (nr. Salzgitter, North-west Germany: **earliest Albian - Late Cenomanian)**
1994a Tocher & Jarvis (Fumichon, Normandy, France: **Early - Middle Cenomanian)**

Dimensions: Range of observed specimens: length of cyst 65 (69) 78 μm, width of cyst 60 (63) 68 μm, length of inner body 45 (51) 56 μm, width of inner body 41 (48) 50 μm. 7 specimens measured.

Comparisons: This species has a differentiated autophragm consisting of a dense cover of intricately linked, fine, fibrous processes which give the cyst a hairy appearance. *Exochosphaeridium phragmites* is similar but has far fewer processes which are acuminate. *Cometodinium? whitei* appears very similar but is smaller and does not have an archaeopyle, paracingulum and apical horn.

Occurrence: Blue Point (Arizona), Bunker Hill (Kansas), Pueblo (Colorado), Wahweap Wash (Utah): Late Cenomanian - Early Turonian. Rebecca K. Bounds core (Kansas): Middle Turonian.

Exochosphaeridium bifidum (Clarke & Verdier, 1967) Clarke, Davey, Sarjeant & Verdier, 1968

Plate 12, Figures 3 & 4

1967 Clarke & Verdier (Isle of Wight, England: **Early Cenomanian - Late Campanian**) as *Baltisphaeridium bifidum*
1978 Bujak & Williams (Offshore South-eastern Canada: **earliest Albian - latest Maastrichtian**)
1980 May (New Jersey, USA: **Latest Campanian - Early Maastrichtian**)
1980 Morgan (Australia: **Late Neocomian - latest Cenomanian**)
1983 Foucher (Paris Basin, France: **earliest Coniacian - Late Campanian**)
1984 Below (Mazagan Plateau, Offshore North-west Africa: **Early Aptian - Late Albian**)
1986 Ioannides (Bylot Island, Arctic Archipelago: **Santonian/Campanian - Early Palaeocene**)
1987 Firth (Georgia, USA: **Early Maastrichtian - Danian**)
1987 Habib & Drugg (Offshore USA, Western North Atlantic: **Late Albian - Late Coniacian**)
1988 Jarvis *et al.* (Dover, Kent, England: **Late Cenomanian**)
1988 Marshall & Batten (Lower Saxony Basin, North Germany: **Early Turonian**)
1989 Habib & Milner (South Carolina & Georgia, USA: **Campanian - Late Maastrichtian**)
1994a Tocher & Jarvis (Fumichon, Normandy, France: **Middle Cenomanian**)

Dimensions: Range of observed specimens: length of endophragm 43 (47) 58 μm, width of endophragm 31 (40) 55 μm, length of processes 10 (14) 16 μm. 7 specimens measured.

Comparisons: This species of *Exochosphaeridium* is very distinctive, with its ornamentation of bifurcate and capitate tipped processes. *Exochosphaeridium phragmites* is similar but has acuminate processes. *Pervosphaeridium pseudhystrichodinium* also appears similar, but has a two-plate precingular archaeopyle, and has broader based processes, some of which are acuminate as well capitate.

Occurrence: Rebecca K. Bounds core (Kansas): Early Cenomanian - Middle Turonian. Blue Point (Arizona): Late Cenomanian - Early Turonian. Pueblo (Colorado), Wahweap Wash (Utah): Early Turonian.

Exochosphaeridium phragmites Davey, Downie, Sarjeant & Williams, 1966

Plate 11, Figures 5 & 6

1966 Davey *et al.* (Fetcham Mill Borehole, Surrey, England: **Cenomanian**)

1969a Davey (Fetcham Mill Borehole, Surrey, England: **Albian - Cenomanian**, Compton Bay, Isle of Wight, England; Escalles, France: **Cenomanian**)

1973 Davey & Verdier (France and Switzerland: **Late Albian - Early Cenomanian**)

1980 Morgan (Australia: **Late Neocomian - latest Cenomanian**)

1983 Foucher (Paris Basin, France: **Early Cenomanian - Late Santonian**)

1983 Singh (North-west Alberta, Canada: **Middle Cenomanian**)

1984 Below (Mazagan Plateau, Offshore North-west Africa: **Early Aptian - earliest Cenomanian**)

1988 Jarvis *et al.* (Dover, Kent, England: **Late Cenomanian**)

1988 Marshall & Batten (Lower Saxony Basin, North Germany: **Late Cenomanian - Early Turonian**)

1989 Habib & Milner (South Carolina & Georgia, USA: **Late Campanian - Late Maastrichtian**)

1990 Harker *et al.* (Interior Plains of Canada: **Late Santonian - Late Campanian**)

1990 Prössl (nr. Salzgitter, North-west Germany: **Early Hauterivian - Late Turonian**)

1993 Courtinat (Pueblo, Colorado, USA: **Late Cenomanian**)

1993 Nøhr-Hansen (North-east Greenland: **Early Barremian - Late Albian/ Early Cenomanian?**)

1994a Tocher & Jarvis (Fumichon, Normandy, France: **Early - Middle Cenomanian**)

Dimensions: Range of observed specimens: length of endophragm 44 (57) 67 µm, width of endophragm 44 (56) 68 µm, length of processes 10 (14) 18 µm. 9 specimens measured.

Comparisons: This species is characterised by its many long, acuminate processes and single-plate precingular archaeopyle. *Exochosphaeridium arnace* is similar but has a much denser covering of finer processes which amalgamate to form a differentiated autophragm. *Exochosphaeridium bifidum* is similar but has more rigid processes, with bifurcate and capitate tips. Several species of *Pervosphaeridium* appear similar but have a two-plate precingular archaeopyle. *Pervosphaeridium* sp. A has a number of adjacent processes fused together with high membranes. *Pervosphaeridium pseudhystrichodinium* also appears similar but has processes with some distally expanded tips. *Pervosphaeridium cenomaniense* has fewer, thicker-walled processes which are shorter and are sometimes truncate.

Occurrence: Rebecca K. Bounds core (Kansas): Early Cenomanian - Middle Turonian. Blue Point (Arizona), Bunker Hill (Kansas), Pueblo (Colorado), Wahweap Wash (Utah): Late Cenomanian - Early Turonian.

Genus *Heterosphaeridium* Cookson & Eisenack, 1968; emend. Yun, 1981

Heterosphaeridium conjunctum Cookson & Eisenack, 1968

Plate 18, Figure 6

1980 Morgan (Australia: **Late Albian - latest Cenomanian**)

Dimensions: Range of observed specimens: length of endophragm 53 (56) 66 µm, width of endophragm 46 (63) 80 µm, maximum length of processes 8 (13) 16 µm, maximum width of processes 5 (6) 8 µm. 7 specimens measured.

Comparisons: The processes are of variable width and are fibrous. *Heterosphaeridium? heteracanthum* has thinner and simpler processes. *Heterosphaeridium difficile* has processes which are much wider and fewer in number.

Occurrence: Pueblo (Colorado): Early Turonian. Rebecca K. Bounds core (Kansas): Middle Turonian.

Heterosphaeridium difficile (Manum & Cookson, 1964) Ioannides, 1986

Plate 17, Figure 1

1964 Manum & Cookson (Arctic Canada: **'mid Cretaceous'**) as *Hystrichosphaeridium difficile*

1969a Davey (Saskatchewan, Canada: **Albian - Cenomanian**) as *Hystrichosphaeridium difficile*

1976 Norvick *in* Norvick & Burger (Bathurst Island, Australia: **Early Cenomanian - Early Turonian**) as *Hystrichosphaeridium difficile*

1986 Ioannides (Bylot Island, Arctic Archipelago: **Santonian/Campanian - Early Palaeocene**)

1988 Jarvis *et al.* (Dover, Kent, England: **Early Turonian**)

1992 Costa & Davey (England and the North Sea: **earliest Turonian - Late Santonian**)

1993 Williams *et al.* (N. Hemisphere: **Turonian - Santonian**)

Dimensions: Range of observed specimens: length of endophragm 47 (61) 78 µm, width of endophragm 50 (60) 72 µm, maximum length of processes 17 (21) 26 µm, maximum width of processes 17 (23) 31 µm. 7 specimens measured.

Comparisons: The processes of this species are much wider and far less numerous than those on the other species of *Heterosphaeridium* within this material. *Cyclonephelium compactum* is very similar but lacks the prominent surface ridges which join the bases of the processes, and often has reduced or no ornamentation in the mid-ventral and mid-dorsal areas.

Occurrence: Rebecca K. Bounds core (Kansas): Middle Turonian.

Heterosphaeridium? heteracanthum (Deflandre & Cookson, 1955) Eisenack & Kjellstrom, 1971a

Plate 18, Figures 3 to 5

1960a Cookson & Eisenack (Perth & Carnarvon Basins, Australia: **Campanian - Santonian**) as *Hystrichosphaeridium heteracanthum*

1966 Davey *et al.* (Fetcham Mill Borehole, Surrey; England: **Cenomanian**) as *Cleistosphaeridium heteracanthum*

1969a Davey (Fetcham Mill Borehole, Surrey; Compton Bay, Isle of Wight, England; Escalles, France: **Late Cenomanian**) as *Cleistosphaeridium heteracanthum*

1973 Davey & Verdier (France and Switzerland: **Early Vraconian - Early Cenomanian**) as *Cleistosphaeridium heteracanthum*

1980 Morgan (Australia: **Late Albian - Middle Cenomanian**)

1982 Below (Morocco: **Late Hauterivian - mid Aptian**)

1983 Foucher (Paris Basin, France: **Early Cenomanian - Early Campanian)**
1984 Below (Mazagan Plateau, Offshore North-west Africa: **Early Aptian - earliest Cenomanian)**
1988 Jarvis *et al.* (Dover, Kent, England: **Late Cenomanian - Early Turonian)**
1988 Masure (Bahamas: **Middle Cenomanian)**
1990 Harker *et al.* (Interior Plains of Canada: **latest Campanian/earliest Maastrichtian?)**
1992 Costa & Davey (England and the North Sea: **earliest Cenomanian - latest Maastrichtian)**
1994a Tocher & Jarvis (Fumichon, Normandy, France: **Early - Middle Cenomanian)**

Dimensions: Range of observed specimens: length of endophragm 52 (67) 86 µm, width of endophragm 53 (68) 80 µm, maximum length of processes 11 (14) 18 µm, maximum width of processes 1 (1.6) 3 µm. 8 specimens measured.

Comparisons: The processes of this species are simple and thin, unlike those of *H. conjunctum* and *H. difficile*. *Heterosphaeridium multifurcatum* is much smaller and although it possesses a fibrous to fossulate central body, it does not have the prominent surface ridges which connect many of the bases of adjacent processes. *Circulodinium distinctum* is very similar with many solid, irregular processes, but also lacks these surface ridges.

Occurrence: Rebecca K. Bounds core (Kansas): Early Cenomanian - Middle Turonian. Blue Point (Arizona), Bunker Hill (Kansas), Pueblo (Colorado), Wahweap Wash (Utah): Late Cenomanian - Early Turonian.

Heterosphaeridium multifurcatum (Deflandre, 1937) Islam, 1993

Plate 16, Figures 4 & 5

1969a Davey (Fetcham Mill Borehole, Surrey; Compton Bay, Isle of Wight, England; Escalles, France: **Cenomanian)** as *Cleistosphaeridium? multifurcatum*
1973 Davey & Verdier (France and Switzerland: **Late Vraconian)** as *Cleistosphaeridium? multifurcatum*
1983 Foucher (Paris Basin, France: **Early Cenomanian - Late Campanian)** as *Cleistosphaeridium? multifurcatum*
1988 Marshall & Batten (Lower Saxony Basin, North Germany: **Late Cenomanian - Early Turonian)** as *Cleistosphaeridium? multifurcatum*
1990 Prössl (nr. Salzgitter, North-west Germany: **earliest Cenomanian - Late Turonian)** as *Cleistosphaeridium? multifurcatum*

Dimensions: Range of observed specimens: length of endophragm 31 (37) 45 µm, width of endophragm 33 (40) 49 µm, maximum length of processes 7 (8) 9 µm. 4 specimens measured.

Remarks: This species was transferred from the genus *Cleistosphaeridium?* (now illegitimate) by Islam (1993). It is considerably smaller than other species of *Heterosphaeridium* within this material, and although it has a finely fibrous to fossulate surface, it does not have any continuous ridges connecting process bases, like other species of *Heterosphaeridium*. Perhaps it should only be questionably included within this genus. Only four specimens were found, in the Pueblo and Blue Point sections.

Comparisons: *Heterosphaeridium? heteracanthum* is very similar but is larger with surface ridges connecting the process bases. *Impletosphaeridium clavulum* is also similar but has processes with clavate tips, and lacks the fibrous to fossulate surface ornamentation. Some species of *Dapsilidinium* are similar but have hollow, tubular processes, and also lack the fibrous to fossulate surface ornamentation. *Dapsilidinium? multispinosum* has many more, and longer processes, which are hollow and terminate with a few short spines.

Occurrence: Blue Point (Arizona), Pueblo (Colorado): Late Cenomanian.

Genus *Impletosphaeridium* Morgenroth, 1966; emend. Islam, 1993

Impletosphaeridium clavulum (Davey, 1969a) Islam, 1993

Plate 16, Figure 6

1969a Davey (Fetcham Mill Borehole, Surrey; Compton Bay, Isle of Wight, England; Escalles, France; Saskatchewan, Canada; Texas, USA: **Cenomanian)** as *Cleistosphaeridium polypes clavulum*

1973 Davey & Verdier (France and Switzerland: **Early - Late Vraconian)** as *Cleistosphaeridium polypes clavulum*

1975 Brideaux & McIntyre (District of Mackenzie, Canada: **Middle Albian)** as *Cleistosphaeridium polypes clavulum*

1984 Below (Mazagan Plateau, Offshore North-west Africa: **Early Aptian - Early Cenomanian)** as *Cleistosphaeridium clavulum*

1988 Jarvis *et al.* (Dover, Kent, England: **Late Cenomanian - Early Turonian)** as *Cleistosphaeridium clavulum*

1988 Mao Shaozhi & Norris (Kashi Area, Xinjiang Province, China: **Late Cretaceous)** as *Bacchidium polypes clavulum*

1990 Prössl (nr. Salzgitter, North-west Germany: **mid Barremian - Late Albian)** as *Cleistosphaeridium clavulum*

1994a Tocher & Jarvis (Fumichon, Normandy, France: **Early - Middle Cenomanian)** as *Cleistosphaeridium clavulum*

Dimensions: Range of observed specimens: length of endophragm 21 (30) 45 μm, width of endophragm 25 (34) 48 μm, maximum length of processes 6 (9) 12 μm, maximum width of processes <1 μm. 7 specimens measured.

Comparisons: *Impletosphaeridium clavulum* is a small cyst, with an apical archaeopyle and solid processes with capitate tips. A number of small skolochorate cysts appear similar. *Protoellipsodinium spinosum* also has solid processes with capitate tips, but has a prolate central body with a precingular archaeopyle. *Heterosphaeridium multifurcatum* has solid processes with bifurcate tips.

Downiesphaeridium multispinosum has hollow, acicular processes. *Dapsilidinium multispinosum* has tubular processes which terminate with small spines.

Occurrence: Rebecca K. Bounds core (Kansas): Early Cenomanian - Middle Turonian. Blue Point (Arizona), Bunker Hill (Kansas), Pueblo (Colorado), Wahweap Wash (Utah): Late Cenomanian - Early Turonian.

Genus *Leberidocysta* Stover & Evitt, 1978

This study rejects the classification of *Leberidocysta* in the Order Peridiniales, Family Peridiniaceae, Subfamily Ovoidinioideae (Fensome *et al.*, 1993) based on an interpretation of the archaeopyle from the plates illustrating the type species *Hexagonifera* (now *Leberidocysta*) *chlamydata* in Cookson & Eisenack, 1962b.

Stover & Evitt (1978) erected the genus *Leberidocysta* based on their interpretation of a total-apical archaeopyle (type tA) as opposed to the genotype of *Hexagonifera* (*H. glabra* in Cookson & Eisenack, 1961a, plate 12, figure 11) which clearly displays a single-plate intercalary archaeopyle.

The figure (plate 7, figure 7) used by Fensome *et al.* (1993) seems to display a combination (tAtI) archaeopyle, hence their interpretation. However the holotype figure (plate 7, figure 2) does not display an archaeopyle involving intercalary plates. A further figure (plate 7, figure 1) very clearly displays a (tA) archaeopyle with a sulcal notch suggesting a position in the Gonyaulacales.

Leberidocysta defloccata (Davey & Verdier, 1973) Stover & Evitt, 1978

Plate 24, Figure 4

1973 Davey & Verdier (France and Switzerland: **Late Albian - Early Cenomanian**) as *Hexagonifera defloccata*

1976 Norvick *in* Norvick & Burger (Bathurst Island, Australia: **Early - Late Cenomanian**) as *Hexagonifera defloccata*

1983 Singh (North-west Alberta, Canada: **Early Cenomanian**)

1987 Habib & Drugg (Offshore USA, Western North Atlantic: **Late Albian - Middle Cenomanian**)

1988 Jarvis *et al.* (Dover, Kent, England: **Late Cenomanian - Early Turonian**)

1990 Prössl (nr. Salzgitter, North-west Germany: **Early Albian - Late Turonian**)

1994a Tocher & Jarvis (Fumichon, Normandy, France: **Middle Cenomanian**)

Dimensions: Range of observed specimens: length of periphragm with no apex 59 (72) 92 µm (3 specimens), length of periphragm with apex 59 (75) 95 µm (3 specimens), width of periphragm 60 (68) 84 µm, length of endophragm with no apex 47 (54) 63 µm (3 specimens), length of endophragm with apex 47 (57) 69 µm (3 specimens), width of endophragm 42 (54) 76 µm. 6 specimens measured.

Comparisons: This is a very distinctive species of cavate cyst, with an apical archaeopyle, and a membranous periphragm loosely wrapped and folded around a much smaller, thicker-walled endophragm. *Leberidocysta chlamydata* is very similar but has a strong ornamentation of verrucae on the endophragm.

Occurrence: Rebecca K. Bounds core (Kansas): Late Cenomanian - Middle Turonian. Pueblo (Colorado): Late Cenomanian - Early Turonian. Bunker Hill (Kansas): Early Turonian.

Genus *Membranilarnacia* Eisenack, 1963; emend. Williams & Downie, 1966

Membranilarnacia polycladiata Cookson & Eisenack *in* Eisenack, 1963

Plate 24, Figures 1 to 3

1958 Cookson & Eisenack (New Guinea: **?Albian)** as *Membranilarnax* sp.
1990 Prössl (nr. Salzgitter, North-west Germany: **earliest Cenomanian - Late Turonian)**
1991 Kirsch (Germany: **Late Santonian - Early Maastrichtian)**
1993 Courtinat (Pueblo, Colorado, USA: **Late Cenomanian)**

Dimensions: Range of observed specimens: length of periphragm 40 (61) 75 µm, width of periphragm 59 (68) 75 µm, length of endophragm 33 (42) 55 µm, width of endophragm 40 (47) 55 µm, maximum length of processes 10 (13) 15 µm. 7 specimens measured.

Remarks: This is an extremely distinctive holocavate cyst, with an apical archaeopyle, and a continuous cover of non-tabular, distally expanded and branched processes, which are joined by thinner membranes from their proximal to distal extremities. *Chlamydophorella nyei* may appear similar but is far smaller with much shorter, thinner processes.

Occurrence: Blue Point (Arizona), Bunker Hill (Kansas), Pueblo (Colorado), Rebecca K. Bounds core (Kansas), Wahweap Wash (Utah): Late Cenomanian.

Genus *Prolixosphaeridium* Davey, Downie, Sarjeant & Williams, 1966;
emend. Davey, 1969a

Prolixosphaeridium conulum Davey, 1969a

Plate 15, Figure 8

1969a Davey (Fetcham Mill Borehole, Surrey; Compton Bay, Isle of Wight, England; Escalles, France: **Late Cenomanian)**
1973 Davey & Verdier (France and Switzerland: **Early Vraconian)**
1976 Norvick *in* Norvick & Burger (Bathurst Island, Australia: **Early - Late Cenomanian)**
1980 Morgan (Australia: **Middle Albian - latest Cenomanian)**
1984 Below (Mazagan Plateau, Offshore North-west Africa: **mid Aptian - earliest Cenomanian)**
1988 Jarvis *et al.* (Dover, Kent, England: **Late Cenomanian - Early Turonian)**
1988 Masure (Bahamas: **Vraconian - Middle Cenomanian)**

1988 Marshall & Batten (Lower Saxony Basin, North Germany: **Late Cenomanian - Early Turonian)**

1990 Prössl (nr. Salzgitter, North-west Germany: **Middle Albian - Middle Turonian)**

1993 Courtinat (Pueblo, Colorado, USA: **Late Cenomanian)**

1994a Tocher & Jarvis (Fumichon, Normandy, France: **Early - Middle Cenomanian)**

Dimensions: Range of observed specimens: length of central body 39 (51) 55 µm, width of central body 21 (30) 36 µm, maximum length of processes 9 (12) 15 µm, maximum width of processes 1.5 (2.4) 3 µm. 8 specimens measured.

Comparisons: This skolochorate species has a prolate central body, apical archaeopyle and numerous, broad-based, acuminate processes. *Prolixosphaeridium parvispinum* is very similar but has acicular processes which sometimes have recurved tips. Species of *Tanyosphaeridium* are very similar but possess processes which have distally expanded or branched tips. *Protoellipsodinium spinosum* is also similar but has a precingular rather than an apical archaeopyle.

Occurrence: Rebecca K. Bounds core (Kansas): Early Cenomanian - Middle Turonian. Blue Point (Arizona), Pueblo (Colorado): Late Cenomanian.

Prolixosphaeridium parvispinum (Deflandre, 1937b) Davey *et al.*, 1969

Plate 15, Figure 11

1980 Morgan (Australia: **Late Neocomian - Middle Cenomanian)**

1983 Singh (North-west Alberta, Canada: **Middle Cenomanian)**

1984 Below (Mazagan Plateau, Offshore North-west Africa: **Early Aptian - earliest Cenomanian)**

1987 Habib & Drugg (Offshore USA, Western North Atlantic: **Late Barremian - Cenomanian)**

1990 Prössl (nr. Salzgitter, North-west Germany: **mid Barremian - Late Albian)**

1992 Costa & Davey (England and the North Sea: **mid Barremian - Middle Cenomanian)**

1993 Nøhr-Hansen (North-east Greenland: **Early Barremian - Middle Albian)**

1993 Williams *et al.* (N. Hemisphere: **Hauterivian - latest Cenomanian)**

1996 Stover *et al.* (World wide: **Early Hauterivian - latest Cenomanian)**

Dimensions: Range of observed specimens: length of central body 45 (55) 62 µm, width of central body 35 (38) 44 µm, maximum length of processes 11 (12) 13 µm, maximum width of processes <1 µm. 3 specimens measured.

Comparisons: *Prolixosphaeridium conulum* is extremely similar but possesses broad-based acuminate processes instead of acicular ones. *Downiesphaeridium multispinosum* is similar but has a spherical central body instead of a prolate one.

Occurrence: Rebecca K. Bounds core (Kansas): Late Cenomanian - Middle Turonian.

Genus *Raetiaedinium* Kirsch, 1991

Raetiaedinium truncigerum (Deflandre, 1937b) Kirsch, 1991

Plate 2, Figures 1 & 2

1967 Clarke & Verdier (Isle of Wight, England: **Early - Late Santonian**) as *Hystrichosphaeridium truncigerum*
1978 Bujak & Williams (Offshore South-eastern Canada: **earliest Coniacian - latest Santonian**) as *Hystrichosphaeridium truncigerum*
1982 Below (Morocco: **Vraconian**) as *Florentinia truncigerum*
1983 Foucher (Paris Basin, France: **Late Turonian - Late Campanian**) as *Florentinia? truncigerum*
1990 Prössl (nr. Salzgitter, North-west Germany: **mid - Late Turonian**) as *Pervosphaeridium truncigerum*
1991 Kirsch (Germany: **Coniacian - mid Campanian**)
1993 Courtinat (Pueblo, Colorado, USA: **Late Cenomanian**) as *Pervosphaeridium truncigerum*
1993 Williams *et al.* (N. Hemisphere: **Turonian/Coniacian boundary - Early Campanian**)

Dimensions: Range of observed specimens: length of central body 51 (66) 82 µm, width of central body 59 (64) 80 µm, maximum length of processes 13 (18) 25 µm, maximum width of processes 9 (14) 19 µm. 11 specimens measured.

Remarks: The central body is coarsely punctate to foveolate and striate and possesses a two-plate precingular archaeopyle (type 2P). This species has two widths of processes, which are also striate. The thinner processes are simple, tapered or parallel sided and distally acuminate or truncate. The wider processes are tubular and closed distally, terminating with a number of acuminate or truncated tubules.

Comparisons: Species of *Pervosphaeridium* have a similar central body (with a 2P archaeopyle) but only thin processes. Species of *Florentinia* (e.g. *F. cooksoniae*) may appear similar but are smaller with very different processes and combination archaeopyles. *Hystrichosphaeridium paracostatum* has similar shaped, striate processes but a granulate central body and an apical archaeopyle.

Occurrence: Rebecca K. Bounds core (Kansas): Middle Turonian.

Genus *Tanyosphaeridium* Davey & Williams, 1966

Tanyosphaeridium salpinx Norvick *in* Norvick & Burger, 1976

Plate 15, Figures 12 & 13

1976 Norvick *in* Norvick & Burger (Bathurst Island, Australia: **Early - latest Cenomanian**)
1980 Morgan (Australia: **earliest Aptian - latest Cenomanian**)
1983 Habib & Drugg (Blake-Bahama Basin, Western Atlantic: **Early Berriasian - Late Albian**)
1983 Singh (North-west Alberta, Canada: **Middle Albian - Early Cenomanian**)
1990 Prössl (nr. Salzgitter, North-west Germany: **Early Hauterivian - Late Turonian**)
1992 Mohr & Gee (Kerguelan Plateau, Southern Indian Ocean: **Late Turonian - Early Coniacian**)
1993 Nøhr-Hansen (North-east Greenland: **Late Albian/ Early Cenomanian?**)

1994a Tocher & Jarvis (Fumichon, Normandy, France: **Early - Middle Cenomanian**)

Dimensions: Range of observed specimens: length of central body 32 (37) 46 µm, width of central body 19 (24) 30 µm, maximum length of processes 12 (14) 16 µm, maximum width of processes 1 (1.3) 2 µm. 7 specimens measured.

Comparisons: This species has a prolate central body with an apical archaeopyle and numerous, distally-open processes with flared and entire or slightly-serrate terminations. *Tanyosphaeridium variecalamus* is similar but has variable process terminations. *Tanyosphaeridium boletus* is also similar but has processes with entire, recurved terminations forming distinctive 'mushroom' shapes. *Tanyosphaeridium isocalamus* is also similar but has processes with cleanly truncate and non-expanded terminations. Species of *Prolixosphaeridium* are similar but have tapering and distally-closed processes.

Occurrence: Rebecca K. Bounds core (Kansas): Late Cenomanian - Middle Turonian. Blue Point (Arizona), Bunker Hill (Kansas), Pueblo (Colorado), Wahweap Wash (Utah): Late Cenomanian - Early Turonian.

Tanyosphaeridium variecalamus Davey & Williams, 1966b

Plate 15, Figures 9 & 10

1966b Davey & Williams (Fetcham Mill Borehole, Surrey, England: **Cenomanian**)

1969a Davey (Fetcham Mill Borehole, Surrey, England: **Albian - Turonian**, Compton Bay, Isle of Wight, England; Escalles, France: **Cenomanian**, Saskatchewan, Canada: **Albian**)

1973 Davey & Verdier (France and Switzerland: **Early Vraconian - Early Cenomanian**)

1978 Bujak & Williams (Offshore South-eastern Canada: **Late Albian - Early Palaeocene**)

1980 Morgan (Australia: **Late Neocomian - latest Vraconian**)

1983 Foucher (Paris Basin, France: **Early Cenomanian - Late Santonian**)

1983 Habib & Drugg (Blake-Bahama Basin, Western Atlantic: **earliest Barremian - Late Albian**)

1986 Ioannides (Bylot Island, Arctic Archipelago: **Santonian/Campanian - Maastrichtian?**)

1987 Firth (Georgia, USA: **Early-Late Maastrichtian**)

1987 Habib & Drugg (Offshore USA, Western North Atlantic: **mid Valanginian - Cenomanian/Turonian**)

1988 Jarvis *et al.* (Dover, Kent, England: **Late Cenomanian**)

1988 Masure (Bahamas: **Vraconian - Middle Cenomanian**)

1988 Marshall & Batten (Lower Saxony Basin, North Germany: **Late Cenomanian**)

1990 Harker *et al.* (Interior Plains of Canada: **Early - Late Campanian**)

1990 Prössl (nr. Salzgitter, North-west Germany: **Early Barremian - Early Cenomanian**)

1992 Costa & Davey (England and the North Sea: **Early Turonian - Late Santonian**)

1993 Williams *et al.* (N. Hemisphere: **Late Valanginian - Early Maastrichtian**)

1996 Stover *et al.* (World wide: **Late Valanginian - Early Maastrichtian**)

Dimensions: Range of observed specimens: length of central body 31 (36) 40 µm, width of central body 19 (22) 24 µm, maximum length of processes 11 (14) 16 µm, maximum width of processes 1 µm. 6 specimens measured.

Comparisons: The processes on this species are distally expanded and open, while the terminations are variable and include truncate, serrate and aculeate tips. *Tanyosphaeridium salpinx* has uniformly flared processes with entire or slightly-serrate terminations. Species of *Prolixosphaeridium* are similar but have tapering and distally-closed processes.

Occurrence: Rebecca K. Bounds core (Kansas): Early Cenomanian - Middle Turonian. Blue Point (Arizona), Bunker Hill (Kansas), Pueblo (Colorado), Wahweap Wash (Utah): Late Cenomanian - Early Turonian.

Genus *Trigonopyxidia* Cookson & Eisenack, 1961,
nom. subst. pro Trigonopyxis Cookson & Eisenack, 1960, *non Trigonopyxis* Penard, 1912

Trigonopyxidia ginella (Cookson & Eisenack, 1960a) Downie & Sarjeant, 1965

Plate 39, Figure 5

1960a	Cookson & Eisenack (Perth & Carnarvon Basins, Australia: **?Late Albian - Cenomanian)** as *Trigonopyxis ginella*
1964	Manum & Cookson (Arctic Canada: **'mid Cretaceous')**
1976	Norvick *in* Norvick & Burger (Bathurst Island, Australia: **Early Cenomanian)**
1978	Bujak & Williams (Offshore South-eastern Canada: **earliest - latest Santonian)**
1986	Ioannides (Bylot Island, Arctic Archipelago: **Santonian/Campanian - Maastrichtian)**
1987	Firth (Georgia, USA: **Late Maastrichtian - Danian)**
1991	Kirsch (Germany: **Late Santonian - Maastrichtian)**

Dimensions: Range of observed specimens: width of periphragm (length along side of triangle opposite the archaeopyle) 60 (73) 79 µm, length of periphragm (maximum height of cyst perpendicular to the width line) 32 (48) 55 µm, width of endophragm 34 (37) 40 µm, length of endophragm 25 (34) 42 µm. 5 specimens measured.

Comparisons: This is a distictive species of circumcavate cyst with an apical archaeopyle. The pericyst has a straight to concave-sided triangular outline with rounded corners. The endocyst has a convex-sided triangular to flask-shaped outline. Species of *Wallodinium* have a similar appearance but are crescent-shaped.

Occurrence: Pueblo (Colorado): Late Cenomanian. Rebecca K. Bounds core (Kansas): Middle Turonian.

Genus *Valensiella* Eisenack, 1963; emend. Courtinat, 1989

Valensiella magna (Davey, 1974) Courtinat, 1989

Plate 22, Figure 3

1980 Morgan (Australia: **earliest Aptian & Late Albian - latest Cenomanian**) as *Cassiculosphaeridia magna*

1984 Below (Mazagan Plateau, Offshore North-west Africa: **earliest Cenomanian**) as *Cassiculosphaeridia magna*

1987 Habib & Drugg (Offshore USA, Western North Atlantic: **mid Valanginian - Early Barremian**) as *Cassiculosphaeridia magna*

1990 Harker *et al.* (Interior Plains of Canada: **Early - mid Campanian**) as *Cassiculosphaeridia magna*

1990 Prössl (nr. Salzgitter, North-west Germany: **Early Hauterivian - mid Barremian**) as *Cassiculosphaeridia magna*

1992 Costa & Davey (England and the North Sea: **Late Jurassic - Late Barremian**) as *Cassiculosphaeridia magna*

1993 Nøhr-Hansen (North-east Greenland: **Late Barremian**) as *Cassiculosphaeridia magna*

1996 Stover *et al.* (Worldwide: **Early Valanginian - mid Barremian**) as *Cassiculosphaeridia magna*

Dimensions: Range of observed specimens: length of endophragm including apex 63 & 64 µm (2 specimens), length of endophragm (no apex) 42 (51) 65 µm, width of endophragm 65 (77) 90 µm. 3 specimens measured.

Comparisons: Only three specimens were found, in the Rebecca Bounds Core, which match the original species descriptions and illustrations. It is quite possible that these have been reworked. Other species of *Valensiella* are similar but are much smaller.

Occurrence: Rebecca K. Bounds core (Kansas): Late Cenomanian - Middle Turonian.

Valensiella reticulata (Davey, 1969a) Courtinat, 1989

Plate 22, Figures 6 to 9

1969a Davey (Fetcham Mill Borehole, Surrey, England; Escalles, France: **Cenomanian**) as *Cassiculosphaeridia reticulata*

1976 Norvick *in* Norvick & Burger (Bathurst Island, Australia: **Early Cenomanian - Early Turonian**) as *Cassiculosphaeridia reticulata*

1980 Morgan (Australia: **Late Neocomian - latest Cenomanian**) as *Cassiculosphaeridia reticulata*

1981 Below (South-west Morocco: **Hauterivian - Albian**) as *Cassiculosphaeridia reticulata*

1983 Foucher (Paris Basin, France: **Early Cenomanian - Early Campanian**) as *Cassiculosphaeridia reticulata*

1983 Habib & Drugg (Blake-Bahama Basin, Western Atlantic: **Late Barremian - Late Aptian**) as *Cassiculosphaeridia reticulata*

1984 Below (Mazagan Plateau, Offshore North-west Africa: **mid Aptian - Late Albian**) as *Cassiculosphaeridia reticulata*

1987 Habib & Drugg (Offshore USA, Western North Atlantic: **Late Barremian - Late Albian**) as *Cassiculosphaeridia reticulata*

1988 Masure (Bahamas: **Middle Cenomanian**) as *Cassiculosphaeridia reticulata*

1990 Harker *et al.* (Interior Plains of Canada: **Early Campanian**) as *Cassiculosphaeridia reticulata*

1990 Prössl (nr. Salzgitter, North-west Germany: **Early Hauterivian - Middle Albian**) as *Cassiculosphaeridia reticulata*

1992 Costa & Davey (England and the North Sea: **Jurassic - latest Santonian**) as *Cassiculosphaeridia reticulata*

1992 Mohr & Gee (Kerguelan Plateau, Southern Indian Ocean: **Early - Late Turonian**)

1993 Nøhr-Hansen (North-east Greenland: **Early Barremian - Middle Albian?**) as *Cassiculosphaeridia reticulata*

1994a Tocher & Jarvis (Fumichon, Normandy, France: **Early - Middle Cenomanian**)

Dimensions: Range of observed specimens: length of periphragm 33 (45) 54 µm, width of periphragm 37 (48) 59 µm, length of endophragm 31 (40) 45 µm, width of endophragm 35 (43) 52 µm. 8 specimens measured.

Comparisons: This is a distinctive species with a membranous periphragm which forms a reticulum of low crests. A gradation exists with *V. tazadensis* which has a periphragm which is irregularly thickened and folded over the endophragm. Only specimens with a clearly expressed and distinct reticulum were recorded as *V. reticulata*. *Valensiella pygmaea* is very similar but has a lower, finer-meshed reticulum and a prolate endophragm. *Valensiella magna* is much larger, also with an irregularly thickened and folded periphragm. Other reticulate-walled cysts with apical archaeopyles (for example *Canningia reticulata*, *C. senonica*, *Cyclonephelium chabaca* and *Senoniasphaera microreticulata*) are generally much larger with finer meshed reticula.

Occurrence: Rebecca K. Bounds core (Kansas): Middle Cenomanian - Middle Turonian. Blue Point (Arizona), Pueblo (Colorado): Late Cenomanian. Wahweap Wash (Utah): Late Cenomanian - Early Turonian.

Valensiella tazadensis (Below, 1981a) Lentin & Williams, 1993

Plate 22, Figures 4 & 5

1981 Below (South-west Morocco: **Hauterivian - Albian**) as *Cassiculosphaeridia tazadensis*

1982 Below (Morocco: **Late Hauterivian - mid Aptian**) as *Cassiculosphaeridia tazadensis*

1984 Below (Mazagan Plateau, Offshore North-west Africa: **mid - Late Aptian**) as *Cassiculosphaeridia tazadensis*

1990 Prössl (nr. Salzgitter, North-west Germany: **Late Hauterivian - Late Barremian**) as *Cassiculosphaeridia tazadensis*

Dimensions: Range of observed specimens: length of periphragm 41 (47) 54 µm, width of periphragm 43 (51) 60 µm, length of endophragm 34 (41) 47 µm, width of endophragm 36 (44) 50 µm. 8 specimens measured.

Comparisons: The periphragm is irregularly thickened and folded over the surface of the endophragm. This species is very similar to and forms a gradation with *V. reticulata* which has a regular reticulum. These intermediate forms were also noted by Below (1981). Specimens with a clearly expressed and distinct reticulum were recorded as *V. reticulata*. *Valensiella magna* also has an irregularly thickened and folded periphragm but is much larger and thicker-walled.

Occurrence: Rebecca K. Bounds core (Kansas): Middle Cenomanian - Middle Turonian. Blue Point (Arizona): Late Cenomanian. Pueblo (Colorado), Wahweap Wash (Utah): Late Cenomanian - Early Turonian. Bunker Hill (Kansas): Early Turonian.

Genus *Xiphophoridium* Sarjeant, 1966b

Xiphophoridium alatum (Cookson & Eisenack, 1962b) Sarjeant, 1966b;
emend. Sarjeant, 1966b
Plate 23, Figures 3 & 4

1962b Cookson & Eisenack (Australia: **Albian - Cenomanian**) as *Hystrichodinium alatum*

1964 Cookson & Hughes (Cambridgeshire, England: **Late Albian - Early Cenomanian**) as *Hystrichodinium alatum*

1966b Sarjeant (Fetcham Mill Borehole, Surrey, England: **Earliest Cenomanian**)

1967 Clarke & Verdier (Isle of Wight, England: **Early Cenomanian - earliest Turonian**) as *Pyramidium alatum*

1970 Davey (Fetcham Mill Borehole, Surrey; Compton Bay, Isle of Wight, England; Escalles, France: **Cenomanian**)

1973 Davey & Verdier (France and Switzerland: **Late Albian - Early Cenomanian**)

1976 Norvick *in* Norvick & Burger (Bathurst Island, Australia: **Early Cenomanian - Early Turonian**)

1978 Bujak & Williams (Offshore South-eastern Canada: **earliest Albian - mid Coniacian**)

1980 Morgan (Australia: **Late Albian - latest Cenomanian**)

1983 Foucher (Paris Basin, France: **Early Cenomanian - Late Santonian**)

1985 Williams & Bujak (World: **Late Albian - Late Santonian**)

1986 Ioannides (Bylot Island, Arctic Archipelago: **Santonian - Campanian**)

1987 Habib & Drugg (Offshore USA, Western North Atlantic: **earliest Cenomanian - Late Coniacian/Santonian**)

1988 Mao Shaozhi & Norris (Kashi Area, Xinjiang Province, China: **Late Cretaceous**)

1988 Marshall & Batten (Lower Saxony Basin, North Germany: **Late Cenomanian - Early Turonian**)

1988 Masure (Bahamas: **Late Albian - Middle Cenomanian**)

1990 Prössl (nr. Salzgitter, North-west Germany: **Middle Albian - Late Turonian**)

1992 Costa & Davey (England and the North Sea: **Late Albian - Early Santonian**)

1993 Courtinat (Pueblo, Colorado, USA: **Late Cenomanian**)

1993 Nøhr-Hansen (North-east Greenland: **Late Albian - Early Cenomanian?)**

1993 Williams *et al.* (N. Hemisphere: **Late Albian - Santonian)**

Dimensions: Range of observed specimens: length of periphragm 59 (78) 89 µm, width of periphragm 60 (77) 87 µm, length of endophragm 40 (50) 58 µm, width of endophragm 39 (51) 60 µm. 8 specimens measured.

Comparisons: This species is very distinctive, with its intergonal and gonal spines projecting from high parasutural membranes. *Dinopterygium cladoides* is similar but does not have any intergonal spines. *Hystrichodinium pulchrum* may also appear similar with many long, thin spines, but without the high parasutural membranes.

Occurrence: Rebecca K. Bounds core (Kansas): Middle Cenomanian - Middle Turonian. Blue Point (Arizona), Bunker Hill (Kansas), Pueblo (Colorado), Wahweap Wash (Utah): Late Cenomanian - Early Turonian.

Order **Peridiniales** Haeckel, 1894

Suborder **Peridiniineae** (Autonym)

Family **Peridiniaceae** Ehrenberg, 1831

Subfamily **Palaeoperidinioideae** (Vozzhennikova, 1961) Bujak & Davies, 1983

Genus *Chichaouadinium* Below, 1981

Chichaouadinium boydii (Morgan, 1975) Bujak & Davies, 1983

Plate 38, Figure 2 & 3

1980 Morgan (Australia: **mid Aptian - Late Albian)** as *Spinidinium boydii*

1990 Prössl (nr. Salzgitter, North-west Germany: **Early Albian - Late Cenomanian)**

Dimensions: Range of observed specimens: length of periphragm 45 (51) 60 µm, width of periphragm 37 (41) 47 µm, length of endophragm 34 (36) 39 µm, width of endophragm 32 (36) 37 µm. Length/width ratio 1.18 (1.26) 1.32. 4 specimens measured.

Comparisons: *Chichaouadinium boydii* is very similar to *C. vestitum* but has a more rounded outline, a shorter length in comparison to its width, and is ornamented with solid granules and truncate spines.

Occurrence: Rebecca K. Bounds core (Kansas): Late Cenomanian - Middle Turonian. Pueblo (Colorado): Late Cenomanian.

Chichaouadinium vestitum (Brideaux, 1971) Bujak & Davies, 1983

Plate 38, Figure 1

1971 Brideaux (Central Alberta, Canada: **Late Albian)** as *Spinidinium vestitum*

1971 Singh (North-west Alberta, Canada: **mid - Late Albian)** as *Spinidinium vestitum*

1971 Burgess (Central Wyoming, USA: **Early Cenomanian)** as *Diconodinium caulleryi*

1978 Bujak & Williams (Offshore South-eastern Canada: **Middle Albian - latest Cenomanian**) as *Spinidinium vestitum*

1979 May & Stein (Alaska, USA: **mid - Late Albian**) as *Spinidinium vestitum*

1979 May (North Slope, Alaska, USA: **Middle Albian**) as *Spinidinium vestitum*

1982 Nichols, Jacobson & Tschudy (Wyoming & Montana, USA: **Albian**) as *Spinidinium vestitum*

1983 Habib & Drugg (Blake-Bahama Basin, Western Atlantic: **Middle Albian - latest Vraconian**) as *Spinidinium vestitum*

1983 Singh (North-west Alberta, Canada: **Early - Middle Cenomanian**) as *Spinidinium vestitum*

1987 Habib & Drugg (Offshore USA, Western North Atlantic: **Late Albian**)

1993 Williams *et al.* (N. Hemisphere: **Late Albian**)

1993 Nøhr-Hansen (North-east Greenland: **Middle Albian**)

Dimensions: Range of observed specimens: length of periphragm 46 (62) 84 μm, width of periphragm 35 (40) 47 μm, length of endophragm 29 (40) 59 μm, width of endophragm 29 (37) 44 μm, maximum height of ornamentation 1 (1.2) 2 μm. Length/width ratio 1.31 (1.54) 1.78. 6 specimens measured.

Comparisons: *Chichaouadinium vestitum* is very similar to *C. boydii* but has a more angular, pentagonal outline, a much longer body in proportion to its width, and is ornamented with spines and cones. The peridinioid genus *Chichaouadinium* is distinguished by its two wall layers, parasutural ornamentation and combination archaeopyle, type I + 3Pa. *Spinidinium echinoideum* is very similar but has a single plate intercalary archaeopyle (type I or Ia). *Isabelidinium gallium* is also similar but also has a single plate intercalary archaeopyle, has fewer spines, is always bicavate and has an oblate endophragm.

Occurrence: Pueblo (Colorado), Rebecca K. Bounds core (Kansas): Late Cenomanian.

Genus *Ginginodinium* Cookson & Eisenack, 1960; emend. Lentin & Williams, 1976

Ginginodinium evittii Singh, 1983

Plate 37, Figure 8

1983 Singh (North-west Alberta, Canada: **Early Cenomanian**)

Dimensions: Range of observed specimens: length of periphragm 36 (43) 51 μm, width of periphragm 33 (40) 46 μm, length of endophragm 35 (42) 48 μm, width of endophragm 33 (40) 46 μm. 7 specimens measured.

Remarks: This is an extremely distinctive, small, peridinioid species with a three-plate intercalary archaeopyle, and echinate ornamentation. The species is cornucavate with extremely small pericoels in the small apical and antapical horns.

Comparisons: Species of *Trithyrodinium* within this material also have a 3I archaeopyle but are much larger, with a thin periphragm and thicker endophragm, have a much less angular outline, and do not have spiny ornamentation. Species of *Chichaouadinium* within this material also may appear similar, but are also larger, circumcavate and have a combination (I + 3Pa) archaeopyle.

Occurrence: Rebecca K. Bounds core (Kansas): Early Cenomanian - Middle Turonian. Blue Point (Arizona), Pueblo (Colorado): Late Cenomanian.

Genus *Palaeohystrichophora* Deflandre, 1935; emend. Deflandre & Cookson, 1955

Palaeohystrichophora infusorioides Deflandre, 1935

Plate 33, Figures 1 & 2

1960a Cookson & Eisenack (Perth & Carnarvon Basins, Australia: **Albian - Campanian)**
1964 Cookson & Hughes (Cambridgeshire, England: **Early Cenomanian)**
1964 Manum & Cookson (Arctic Canada: **'mid Cretaceous')**
1967 Clarke & Verdier (Isle of Wight, England: **Early Cenomanian - Late Santonian)**
1969 Cookson & Eisenack (Balcatta, nr. Perth, Australia: **Albian/Cenomanian)**
1970 Davey (Fetcham Mill Borehole, Surrey; Compton Bay, Isle of Wight, England; Escalles, France: **Cenomanian)**
1970 Habib (Bahamas: **Albian/Cenomanian)**
1973 Davey & Verdier (France and Switzerland: **Early Vraconian - Early Cenomanian)**
1976 Norvick *in* Norvick & Burger (Bathurst Island, Australia: **Early Cenomanian - Early Turonian)**
1978 Bujak & Williams (Offshore South-eastern Canada: **Late Albian - Late Campanian)**
1980 May (New Jersey, USA: **Late Campanian)**
1980 Morgan (Australia: **earliest Vraconian - latest Cenomanian)**
1981 Below (South-west Morocco: **Vraconian - Early Cenomanian)**
1982 Below (Morocco: **Vraconian - Early Cenomanian)**
1982 Nichols, Jacobson & Tschudy (Wyoming & Montana, USA: **earliest Turonian - latest Santonian)**
1983 Foucher (Paris Basin, France: **Early Cenomanian - Late Campanian)**
1983 Habib & Drugg (Blake-Bahama Basin, Western Atlantic: **Middle Albian - latest Vraconian)**
1983 Singh (North-west Alberta, Canada: **Middle Cenomanian)**
1984 Below (Mazagan Plateau, Offshore North-west Africa: **Late Albian - Early Cenomanian)**
1986 Ioannides (Bylot Island, Arctic Archipelago: **Santonian/Campanian - Maastrichtian)**
1987 Habib & Drugg (Offshore USA, Western North Atlantic: **Middle Albian - Late Coniacian/Santonian)**
1988 Mao Shaozhi & Norris (Kashi Area, Xinjiang Province, China: **Late Cretaceous)**
1988 Marshall & Batten (Lower Saxony Basin, North Germany: **Late Cenomanian - Early Turonian)**
1989 Aurisano (New Jersey & Delaware, USA: **Cenomanian - Early Maastrichtian)**
1989 Habib & Milner (South Carolina & Georgia, USA: **Campanian - Early Maastrichtian)**

1990 Harker *et al.* (Interior Plains of Canada: **Early - Late Campanian**)
1990 Prössl (nr. Salzgitter, North-west Germany: **earliest Cenomanian - Late Turonian**)
1991 Kirsch (Germany: **Turonian - mid Campanian**)
1992 Costa & Davey (England and the North Sea: **Late Albian - latest Campanian**)
1992 Mohr & Gee (Kerguelan Plateau, Southern Indian Ocean: **Late Cenomanian - Late Coniacian**)
1993 Courtinat (Pueblo, Colorado, USA: **Late Cenomanian**)
1993 Nøhr-Hansen (North-east Greenland: **Late Albian - Early Cenomanian?**)
1993 Williams *et al.* (N. Hemisphere: **Cenomanian - Early Maastrichtian**)
1994a Tocher & Jarvis (Fumichon, Normandy, France: **Early - Middle Cenomanian**)

Dimensions: Range of observed specimens: length of periphragm 45 (49) 52 µm, width of periphragm 28 (34) 40 µm, length of endophragm 29 (33) 38 µm, width of endophragm 28 (34) 40 µm, maximum length of processes 4 (9) 12 µm. 8 specimens measured.

Comparisons: This small species of peridinioid cyst is easily recognised with its bicavate to cornucavate, often bi-conical shape and fairly long, rigid hair-like processes. A complete gradation exists with *Subtilisphaera cheit* which may be slightly larger, with smaller pericoels and much shorter, finer hairs. Any specimens with either long, rigid hairs or a bi-conical shape were placed in *P. infusorioides*. *Subtilisphaera zawia* is also similar, with a more angular body, a thin and long left antapical horn, and shorter, finer hairs. *Subtilisphaera habibi* is also very similar but possesses parasutural ridges and the hairs are pandasuturally aligned.

Occurrence: Rebecca K. Bounds core (Kansas): Early Cenomanian - Middle Turonian. Blue Point (Arizona), Bunker Hill (Kansas), Pueblo (Colorado), Wahweap Wash (Utah): Late Cenomanian - Early Turonian.

Genus *Palaeoperidinium* Deflandre, 1935; emend. Sarjeant, 1967b

Palaeoperidinium cretaceum Pocock, 1962; emend. Davey, 1970; emend. Harding, 1990a

Plate 38, Figure 5

1970 Davey (Saskatchewan, Canada: **Albian**) as *Astrocysta cretacea*
1971 Brideaux (Central Alberta, Canada: **mid - Late Albian**) as *Lejeunia? cretacea*
1971 Singh (North-west Alberta, Canada: **mid - Late Albian**)
1975 Brideaux & McIntyre (District of Mackenzie, Canada: **Aptian - Middle Albian**)
1978 Bujak & Williams (Offshore South-eastern Canada: **earliest Barremian - Middle Cenomanian**)
1979 May (North Slope, Alaska, USA: **Middle Albian**)
1980 Morgan (Australia: **Late Neocomian - latest Cenomanian**) as *Astrocysta cretacea*
1981 Below (South-west Morocco: **Barremian - Vraconian**)
1982 Below (Morocco: **earliest Aptian - Late Albian**)

1983 Habib & Drugg (Blake-Bahama Basin, Western Atlantic: **Late Aptian - Middle Albian)**
1983 Singh (North-west Alberta, Canada: **Early - Middle Cenomanian)**
1984 Below (Mazagan Plateau, Offshore North-west Africa: **mid Aptian - Early Cenomanian)**
1987 Habib & Drugg (Offshore USA, Western North Atlantic: **Late Barremian - Cenomanian/Turonian)**
1989 Aurisano (New Jersey & Delaware, USA: **earliest - mid Santonian)**
1990 Harker *et al.* (Interior Plains of Canada: **Late Santonian - Early Maastrichtian)**
1990 Prössl (nr. Salzgitter, North-west Germany: **Early Barremian - Late Turonian)**
1993 Courtinat (Pueblo, Colorado, USA: **Late Cenomanian)**
1993 Nøhr-Hansen (North-east Greenland: **Late Barremian - Late Albian/ Early Cenomanian?)**

Dimensions: Range of observed specimens: length of periphragm 53 (71) 81 µm, width of periphragm 41 (59) 70 µm, length of endophragm 45 (61) 70 µm, width of endophragm 38 (57) 69 µm. 8 specimens measured.

Remarks: This is a distinctive peridinioid cyst, with acuminate antapical horns and a thin, wrinkled periphragm.

Occurrence: Rebecca K. Bounds core (Kansas): Middle Cenomanian - Middle Turonian. Blue Point (Arizona), Bunker Hill (Kansas), Pueblo (Colorado), Wahweap Wash (Utah): Late Cenomanian - Early Turonian.

Genus *Subtilisphaera* Jain & Millepied, 1973; emend. Lentin & Williams, 1976

Subtilisphaera cheit Below, 1981a

Plate 33, Figures 3 & 4

1973 Davey & Verdier (France and Switzerland: **Vraconian)** as *Palaeohystrichophora* cf. *infusorioides*
1981a Below (South-west Morocco: **Aptian - Early Cenomanian)**
1982c Below (Morocco: **Albian - Early Cenomanian)**
1984 Below (Mazagan Plateau, Offshore North-west Africa: **Late Aptian - earliest Cenomanian)**
1989 Aurisano (New Jersey & Delaware, USA: **Cenomanian - Early Maastrichtian)** as *Palaeohystrichophora infusorioides* Variant B (p.170 & pl.4, No.2 & 3) (pars)
1990 Prössl (nr. Salzgitter, North-west Germany: **Middle Albian - Late Cenomanian)**

Dimensions: Range of observed specimens: length of periphragm 44 (57) 71 µm, width of periphragm 34 (42) 53 µm, length of endophragm 36 (45) 52 µm, width of endophragm 34 (42) 52 µm, maximum length of ornamentation 1 (3) 6 µm. 10 specimens measured.

Comparisons: This small species of peridinioid cyst is cornucavate with an oval to rounded endocyst, and is ornamented with short fine hairs. A complete gradation exists with *Palaeohystrichophora infusorioides* which is bicavate to cornucavate, may be slightly smaller, and is covered with much longer, coarser and more rigid hairs. Any specimens with either long, rigid hairs or a bi-conical shape were placed in *P. infusorioides*. *Subtilisphaera habibi* may appear similar but is bicavate, possesses parasutural ridges and the coarser, more rigid hairs are pandasuturally aligned. A gradation also exists with *S. zawia* which is also very similar, with a more angular body, a thin and long left antapical horn, and ornamented with fine granules or very short, fine hairs. Only specimens with a distinctively long antapical horn and angular outline were recorded as *S. zawia*. Other species of *Subtilisphaera* within this material lack the ornamentation of hairs.

Occurrence: Rebecca K. Bounds core (Kansas): Early Cenomanian - Middle Turonian. Blue Point (Arizona), Bunker Hill (Kansas), Pueblo (Colorado), Wahweap Wash (Utah): Late Cenomanian - Early Turonian.

Subtilisphaera foliacea (Eisenack & Cookson, 1960) Stover & Evitt, 1978

Plate 33, Figure 13

1960 Eisenack & Cookson (Western Australia: **Turonian - middle Senonian**) as *Deflandrea foliacea*

Dimensions: Range of observed specimens: length of periphragm 48 (52) 59 µm, width of periphragm 38 (46) 55 µm, length of endophragm 33 (37) 43 µm, width of endophragm 32 (38) 43 µm. 8 specimens measured.

Comparisons: This is a circumcavate species of *Subtilisphaera* with a subspherical endocyst and short, blunt apical and antapical horns. *Subtilisphaera? inaffecta* is similar but is cornucavate, with small pericoels. *Subtilisphaera cheit* is ornamented with fine hairs. Other species of *Subtilisphaera* within this material, have much longer and more pointed apical and antapical horns.

Occurrence: Rebecca K. Bounds core (Kansas): Late Cenomanian - Middle Turonian. Bunker Hill (Kansas): Late Cenomanian. Pueblo (Colorado): Late Cenomanian - Early Turonian. Wahweap Wash (Utah): Early Turonian.

Subtilisphaera hyalina Singh, 1983

Plate 33, Figures 11 & 12

1983 Singh (North-west Alberta, Canada: **Middle Cenomanian**)

Dimensions: Range of observed specimens: length of periphragm 68 (77) 87 µm, width of periphragm 46 (50) 54 µm, length of endophragm 37 (42) 50 µm, width of endophragm 42 (45) 50 µm. 7 specimens measured.

Comparisons: This species is distinguished by a well defined paracingulum, and a very thin, hyaline periphragm, which consistently forms a short right antapical horn and long left antapical horn which is almost as long as the conical apical horn. Consequently, the species has a very concave antapical keel. *Subtilisphaera pirnaensis* is very similar but is slightly thicker-walled, with a very reduced right antapical horn forming a much flatter antapical keel.

Occurrence: Rebecca K. Bounds core (Kansas): Early Cenomanian.

Subtilisphaera? inaffecta (Drugg, 1978) Bujak & Davies, 1983

Plate 33, Figures 5 & 6

1983 Singh (North-west Alberta, Canada: **Early - Middle Cenomanian**) as *Geiselodinium inaffectum*

> **Original description:** Drugg, 1978, p. 68: *Geiselodinium inaffectum*
> Cavate cysts with a pentagonal to elliptical outline. The endocyst is circular to elliptical in outline. The pericoel is generally restricted except at the apex where the periphragm forms a broad conical horn. Specimens with a pentagonal outline sometimes exhibit a slightly expanded antapical pericoel and occasionally there is a weak development of two low antapical horns. A paracingulum about 6µm wide is often, but not always, present. The paracingulum is delineated by low folds or wrinkles developed on the periphragm. Additional folds are often present but there is no suggestion of any true paratabulation. The parasulcus is suggested by a break in the paracingular folds. The endophragm is slightly thicker than the periphragm but both are very thin and smooth to faintly and finely granulate. No archeopyle has been observed. The length ranges from 49 to 62 µm with most specimens being about 55 µm. The width ranges from 42 to 52 µm.

Dimensions: Range of observed specimens: length of periphragm 39 (50) 68 µm, width of periphragm 34 (41) 50 µm, length of endophragm 29 (40) 52 µm, width of endophragm 34 (41) 50 µm. 12 specimens measured.

Remarks: This is very common in the material studied and conforms exactly with the original description of the species which was initially found in the Jurassic of Southern England.

Comparisons: *Subtilisphaera cheit* is very similar in shape and size, but has a variable ornamentation of short, fine hairs. *Subtilisphaera foliacea* is also similar but is circumcavate. Other species of *Subtilisphaera* have much longer apical and antapical horns.

Occurrence: Rebecca K. Bounds core (Kansas): Early Cenomanian - Middle Turonian. Blue Point (Arizona), Bunker Hill (Kansas), Pueblo (Colorado), Wahweap Wash (Utah): Late Cenomanian - Early Turonian.

Subtilisphaera? pirnaensis (Alberti, 1959b) Jain & Millipied, 1973

Plate 33, Figure 10

1978 Bujak & Williams (Offshore South-eastern Canada: **earliest Turonian - mid Coniacian)**

1988 Mao Shaozhi & Norris (Kashi Area, Xinjiang Province, China: **Late Cretaceous)**

1990 Harker *et al.* (Interior Plains of Canada: **Early - Late Campanian)**

Dimensions: Range of observed specimens: length of periphragm 56 (69) 83 µm, width of periphragm 35 (44) 53 µm, length of endophragm 37 (43) 53 µm, width of endophragm 33 (40) 49 µm. 9 specimens measured.

Comparisons: This is a large, circumcavate species of *Subtilisphaera*. The triangular epicyst is larger than the hypocyst, and forms a conical apical horn with concave sides. Two antapical horns are present, one of which is very reduced, and which are joined by a flat to slightly concave antapical keel. *Subtilisphaera hyalina* is very similar but has a thinner periphragm and much longer antapical horns with a very concave antapical keel. *Subtilisphaera deformans* is also similar but is camocavate, with the endocyst laterally appressed to one side of the pericyst. *Subtilisphaera pontis-marie* is also similar with a long apical horn but only a single, asymmetrically placed, long antapical horn. *Subtilisphaera zawia* has a similar shape but is smaller, cornucavate to bicavate and ornamented with fine granules or very short, fine hairs.

Occurrence: Rebecca K. Bounds core (Kansas): Early Cenomanian - Middle Turonian. Blue Point (Arizona), Bunker Hill (Kansas), Pueblo (Colorado), Wahweap Wash (Utah): Late Cenomanian - Early Turonian.

Subtilisphaera pontis-marie (Deflandre, 1936b) Lentin & Williams, 1976

Plate 33, Figures 7 & 8

1970 Davey (Saskatchewan, Canada: **Albian - Cenomanian**) as *Deflandrea pontis-mariae*

1978 Bujak & Williams (Offshore South-eastern Canada: **earliest Albian - latest Cenomanian)**

1983 Foucher (Paris Basin, France: **Late Turonian - latest Santonian)**

1983 Habib & Drugg (Blake-Bahama Basin, Western Atlantic: **Late Albian - latest Vraconian)**

1983 Singh (North-west Alberta, Canada: **Early Cenomanian)**

1987 Habib & Drugg (Offshore USA, Western North Atlantic: **Late Albian - Cenomanian/Turonian)**

1988 Marshall & Batten (Lower Saxony Basin, North Germany: **Late Cenomanian - Early Turonian)**

1993 Courtinat (Pueblo, Colorado, USA: **Late Cenomanian)**

Dimensions: Range of observed specimens: length of periphragm 55 (66) 89 µm, width of periphragm 33 (40) 51 µm, length of endophragm 36 (40) 49 µm, width of endophragm 33 (39) 50 µm. 9 specimens measured.

Comparisons: This is a distinctive bicavate to circumcavate species of *Subtilisphaera* with a rounded endocyst, a long apical horn and a single, long, asymmetrically placed antapical horn, both of which have concave sides. *Subtilisphaera pirnaensis* and *S. deformans* are similar but have broader horns, a more angular endocyst and two antapical horns, one of which is very reduced. *Subtilisphaera hyalina* has two distinct antapical horns. Other species of *Subtilisphaera* have much shorter horns. *Palaeohystrichophora infusorioides* has a similar shape but possesses many rigid, coarse hairs.

Occurrence: Rebecca K. Bounds core (Kansas): Early Cenomanian - Middle Turonian. Bunker Hill (Kansas), Pueblo (Colorado), Wahweap Wash (Utah): Late Cenomanian - Early Turonian.

Subtilisphaera zawia Below, 1981a

Plate 33, Figure 9

1981 Below (South-west Morocco: **Albian)**

1982 Below (Morocco: **Albian)**

1989 Aurisano (New Jersey & Delaware, USA: **Cenomanian - Early Maastrichtian)** as *Palaeohystrichophora infusorioides* Variant B (p. 170 & pl. 4, No. 4 & 5) (pars)

Dimensions: Range of observed specimens: length of periphragm 51 (59) 70 μm, width of periphragm 39 (43) 49 μm, length of endophragm 37 (43) 49 μm, width of endophragm 37 (41) 49 μm, maximum length of ornamentation 1 (2.2) 3 μm, length of larger antapical horn 5 (8) 10 μm. 6 specimens measured.

Remarks: This cornucavate to bicavate species has a triangular epicyst with a short, narrow apical horn, and a trapezoidal hypocyst with straight to concave sides and two antapical horns, one of which is short and blunted, while the other is longer, narrower, continuously tapering and curves outwards. The cyst is variably ornamented with fine granules or very short, fine hairs.

Comparisons: A gradation exists with *S. cheit* which is cornucavate, has a less angular outline with an oval to rounded endocyst, has less acute horns and is ornamented with short fine hairs. Only specimens with a distinctively long antapical horn and angular outline were recorded as *S. zawia*. *Subtilisphaera pirnaensis* is similar but is hairless and circumcavate with a more elongate outline and much larger pericoels.

Occurrence: Rebecca K. Bounds core (Kansas): Early Cenomanian - Middle Turonian. Pueblo (Colorado): Late Cenomanian. Wahweap Wash (Utah): Late Cenomanian - Early Turonian. Blue Point (Arizona): Early Turonian.

Subfamily **Deflandreoideae** Bujak & Davies, 1983

Genus *Alterbidinium* Lentin & Williams, 1985; emend. Khowaja-Ateequzzaman *et al.*, 1991, *nom. subst. pro Albertia* Vozzhennikova, 1967, *non Albertia* Lentin & Williams, 1976

Alterbidinium emulatum Mao Shaozhi & Norris, 1988

Plate 35, Figures 7 & 8

1971 Burgess (Central Wyoming, USA: **Cenomanian - Early Turonian)** as *Deflandrea* sp. cf. *D. acuminata* (pars)

1982 Nichols & Jacobson (Wyoming & Montana, USA: **Middle Cenomanian - Late Turonian)** as *Alterbia* sp. A

1982 Nichols, Jacobson & Tschudy (Wyoming & Montana, USA: **Middle Cenomanian - Late Turonian)** as *Alterbia* sp. A

1988 Mao Shaozhi & Norris (Kashi Area, Xinjiang Province, China: **Late Cretaceous)**

Original diagnosis: Mao Shaozhi and Norris, 1988, p. 41
Cyst proximate, circumcavate, elongated pentagonal with straight or convex sides. Both apical and left antapical horns short with broad bases. Endoblast subspherical to oval, relatively large, close to periphragm laterally, resulting typically in two narrow ambital pericoels. Archeopyle intercalary, type (I), attenuated hexa 2a. Transverse archeopyle index (AI) 0.35 to 0.47.

Original description: Mao Shaozhi and Norris, 1988, p. 41
Cyst laterally assymetrical, ambitus biconical. Apical horn short, bluntly pointed, formed by tapering of two sides of epitract; a small circular thickening, about 2 to 3 μm diameter, usually at

top. Left antapical horn pointed with very broad base; right one either poorly developed or, more often, undeveloped. Shape of endoblast approximately paralleling that of periblast (see Text-Fig. 12); sometimes endoblast protruding to base of apical and left antapical horns. Periphragm thin and granulate, endophragm smooth. Cingulum usually present, 4 to 6 μm wide, slightly laevorotary, delineated by wavy folds or low denticulate ridges. Sulcus restricted to hypotract. Archeopyle on periphragm attenuated hexa, with hexagonal 2a, relatively longer anterior lateral sides (H2 and H6), and reduced posterior lateral sides (H3 and H5); the anterior margin (H,) much shorter than posterior margin (H4), giving hexagonal archeopyle a superficially triangular shape. Archeopyle on endophragm not clearly discernible. Dimensions - Overall: length 61 to 80 μm (holotype 75 μm), width 40 to 50 μm (holotype 46 μm); endoblast: length 36 to 60 μm (holotype 50 μm), width 30 to 45 μm (holotype 42 μm).
Affinities: Mao Shaozhi and Norris, 1988, p. 41
Alterbidinium emulatum resembles *A. acutulum* and *Isabelidinium acuminatum*. It differs *from A. acutulum* in having a cyst that is plump, with two sides of the epitract straight or convex, and apical and left antapical horns that are much shorter. *I. acuminatum* differs from *A. emulatum* in possessing (1) an endoblast of smaller size, located more centrally in the cyst, and a circular ambitus slightly pointed towards the apex and (2) a relatively wide pericoel between the endophragm and periphragm. *A. emulatum* also shows some similarity to *Deflandrea psilata*, but the latter is smaller (48 to 50 μm).

Dimensions: Range of observed specimens: length of periphragm 57 (66) 76 μm, width of periphragm 38 (44) 55 μm, length of endophragm 38 (48) 64 μm, width of endophragm 31 (38) 47 μm. 14 specimens measured.

Remarks: The specimens of *Alterbidinium emulatum* found were consistent with the original description. It seems probable, from the scant descriptions and plates, that *Alterbia* sp. A of Nichols & Jacobson (1982), and Nichols, Jacobson & Tschudy (1982), and some of the specimens of *Deflandrea* sp. cf. *D. acuminata* of Burgess (1971), are conspecific with *A. emulatum*.

Comparisons: The genus *Alterbidinium* is distinguishable by an endophragm which parallels the shape of the periphragm (i.e. which has blunted apical and antapical horns). *Alterbidinium emulatum* is distinguishable from other similar cysts, by its finely granular periphragm, long, conical epicyst and comparatively small antapical pericoel. *Eurydinium ingramii* is similar but is psilate, with a rounded endophragm. *Eurydinium eyrensis* is also similar but is more coarsely and densely granulate with a rounded endophragm. *Alterbidinium emulatum* has a narrower, more elongate body and a narrower, more conical epicyst, than *A. rhombovale*, which is psilate. *Isabelidinium magnum* is also similar but is larger and psilate, with a thinner, flimsy periphragm and larger apical and antapical pericoels.

Occurrence: Blue Point (Arizona), Bunker Hill (Kansas): Late Cenomanian - Early Turonian. Pueblo (Colorado): Late Cenomanian. Wahweap Wash (Utah): Early Turonian.

Alterbidinium rhombovale (Cookson & Eisenack, 1970a) n. comb.

Plate 36, Figures 5 & 6

1970 Cookson & Eisenack (Eucla Basin, Western Australia: **Albian - Senonian**) as *Deflandrea rhombovale*

1970 Davey (Saskatchewan, Canada: **Albian - Cenomanian,** Fetcham Mill Borehole, Surrey, England: **Turonian**) as *Deflandrea pirnaensis*

1983 Singh (North-west Alberta, Canada: **Middle Cenomanian**) as *Alterbia daveyi*

1986 Ioannides (Bylot Island, Arctic Archipelago: Santonian/Campanian) as *Alterbia* sp. cf. *A. foliacea*

Original description: Cookson and Eisenack, 1970, p.143: *Deflandrea rhombovalis*
Shell small, somewhat flat, rounded-rhomboidal to nearly oval in outline, with a short, blunt to truncate apical horn and a small, pointed to rounded antapical horn situated towards one side of the hypotheca. Girdle median, slightly indicated or missing. In the holotype the ventral furrow is in evidence and the wavy thickening which we associate with the flagellum pore and have herein recorded for several other types is clearly indicated.
The capsule is approximately circular in outline and does not fill the shell laterally; its wall is only slightly thicker than that of the shell. The shell opens by means of a small, approximately five-sided archeopyle, as is evident in the holotype, but to one side of the epitheca due to faulty preservation.
Dimensions: Based on 20 examples. Holotype: length c. 54 μm, breadth 44 μm. Range: length c. 46-56 μm, breadth 36-44 μm.
Affinities: Cookson and Eisenack, 1970, p.143: *Deflandrea rhombovalis*
The differences between this species and other small and smooth species of *Deflandrea* are the blunt, truncate and slightly inverted apical horn and the pointed antapical horn.

Alterbidinium "daveyi" (Stover and Evitt, 1978, = *Deflandrea pirnaensis* Alberti, 1959b of Davey, 1970, non *Deflandrea pirnaensis* Alberti, 1959b) Lentin and Williams, 1985
Holotype: not designated; name not validly published. Originally *Alterbia* (an illegitimate generic name and name not validly published), subsequently *Alterbidinium* (name not validly published).

Original Description: Davey, 1970, p. 338, pl.1 figs. 3, 4: *Deflandrea pirnaensis*
This is a variable species having a broadly ovoidal shell with a well developed apical horn and typically one antapical horn. Rarely a second, much reduced, antapical horn is present. The periphragm is smooth or lightly granular. The cingulum is marked by two low ledges, sometimes having knobbly margins, and is occasionally crossed by low ridges delimiting the plate boundaries. The sulcus is rarely visible. The intercalary archaeopyle, when discernable, possesses a rounded polygonal outline. The operculum is usually in position and opened as a flap. The inner body is oval, slightly thicker than the periphragm, and is occasionally concave posteriorly. It is usually separated for most of its circumference from the outer membrane by a narrow space.
Dimensions: Range of observed specimens: overall length 46 (62.7) 87 μm, overall width 34 (45.5) 63 μm, length of inner body 33 (43.9) 57 μm, width of inner body 31 (38.2) 45 μm. Number of specimens measured, 15.

Dimensions: Range of observed specimens: length of periphragm 53 (65) 80 μm, width of periphragm 42 (53) 65 μm, length of endophragm 35 (45) 56 μm, width of endophragm 38 (45) 56 μm. 12 specimens measured.

Remarks: Cookson & Eisenack (1970a) described and named a species *Deflandrea rhombovale* which was transferred to *Isabelidinium?* by Lentin & Williams (1977a).

Davey (1970) described (and incorrectly named) a species he had found, as *Deflandrea* (now *Subtilisphaera*) *pirnaensis*. Stover & Evitt (1978) transferred this species to *Alterbidinium daveyi* but no holotype was designated, and consequently, Lentin & Williams (1993) declared this species invalid.

My material contains a species with numerous specimens, which fulfills both species descriptions, some of which match the holotype illustration of *Isabelidinium? rhombovale* and some of which match the holotype illustration of *Alterbidinium 'daveyi'*, which are only slightly and subtly different. From observations of the population within this material, and allowing for only minor intraspecific variation, which is noted and included within both original species descriptions, I conclude that these two species are conspecific. Since no holotype has been validly published for *Alterbidinum 'daveyi'* (and hence the name is illegitimate), the species *Deflandrea rhombovale* must take priority.

Species assigned to the genus *Isabelidinium* are supposed to have circular to oblate endocysts (i.e. width equal to or longer than longitudinal length), and are bicavate to circumcavate. Species assigned to the genus *Alterbidinium* are circumcavate to bicavate, with circular/ovoidal/rhomboidal endophragms, often with a slight apical protuberance. The shape of the endophragm approximates that of the periphragm except in the vicinity of the horns. The endocyst is elongated in an anterior-posterior direction.

Consequently, I reject the transferal of *Deflandrea rhombovale* to *Isabelidinium?* on the basis of the shape of the endocyst, which often approximates that of the pericyst, is often longer than it is wide, and sometimes has a slight apical protuberance, and occasionally slight antapical protuberances. This endocyst outline is typical of the genus *Alterbidinium* to which the original Davey material had been transferred.

Occurrence: Rebecca K. Bounds core (Kansas): Middle Cenomanian - Middle Turonian. Blue Point (Arizona), Bunker Hill (Kansas), Pueblo (Colorado), Wahweap Wash (Utah): Late Cenomanian - Early Turonian.

Genus *Chatangiella* Vozzhennikova, 1967; emend. Lentin & Williams, 1976; emend. Marshall, 1988

Chatangiella granulifera granulifera (Manum, 1963) Lentin & Williams, 1976

Plate 36, Figure 1 & 2

1964 Manum & Cookson (Arctic Canada: **'mid Cretaceous'**) as *Deflandrea granulifera*

1978 Bujak & Williams (Offshore South-eastern Canada: **earliest Campanian - latest Maastrichtian**)

1986 Ioannides (Bylot Island, Arctic Archipelago: **Santonian/Campanian**)

1989 Aurisano (New Jersey & Delaware, USA: **Early Santonian - Campanian**) as *Chatangiella vnigri*

1990 Harker *et al.* (Interior Plains of Canada: **Early - Late Campanian**)

1992 Costa & Davey (England and the North Sea: **earliest Turonian - latest Campanian**)

Dimensions: Range of observed specimens: length of periphragm 96 (107) 118 μm, width of periphragm 65 (69) 72 μm, length of endophragm 51 (59) 68 μm, width of endophragm 60 (64) 72 μm. 5 specimens measured.

Comparisons: It is distinguished from other species of the genus *Chatangiella* within this material, by its very broad, prominent 'shoulders' and near parallel sides. This species is always bicavate, with a standard rounded to subhexagonal hexa archaeopyle and a fine and continuous cover of granulae. Only the specimens which fulfil all the above criteria have been placed within this species. *Chatangiella spectabilis* is thinner-walled, psilate to very finely granulate, circumcavate, and generally has convergent sides, sloping 'shoulders', and a standard to attenuated hexa archaeopyle. *Chatangiella granulifera tenuis* is an intermediate form between *C. granulifera* and *C. spectabilis*, and may be circumcavate, thinner walled, psilate to finely granulate, have convergent sides, sloping 'shoulders' and an attenuated hexa archaeopyle. *Chatangiella victoriensis* is ornamented with scattered baculae, generally with convergent sides and sloping 'shoulders'.

Occurrence: Rebecca K. Bounds core (Kansas): Middle Turonian.

Chatangiella granulifera tenuis Davey, 1970

Plate 36, Figure 3 & 4

1964 Manum & Cookson (Arctic Canada: **'mid Cretaceous'**) as *Deflandrea granulifera*

1970 Davey (Saskatchewan, Canada: **Albian - Cenomanian**) as *Deflandrea granulifera* var. *tenuis*

Original Diagnosis: Davey, 1970, pp. 340 - 341: *Deflandrea granulifera* var. *tenuis*
A variety of *D. granulifera* Manum possessing smooth to lightly granular outer membrane surrounding relatively small, thin-walled inner body.

Original Dimensions: Holotype : shell diameter 85 by 60 μm, inner body diameter 39 by 60 μm. Range : overall length 85-114 μm, overall width 52-63 μm, diameter of inner body 39-60 μm. Number of specimens measured, 8.

Original Description: *D. granulifera* var. *tenuis* has only been obtained from the Saskatchewan samples and appears to be quite variable. The shell is elongate, typically widest in the cingular region and narrowing anteriorly before broadening to form rounded 'shoulders'. The epitract terminates with a conical apical horn, blunted distally. The posterior end of the shell is flat to concave, bearing one pointed conical horn and sometimes a secondary rudimentary one. The slightly spiral cingulum is always well developed and bordered by fairly high ridges possessing knobbly margins. At regular intervals the bordering ridges of the cingulum are absent, thus it is discontinuous. The sulcus is wide and extends anteriorly from the antapical horns. A rounded, hexagonal intercalary archaeopyle is typically present. The outer membrane is thin and may be smooth or densely granular. The inner body is subspherical, has a slightly thicker wall and is usually more heavily granular than the outer membrane. Occasionally the inner body is in contact with the lateral walls of the shell but more often its small size does not permit this.

Original Remarks: Manum (1962) gave a detailed analysis of *D. granulifera* from the Upper Cretaceous of Arctic Canada and noted that two forms appeared to be present. These forms differed in the density of the granulation and also in the thickness of the inner body wall. Since some intergradation between the two forms existed, Manum considered that both forms should be placed in the single species of *D. granulifera*. The more typical form possesses a dense granulation with an inner body wall of approximately 2 μm thickness. The other, rarer form, which is the only one represented in the Saskatchewan material, possesses a smooth to lightly granular outer membrane, and an inner body with a thin wall only slightly thicker than the outer membrane. Another differentiating feature is that the inner body is smaller in this form and is not in contact with the lateral walls of the shell. This form, because of these distinguishing features is here created a variety of *D.granulifera*. *D. granulifera* var. *tenuis* nov. is rather similar to *D. spectabilis* Alberti (1959), especially in some specimens when the shoulders are not particularly pronounced. The inner body of *D. spectabilis*, from the Senonian of Germany, is extremely delicate and difficult to discern. Thus *D. granulifera* var. *tenuis*, which possesses a light granulation and a thin-walled inner body, appears to occupy an intermediate position between the typical form of *D. granulifera* and *D. spectabilis* and warrants its distinction as a variety.

Moderately, well preserved specimens are extremely rare due to the thinness of the shell wall.

Dimensions: Range of observed specimens: length of periphragm 90 (100) 118 µm, width of periphragm 56 (64) 77 µm, length of endophragm 30 (51) 68 µm, width of endophragm 50 (59) 72 µm. 13 specimens measured.

Comparisons: This subspecies was originally set up as a variety, probably to fill in a taxonomic gap. In practice, a complete gradation exists between two end member species; *Chatangiella spectabilis* and *C. granulifera*. This gradation was noted by Davey (1970) and those specimens occupying an intermediate position were placed in *C. granulifera* var. *tenuis*. The gradation is not a simple one but includes a number of variables, including: the size and prominence of 'shoulders'; the shape of the archaeopyle (from a standard hexa (roughly equidimensional) to an attenuated hexa (vertically elongate and narrowing towards the apex); whether the cyst is bicavate or circumcavate; the thickness of wall layers (with particular taxonomic importance resting on the thickness of the endophragm); and the degree of granulation (ranging from psilate to granulate). After careful observation of the populations of these species, I have decided to follow this proposal. Consequently, *C. granulifera tenuis* has become a 'bucket' for all of the intermediate forms between the two end member species. Many of the specimens are very similar to *C. tripartita* which is longer in proportion to its width, bicavate and finely to coarsely granulate, with a thicker endophragm.

Occurrence: Rebecca K. Bounds core (Kansas): Middle Turonian.

Chatangiella spectabilis (Alberti, 1959b) Lentin & Williams, 1976

Plate 35, Figures 4 & 5

1986 Ioannides (Bylot Island, Arctic Archipelago: **Santonian/Campanian)**
1990 Harker *et al.* (Interior Plains of Canada: **Late Santonian - Early Maastrichtian)**
1991 Kirsch (Germany: **Late Santonian)**
1992 Costa & Davey (England and the North Sea: **Late Santonian - Late Maastrichtian)**

Dimensions: Range of observed specimens: length of periphragm 95 (108) 117 µm, width of periphragm 65 (73) 81 µm, length of endophragm 41 (53) 69 µm, width of endophragm 43 (56) 70 µm. 11 specimens measured.

Comparisons: The specimens placed within *C. spectabilis*, have been restricted to those which are definitely circumcavate, with a thin periphragm, an extremely thin endophragm and no more than very fine granulation. A gradation exists with *C. granulifera*, with intermediate forms which may be bicavate and/or have thicker endophragms and/or have coarser granulation, placed within *Chatangiella granulifera tenuis*.

A gradation exists with *Isabelidinium magnum* which is very similar but tends to have a thinner wall (which is often folded to some extent), has a conical epi-periphragm (i.e. with straight, or even slightly concave sides instead of convex with 'shoulders'), has a flatter-based antapical keel, and may be bicavate. Only those specimens with a thin, membranous periphragm and very poorly developed 'shoulders' were placed in *I. magnum*. *Eurydinium ingrammii* is also similar to *C. spectabilis* but is slightly smaller, with a prolate endophragm and an oval (rather than a rounded pentagonal) outline.

Occurrence: Bunker Hill (Kansas), Pueblo (Colorado): Early Turonian. Rebecca K. Bounds core (Kansas): Early Turonian - Middle Turonian.

Chatangiella victoriensis (Cookson & Manum, 1964) Lentin & Williams, 1976

Plate 35, Figure 6

1967 Clarke & Verdier (Isle of Wight, England: **Late Santonian)** as *Deflandrea victoriensis*
1978 Bujak & Williams (Offshore South-eastern Canada: **earliest Coniacian - mid Campanian**
1983 Foucher (Paris Basin, France: **Middle Turonian - Late Santonian)**
1985 Williams & Bujak (World: **Turonian/Coniacian boundary - Early Maastrichtian)**
1989 Aurisano (New Jersey & Delaware, USA: **Late Campanian - Early Maastrichtian)**
1989 Habib & Milner (South Carolina & Georgia, USA: **Campanian - Early Maastrichtian)**
1990 Harker *et al.* (Interior Plains of Canada: **Early - Late Campanian)**
1992 Costa & Davey (England and the North Sea: **Late Cenomanian - Early Maastrichtian)**

Dimensions: Range of observed specimens: length of periphragm 73 (97) 108 µm, width of periphragm 56 (64) 77 µm, length of mesophragm 45 (53) 62 µm (3 specimens), width of mesophragm 52 (59) 65 µm (3 specimens), length of endophragm 38 (48) 56 µm, width of endophragm 50 (57) 66 µm. 9 specimens measured.

Remarks: Three of the specimens within the population displayed a thin, finely granular to psilate mesophragm between the peri- and endocysts.

Comparisons: This species is discernible from other species of *Chatangiella* within this material, by its ornamentation of scattered rods or baculae. *Chatangiella granulifera* is similar but is only finely to coarsely granulate and generally has sides which are less convergent towards the apices, with larger, more prominent 'shoulders'.

Occurrence: Rebecca K. Bounds core (Kansas): Middle Turonian.

Genus *Eurydinium* Stover & Evitt, 1978

Eurydinium eyrensis (Cookson & Eisenack, 1971) Stover & Evitt, 1978

Plate 34, Figures 5 to 7

1971 Cookson & Eisenack (Eucla Basin, Western Australia: **'mid' Cretaceous)** as *Deflandrea eyrensis*
1988 Mao Shaozhi & Norris (Kashi Area, Xinjiang Province, China: **Late Cretaceous)**

> **Original Description:** Cookson & Eisenack, 1971, pp. 217-218; *Deflandrea eyrensis*
> Shell considerably longer than broad, resembling in that respect *D. bakeri* Deflandre & Cookson (1955) and *D. scheii* Manum (1963).
>
> Epitheca longer than the hypotheca, dome-shaped with a very short centrally-placed apical horn. Hypotheca with convex sides which slant towards a very short antapical prominence situated towards the left-hand side of the dorsal surface. Girdle circular and rather broad. Wall of shell thin, slightly to rather coarsely and densely granular especially in the upper portion of the epitheca.

> Capsule relatively large, roughly oval in shape but not reaching the lateral walls of the shell. Surface closely granular varying somewhat in the degrees of density. Archaeopyle relatively small, when clearly developed, as in the holotype, six-sided.

Dimensions: Range of observed specimens: length of periphragm 66 (80) 91 μm, width of periphragm 49 (53) 62 μm, length of endophragm 49 (55) 60 μm, width of endophragm 41 (47) 53 μm. 10 specimens measured.

Remarks: Only a few specimens were found from the Middle Turonian of the Rebecca Bounds core, but these conform well with the original description and illustration.

Comparisons: This species differs from other species of *Eurydinium* within this material, with its ornamentation of variably dense granules.

Occurrence: Pueblo (Colorado): Late Cenomanian. Blue Point (Arizona), Bunker Hill (Kansas): Early Turonian. Rebecca K. Bounds core (Kansas): Middle Turonian.

Eurydinium glomeratum (Davey, 1970) Stover & Evitt, 1978

Plate 34, Figure 3

1970 Davey (Saskatchewan, Canada: **Albian - Cenomanian**) as *Deflandrea glomerata*

Dimensions: Range of observed specimens: length of periphragm 77 (84) 89 μm, width of periphragm 65 (71) 80 μm, length of endophragm 60 (65) 73 μm, width of endophragm 60 (69) 80 μm. 6 specimens measured.

Comparisons: This is a distinctive thick-walled species with a very rounded epi-pericyst. It is longer than broad, and ideally bicavate, with a small epi-pericoel and much larger hypo-pericoel, with a relatively flat antapical keel. It seems to form a gradation with *E. saxoniense* which is shorter and circumcavate. Only specimens with a shorter length which were circumcavate were placed in *E. saxoniense*.

A gradation was also noted with *I.? globosum* which is as wide as it is long, is circumcavate to bicavate, ideally with its wall layers fairly closely appressed, with very small pericoels and with a very reduced antapical horn. Only specimens with very small pericoels and an extremely reduced antapical horn were placed in *I.? globosum*. *Eurydinium ingramii* is also similar to *E. glomeratum* but is more obviously bicavate, with a more conical epicyst and less distinctive antapical keel.

Occurrence: Blue Point (Arizona), Bunker Hill (Kansas): Early Turonian. Rebecca K. Bounds core (Kansas): Early Turonian - Middle Turonian.

Eurydinium ingramii (Cookson & Eisenack, 1970a) Stover & Evitt, 1978

Plate 34, Figure 2

1970a Cookson & Eisenack (Eucla Basin, Western Australia: **'mid' Cretaceous**)

1988 Mao Shaozhi & Norris (Kashi Area, Xinjiang Province, China: **Late Cretaceous**)

Dimensions: Range of observed specimens: length of periphragm 61 (75) 98 μm, width of periphragm 40 (54) 65 μm, length of endophragm 47 (56) 70 μm, width of endophragm 37 (47) 59 μm. 10 specimens measured.

Comparisons: This species is circumcavate to bicavate, and longer than it is wide. It differs from *E. glomeratum* in having larger pericoels, particularly beneath the apex, with a pronounced apical horn, and a narrower antapex with a less pronounced antapical horn and keel. *Eurydinium saxoniense* is similar but has a shorter length in comparison to its width, with a smaller apical horn and larger antapical horn. *Isabelidinium cooksoniae* is similar but is bicavate with an oblate endophragm. *Eurydinium eyrensis* is similar in shape but is densely ornamented with granulae.

Occurrence: Rebecca K. Bounds core (Kansas): Late Cenomanian - Middle Turonian. Blue Point (Arizona), Bunker Hill (Kansas), Pueblo (Colorado), Wahweap Wash (Utah): Late Cenomanian - Early Turonian.

Eurydinium saxoniense Marshall & Batten, 1988

Plate 34, Figure 4

1988	Marshall & Batten (Lower Saxony Basin, North Germany: **Late Cenomanian - Early Turonian)**
1993	Courtinat (Pueblo, Colorado, USA: **Late Cenomanian)**

Dimensions: Range of observed specimens: length of periphragm 51 (68) 77 μm, width of periphragm 47 (62) 73 μm, length of endophragm 42 (52) 62 μm, width of endophragm 42 (56) 67 μm. 6 specimens measured.

Comparisons: *Eurydinium saxoniense* is smaller than *E. glomeratum* and *E. ingramii* and has a rounded to slightly sub-angular epicyst, sometimes with a small apical prominence. It seems to form a gradation or complex with *E. glomeratum* which is longer, bicavate and has a large antapical pericoel. Only those specimens with a shorter length that were circumcavate were placed in *E. saxoniense*.

It also seems to form a gradation or complex with *Isabelidinium? globosum* but is circumcavate with much larger pericoels and a more pronounced antapical horn. Only those specimens with very closely appressed wall layers and a very reduced antapical horn were placed in *I.? globosum*. *Isabelidinium? rhombovale* also appears similar but is smaller and thinner walled, with a flatter-sided and more angular epicyst, and a more pronounced (though blunted) apical horn.

Occurrence: Bunker Hill (Kansas): Early Turonian. Rebecca K. Bounds core (Kansas): Early Cenomanian - Middle Turonian.

Genus *Isabelidinium* Lentin & Williams, 1977

nom. subst. pro Isabelia Lentin & Williams, 1976 *non Isabelia* Barbosa Rodrigues, 1877; emend. Marshall, 1988

Isabelidinium cooksoniae (Alberti, 1959b) Lentin & Williams, 1977a

Plate 35, Figure 3

1978 Bujak & Williams (Offshore South-eastern Canada: **earliest Santonian - mid Early Palaeocene)**

1980 May (New Jersey, USA: **Late Campanian - Maastrichtian)**

1983 Foucher (Paris Basin, France: **Late Turonian - Late Santonian)** as *Isabelia cooksoniae*

1986 Ioannides (Bylot Island, Arctic Archipelago: **Santonian/Campanian - Maastrichtian?)**

1987 Firth (Georgia, USA: **Early-Late Maastrichtian)**

1990 Harker *et al.* (Interior Plains of Canada: **earliest Campanian - Early Maastrichtian)**

1991 Kirsch (Germany: **Maastrichtian)**

1992 Costa & Davey (England and the North Sea: **Middle Turonian - Late Maastrichtian)**

> **Original Diagnosis:** Alberti, 1959b, p.97; *Deflandrea cooksoni*
> Armour flattened, its contour stretched out, pentagonal to roundish, sometimes oval, often more or less irregular. The shoulder-shaped epitheca, of approximately the length of the hypotheca, is stretched out into a tiny, more or less detached apical horn. Transverse groove usually missing, and/or slightly indented where it exists. Usually only one antapical horn, which often forms an oblique angle with the length axle of the armour. Inner body ellipsoidal, with its length crossing the one of the armour, which results in the bulging of the armour clinging close to the inner body. Armour membrane granulated, membrane of inner body rough.
> **Original Appendices:** One of the two antapical horns can be reduced partly or completely. At the level of the entirely degenerated lateral horns the armour occasionally is slightly notched, and there is seldom a transverse groove. The slip-hole is trapezoidal to roundish, the apical horn has an opening at its free end.

Dimensions: Range of observed specimens: length of periphragm 58 (71) 79 µm, width of periphragm 42 (50) 56 µm, length of endophragm 29 (34) 38 µm, width of endophragm 40 (49) 56 µm. 5 specimens measured.

Comparisons: The specimens found agree with the original description and illustrations. *Isabelidinium rhombovale* is similar but has a less elongate periphragm, with more reduced horns and is circumcavate. *Isabelidinium magnum* is also similar but has a distinctive, thin and folded periphragm, and a conical (or even concave) epicyst, with a wide, fairly flat, antapical keel. Species of *Chatangiella* are larger and have more pronounced 'shoulders'. *Chatangiella spectabilis* is similar but circumcavate and thinner walled. *Chatangiella granulifera tenuis* is also similar and may be circumcavate. *Chatangiella victoriensis* is more heavily ornamented with granulae and scattered baculae.

Occurrence: Rebecca K. Bounds core (Kansas): Middle Turonian.

Isabelidinium? globosum (Davey, 1970) Lentin & Williams, 1977a

Plate 34, Figure 1

1970 Davey (Saskatchewan, Canada: **Cenomanian)** as *Deflandrea globosa*

> **Original diagnosis:** Davey, 1970, p. 344: *Deflandrea globosa*
> Shell subspherical to subpolygonal, with small number of concentric folds at apex, and very reduced single antapical horn placed asymmetrically. Apical horn, cingulum and sulcus absent. Inner body

> entirely in contact with outer membrane. Wall smooth to slightly granular. Intercalary archaeopyle, angular, sixsided.
> **Dimensions:** Holotype: shell length 69 µm, shell width 66 µm. Range: shell length 62 (67.5) 78 µm, shell width 48 (58.8) 66 µm. Number of specimens measured, 6.
> **Original description:** This species is extremely simple in form, possessing only a very rudimentary antapical horn to mar its smooth outline. The operculum is typically in place and the archaeopyle outline is only discerned with some difficulty.
> **Affinities:** In overall appearance *D. globosa* strongly resembles *D. glomerata*. They differ in that *D. globosa* possesses a very rudimentary antapical horn and that the inner body is entirely in contact with the outer membrane. The lack of an apical horn (apical wrinkles being present), any tabulation and the spherical form indicate that these two species are closely related. Because of this and the presence of an intercalary archaeopyle, *D. globosa* is placed in the genus *Deflandrea*.

Dimensions: Range of observed specimens: length of periphragm 53 (64) 72 µm, width of periphragm 45 (57) 70 µm, length of endophragm 50 (62) 70 µm, width of endophragm 45 (56) 67 µm. 9 specimens measured.

Remarks: This species is quite distinctive, but within this material, does not strictly follow the original description all of the time. Often the wall layers are not completely appressed but are slightly separated, the cyst being circumcavate. Sometimes, on slightly more polygonal specimens, the antapical keel is a little more pronounced, with slightly larger separation of the periphragm from the endophragm, and with a larger (though still very reduced) antapical horn.

Comparisons: In practice a gradation exists with *Eurydinium glomeratum*, which is bicavate, has much larger pericoels and a much larger antapical horn. Only specimens with very small pericoels and an extremely reduced antapical horn were placed in *I.? globosum*. A gradation or complex also occurs with *E. saxoniense* which is circumcavate with a much greater separation of wall layers and a larger antapical horn. Only those specimens with very closely appressed wall layers and a very reduced antapical horn were placed in *I.? globosum*.

Occurrence: Rebecca K. Bounds core (Kansas): Early Turonian - Middle Turonian. Blue Point (Arizona), Bunker Hill (Kansas), Pueblo (Colorado): Early Turonian.

Isabelidinium magnum (Davey, 1970) Stover & Evitt, 1978

Plate 35, Figures 1 & 2

1970 Davey (Saskatchewan, Canada: **Cenomanian)** as *Deflandrea magna*
1990 Harker *et al.* (Interior Plains of Canada: **Early - mid Campanian)**
1992 Costa & Davey (England and the North Sea: **Late Cenomanian - latest Coniacian)**

Dimensions: Range of observed specimens: length of periphragm 49 (74) 94 µm, width of periphragm 38 (50) 71 µm, length of endophragm, 18 (37) 58 µm, width of endophragm 37 (46) 68 µm. 9 specimens measured.

Remarks: This large species of *Isabelidinium*, is circumcavate to bicavate, with a distinctive, thin, folded periphragm, a large, thicker endophragm, a conical (or even concave) epicyst, and a wide, fairly flat, antapical keel. The population is slightly smaller than in the original type material, but in all other respects, corresponds exactly with the original description and illustrations.

Comparisons: A gradation exists with *Chatangiella spectabilis* which is extremely similar, but is always circumcavate, has a thicker, less folded periphragm, a thinner endophragm, and narrower, concave antapical keel. Only those specimens with a thin, membranous periphragm, thicker endophragm and very poorly developed 'shoulders' were placed in *I. magnum*.

Chatangiella granulifera tenuis is also similar, with a thicker, less folded periphragm, a convex epicyst with better defined 'shoulders', a narrower, concave antapical keel, and sometimes coarser granulation. Other species of *Chatangiella* also have much better developed shoulders and tend to be bicavate. *Isabelidinium cooksoniae* is smaller, thicker walled, and bicavate, with a more rounded or convex epicyst.

Occurrence: Rebecca K. Bounds core (Kansas): Late Cenomanian - Middle Turonian. Bunker Hill (Kansas), Pueblo (Colorado): Late Cenomanian - Early Turonian. Wahweap Wash (Utah): Late Cenomanian. Blue Point (Arizona): Early Turonian.

Genus *Nelsoniella* Cookson & Eisenack, 1960a

Nelsoniella aceras Cookson & Eisenack, 1960a

Plate 38, Figure 4

1960a Cookson & Eisenack (Perth & Carnarvon Basins, Australia: **Late Turonian - Campanian/Santonian)**

Dimensions: Size of observed specimen: length of periphragm 51 μm, width of periphragm 58 μm, length of endophragm 33 μm, width of endophragm 58 μm. 1 specimen measured.

Remarks: This is a very distinctive species of camocavate peridinioid cyst, with a sub-circular outline, a large apical pericoel, no antapical pericoel, and a single-plate intercalary archaeopyle. The single specimen found is only sparsely granulate, with a very reduced apical horn, but still falls within the original description.

Occurrence: Rebecca K. Bounds core (Kansas): Early Cenomanian.

Genus *Trithyrodinium* Drugg, 1967; emend. Lentin & Williams, 1976; emend. Marheinecke, 1992

Trithyrodinium dubium Singh, 1983

Plate 37, Figures 1 to 3

1983 Singh (North-west Alberta, Canada: **Middle Cenomanian)**

Dimensions: Range of observed specimens: length of periphragm 56 (64) 73 μm, width of periphragm 39 (45) 51 μm, length of endophragm 27 (38) 49 μm, width of endophragm 31 (39) 47 μm. 9 specimens measured.

Remarks: This is a very distinctive species of *Trithyrodinium* which is bicavate to circumcavate with a much larger epi-pericoel and hypo-pericoel than is typical of the genus. The archaeopyle is also very distinctive, of type 3Ia. The operculum involves the separation of the three intercalary plates except where they are joined to their corresponding precingular plates.

Comparisons: All other species of *Trithyrodinium* within this material have 3I archaeopyles where the plates of the operculum are normally lost. *Williamsidinium banksianum* may appear similar, as it is also bicavate and has a 3(IP)a archaeopyle, with each intercalary plate joined with its neighbouring precingular plate and separated from the rest of the cyst wall, except along the margins of the precingular plates close to the paracingulum.

Occurrence: Rebecca K. Bounds core (Kansas): Middle Cenomanian - Middle Turonian. Bunker Hill (Kansas): Late Cenomanian. Pueblo (Colorado), Wahweap Wash (Utah): Late Cenomanian - Early Turonian.

Trithyrodinium evittii Drugg, 1967

1967 Drugg (California: **Danian)**

1978 Bujak & Williams (Offshore South-eastern Canada: **earliest Maastrichtian - Early Palaeocene)**

1980 May (New Jersey, USA: **Maastrichtian)**

1987 Firth (Georgia, USA: **Late Maastrichtian)**

1988 Mao Shaozhi & Norris (Kashi Area, Xinjiang Province, China: **Late Cretaceous)**

> **Original diagnosis:** Drugg, 1967, p.20 : *Trithyrodinium evittii*
> Similar in morphology to members of the genus *Deflandrea* except that the archeopyle operculum is composed of three intercalary plates functioning as a unit (see pl. 9 fig. 2). Test rounded with one short apical and two short antapical horns. The test wall is thin and smooth. The test cavity is filled by a large rounded cyst of fairly rigid construction. The cyst wall is about 1µm thick and often finely punctate. The cysts are commonly found separated from the tests in which case they are easily identifiable by the peculiar nature of the opening. A circular girdle is present on the test and is delineated by low flanges. A longitudinal furrow is suggested by folds originating near the antapical horns. The length of the test ranges from 75 to 95 µm and the width ranges from 60 to 80 µm.

Trithyrodinium sp. cf. *T. evittii* Drugg, 1967

Plate 37, Figures 6 & 7

1976 Norvick *in* Norvick & Burger (Bathurst Island, Australia: **Early Cenomanian)** as *Trithyrodinium* sp. A

Dimensions: Range of observed specimens: length of periphragm 49 (63) 75 µm, width of periphragm 44 (53) 63 µm, length of endophragm 39 (48) 51 µm, width of endophragm 41 (49) 58 µm. 12 specimens measured.

Remarks: This species is common in the material studied. Within the population from the Western Interior Basin, a certain amount of variation occurs both in the ornamentation, in the size of the archaeopyle and in the shape of the cyst itself. The periphragm is smooth, and the endophragm is smooth to finely punctate and/or finely granulate. The archaeopyle varies in size across the width of the cyst, as it does in other species of *Trithyrodinium* (for example *T. suspectum*) within this material. The shape of the endo- and periphragms also vary, sometimes with a strongly developed apical horn, sometimes with a single antapical horn and sometimes with two antapical horns. As with other species of *Trithyrodinium*, it is also common for only the endocyst to be preserved.

This species conforms well with the original description and plates of *Trithyrodinium evittii*, in most respects. However, the original description of *T. evittii* describes a smooth walled periphragm and finely punctate endophragm. In addition, previous stratigraphic occurrences of this species have been restricted to the latest Cretaceous.

However, this or a very similar species would seem to have already been described from material of this age. The description and plates of the species *Trithyrodinium* sp. A described by Norvick *in* Norvick & Burger (1976) from the Early Cenomanian of Australia, also describe a very similar form, but with no surface ornamentation. As a comparison, Norvick suggests that "*T. evittii* ... has a more inflated subspherical endocoel and a laterally less extended archaeopyle." Nevertheless, his species closely matches the original description and illustrations of *T. evittii*, and the population of *Trithyrodinium* sp. cf. *T. evittii* from this basin.

The holotype, other illustrations and the description of *T. evittii* and the illustrations and description of *Trithyrodinium* sp. A of Norvick *in* Norvick & Burger (1976), all fall within the intraspecific variation found within this material. Nevertheless, since the description for *T. evittii* does not match the full range of my own material, the synonymy can only be a tentative and equivocal one.

Comparisons: *Trithyrodinium dubium* is psilate but has much larger pericoels than *T. evittii*, and the three intercalary opercular plates remain attached along their precingular surfaces. *Trithyrodinium suspectum* has a variably dense ornamentation of baculae on its endophragm.

Occurrence: Rebecca K. Bounds core (Kansas): Early Cenomanian - Middle Turonian. Blue Point (Arizona), Bunker Hill (Kansas), Pueblo (Colorado), Wahweap Wash (Utah): Late Cenomanian - Early Turonian.

Trithyrodinium suspectum (Manum & Cookson, 1964) Davey, 1969b

Plate 37, Figures 4 & 5

1970	Davey (Saskatchewan, Canada: **Cenomanian**) as *Deflandrea suspecta*
1986	Ioannides (Bylot Island, Arctic Archipelago: **Santonian/Campanian - Maastrichtian**)
1987	Habib & Drugg (Offshore USA, Western North Atlantic: **Middle Cenomanian - Late Cenomanian/Turonian**)
1989	Aurisano (New Jersey & Delaware, USA: **Cenomanian - Early Maastrichtian**)
1991	Kirsch (Germany: **Coniacian - Late Camapanian, ?Lower Maastrichtian**)
1992	Costa & Davey (England and the North Sea: **Late Cenomanian - Early Maastrichtian**)

Dimensions: Range of observed specimens: length of periphragm 64 (67) 71 µm (7 specimens), width of periphragm 46 (53) 62 µm (7 specimens), length of endophragm 50 (57) 70 µm, width of endophragm 44 (54) 65 µm. 9 specimens measured.

Comparisons: This species is distinguished by its variably dense ornamentation of baculae on the endophragm. The periphragm is much thinner-walled and is often not preserved or in place. *Trithyrodinium rhomboideum* is similar but the endophragm is ornamented with granulae and small coni and both wall layers have two variably developed antapical horns. Other species of *Trithyrodinium* in this material have little or no ornamentation. *Ginginodinium evittii* also has a three-plate intercalary archaeopyle, but this species is much smaller, has a more angular outline, is cornucavate with extremely small pericoels in the small apical and antapical horns, and has echinate ornamentation.

Occurrence: Rebecca K. Bounds core (Kansas): Late Cenomanian - Middle Turonian. Blue Point (Arizona), Bunker Hill (Kansas), Pueblo (Colorado), Wahweap Wash (Utah): Late Cenomanian - Early Turonian.

Subfamily **Ovoidinioideae** (Norris, 1978b) Bujak & Davies, 1983

Genus *Epelidosphaeridia* Davey, 1969

Epelidosphaeridia spinosa (Cookson & Hughes, 1964) Davey, 1969a

Plate 38, Figure 6

1964 Cookson & Hughes (Cambridgeshire, England: **Early Cenomanian**) as *Palaeoperidinium spinosum*
1967 Clarke & Verdier (Isle of Wight, England: **Early - Middle Cenomanian**) as *Palaeoperidinium spinosum*
1969a Davey (Saskatchewan, Canada; Compton Bay, Isle of Wight; Fetcham Mill Borehole, Surrey, England; Escalles, France: **Albian, Cenomanian**)
1973 Davey & Verdier (France and Switzerland: **Late Albian - Early Cenomanian**)
1978 Bujak & Williams (Offshore South-eastern Canada: **earliest Albian - Middle Turonian**)
1983 Foucher (Paris Basin, France: **Early - Late Cenomanian**)
1983 Habib & Drugg (Blake-Bahama Basin, Western Atlantic: **Vraconian**)
1984 Below (Mazagan Plateau, Offshore North-west Africa: **Early Cenomanian**)
1987 Habib & Drugg (Offshore USA, Western North Atlantic: **Middle Albian - Early Cenomanian**)
1988 Masure (Bahamas: **Early - Middle Cenomanian**)
1990 Prössl (nr. Salzgitter, North-west Germany: **Late Albian - Late Cenomanian**)
1992 Costa & Davey (England and the North Sea: **Late Albian - Middle Cenomanian**)
1993 Courtinat (Pueblo, Colorado, USA: **Late Cenomanian**)
1993 Nøhr-Hansen (North-east Greenland: **Late Albian/ Early Cenomanian?**)
1994a Tocher & Jarvis (Fumichon, Normandy, France: **Early - Middle Cenomanian**)

Dimensions: Range of observed specimens: length of endophragm 40 & 50 μm, width of endophragm 37 & 40 μm, maximum height of ornamentation 2 & 1 μm, respectively. 2 specimens measured.

Remarks: This is a distinctive acavate peridinioid cyst with a combination apical-intercalary archaeopyle (tAtI) and ornamentation of short (and sometimes capitate) spines, which show some parasutural alignment.

Occurrence: Pueblo (Colorado): Late Cenomanian.

Genus *Ovoidinium* Davey, 1970; emend. Lentin & Williams, 1976; emend. Duxbury, 1983

Ovoidinium scabrosum (Cookson & Hughes, 1964) Davey, 1970

Plate 38, Figure 8

1964 Cookson & Hughes (Cambridgeshire, England: **Late Albian - Early Cenomanian**) as *Ascodinium scabrosum*
1970 Davey (Compton Bay, Isle of Wight, England: **Earliest Cenomanian**)
1973 Davey & Verdier (France and Switzerland: **Late Albian**)
1978 Bujak & Williams (Offshore South-eastern Canada: **Late Albian**)
1984 Below (Mazagan Plateau, Offshore North-west Africa: **Early Aptian - earliest Cenomanian**)
1990 Prössl (nr. Salzgitter, North-west Germany: **Middle Albian - Late Cenomanian**) as *Ascodinium scabrosum*
1992 Costa & Davey (England and the North Sea: **Late Aptian - latest Albian**)

Dimensions: Range of observed specimens (no apices): length of periphragm 31 (37) 41 µm, width of periphragm 31 (37) 43 µm, length of endophragm 26 (30) 34 µm, width of endophragm 31 (37) 43 µm. 7 specimens measured.

Comparisons: This bicavate peridinioid cyst has a detached, combination apical-intercalary archaeopyle and a scabrate to finely granulate ornamentation. *Ovoidinium verrucosum* is similar but is heavily ornamented with granulae and tuberculae. Species of *Ascodinium* have a similar archaeopyle except the operculum is adnate and they are often circumcavate.

Occurrence: Rebecca K. Bounds core (Kansas): Early Cenomanian - Late Cenomanian.

Ovoidinium verrucosum (Cookson & Hughes, 1964) Davey, 1970

Plate 38, Figure 7

1964 Cookson & Hughes (Cambridgeshire, England: **Early Cenomanian**) as *Ascodinium verrucosum*
1970 Davey (Fetcham Mill Borehole, Surrey; Compton Bay, Isle of Wight, England: **Early Cenomanian**)
1971 Burgess (Central Wyoming, USA: **Late Albian - Early Cenomanian**) as *Ascodinium* sp. cf. *A. verrucosum*
1971 Singh (North-west Alberta, Canada: **Late Albian**)
1973 Davey & Verdier (France and Switzerland: **Early Vraconian - Early Cenomanian**)
1978 Bujak & Williams (Offshore South-eastern Canada: **Late Albian**)

1982 Nichols, Jacobson & Tschudy (Wyoming & Montana, USA: **Late Albian - Middle Turonian)**
1983 Singh (North-west Alberta, Canada: **Early - Middle Cenomanian)**
1984 Below (Mazagan Plateau, Offshore North-west Africa: **earliest - Early Cenomanian)**
1990 Harker *et al.* (Interior Plains of Canada: **Early - mid Campanian)** as *Ascodinium verrucosum*
1990 Prössl (nr. Salzgitter, North-west Germany: **latest Albian - Late Cenomanian)** as *Ascodinium verrucosum*
1992 Costa & Davey (England and the North Sea: **Late Albian - Early Cenomanian)**

Dimensions: Range of observed specimens (no apices): length of periphragm 36 (44) 55 µm, width of periphragm 33 (41) 46 µm, length of endophragm 29 (32) 34 µm, width of endophragm 33 (41) 46 µm. 8 specimens measured.
Comparisons: *Ovoidinium scabrosum* is similar but has a scabrate to finely granulate ornamentation.
Occurrence: Rebecca K. Bounds core (Kansas): Early Cenomanian - Late Cenomanian. Pueblo (Colorado): Late Cenomanian.

Order uncertain

Genus *Fromea* Cookson & Eisenack, 1958; emend. Yun, 1981

This study rejects the classification of *Fromea* as an acritarch genus (Fensome *et al.*, 1993) as many specimens display a clear paracingular thickening.

Fromea amphora Cookson & Eisenack, 1958

Plate 39, Figure 8

1958 Cookson & Eisenack, (Australia: **Aptian - Cenomanian)**
1964 Cookson & Hughes (Cambridgeshire, England: **Late Albian)**
1964 Manum & Cookson (Arctic Canada: **'mid Cretaceous')**
1969a Davey (Fetcham Mill Borehole, Surrey, England; Escalles, France: **Cenomanian)**
1970 Habib (Bahamas: **Albian/Cenomanian)**
1971 Brideaux (Central Alberta, Canada: **mid - Late Albian)**
1971 Singh (North-west Alberta, Canada: **mid - Late Albian)**
1975 Brideaux & McIntyre (District of Mackenzie, Canada: **Aptian - Middle Albian)**
1978 Bujak & Williams (Offshore South-eastern Canada: **earliest Albian - mid Campanian)**
1980 Morgan (Australia: **Early Aptian - latest Cenomanian)**
1981 Below (South-west Morocco: **Hauterivian - Albian)**
1982 Below (Morocco: **Late Hauterivian - Albian)**
1983 Singh (North-west Alberta, Canada: **Early - Middle Cenomanian)**
1984 Below (Mazagan Plateau, Offshore North-west Africa: **mid Aptian - Late Albian)**
1987 Firth (Georgia, USA: **Early Maastrichtian)**

1988 Marshall & Batten (Lower Saxony Basin, North Germany: **Late Cenomanian - Early Turonian)**
1989 Habib & Milner (South Carolina & Georgia, USA: **Late Campanian)**
1990 Harker *et al.* (Interior Plains of Canada: **Late Campanian)**
1991 Kirsch (Germany: **Early Campanian)**
1992 Costa & Davey (England and the North Sea: **Late Ryazanian - Late Cenomanian)**
1993 Courtinat (Pueblo, Colorado, USA: **Late Cenomanian)**
1993 Nøhr-Hansen (North-east Greenland: **Early Barremian - Late Albian/ Early Cenomanian?)**

Dimensions: Range of observed specimens: length of cyst 48 (75) 101 μm, width of cyst 48 (68) 89 μm. 8 specimens measured.

Comparisons: This species is larger and thicker-walled than *F. fragilis* with a thickened rim to the apical archaeopyle.

Occurrence: Rebecca K. Bounds core (Kansas): Early Cenomanian - Middle Turonian. Blue Point (Arizona), Pueblo (Colorado): Late Cenomanian - Early Turonian. Bunker Hill (Kansas), Wahweap Wash (Utah): Early Turonian.

Fromea fragilis (Cookson & Eisenack, 1962b) Stover & Evitt, 1978

Plate 39, Figure 9

1962b Cookson & Eisenack (Australia: **Aptian - Cenomanian)** as *Palaeostomocystis fragilis*
1964 Manum & Cookson (Arctic Canada: **'mid Cretaceous')** as *Palaeostomocystis fragilis*
1969 Habib (Bahamas: **Albian/Early Cenomanian)** as *Palaeostomocystis fragilis*
1970 Habib (Bahamas: **Albian/Cenomanian)** as *Palaeostomocystis fragilis*
1971 Brideaux (Central Alberta, Canada: **mid - Late Albian)** as *Palaeostomocystis fragilis*
1971 Singh (North-west Alberta, Canada: **Late Albian)** as *Palaeostomocystis fragilis*
1975 Brideaux & McIntyre (District of Mackenzie, Canada: **Aptian - Middle Albian)** as *Palaeostomocystis fragilis*
1976 Norvick *in* Norvick & Burger (Bathurst Island, Australia: **Early Cenomanian - Early Turonian)** as *Palaeostomocystis fragilis*
1978 Bujak & Williams (Offshore South-eastern Canada: **Late Albian - latest Maastrichtian)** as *Palaeostomocystis fragilis*
1979 May (North Slope, Alaska, USA: **Middle Albian)** as *Palaeostomocystis fragilis*
1980 Morgan (Australia: **Late Neocomian - latest Cenomanian)** as *Palaeostomocystis fragilis*
1983 Singh (North-west Alberta, Canada: **Early Cenomanian)**
1986 Ioannides (Bylot Island, Arctic Archipelago: **Santonian/Campanian - Early Maastrichtian)**
1987 Firth (Georgia, USA: **Early Maastrichtian - Danian)**
1989 Habib & Milner (South Carolina & Georgia, USA: **Late Campanian - Late Maastrichtian)**
1990 Harker *et al.* (Interior Plains of Canada: **Late Santonian - Late Campanian)**
1991 Kirsch (Germany: **Santonian - Maastrichtian)**
1993 Nøhr-Hansen (North-east Greenland: **Early Barremian - Late Albian)**

Dimensions: Range of observed specimens: length of cyst 37 (61) 90 µm, width of cyst 29 (43) 55 µm. 7 specimens measured.

Comparisons: This species is smaller and thinner-walled than *F. amphora*, and is commonly folded longitudinally. *Wuroia* sp. A is similar but is much longer (though of a similar width), has a slightly crescent shaped outline, and is commonly bent into a curve.

Occurrence: Rebecca K. Bounds core (Kansas): Early Cenomanian - Middle Turonian. Wahweap Wash (Utah): Late Cenomanian. Blue Point (Arizona), Bunker Hill (Kansas), Pueblo (Colorado): Late Cenomanian - Early Turonian.

Genus *Palaeotetradinium* Deflandre, 1936b; emend. Deflandre & Sarjeant, 1970; emend. Stover & Evitt, 1978

Palaeotetradinium silicorum Deflandre, 1936b; emend. Deflandre & Sarjeant, 1970

Plate 39, Figure 2

1983 Foucher (Paris Basin, France: **Late Turonian - Late Campanian)**
1986 Ioannides (Bylot Island, Arctic Archipelago: **Santonian/Campanian)**
1989 Aurisano (New Jersey & Delaware, USA: **Late Campanian - Late Maastrichtian)**
1990 Prössl (nr. Salzgitter, North-west Germany: **Early Albian - Late Cenomanian)**
1991 Kirsch (Germany: **Late Santonian - Maastrichtian)**

Dimensions: Range of observed specimens: length of cyst 48 (59) 97 µm, width of cyst 27 (40) 68 µm. 7 specimens measured.

Remarks: This is an extremely distinctive species of tetrahedral (crucifix-shaped) cyst.

Occurrence: Rebecca K. Bounds core (Kansas): Late Cenomanian - Middle Turonian. Blue Point (Arizona), Wahweap Wash (Utah): Late Cenomanian - Early Turonian.

Genus *Wallodinium* Loeblich & Loeblich, 1968, *nom. subst. pro Diplotesta* Cookson & Eisenack, 1960, *non* Brogniart, 1874

This study rejects the classification of *Wallodinium* as an acritarch genus (Fensome *et al.*, 1993) as specimens display an apical archaeopyle although further evidence of paratabulation is not shown.

Wallodinium anglicum (Cookson & Hughes, 1964) Lentin & Williams, 1973

Plate 39, Figure 4

1964 Cookson & Hughes (Cambridgeshire, England: **Late Albian - Early Cenomanian)** as *Diplotesta anglica*
1964 Manum & Cookson (Arctic Canada: **'mid Cretaceous')** as *Diplotesta anglica*

1970 Davey (Fetcham Mill Borehole, Surrey; Compton Bay, Isle of Wight, England; Escalles, France; Saskatchewan, Canada: **Cenomanian**) as *Diplotesta anglica*

1973 Davey & Verdier (France and Switzerland: **Early Vraconian - Early Cenomanian**) as *Diplotesta anglica*

1983 Singh (North-west Alberta, Canada: **Early - Middle Cenomanian**)

1988 Marshall & Batten (Lower Saxony Basin, North Germany: **Late Cenomanian - Early Turonian**)

1990 Harker *et al.* (Interior Plains of Canada: **Early Campanian - Early Maastrichtian**)

Dimensions: Range of observed specimens: length of periphragm 54 (66) 87 µm, width of periphragm 30 (35) 48 µm, length of endophragm 42 (49) 67 µm, width of endophragm 21 (28) 42 µm. 6 specimens measured.

Comparisons: This species of *Wallodinium* has one straight or slightly concave and one strongly convex side, forming a half-moon shape. *Wallodinium luna* is similar but has one side strongly concave.

Occurrence: Rebecca K. Bounds core (Kansas): Middle Cenomanian - Middle Turonian. Wahweap Wash (Utah): Late Cenomanian. Pueblo (Colorado): Late Cenomanian - Early Turonian. Bunker Hill (Kansas): Early Turonian.

Wallodinium luna (Cookson & Eisenack, 1960a) Lentin & Williams, 1973

Plate 39, Figures 6 & 7

1960a Cookson & Eisenack (Perth & Carnarvon Basins, Australia: **?Late Albian - Cenomanian**) as *Diplotesta luna*

1964 Manum & Cookson (Arctic Canada: **'mid Cretaceous'**) as *Diplotesta luna*

1969 Cookson & Eisenack (Balcatta, nr. Perth, Australia: **Albian/Cenomanian**) as *Diplotesta luna*

1976 Norvick *in* Norvick & Burger (Bathurst Island, Australia: **Early Cenomanian**)

1980 Morgan (Australia: **Late Neocomian - Middle Cenomanian**)

1981 Below (South-west Morocco: **Hauterivian - Aptian**)

1982 Below (Morocco: **Late Hauterivian**)

1984 Below (Mazagan Plateau, Offshore North-west Africa: **Late Aptian**)

1985 Williams & Bujak (World: **Berriasian - Campanian**)

1986 Ioannides (Bylot Island, Arctic Archipelago: **Santonian/Campanian**)

1988 Mao Shaozhi & Norris (Kashi Area, Xinjiang Province, China: **Late Cretaceous**)

1990 Prössl (nr. Salzgitter, North-west Germany: **Early Hauterivian - Late Turonian**)

1993 Nøhr-Hansen (North-east Greenland: **Early Barremian - Late Albian**)

Dimensions: Range of observed specimens: length of periphragm 38 (57) 66 µm, width of periphragm 41 (50) 61 µm, length of endophragm 28 (41) 49 µm, width of endophragm 15 (25) 33 µm. 7 specimens measured.

Comparisons: This species is very similar to *W. anglicum* but has one strongly convex side and one strongly concave side, forming a crescent-moon shape, with longer and more pointed apices.

Trigonopyxidia ginella has a similar wall layout but has a triangular outline with two or three concave sides.

Occurrence: Rebecca K. Bounds core (Kansas): Middle Cenomanian - Late Cenomanian. Pueblo (Colorado), Wahweap Wash (Utah): Late Cenomanian - Early Turonian. Blue Point (Arizona), Bunker Hill (Kansas): Early Turonian.

4.3 GROUP ACRITARCHA Evitt, 1963

Genus *Baltisphaeridium* Eisenack, 1958; emend. Staplin *et al.*, 1965; emend. Eisenack, 1969

Baltisphaeridium crameri Singh, 1971

Plate 41, Figure 4

1971 Singh (North-west Alberta, Canada: **Middle - Late Albian)**

> **Original Description:** Singh, 1971, p. 393
> Central body polygonal, smooth, thin walled, and bearing 7 to 10, long, sharply pointed processes; 4 to 6 processes situated at the apices, the remainder on the upper and lower surfaces of the central body; processes 1.5 to 2 microns wide, unbranched, and slightly curved; processes hollow, slightly expanded at their bases, and opening proximally into the body cavity; length of the processes equal to or more than the diameter of the central body.
> **Size Range:** Total diameter of the test, including the processes (5 specimens) 54 (65) 78 microns. Holotype 75 microns. Diameter of the central body (5 specimens) 19 (23) 26 microns. Holotype 26 microns. Length of the processes (5 specimens) 22 (26) 29 microns. Holotype 29 microns.

Dimensions: Range of observed specimens: maximum diameter of central body 20 (22) 25 µm, maximum length of processes 16 (21) 26 µm. 7 specimens measured.

Remarks: Specimens found conform to the original description, except that in some cases, up to 15 processes extend from the central body.

Occurrence: Rebecca K. Bounds core (Kansas): Early Cenomanian - Middle Turonian. Blue Point (Arizona), Bunker Hill (Kansas), Wahweap Wash (Utah): Late Cenomanian - Early Turonian.

Genus *Diplofusa* Cookson & Eisenack, 1960a

Diplofusa gearlensis Cookson & Eisenack, 1960a

Plate 42, Figure 1

1960a Cookson & Eisenack (Perth & Carnarvon Basins, Australia: **Cenomanian)**

1980 Morgan (Australia: **mid - latest Cenomanian)**

Dimensions: Range of observed specimens: length of outer body 102 & 127 μm, width of outer body 28 & 50 μm, length of inner body 70 & 96 μm, width of inner body 23 & 42 μm, respectively. 2 specimens measured.

Comparisons: Only two specimens were found, from the Wahweap Wash and Bunker Hill sections. This species is very distinctive with its two wall layers and narrow apical and antapical projections on the elongate inner body. Species of *Wallodinium* in this material appear similar but are crescent shaped and lack the apical and antapical projections. *Wuroia* sp. A is also similar but only has one wall, has a pylome at one end and is often longer and curved.

Occurrence: Bunker Hill (Kansas): Late Cenomanian. Wahweap Wash (Utah): Early Turonian.

Genus *Eyrea* Cookson & Eisenack, 1970b

Eyrea nebulosa Cookson & Eisenack, 1970b

Plate 43, Figures 5 & 6

1970b Cookson & Eisenack (Eucla Basin, Western Australia: **'mid' Cretaceous)**
1984 Below (Mazagan Plateau, Offshore North-west Africa: **Late Aptian - earliest Cenomanian)**
1992 Mohr & Gee (Kerguelan Plateau, Southern Indian Ocean: **Late Cenomanian - Late Coniacian)**
1993 Courtinat (Pueblo, Colorado, USA: **Late Cenomanian)**

Dimensions: Range of observed specimens: maximum diameter of cells 24 (27) 32 μm, number of cells in clump 7 (22) 63. 7 specimens measured.

Comparisons: In this material, the species has only been found in clumps. *Paralecaniella indentata* appears similar but has only been found as single units and has a thicker and more obvious double-layered wall.

Occurrence: Blue Point (Arizona): Late Cenomanian. Wahweap Wash (Utah): Late Cenomanian - Early Turonian. Bunker Hill (Kansas): Early Turonian. Rebecca K. Bounds core (Kansas): Middle Turonian.

Genus *Leiofusa* Eisenack, 1938a; emend. Eisenack, 1965a; emend. Combaz, Lange & Pansart, 1967

Leiofusa jurassica Cookson & Eisenack, 1958

Plate 42, Figure 2

1971 Brideaux (Central Alberta, Canada: **Late Albian)**
1971 Singh (North-west Alberta, Canada: **mid - Late Albian)**
1983 Singh (North-west Alberta, Canada: **Early - Middle Cenomanian)**

Dimensions: Range of observed specimens: length of body 56 & 69 µm, width of body 15 & 13 µm, respectively. 2 specimens measured.

Comparisons: This is a distinctive species of fusiform acritarch with elongate, acicular apical and antapical processes. Species of *Veryhachium* may appear similar but have at least three processes.

Occurrence: Blue Point (Arizona), Wahweap Wash (Utah): Late Cenomanian.

Genus *Micrhystridium* Deflandre, 1937b; emend. Staplin, 1961; emend. Sarjeant, 1967c; emend. Lister, 1970

Micrhystridium minutispinum Wall, 1965

Plate 41, Figure 1

1970 Davey (Fetcham Mill Borehole, Surrey, England: **Cenomanian)**

Dimensions: Range of observed specimens: diameter of central body 24 & 26 µm, maximum length of spines 2 µm. 2 specimens measured.

Comparisons: This species has a number of minute, conical spines on its subspherical body. Other species of *Micrhystridium* have much longer spines.

Occurrence: Blue Point (Arizona): Late Cenomanian. Rebecca K. Bounds core (Kansas): Middle Turonian.

Micrhystridium recurvatum Valensi, 1953

Plate 41, Figure 2

1970 Davey (Fetcham Mill Borehole, Surrey, England; Escalles, France; Saskatchewan, Canada: **Cenomanian)**

1983 Singh (North-west Alberta, Canada: **Early - Middle Cenomanian)**

Dimensions: Range of observed specimens: diameter of central body 18 (22) 28 µm, maximum length of spines 5 (11) 17 µm. 7 specimens measured.

Comparisons: This species has a number of short, slightly curved, acicular spines. *Micrhystridium stellatum* has fewer spines, which are longer and broader.

Occurrence: Rebecca K. Bounds core (Kansas): Middle Cenomanian - Middle Turonian. Blue Point (Arizona), Wahweap Wash (Utah): Late Cenomanian - Early Turonian. Bunker Hill (Kansas): Late Cenomanian. Pueblo (Colorado): Early Turonian.

Micrhystridium stellatum Deflandre, 1945a

Plate 41, Figure 3

1970 Habib (Bahamas: **Albian/Cenomanian)** as *Baltisphaeridium stellatum*

1971 Singh (North-west Alberta, Canada: **mid - Late Albian)**

1983 Singh (North-west Alberta, Canada: **Early - Middle Cenomanian)**

Dimensions: Range of observed specimens: diameter of central body 18 (20) 25 µm, maximum length of spines 10 (14) 17 µm. 6 specimens measured.

Comparisons: This species has a relatively small number of acuminate spines. *Micrhystridium recurvatum* has more spines, which are thinner and recurved.

Occurrence: Rebecca K. Bounds core (Kansas): Early Cenomanian - Middle Turonian. Bunker Hill (Kansas), Pueblo (Colorado): Late Cenomanian. Wahweap Wash (Utah): Late Cenomanian - Early Turonian. Blue Point (Arizona): Early Turonian.

Genus *Paralecaniella* Cookson & Eisenack, 1970b; emend. Elsik, 1977

Paralecaniella indentata (Deflandre and Cookson, 1955) Cookson and Eisenack, 1970b; emend. Elsik, 1977

Plate 44, Figure 6

1967 Clarke & Verdier (Isle of Wight, England: **Early Cenomanian - Late Santonian)** as *Epicephalopyxis indentata*

1973 Davey & Verdier (France and Switzerland: **Early Vraconian - Early Cenomanian)** as *Epicephalopyxis indentata*

1983 Foucher (Paris Basin, France: **Early Cenomanian - Early Campanian)** as *Epicephalopyxis indentata*

1986 Ioannides (Bylot Island, Arctic Archipelago: **Santonian/Campanian - Early Palaeocene)**

1987 Firth (Georgia, USA: **Early Maastrichtian - Danian)**

1989 Habib & Milner (South Carolina & Georgia, USA: **Late Campanian - Late Maastrichtian)**

Original description: Deflandre and Cookson, 1955, p. 292-293: *Epicephalopyxis indentata*.
Diagnosis: Organism more or less deeply cap- or dome-shaped, with a circular or elliptical outline provided with a relatively narrow, smooth, irregularly notched, slightly wavy rim. Surface membrane finely granular.
Dimensions: 51-74 by 43-69 µm, extremes 51 by 51 µm, 74 by 59 µm.

Emended description: Elsik, 1977, p. 96-100.
Diagnosis as for the genus:
Separate layers extremely thin to ca. 1 µm thick.
Remarks (annotated): Morphologic variations and criteria for recognition of *Paralecaniella* exhibited by specimens illustrated by specimens illustrated in Plate 1 and Plate 2 include:
1. A thin walled, generally psilate inner body which may split into near equal or unequal parts.2. A psilate to ornamented outer wall of variable thickness, layering and continuity.3. A flange of variable expression, both structurally and in rigidity.4. The outer wall complex, apparently including the flange area, may also split into near equal or unequal parts.5. Irregular invaginations of the outer wall apparently anchor the inner body. Invaginations on opposite sides a specimen may be joined by continual line, or at least continuous equatorial shadow band across the width of the specimen. Occasional specimens have paired invaginations suggestive of a flagellar sulcus or cingulum, depending upon interpretation of the orientation of the cysts.6. Both the inner body and outer wall may be of unequal development in thickness and ornament between the two halves of a specimen.7. A complete specimen has not been seen in edge view to establish the presence or absence of an equatorial cingulum or sulcus. Generally, half specimens either lacking invaginations or having two

opposite invaginations are recovered. Unfortunately, entire specimens also may or may not have the invagination, thus it is not certain that the half lacking the invagination is apical and the half with it is antapical! The irregular notches, when more than two are developed (text-fig. 1A), are perhaps expressions of plate structure. The morphology of the cyst and possible orientation and direction of travel of the living organism are depicted by line drawing in text-fig. 1.
Affinities: Elsik, 1977, p. 100: *Paralecaniella indentata* occurs in marginal marine to marine strata with dinoflagellates and acritarchs. The basic morphology, if interpreted as nearly equal parts of a whole, places the form in that broad group of schizosporous microfossils in which various expressions of wall layering and presence or absence of inner bodies may be found. Alternately, the equatorial sulcus/cingulum-like modification that may be present on one half of *Paralecaniella indentata* is not characteristic of that broad group of schizospores, whether algae or acritarchs.

Dimensions: Range of observed specimens: diameter of outer body 33 (47) 64 µm, diameter of inner body 29 (40) 57 µm. 18 specimens measured.

Comparisons: The specimens found conform well with the original description of *P. indentata*. *Lecaniella foveata* appears similar but has a single wall with foveo-rugulate sculpture and a marginal rim. Acritarch sp. B has two concentric walls, the inner wall covered with a very even and dense distribution of very fine, radiating pillars/hairs which support the thinner outer wall, giving the body a radially fibrous appearance. *Palambages morulosa* and *Eyrea nebulosa* both occur in clumps, the individual cells only having a single wall. Species of *Leiosphaeridia* only have a single wall, which is smooth and without indentations.

Occurrence: Rebecca K. Bounds core (Kansas): Late Cenomanian - Middle Turonian. Blue Point (Arizona), Bunker Hill (Kansas), Pueblo (Colorado), Wahweap Wash (Utah): Late Cenomanian - Early Turonian.

Genus *Platycystidia* Cookson & Eisenack, 1960a

Platycystidia diptera Cookson & Eisenack, 1960a

Plate 41, Figure 6

1960a Cookson & Eisenack (Perth & Carnarvon Basins, Australia: **?Late Albian - Cenomanian)**

Dimensions: Size of observed specimen: length of outer body 47 µm, width of outer body 44 µm, length of inner body 48 µm, width of inner body 18 µm. 1 specimen measured.

Remarks: Only one specimen was found, from the Rebecca Bounds Core. This was only poorly preserved but nevertheless appears to match the original description and illustration.

Occurrence: Rebecca K. Bounds core (Kansas): Late Cenomanian.

Genus *Scuticabolus* Loeblich III, 1967

Scuticabolus lapidaris (Wetzel, 1933) Loeblich III, 1967

nom. subst. pro Ophiobolus Wetzel, 1935a *non Ophiobolus* Reiss 1854

Plate 43, Figure 4

1986 Ioannides (Bylot Island, Arctic Archipelago: **Maastrichtian**) as *Ophiobolus lapidaris*

1990 Harker *et al.* (Interior Plains of Canada: **Late Santonian - Early Maastrichtian**) as *Ophiobolus lapidaris*

Dimensions: Range of observed specimens: length of central body 29 (36) 46 µm, width of central body 29 (34) 41 µm, maximum length of antapical protuberance 47 (79) 116 µm. 3 specimens measured.
Remarks: This is a distictive species with a subspherical central body and a very long, thin antapical extrusion which splits at the distal end into a multitude of finer filaments.
Occurrence: Bunker Hill (Kansas), Pueblo (Colorado): Late Cenomanian.

Genus *Veryhachium* Deunff, 1954; emend. Downie & Sarjeant, 1963; emend. Turner, 1984

Veryhachium collectum Wall, 1965

Plate 40, Figure 4

1971 Singh (North-west Alberta, Canada: **Middle Albian**)

1983 Singh (North-west Alberta, Canada: **Early Cenomanian**)

Dimensions: Range of observed specimens: length of central body 20 (21) 23 µm, width of central body 17 (20) 23 µm, maximum length of processes 8 (13) 16 µm. 3 specimens measured.
Remarks: This species has a sub-triangular to sub-rectangular central body with one side smaller than the other three, and with four to eight spines.
Occurrence: Rebecca K. Bounds core (Kansas): Early Cenomanian - Early Turonian. Pueblo (Colorado), Wahweap Wash (Utah): Late Cenomanian - Early Turonian. Blue Point (Arizona), Bunker Hill (Kansas): Early Turonian.

Veryhachium europeum Stockmans & Williere, 1960

Plate 40, Figures 1 & 2

1971 Brideaux (Central Alberta, Canada: **Late Albian**)

1971 Singh (North-west Alberta, Canada: **mid - Late Albian**)

1983 Singh (North-west Alberta, Canada: **Early - Middle Cenomanian**)

Dimensions: Range of observed specimens: maximum length of central body 18 (24) 28 µm, maximum length of processes 12 (15) 16 µm. 6 specimens measured.
Remarks: This species has a tetrahedral central body with four spines.

Occurrence: Rebecca K. Bounds core (Kansas): Early Cenomanian - Middle Turonian. Pueblo (Colorado): Late Cenomanian. Bunker Hill (Kansas), Wahweap Wash (Utah): Late Cenomanian - Early Turonian. Blue Point (Arizona): Early Turonian.

Veryhachium formosum Stockmans & Williere, 1960

Plate 40, Figure 5

1971 Singh (North-west Alberta, Canada: **mid - Late Albian**)

1983 Singh (North-west Alberta, Canada: **Middle Cenomanian**)

Dimensions: Range of observed specimens: length of central body 21 (24) 28 µm, width of central body 17 (19) 23 µm, maximum length of processes 18 (21) 24 µm. 8 specimens measured.

Remarks: This species has a sub-triangular to sub-spherical central body with five to eight spines.

Occurrence: Rebecca K. Bounds core (Kansas): Early Cenomanian - Middle Turonian. Blue Point (Arizona), Pueblo (Colorado), Wahweap Wash (Utah): Late Cenomanian - Early Turonian. Bunker Hill (Kansas): Early Turonian.

Veryhachium irregulare de Jekhowsky, 1961

Plate 40, Figure 8

1970 Davey (Fetcham Mill Borehole, Surrey, England: **Cenomanian**)

1971 Singh (North-west Alberta, Canada: **mid - Late Albian**)

1983 Singh (North-west Alberta, Canada: **Middle Cenomanian**)

Dimensions: Range of observed specimens: length of central body 19 (23) 27 µm, width of central body 17 (20) 23 µm, maximum length of processes 14 (19) 23 µm. 7 specimens measured.

Remarks: This species has a sub-rectangular to sub-spherical central body with five or six spines.

Occurrence: Rebecca K. Bounds core (Kansas): Early Cenomanian - Middle Turonian. Wahweap Wash (Utah): Late Cenomanian. Blue Point (Arizona), Pueblo (Colorado): Late Cenomanian - Early Turonian. Bunker Hill (Kansas): Early Turonian.

Veryhachium reductum (Deunff, 1959) Downie & Sarjeant, 1965

Plate 40, Figure 7

1962b Cookson & Eisenack (Australia: **Aptian - Cenomanian**)

1964 Cookson & Hughes (Cambridgeshire, England: **Late Albian - Early Cenomanian**)

1970 Davey (Fetcham Mill Borehole, Surrey; Compton Bay, Isle of Wight, England; Escalles, France: **Cenomanian**)

1971 Brideaux (Central Alberta, Canada: **Late Albian**)

1971 Singh (North-west Alberta, Canada: **mid - Late Albian**)

1976 Norvick *in* Norvick & Burger (Bathurst Island, Australia: **Early Cenomanian - Early Turonian**)

1983 Singh (North-west Alberta, Canada: **Early - Middle Cenomanian**)

Dimensions: Range of observed specimens: maximum length of central body 27 & 30 µm, maximum length of processes 18 & 32 µm. 2 specimens measured.

Remarks: This species has a triangular central body and four spines.

Occurrence: Rebecca K. Bounds core (Kansas): Late Cenomanian - Middle Turonian. Pueblo (Colorado): Late Cenomanian.

Veryhachium rhomboideum Downie, 1959

Plate 40, Figure 6

1970 Davey (Saskatchewan, Canada: **Albian,** Fetcham Mill Borehole, Surrey; Compton Bay, Isle of Wight, England; Escalles, France: **Cenomanian)**
1971 Singh (North-west Alberta, Canada: **mid - Late Albian)**
1983 Singh (North-west Alberta, Canada: **Early - Middle Cenomanian)**
1990 Harker *et al.* (Interior Plains of Canada: **Late Campanian)**

Dimensions: Range of observed specimens: length of central body 21 (25) 28 µm, width of central body 14 (18) 24 µm, maximum length of processes 14 (17) 21 µm. 7 specimens measured.

Remarks: This species has a rhomboidal to rectangular central body with six evenly distributed spines.

Occurrence: Rebecca K. Bounds core (Kansas): Middle Cenomanian - Middle Turonian. Blue Point (Arizona), Pueblo (Colorado): Late Cenomanian - Early Turonian. Bunker Hill (Kansas): Early Turonian.

Veryhachium valiente Deflandre, 1946c

Plate 40, Figure 3

1971 Singh (North-west Alberta, Canada: **mid - Late Albian)** as *Veryhachium lairdii*
1983 Singh (North-west Alberta, Canada: **Early - Middle Cenomanian)** as *Veryhachium lairdii*

Dimensions: Range of observed specimens: length of central body 20 (24) 27 µm, width of central body 17 (20) 21 µm, maximum length of processes 14 (19) 24 µm. 6 specimens measured.

Remarks: This species has a rectangular central body with four spines, evenly distributed with one at each corner.

Occurrence: Rebecca K. Bounds core (Kansas): Early Cenomanian - Middle Turonian. Pueblo (Colorado): Late Cenomanian - Early Turonian.

Genus *Wuroia* Stover & Helby, 1987a

Wuroia sp. A
Plate 42, Figures 5 & 6

Description: This species has a distinctive elongate, narrowly ellipsoidal to slightly crescent-shaped body which (in longer specimens) often curves into a large 'u'-shape. The cyst is composed of a single wall layer with a smooth surface, which may be slightly folded or wrinkled. The wall is comparatively slightly thicker in the middle of the body, thinning towards each pole, where the cyst may be slightly more membranous and wrinkled. One end of the cyst is widely to narrowly rounded and closed. The other is open, sometimes with a round pylome with its margin slightly thickened, and sometimes with the suture truncate or even slightly torn. No operculum was observed. Within the population, the cyst has quite a variable length but in comparison, the width is relatively constant. The body only occasionally possesses longitudinal folds which the generic and various specific descriptions suggest are always present. Despite this general lack of longitudinal folds, the species has still been included within the genus *Wuroia*.

Dimensions: Range of observed specimens: length of body 82 (157) 242 μm, width of body 22 (31) 41 μm. 20 specimens measured.

Remarks: The species previously ascribed to this genus were described from deposits suggested to originate in non-marine or nearshore environments (i.e. not open marine) from the Turonian to Santonian of the Gippsland Basin, offshore, southeastern Australia.

Comparisons: This species compares well with other species described from this genus, with the exception of the lack of longitudinal folds. *Wuroia tubiformis* seems to be the most similar, with the wall thicker, and less membranous and wrinkled than other species, and with a thickened wall around the pylome. However, it still possesses the longitudinal folds and has an evenly scabrate to finely granulate surface ornamentation. *Wuroia* sp. A appears similar to some species of *Wallodinium* but is much larger and only has a single wall layer. *Diplofusa gearlensis* may appear similar but has two wall layers, with narrow apical and antapical projections on the elongate inner body.

Occurrence: Rebecca K. Bounds core (Kansas): Middle Cenomanian - Middle Turonian. Pueblo (Colorado): Late Cenomanian - Early Turonian.

Miscellaneous Acritarchs

Acritarch sp. A
Plate 41, Figure 5

Description: Central body subspherical, smooth, comparatively thick walled (1 to 1.5 μm), and bearing between 9 and 16 long, acicular, solid processes with acuminate or occasionally bifid tips. The length of the processes approximately equal the diameter of the central body. In two cases, a partial rupture is developed. Only four specimens were seen, two from Blue Point, and two from the Rebecca Bounds Core.

Dimensions: Range of observed specimens: maximum diameter of central body 12 (15) 18 μm, maximum length of processes 11 (15) 17 μm. 4 specimens measured.

Comparisons: *Baltisphaeridium crameri* is much larger with a thinner wall (in comparison to the size of the central body) and hollow, acuminate processes. Species of *Micrhystridium* are also similar but have more numerous and generally shorter spines.

Occurrence: Rebecca K. Bounds core (Kansas): Early Cenomanian - Late Cenomanian. Blue Point (Arizona): Late Cenomanian - Early Turonian.

Acritarch sp. B

Plate 45, Figures 5 to 7

Description: This is a distinctive small, spherical to subspherical species with two concentric walls. The inner wall is thicker and covered with a very even and dense distribution of very fine, radiating pillars/hairs which support the thinner outer wall. These pillars measure between 1 and 3 μm long but have a constant length on individual specimens. On many specimens, the pillars extend into very fine hairs above the surface of the outer wall. The wall structure gives the body a radially fibrous appearance. On some specimens a fine split is visible.

Dimensions: Range of observed specimens: maximum diameter of outer body 26 (30) 34 μm, maximum diameter of central body 21 (25) 29 μm, height of pillars 1.5 (2.3) 3 μm. 13 specimens measured.

Comparisons: *Chlamydophorella discreta* may appear similar but is slightly larger, with an ornamentation of shorter, flat-topped pillars supporting its ectophragm, and an apical archaeopyle. *Cometodinium? whitei* also appears similar but has a differentiated autophragm consisting of a dense covering of fine hairs and so lacks the outer wall.

Occurrence: Rebecca K. Bounds core (Kansas): Late Cenomanian - Middle Turonian. Pueblo (Colorado): Late Cenomanian - Early Turonian.

Acritarch sp. C

Plate 42, Figures 3 & 4

Description: This species has an elongate, oval body, with rounded, closed ends. The single-wall is opaque and irregularly surfaced or shagreenate. The length of the body is approximately one and a half times the size of the width.

The excystment aperture involves a pylome which can be variably developed. On some specimens, only two partial ruptures can be seen (latitudinally around the width), at a roughly equatorial position and close to one end. On one specimen, the aperture was also seen to extend along the middle of one surface (longitudinally). Other specimens have fully developed the pylome (joining the sutures between the equator and one end) with perhaps some accessory sutures as well.

Dimensions: Range of observed specimens: length of body 48 (55) 60 μm, width of body 32 (36) 40 μm. Length/width ratio 1.41 (1.52) 1.76. 6 specimens measured.

Comparisons: This species differs from all others in the material with its elongate, oval shape and opaque, shagreenate wall. *Wuroia* sp. A is much larger and longer, with a smooth wall and an opening at one end. *Petalosporites quadrangulus* has a similar appearance, particularly with wall thickness and ornamentation, but differs in having a rhomboidal shape and a parallel or diagonal rupture for the aperture.

Occurrence: Rebecca K. Bounds core (Kansas): Early Cenomanian.

4.4 ?DIVISION CHLOROPHYTA Pascher, 1914

Genus *Lecaniella* Cookson & Eisenack, 1962

Lecaniella foveata Singh, 1971

Plate 44, Figure 5

1971 Singh (North-west Alberta, Canada: **Late Albian)**
1975 Brideaux & McIntyre (District of Mackenzie, Canada: **Middle Albian)**
1983 Singh (North-west Alberta, Canada: **Middle Cenomanian)**

Dimensions: Size of observed specimen: diameter of cyst 49 µm. 1 specimen measured.

Remarks: Only one specimen was found from the base of the material studied from the Rebecca K. Bounds core. This was consistent with the original description and illustration.

Occurrence: Rebecca K. Bounds core (Kansas): Early Cenomanian.

Genus *Palambages* Wetzel, 1961

Palambages morulosa Wetzel, 1961

Plate 43, Figure 3

1964 Manum & Cookson (Arctic Canada: **'mid Cretaceous')** as *Palambages* Forms A, B & C
1970 Davey (Saskatchewan, Canada: **Albian - Cenomanian)** as *Palambages* Form A
1971 Singh (North-west Alberta, Canada: **Late Albian)** as *Palambages* Form A
1976 Norvick *in* Norvick & Burger (Bathurst Island, Australia: **Early - Late Cenomanian)** as *Palambages* Form A
1983 Singh (North-west Alberta, Canada: **Early - Middle Cenomanian)** as *Palambages* Form A
1986 Ioannides (Bylot Island, Arctic Archipelago: **Santonian/Campanian - Early Palaeocene)** as *Palambages* spp.
1990 Harker *et al.* (Interior Plains of Canada: **Late Santonian - Early Maastrichtian)**

Dimensions: Range of observed specimens: diameter of colony 60 (88) 170 µm, maximum diameter of individual cells 20 (23) 25 µm. 7 specimens measured.

Comparisons: These colonial cellular masses are very distinctive forming large balls of spheres. *Eyrea nebulosa* is also composed of a number of cells, but these are smaller and form irregular masses.
Occurrence: Rebecca K. Bounds core (Kansas): Late Cenomanian - Middle Turonian. Blue Point (Arizona), Pueblo (Colorado): Late Cenomanian.

Genus *Petalosporites* Agasie, 1969

Petalosporites quadrangulus Agasie, 1969

Plate 41, Figure 10

1964 Manum & Cookson (Arctic Canada: **'mid Cretaceous'**) as *Schizocysta laevigata* (pars)
1969 Agasie (Black Mesa Basin, Arizona, USA: **Late Cenomanian**)

> **Original Description:** Monolete spore; equatorial outline sub-rectangular to somewhat square with slightly rounded corners; laesurae simple, frequently gaping, extending about 1/2 to 2/3 of length of proximal surface, parallel or oblique to sides of spore. Spore wall about 0.5 to 1 micron thick, scabrate to faintly foveolate.
> **Size range:** Length 35 (48) 55 microns; width 33 (43) 55 microns (25 specimens).

Dimensions: Range of observed specimens: length of body 36 (47) 55 µm, width of body 35 (43) 52 µm. 12 specimens measured.
Remarks: This species was originally described as a spore, from the Dakota Sandstone Formation, immediately below the Mancos Shale from the Black Mesa Basin. Subsequent authors have not regarded this species as a spore but as an acritarch (e.g. Traverse, 1988), probably since the split can either be parallel to the sides or diagonally across the body. The species does not have the appearance of a spore but 'stands out' on the slide (from the debris) along with the other cysts.
Comparisons: It may be related to *Schizocysta laevigata* which has a similar shaped body except that two of the opposing sides are slightly to deeply concave. One of the specimens illustrated by Manum & Cookson (1964: plate 7, fig. 2), as *S. laevigata*, appears to be *P. quadrangulus*. *Tetraporina* sp. A is similar but is smaller and much thinner walled (appearing hyaline), with a more angular outline.
Occurrence: Rebecca K. Bounds core (Kansas): Early Cenomanian.

Genus *Schizocysta* Cookson & Eisenack, 1962

Schizocysta laevigata Cookson & Eisenack, 1962a

Plate 41, Figure 8

1962a Cookson & Eisenack (Western Australia: **?Late Albian-Cenomanian**)
1964 Manum & Cookson (Arctic Canada: **'mid Cretaceous'**)
1971 Singh (North-west Alberta, Canada: **Late Albian**)
1983 Singh (North-west Alberta, Canada: **Early Cenomanian**)

1986 Ioannides (Bylot Island, Arctic Archipelago: **Santonian/Campanian - Maastrichtian)**
1987 Habib & Drugg (Offshore USA, Western North Atlantic: **Late Coniacian/Santonian)**
1990 Harker *et al.* (Interior Plains of Canada: **Late Campanian)**
1993 Nøhr-Hansen (North-east Greenland: **mid - Late Albian)** as *Schizocystia*

Dimensions: Range of observed specimens: length of body 35 (39) 42 µm, width of body (parallel to median split) 48 (50) 51 µm. 4 specimens measured (half bodies only).

Comparisons: This distinctive species has a thick wall with two slightly to deeply concave, opposing sides, and a low and lightly indicated vermiculate pattern. Characteristically, the two halves of the body generally split apart and (in all cases here) only one half is seen, which resembles a pair of trousers. *Schizocysta rugosa* is similar but has a strongly marked vermiculate pattern across the surface. *Petalosporites quadrangulus* may be related, with a similar shaped body except that the opposing sides are straight or only very slightly concave, and the split can either be parallel to the sides or diagonally across the body, and does not result in the splitting apart of two halves.

Occurrence: Rebecca K. Bounds core (Kansas): Early Cenomanian - Middle Turonian.

Genus *Tetraedron* Kützing, 1845

Tetraedron sp. A

Plate 41, Figure 9

Description: This species has a sub-rectangular outline, with angular (v-shaped), concave opposing sides forming a four-pointed star-shape. Each corner terminates with a small, bulbous knob-like protrusion. The external surface of the wall is irregular and has granulo-punctate ornamentation. The internal surface of the wall is smooth. The cyst has a median split developed between two of the opposing sides, and further ruptures developed perpendicular to the major split and connecting a third side.

Dimensions: Size of observed specimen: diagonal length of body 55 µm, perpendicular length of body 32 µm, length of projections on corners of body 3 µm. 1 specimen measured.

Comparisons: *Tetraporina* sp. A is similar but thinner-walled and hyaline, without conspicuously concave opposing sides and without any visible ruptures. *Schizocysta laevigata* is also similar but does not have protuberances on the cyst 'corners', and has only two concave opposing sides, which curve regularly inwards in a u-shape.

Occurrence: Bunker Hill (Kansas): Early Turonian.

Genus *Tetraporina* Naumova, 1939, *ex.* Bolkhovitina, 1953

Tetraporina sp. A

Plate 41, Figure 7

Description: This species has a rhomboidal outline, with slightly concave opposing sides. Each corner is narrowly-rounded, the wall folded to a variable but small extent, around a slight terminal protrusion. The wall is very thin, appearing hyaline, and hence is finely wrinkled and folded. The external surface of the wall is smooth to slightly shagreenate. None of the specimens show any visible openings or ruptures.

Dimensions: Range of observed specimens: maximum diagonal length of body 37 (42) 46 µm, length of body 30 (34) 40 µm, width of body 27 (30) 33 µm. 7 specimens measured.

Comparisons: This species has a similar appearance to *Palaeotetradinium silicorum* but without each corner extended and lengthened to form a crucifix-shape. *Tetraedron* sp. A is similar but thicker-walled, with distinctive, angularly concave opposing sides, bulbous knob-like protrusions at each corner and with a median split and further ruptures developed. *Petalosporites quadrangulus* is also thicker-walled with broadly rounded corners and a partial rupture. Species of *Veryhachium* also have a thicker wall with acuminate processes projecting from corners of the central body.

Occurrence: Rebecca K. Bounds core (Kansas): Middle Cenomanian - Early Turonian. Pueblo (Colorado): Late Cenomanian. Bunker Hill (Kansas): Early Turonian.

4.5 DIVISION PRASINOPHYTA Round, 1971

Genus *Crassosphaera* Cookson & Manum, 1960

Crassosphaera papillata Singh, 1971

Plate 44, Figure 4

1971 Singh (North-west Alberta, Canada: **Late Albian)**

1983 Singh (North-west Alberta, Canada: **Early Cenomanian)**

> **Original Description:** Test spherical, hollow, thick walled, and usually flattened due to compression; outer surface covered with closely spaced prominences having subcircular to hexagonal outline in surface view; prominences forming a surface pattern resembling the cast of a honeycomb and appearing as 1.5 to 2 microns high and about 1.5 microns wide, straight-sided papillae in profile; hexagonal prominences about 2 microns wide at the base and spaced about 0.5 microns apart; each prominence with a minute axial tubule running radially from the top of the prominence to the inner surface of the wall; test yellowish brown in colour.

Dimensions: Range of observed specimens: diameter of central body 35 (51) 66 µm, height of papillae 0.5 (0.6) 1 µm. 8 specimens measured.

Remarks: This species of prasinophyte is very distinctive. The specimens found conform well with the original description, except that the papillae are not as prominent, giving the perimeter a slightly smoother appearance.

Occurrence: Rebecca K. Bounds core (Kansas): Middle Cenomanian - Middle Turonian. Pueblo (Colorado): Late Cenomanian. Bunker Hill (Kansas): Early Turonian.

Genus *Cymatiosphaera* Wetzel, 1933; emend. Deflandre, 1954

Cymatiosphaera costata Davey, 1970

Plate 44, Figure 7

1970 Davey (Saskatchewan, Canada: **Cenomanian)**

1983 Singh (North-west Alberta, Canada: **Middle Cenomanian)**

Dimensions: Range of specimens: diameter of central body 17 & 20 μm, height of muri 1.5 & 2 μm, respectively. 2 specimens measured.

Comparisons: This species is easily distinguished within this material, by its extremely small size. *Pterosphaeridia pachytheca* is similar in appearance but much larger.

Occurrence: Blue Point (Arizona), Pueblo (Colorado): Late Cenomanian. Rebecca K. Bounds core (Kansas): Middle Turonian.

Genus *Leiosphaeridia* Eisenack, 1958; emend. Downie & Sarjeant, 1963

Leiosphaeridia spp.

Plate 43, Figures 1 & 2

Remarks: All sphaeromorphs have been logged as a group. These include specimens of considerable variation in size, but generally are smooth and thin walled, with numerous folds.

Dimensions: Range of observed specimens: diameter of body 40 to 118 μm. 10 specimens measured.

Occurrence: Rebecca K. Bounds core (Kansas): Early Cenomanian - Middle Turonian. Blue Point (Arizona), Bunker Hill (Kansas), Pueblo (Colorado), Wahweap Wash (Utah): Late Cenomanian - Early Turonian.

Genus *Pterospermella* Eisenack, 1972

Pterospermella aureolata (Cookson & Eisenack, 1958) Eisenack, 1972

Plate 45, Figure 1

1958 Cookson & Eisenack (Western and Southern Australia: **Aptian - Turonian)** as *Pterospermopsis aureolata* and *Pterospermopsis eurypteris*

1971 Singh (North-west Alberta, Canada: **mid - Late Albian)** as *Pterospermopsis aureolata* and *Pterospermopsis eurypteris*

1980 Morgan (Australia: **Early Neocomian - Early Aptian**) as *Pterospermella eurypteris*

1983 Singh (North-west Alberta, Canada: **Early - Middle Cenomanian**)

Dimensions: Range of observed specimens: maximum diameter of outer body 58 (91) 113 µm, maximum diameter of inner body 36 (58) 75 µm, maximum width of wing 11 (17) 24 µm. 7 specimens measured.

Comparisons: This is a large, thick-walled species of prasinophyte. *Pterospermella* sp. A is similar but the equatorial wing has a radially fibrous structure and appearance. *Pterospermella centrata* is smaller and has a distinctive series of concentric rings on its central body. *Pterospermella australiensis* is much smaller again, with a thinner, radially folded wing.

Occurrence: Rebecca K. Bounds core (Kansas): Early Cenomanian - Middle Turonian. Blue Point (Arizona), Wahweap Wash (Utah): Late Cenomanian. Bunker Hill (Kansas), Pueblo (Colorado): Late Cenomanian - Early Turonian.

Pterospermella australiensis (Deflandre & Cookson, 1955) Eisenack, Cramer & Diez, 1973

Plate 45, Figure 3

1955 Deflandre & Cookson (New South Wales, Australia: **Lower Cretaceous**) as *Pterospermopsis australiensis*

1971 Brideaux (Central Alberta, Canada: **mid - Late Albian**) as *Pterospermopsis australiensis*

1971 Singh (North-west Alberta, Canada: **mid - Late Albian**) as *Pterospermopsis australiensis*

1976 Norvick *in* Norvick & Burger (Bathurst Island, Australia: **Early Cenomanian - Early Turonian**) as *Pterospermopsis australiensis*

1980 Morgan (Australia: **Late Neocomian - latest Cenomanian**)

1983 Singh (North-west Alberta, Canada: **Early - Middle Cenomanian**)

1988 Mao Shaozhi & Norris (Kashi Area, Xinjiang Province, China: **Late Cretaceous**)

1990 Harker *et al.* (Interior Plains of Canada: **mid Campanian**) as *Pterospermopsis australiensis*

Dimensions: Range of observed specimens: maximum diameter of outer body 34 (47) 54 µm, maximum diameter of inner body 20 (26) 32 µm, maximum width of wing 5 (11) 14 µm. 7 specimens measured.

Comparisons: This is a small species of *Pterospermella* with a thin-walled, radially folded wing. Other species of *Pterospermella* within this material are much larger with little folding on their wings.

Occurrence: Rebecca K. Bounds core (Kansas): Early Cenomanian - Middle Turonian. Blue Point (Arizona), Bunker Hill (Kansas), Pueblo (Colorado): Late Cenomanian - Early Turonian.

Pterospermella centrata (Cookson & Eisenack, 1971) Eisenack, Cramer & Diez, 1973

Plate 45, Figure 2

1971 Cookson & Eisenack (Eucla Basin, Western Australia: **'mid' Cretaceous**) as *Pterospermopsis centrata*

Dimensions: Range of observed specimens: maximum diameter of outer body 53 (65) 76 µm, maximum diameter of inner body 27 (35) 40 µm, maximum diameter of central boss 12 (16) 20 µm, maximum width of wing 14 (16) 19 µm. 6 specimens measured.

Comparisons: This species is distinguished by a thicker walled, circular area in the middle of the central body, giving the central body the appearance of a series of concentric circles. *Pterospermella aureolata* is larger and has an even wall thickness across the central body. *Pterospermella* sp. A is similar but the equatorial wing has a radially fibrous structure and appearance. *Pterospermella australiensis* is smaller with a thinner-walled wing which is radially folded.

Occurrence: Rebecca K. Bounds core (Kansas): Middle Cenomanian - Middle Turonian. Pueblo (Colorado): Late Cenomanian - Early Turonian.

Pterospermella? sp. A

Plate 45, Figure 4

Description: A medium to large species of *Pterospermella*, with the characteristic concentric wall arrangement. The circular outer layer forms an equatorial wing which has a radially fibrous structure and appearance. The structure is unlike other species of *Pterospermella* within this material in that it seems to be composed of an even and dense distribution of very fine, radiating fibres/hairs which form this thinner outer layer. The circular inner body is thicker-walled. The wing appears to be fairly delicate, for in many cases, poor preservation removes much of it, leaving the central body surrounded by a narrow flange which is uneven and appears to thin distally, giving the appearance of a tasmanitid or thick-walled leiosphere with a gradational outer wall.

Dimensions: Range of observed specimens: maximum diameter of outer body 54 (79) 114 µm, maximum diameter of inner body 43 (64) 93 µm, maximum width of wing 4 (10) 26 µm (many specimens with narrow wings presumed to have lost much due to poor preservation). 20 specimens measured.

Comparisons: Other species of *Pterospermella* have a more substantial and less fragile equatorial wing with a more definitive outer wall, and without the radiating and fibrous texture.

Occurrence: Rebecca K. Bounds core (Kansas): Middle Cenomanian - Middle Turonian. Blue Point (Arizona): Late Cenomanian. Bunker Hill (Kansas), Pueblo (Colorado), Wahweap Wash (Utah): Late Cenomanian - Early Turonian.

Genus *Pterosphaeridia* Madler, 1963

Pterosphaeridia pachytheca (Eisenack, 1957) Madler, 1963

Plate 44, Figure 3

1971 Singh (North-west Alberta, Canada: **mid - Late Albian**)

1983 Singh (North-west Alberta, Canada: **Middle Cenomanian**)

Dimensions: Range of observed specimens: maximum diameter of central body 30 (39) 56 µm, maximum height of muri 1 (2.3) 4 µm. 16 specimens measured.

Remarks: This is a distinctive, thick-walled species of prasinophyte, with the surface divided into a number of pentagonal to hexagonal fields by low crests. Some specimens have pore canals at the centre of each field.

Comparisons: *Cymatiosphaera costata* may appear similar, but is considerably smaller in size.

Occurrence: Rebecca K. Bounds core (Kansas): Middle Cenomanian - Middle Turonian. Blue Point (Arizona), Pueblo (Colorado): Late Cenomanian. Bunker Hill (Kansas), Wahweap Wash (Utah): Late Cenomanian - Early Turonian.

Genus *Tasmanites* Newton, 1875

Tasmanites spp.

Plate 44; Figures 1 & 2

1971 Singh (North-west Alberta, Canada: **mid - Late Albian)**

1983 Singh (North-west Alberta, Canada: **Early Cenomanian)**

Dimensions: Range of observed specimens: maximum diameter of body 50 to 179 µm. 9 specimens measured.

Comparisons: No attempt has been made to differentiate between the very large, very thick-walled prasinophytes with no morphological differences other than variably developed fine pores. *Crassosphaera papillata* is similar but has close-spaced, low, circular projections (papillae) around each pore. *Pterosphaeridia pachytheca* has the surface divided into a number of pentagonal to hexagonal fields by low crests.

Occurrence: Rebecca K. Bounds core (Kansas): Early Cenomanian - Middle Turonian. Blue Point (Arizona), Bunker Hill (Kansas), Pueblo (Colorado), Wahweap Wash (Utah): Late Cenomanian - Early Turonian.

CHAPTER 5

DINOFLAGELLATE CYST BIOSTRATIGRAPHY

5.1 PREVIOUS WORK

Numerous studies have been carried out on Cretaceous dinoflagellate cysts, particularly from Europe, Australia, and North America. However, very few, in-depth studies have been published from the Western Interior Basin of the United States.

Many long-ranging studies of dinoflagellate cysts have spanned the Cenomanian and/or Turonian ages. These include work by Deflandre, who published a series of mostly taxonomic studies on Cretaceous dinoflagellate cysts from flints (e.g. Deflandre, 1937b), Cookson and Eisenack who pioneered marine palynology in Australia (e.g. Deflandre & Cookson, 1955, Cookson & Eisenack, 1958, 1960a, 1960b, 1961a, 1962a, 1962b, 1968, 1969, 1970a, 1971, 1974, 1982), Cookson & Hughes (1964) who studied the assemblages from the Cenomanian Greensand of Cambridgeshire, England, and Clarke & Verdier (1967) who published a detailed taxonomic and stratigraphic work on species from Cenomanian to Campanian sediments from the Isle of Wight, England.

An extensive taxonomic analysis was published by Davey *et al.* (1966) and continued in Davey *et al.*, 1969. Davey (1969a, 1970) made a comprehensive study of dinoflagellate cysts from the Cenomanian of England, Northern France and North America. Davey and Verdier published various stratigraphic and taxonomic studies (e.g. Davey & Verdier, 1971, 1973) including important taxonomic work on the genus *Florentinia* (Davey & Verdier, 1976). Davey (1978) published on species from the Aptian to Maastrichtian from a DSDP core (site 361) from offshore southwest Africa.

Further work from Australia included a detailed taxonomic and biostratigraphic study from the Cenomanian and Turonian of Bathurst Island in the Northern Territory (Norvick & Burger, 1976). Morgan (1980) also looked in detail at the taxonomy along with the biostratigraphy from the Neocomian to Cenomanian of Australia.

Below has published in comprehensive detail on cyst taxonomy and biostratigraphy from the Upper Hauterivian to Lower Cenomanian from Morocco (Below, 1981a, 1982) and from the Aptian to Cenomanian from DSDP cores (sites 545 & 547) from offshore northwest Africa (Below, 1984). Mao Shaozhi & Norris (1988) looked at the taxonomy and biostratigraphy of Late Cretaceous sediments from western China.

Long-ranging biostratigraphic studies from Europe include Foucher (1983) from the 'mid' to Late Cretaceous of the Paris Basin. Prössl (1990) presented a thorough biostratigraphic work from the Lower Hauterivian to the Upper Turonian from a core in northwest Germany. The biostratigraphy of many species was illustrated in detail through the Cretaceous, for England and the North Sea in Costa & Davey (1992). More recent studies from more varied geographical sites have included those from ODP cores including Mohr & Gee (1992) from the Southern Indian Ocean (sites 748 & 750).

A number of geographically wide-ranging biostratigraphic compilation studies have been published, including Williams & Bujak (1985), Williams *et al.* (1993), and Stover *et al.* (1996).

5.1.1 Palynological Studies from the North American Continent

A number of studies have been published over the years, from the Western Interior Basin of Canada. The palynology of parts of the Lower Cretaceous of Alberta, Canada, were thoroughly studied and illustrated by Singh (1964, 1971) who also published in detail on the Lower and Middle Cenomanian from Alberta (Singh, 1983), forming a useful comparison with material in this study. Davey (1969 and 1970) included material taken from the Albian and Cenomanian of southeast Saskatchewan in Canada, and from the Upper Cenomanian of north Texas in the United States. Further useful studies from Canada have included those from the Albian of the Lower Colorado Group of Alberta (Brideaux, 1971) and from the Aptian and Albian from the District Of Mackenzie in northernmost Canada (Brideax & McIntyre, 1975). The biostratigraphy of dinoflagellate cyst assemblages from the Albian to Turonian, Lower Colorado Group have been discussed in relation to the lithostratigraphy and other fossil groups in Bloch *et al.* (1993). May (1979) also published on the biostratigraphy from the Albian to possible Cenomanian from cores from the North Slope of Alaska. The Late Santonian to Early Maastrichtian from the Canadian plains was studied and published by Harker *et al.* (1990).

Further studies have also been published from the North American Arctic. Material dated as mid Cretaceous was studied from Graham Island, Arctic Canada by Manum & Cookson (1964). Ioannides (1986) published a comprehensive study from the latest Cretaceous (Santonian to Maastrichtian) and Palaeocene of the Bylot and Devon Islands of the Arctic archipelago. Nøhr-Hansen (1993) looked in detail at dinoflagellate cyst biostratigraphy and taxonomy from the Early Barremian to earliest Cenomanian of northeast Greenland.

Material from the Atlantic coast of Canada and the United States has also been studied. Bujak & Williams (1978) published a long-ranging biostratigraphic paper (latest Jurassic through to the earliest Tertiary) based on core data from offshore southeastern Canada. Habib & Drugg (1987) examined the biostratigraphy of Berriasian through to the latest Cenomanian or earliest Turonian material from DSDP cores (sites 603 and 605), from offshore of the United States. May (1980) carried out a biostratigraphic study of the Campanian and Maastrichtian of New Jersey. The latest Cenomanian to Maastrichtian from cores from New Jersey and Delaware (U.S.A.) has also been discussed with relation to biostratigraphy by Aurisano (1989).

A number of studies have been made from the Bahamas area, offshore south-eastern United States. These include Habib (1969, 1970; Albian to Cenomanian from offshore cores), Habib & Drugg (1983; Berriasian to Vraconian of the Blake-Bahama Basin, DSDP sites 534A and 391C), and Masure (1988; Albian to Cenomanian, ODP sites 627 and 635).

Within the Western Interior Basin of the United States, there has been relatively little published on dinoflagellate cysts. Bint (1986), made a detailed taxonomic study and brief biostratigraphic study of ceratioid cysts from the Albian to Cenomanian of Kansas, in the Western Interior Basin.

Biostratigraphic studies of the Albian to Maastrichtian of Wyoming, Montana and Utah were carried out by Nichols & Jacobson (1982) and Nichols *et al.* (1982). These concentrated mostly on miospores but included some dinoflagellate cyst data. Very few dinoflagellate cysts ranges were indicated, and of these a number were found not to be in agreement with this study. Little discussion was given to the systematics and only very brief species lists were provided for the various dinoflagellate cyst range zones.

5.1.2 Cenomanian and Turonian studies

A number of studies from the Cenomanian and Turonian of Europe have been published. Jarvis *et al.* (1988) is a comprehensive study across the Cenomanian - Turonian boundary from Dover, England, integrating dinoflagellate cyst, macrofossil, other microfossil and geochemical studies. Marshall & Batten (1988) studied the dinoflagellate cyst assemblages and palynofacies changes from Cenomanian - Turonian boundary sections in the Saxony Basin, north Germany. Other biostratigraphical studies from this interval include Tocher & Jarvis (1987) from the Turonian chalk in Devon, England, and Tocher & Jarvis (1994) from the Lower and Middle Cenomanian from Normandy, France.

Within the Western Interior of the United States, few papers have as yet been published, on work from the Cenomanian - Turonian interval. Burgess (1971) looked at the palynology of the Frontier Formation (Cenomanian and Turonian) of Wyoming to correlate a number of cores. Little taxonomy was published and no detailed biostratigraphy was discussed either.

Thompson (1972) looked at the palynology of the Mancos Shale Formation in southwestern Colorado. No taxonomic discussion or illustrations were given, while the taxonomically-limited data set published, included either the common, long-ranging taxa found in this study, undescribed forms, or simply species not seen at all in this study. Much of the paper was used to describe the multivariate statistical analyses of the data sets, but the results were not discussed in any depth. The palynomorphs were suggested to be groupable into three sets, representing nearshore, intermediate and offshore taxa, but Thompson failed to describe which data set was which, or which taxa belonged to which data set. No substantial or usable/comparable conclusions were reached.

Courtinat (1993) published on palynofacies fluctuations and dinoflagellate cyst assemblages from the upper Hartland Member and lower Bridge Creek Limestone Member (Late Cenomanian only) at Pueblo. No material was discussed from PBC15 or above (levels containing high concentrations of amorphous organic matter). The Hartland Member was not thoroughly studied for dinoflagellate cysts, as only eight cyst species were found below the Bridge Creek Limestone Member. No systematics were discussed, and the species listed in the range charts only showed a reasonable accordance with the taxa found in this study.

5.2 BIOSTRATIGRAPHY OF SECTIONS

5.2.1 Introduction

The strata of the Greenhorn cyclothem and the Cenomanian - Turonian boundary sections were originally dated using macrofossils. These ages are supported by the dinoflagellate cyst data. High resolution biostratigraphy (using the detailed lithostratigraphy) also suggests that where the relevant taxa occur, many of the dinoflagellate cyst range-bases and tops were synchronous across the basin.

Many of the species, in particular the more common species, are stratigraphically long-ranging and of little use for placing the strata within an age. These also tend to be the environmentally tolerant species which may be one reason why they are 'long-lived'.

The stratigraphically useful species tend to be more environmentally controlled and may have had greater affinities with the Boreal or Tethyan water masses. Many of these stratigraphically useful species do not occur in the sections from the western part of the basin (i.e. Blue Point and Wahweap Wash). These include *Adnatosphaeridium tutulosum*, *Chichaouadinium vestitum*, *Dinogymnium vozzhennikovae*, *Chatangiella spectabilis*, *Isabelidinium? globosum*, and *Ovoidinium verrucosum*.

All the biostratigraphic ranges for dinoflagellate cysts noted from the Rebecca K. Bounds core, strictly apply only to the Greenhorn cyclothem, for sediments from just below the top of the Dakota Formation (1128') through to the top of the Blue Hill Shale Member of the Carlile Formation (750'). It is probable that most of the species have stratigraphic occurrences outside this interval, but it must be emphasised that the ranges suggested for the species below are only mentioned for the interval studied. Those species used as markers in the Rebecca K. Bounds core from stratigraphy outside the immediate Cenomanian-Turonian boundary interval are only tentatively suggested, as no direct correlation can be made with any other long-ranging, equivalent section in this study. Only after comparisons with other Greenhorn cyclothem sections can these markers offer any real value.

Throughout this chapter, the stratigraphic ranges of individual species discussed are illustrated in biostratigraphic range charts, located in Appendix E. These include the ranges of the acritarchs, chlorophytes and prasinophytes (all collectively grouped under acritarchs) and of the dinoflagellate cysts. For each section two charts are available with the taxa in order of first appearance datum (chart 'A') and last appearance datum (chart 'B'). The charts are numbered for the sections as follows: Charts 1A and 1B for the Rebecca K. Bounds core, Kansas; Charts 2A and 2B for the section at Blue Point, Arizona; Charts 3A and 3B for the section at Wahweap Wash, Utah; Charts 4A and 4B for the section at Pueblo, Colorado; and Charts 5A and 5B for the section at Bunker Hill, Kansas. For detailed comparison of stratigraphic occurrences of taxa alongside the lithostratigraphy, the chart plot depths are included against the lithological logs in Chapter 3: Figures 3.6 and 3.8 for the Rebecca K. Bounds core, Figure 3.16 for the Blue Point section, Figure 3.13 for the Wahweap Wash section, Figure 3.9 for the Pueblo section, and Figure 3.11 for the Bunker Hill section.

The locations of the core and section sites are described in Appendix A, the samples used along with their range-chart plot depths are listed in Appendix B, the authors for the dinoflagellate cyst and other palynomorph species are listed in Appendix C, and the species are illustrated in Appendix D.

5.2.2 Rebecca K. Bounds core

Samples from the Rebecca K. Bounds core generally yielded diverse assemblages of dinoflagellate cysts and other marine palynomorphs. The overall high diversity results mostly from the much greater stratigraphic coverage of the samples studied. The assemblages include one hundred and seventy one species and subspecies of dinoflagellate cyst, seventeen species of acritarch, nine species of prasinophyte algae and five species of ?chlorophyte algae (Appendix E, Charts 1A and 1B).

The assemblages from the Dakota Formation are discussed in depth in Chapter 8. The most common dinoflagellate cyst species include *Nyktericysta* sp. A, *Ovoidinium verrucosum*, *Florentinia clavigera* and *Florentinia cooksoniae*.

The most common species through the strata of the Graneros Shale, Greenhorn Limestone and Carlile Shale Formations include *Palaeohystrichophora infusorioides*, *Spiniferites ramosus ramosus*, *Subtilisphaera cheit* and *Subtilisphaera? inaffecta*. Leiospheres are also abundant, becoming dominant at certain intervals.

Common species in the Graneros Shale Formation also include *Cyclonephelium brevispinatum*, *Batiacasphaera granulosa* and *Downiesphaeridium multispinosum*. Additional common species in the 'lower shale member' of the Graneros Shale Formation (Lower Cenomanian) include *Spiniferites lenzii*, *Cyclonephelium vannophorum*, *Cribroperidinium cooksoniae*, *Canningia scabrosa* and *Oligosphaeridium albertense*. The top of the 'lower shale member' is also dominated by leiospheres. In the 'upper shale member' of the Graneros Shale Formation (Middle Cenomanian), common species include *Canninginopsis colliveri* and *Litosphaeridium siphoniphorum*.

In the assemblages of the Greenhorn Limestone Formation, *Alterbidinium rhombovale* first becomes important. Leiospheres dominate the assemblages of the Lincoln and Hartland Members along with large numbers of tasmanitids, species of *Pterospermella*, *Crassosphaera papillata* and *Wuroia* sp. A. *Heterosphaeridium? heteracanthum* first appears and reaches significant numbers in the Lincoln Member. *Odontochitina costata* and *Odontochitina operculata* also first become common in the Lincoln Member. Additional common species in the Hartland Member include *Isabelidinum magnum*, *Litosphaeridium siphoniphorum*, *Surculosphaeridium? longifurcatum* and the *Chlamydophorella nyei/Dapsilidinium ambiguum* complex. *Trithyrodinium* sp. cf. *T. evittii* is also common in the samples from the Hartland Member and lower part of the Bridge Creek Limestone Member. The base of the Bridge Creek Limestone Member is marked by an acme of *Pterodinium cingulatum* and higher numbers of *Tenua hystrix*. *Cyclonephelium compactum* also becomes an important part of the assemblages in the samples from the member. In the middle of the member, leiospheres again reach substantial numbers and *Circulodinium distinctum* becomes more common. In the upper half of the Bridge Creek Limestone Member *Eurydinium glomeratum* becomes very common.

Chatangiella spectabilis is common in the strata of the Carlile Shale Formation. The base of the formation is also marked by an acme of the *Chlamydophorella nyei/Dapsilidinium ambiguum* complex. *Isabelidinium? globosum* and *Eurydinium glomeratum* are very common in the lower part of the Fairport Chalky Shale Member along with *Canninginopsis colliveri*. In the upper part of the member, *Tenua hystrix* becomes common and *Cyclonephelium compactum* again forms a significant part of the assemblage after low numbers through the lower Fairport. At the top of the Fairport Chalky Shale Member, *Alterbidinium rhombovale* becomes very important and maintains large numbers through much of the Blue Hill Shale Member. *Chatangiella granulifera tenuis* is also common in the Blue Hill Shale Member.

5.2.3 Blue Point section

The assemblages include one hundred and twenty three species and subspecies of dinoflagellate cyst, thirteen species of acritarch, seven species of prasinophyte algae and one species of ?chlorophyte alga (Appendix E, Charts 2A and 2B).

In the *Sciponoceras* Zone the samples from the top of the Dakota Formation are dominated by *Palaeohystrichophora infusorioides*, *Tenua hystrix*, *Spiniferites ramosus* subspecies and *Florentinia mantellii*, which all gradually decrease in importance in the lower part of the Mancos Shale Formation. The upper part of the *Sciponoceras* Zone (Mancos Shale Formation) contains substantial numbers of *Cyclonephelium brevispinatum*. An acme of *Odontochitina costata* marks the horizon equivalent to PBC6, while the top of the zone is marked by a large acme of *Cyclonephelium compactum*.

The base of the *Neocardioceras* Zone is marked by large increase in *Subtilisphaera cheit*, *S. inaffecta*, and *Palaeohystrichophora infusorioides* which make up a substantial part of the assemblage through the rest of the *Neocardioceras* and *Watinoceras* Zones. The *Neocardioceras* Zone also contains fluctuating but significant numbers of *Spiniferites lenzii* and *Exochosphaeridium phragmites*. *Trithyrodinium* sp. cf. *T. evitti* first becomes important in the zone and remains fairly common to the top of section studied.

The base of the *Watinoceras* Zone is marked by an acme of *Pseudoceratium eisenackii*. A further large increase in *Palaeohystrichophora infusorioides* and *Subtilisphaera cheit* occurs in the sample from the horizon equivalent to PBC17. The upper part of the *Watinoceras* Zone is marked by a substantial numbers of *Spiniferites lenzii*, and the top of the zone is marked by an acme of *Circulodinium distinctum* and higher numbers of foraminiferal test linings.

The base of the *Mammites* Zone is marked by a major acme of *Odontochitina costata* and a decline in the numbers of *Palaeohystrichophora infusorioides* and *Subtilisphaera cheit*.

5.2.4 Wahweap Wash section

The assemblages include one hundred and twenty two species and subspecies of dinoflagellate cyst, eleven species of acritarch and five species of prasinophyte algae (Appendix E, Charts 3A and 3B). *Odontochitina costata*, *Spiniferites ramosus gracilis*, *Tenua hystrix*, and *Exochosphaeridium phragmites* are common in the samples from the section but in the *Sciponoceras*, *Neocardioceras* and lower part of the *Watinoceras* Zones are more abundant though with variable numbers.

Spiniferites ramosus ramosus is significant in the *Sciponoceras* Zone but generally becomes less abundant higher in the section. The lower part of the *Sciponoceras* Zone also contains larger numbers of *Achomosphaera ramulifera*. A major acme of *Cyclonephelium compactum* occurs in the upper part of the *Sciponoceras* Zone, particularly below the equivalent of PBC7.

Subtilisphaera cheit and *Trithyrodinium* sp. cf. *T. evittii* are common through all of the section but reach much larger numbers through the *Neocardioceras* Zone. The samples from the base of this zone are marked by a sharp increase in *Oligosphaeridium complex*. The lower part of the zone also contains the highest numbers of foraminiferal test linings found in the section. *Palaeohystrichophora infusorioides* has comparatively low numbers through the *Sciponoceras* Zone but dominates the assemblages in many of the samples from the *Neocardioceras* and *Watinoceras* Zones

The base of the *Watinoceras* Zone is marked by an acme of *Pseudoceratium eisenackii, Circulodinium distinctum* and *Xenascus australensis*. The lower part of the zone is also marked by substantial numbers of *Exochosphaeridium phragmites* especially below the equivalent of PBC17. The samples from the section contain a number of peaks of *Spiniferites lenzii* but the largest occurs at the top of the *Watinoceras* Zone, along with peaks of *Circulodinium distinctum, Cyclonephelium brevispinatum* and *C. vannophorum*. *Subtilisphaera cheit* is present in lower samples but also reaches substantial numbers in the upper part of the *Watinoceras* Zone.

5.2.5 Pueblo section

The assemblages include one hundred and forty eight species and subspecies of dinoflagellate cyst, twelve species of acritarch, nine species of prasinophyte algae and two species of ?chlorophyte algae (Appendix E, Charts 4A and 4B). The samples from the Pueblo section generally contain diverse dinoflagellate cyst assemblages with comparatively little dominance by individual species except for continual high numbers of *Palaeohystrichophora infusorioides, Subtilisphaera cheit, Subtilisphaera? inaffecta, Spiniferites ramosus* subspecies, *S. twistringiensis* and *Tenua hystrix*.

The assemblages from the Hartland Member are dominated by leiospheres, tasmanitids, species of *Pterospermella* and *Wuroia* sp. A. Important dinoflagellate cyst species in the member include *Circulodinium distinctum, Alterbidinium rhombovale, Isabelidinium magnum, Odontochitina costata* and *O. operculata*.

An additional common species through most of the samples of the Bridge Creek Limestone Member is *Achomosphaera ramulifera*. The main acme event in the lower part of the *Sciponoceras* Zone is a large peak in abundance of *Odontochitina costata* which occurs in the shale between PBC2 and PBC3. *Cyclonephelium compactum* has a number of peaks in the samples from the *Sciponoceras* and *Neocardioceras* Zones but the largest is in the upper part of the *Neocardioceras* Zone.

Notable acme events in the *Watinoceras* Zone include higher numbers of *Cyclonephelium uncinatum* in some of the samples from the lower part, a peak of *Heterosphaeridium? heteracanthum* in the middle of the zone and an increase in *Trichodinium castanea* in the upper part of the zone. The top of the *Watinoceras* Zone and the base of the *Mammites* Zone also contain substantial numbers of *Hystrichodinium pulchrum*.

5.2.6 Bunker Hill section

The assemblages include one hundred and ten species and subspecies of dinoflagellate cyst, eleven species of acritarch, seven species of prasinophyte algae and two species of ?chlorophyte algae (Appendix E, Charts 5A and 5B).

The assemblages through all of the section are very strongly dominated by *Palaeohystrichophora infusorioides* and *Subtilisphaera inaffecta*. Additional common species include *Spiniferites ramosus* subspecies and *Subtilisphaera cheit*. *Subtilisphaera pontis-marie* is also very common at the top of the *Sciponoceras* Zone, at the top of the *Neocardioceras* Zone, through the lower half of the *Watinoceras* Zone and at the top of the *Watinoceras* Zone and base of the *Mammites* zone.

Few notable acme events occur in the section apart from larger numbers of *Cyclonephelium compactum* and *C. uncinatum* in the sample from the horizon including the equivalent of PBC10 from the *Neocardioceras* Zone and larger numbers of *C. compactum* and *Odontochitina costata* at the top of the *Neocardioceras* zone. In addition, the top of the *Watinoceras* Zone is marked by larger numbers of *Florentinia radiculata* and *Trithyrodinium suspectum.*

5.3 BIOSTRATIGRAPHIC MARKER-SPECIES

5.3.1 Cenomanian and Turonian marker-species

A number of species place the sediments of the Greenhorn cyclothem in the 'mid' Cretaceous. *Alterbidinium emulatum* is documented as a Cenomanian to Turonian marker for the Western Interior Basin from sections further north with a range restricted to the Greenhorn cyclothem (e.g. as *Deflandrea* sp. cf. *D. acuminata* in Burgess (1971) as discussed by Nichols & Jacobson (1982); and as *Alterbia* sp. A in Nichols *et al.* (1982) and Nichols & Jacobson (1982)). Burgess (1971) suggested that the species might have a range base at the Cenomanian-Turonian boundary. The only other recorded occurrence of this species is from the Late Cretaceous of China (Mao Shaozhi & Norris, 1987). In the Rebecca K. Bounds core, this species has only been found in two samples from the Fairport Chalky Shale Member (Middle Turonian). At Pueblo, this species is rare with a single occurrence in the Hartland Member. At Bunker Hill, the species is also rare with a single occurrence in the Cenomanian at the base of the *Neocardioceras* Zone (just below PBC9) and a single occurrence in the Turonian at the top of the *Watinoceras* Zone/base of the *Mammites* Zone (around PBC23). At Blue Point, this species is also rare with a single occurrence just below bentonite PBC11 in the *Neocardioceras* Zone and a single occurrence between bentonites PBC17 and WB18 in the *Watinoceras* Zone. The species is most common in the Wahweap Wash section (the most northerly of the sections in 'mid' Cretaceous time), where it occurs through the Turonian, from just above the calcisiltite horizon, above the bentonite marker equivalent to PBC17 in the *Watinoceras* Zone.

Batiacasphaera euteiches is only recorded in the literature from Cenomanian and Turonian strata although its occurrence in the Greenhorn cyclothem of the Rebecca K. Bounds core is infrequent.

Disphaeria macropyla has a previously been described from Vraconian to Turonian strata (Cookson & Eisenack, 1960a, Norvick *in* Norvick & Burger, 1976, Morgan, 1980). In the Rebecca K. Bounds core it occurs from the Lincoln Member (Late Cenomanian) through to the top of the Fairport Chalky Shale Member (Middle Turonian). At Pueblo, it occurs in the limestone horizon PBC1, and again in the sample below and including PBC6 in the *Sciponoceras* Zone. At both Blue Point and Wahweap Wash, on the west side of the basin, it occurs in samples at the same stratigraphic interval, between the bentonite equivalent to PBC17 and the one above, in the *Watinoceras* Zone.

Xenascus australensis has been recorded from the Albian/Cenomanian and Turonian (Cookson & Eisenack, 1969, Prössl, 1990). The occurrence of this species, in all the sections reinforces a 'mid' Cretaceous age for the strata. Its earliest occurrence in the Rebecca K. Bounds core is at the base of the Lincoln Member, in the Late Cenomanian, with no further occurrence until the Blue Hill Shale Member

(Middle Turonian). The species also appears through the Late Cenomanian and Early Turonian of Blue Point, Pueblo and Wahweap Wash, and in the Late Cenomanian at Bunker Hill.

5.3.2 Cenomanian or younger marker-species

Apart from one record (Davey & Verdier, 1973, in the Vraconian), *Dapsilidinium? pumilum* has a published range from the Cenomanian onwards (e.g. Davey, 1969a, Foucher, 1983). It occurs from the base of the Graneros Shale Formation (Early Cenomanian) right through to the Blue Hill Shale Member (Middle Turonian) in the Rebecca K. Bounds core, and in all the other sections studied, and confirms their age as Cenomanian or younger.

Downiesphaeridium armatum also has a single record from the Late Albian (Davey & Verdier, 1973) but has been noted from the Cenomanian onwards by many authors (e.g. Clarke & Verdier, 1967, Morgan, 1980, Foucher, 1983, Prössl, 1990), and generally verifies the strata as Cenomanian or younger. It appears in all the sections studied, and in the Rebecca K. Bounds core appears in the Lincoln Member (Late Cenomanian) and has a last occurrence at the top of the Fairport Chalky Shale Member (Middle Turonian).

Isabelidinium magnum has not been recorded in strata older than Cenomanian (e.g. Davey, 1970, Costa & Davey, 1992). It is present in all five sections studied. In the Rebecca K. Bounds core it appears in the Late Cenomanian in the Lincoln Member and continues through to the Blue Hill Shale Member and confirms the age as Cenomanian or younger.

Trithyrodinium suspectum has only been described from strata of Cenomanian or younger age (Davey, 1970, Habib & Drugg, 1987, Aurisano, 1989, Costa & Davey, 1992). It is relatively common in all the sections through the Late Cenomanian and Early Turonian. In the core, the species first appears in the Hartland Member (Late Cenomanian) and continues through to the top of the Blue Hill Shale Member (Middle Turonian).

Xenascus perforatus has only previously been described from Cenomanian or younger strata (Below, 1981, 1982, Prössl, 1990), and has been found in the Late Cenomanian and Early Turonian at Blue Point and Wahweap Wash, and in the Early Turonian at Pueblo.

5.3.3 Turonian or older marker-species

Cribroperidinium cooksoniae has a first occurrence datum in the Hauterivian but occurs no later than the Late Turonian (e.g. Prössl, 1990, Mohr & Gee, 1992). It is present in all of the sections studied and in the Rebecca K. Bounds core occurs through to the top of the Blue Hill Shale Member, in the Middle Turonian. It verifies the age of the studied sections as no younger than the Turonian.

Cyclonephelium compactum has a previously recorded range from the Aptian to the Late Turonian (e.g. Prössl, 1990). In this study, the species does not appear until the Late Cenomanian (in the Lincoln Member in the Rebecca K. Bounds core) but forms an important component of assemblages in all of the sections, and ranges up to the top of the Blue Hill Shale Member in the Rebecca K. Bounds core. It confirms the age of the sections, therefore, as Turonian or older.

Similarly, *Florentinia cooksoniae* has a fairly long stratigraphic range but does not have a recorded occurrence later than the Late Turonian (Stover *et al.*, 1996). *Florentinia resex* has not been recorded later than the Middle Turonian (Davey & Verdier, 1976). Both occur in all of the sections studied. In the Rebecca K. Bounds core they range from the top of the Dakota Formation and the base of the Graneros Shale Formation (Early Cenomanian), respectively, through to the top of the Blue Hill Shale Member (Middle Turonian).

Kiokansium unituberculatum is a geographically widespread, and stratigraphically long-ranging form which has been recorded as early as the Berriasian (Habib & Drugg, 1983). Although many authors record the last occurrence of this species in the Cenomanian (e.g. Bujak & Williams, 1978, Costa & Davey, 1992), some authors have described it from the Turonian (e.g. Norvick *in* Norvick & Burger, 1976, Habib & Drugg, 1987, Mohr & Gee, 1992). This species was found in all the studied sections except for Bunker Hill, although its occurrence was rare. In the Rebecca K. Bounds core, this species was only found in the 'lower shale member' of the Graneros Shale Formation (Early Cenomanian). At Blue Point and Wahweap Wash this species only occurs in the Late Cenomanian, appearing only briefly in the *Sciponoceras* Zone at Blue Point, and in the *Sciponoceras* and *Neocardioceras* Zones at Wahweap Wash. At Pueblo, this species not only appears in the *Sciponoceras* and *Neocardioceras* Zones in the Late Cenomanian, but also has a single occurrence in the Early Turonian, at the top of the *Watinoceras* Zone.

Leberidocysta defloccata has only been previously described from Albian through to Turonian strata (e.g. Davey & Verdier, 1973, Habib & Drugg, 1987, Prössl, 1990), and hence dates the eastern study sections as 'mid' Cretaceous in age. However, it was not seen in the Blue Point or Wahweap Wash sections. In the Rebecca K. Bounds core it ranges from the base of the Lincoln Member (Late Cenomanian) through to the Blue Hill Shale Member (Middle Turonian). At Pueblo it occurred in the Late Cenomanian and Early Turonian, but at Bunker Hill, it only occurred in the Early Turonian.

Litosphaeridium siphoniphorum has also been described from Aptian/Albian to Turonian strata by many authors. It is used as a Cenomanian range-top marker in many studies (e.g. Clarke & Verdier, 1967, Prössl, 1990), but a number of authors have recorded this species in the Turonian (e.g. Norvick *in* Norvick & Burger, 1976, Bujak & Williams, 1978, Lucas-Clark, 1984, Habib & Drugg, 1987, Costa & Davey, 1992, Mohr & Gee, 1992, Williams *et al.*, 1993) and even into the Coniacian (Foucher, 1983). In the Rebecca K. Bounds core it is common from the top of the 'lower shale member' of the Graneros Shale Formation (1090') in the late Early Cenomanian, through to the top of the Hartland Member (990') in the Late Cenomanian, and then occurs only rarely from the Bridge Creek Limestone Member to the middle of the Fairport Chalky Shale Member (840' to 930') in the Early and Middle Turonian. In the Pueblo material the species is present and even common in the Hartland Member and *Sciponoceras* Zone of the Bridge Creek Limestone Member (as far as just below PBC7). One further sample (from PBC15) near the base of the *Watinoceras* Zone in the Early Turonian also contained this species. At Wahweap Wash, this species only occurred at the base of the section studied, in the *Sciponoceras* Zone (with a last occurrence just below the equivalent of PBC6). This species was not seen in the Blue Point or Bunker Hill sections. In this study, the species can be regarded as a good Cenomanian marker with limited further occurrences into the Turonian.

Prolixosphaeridium conulum is another species with a recorded range of Albian to Turonian (e.g. Morgan, 1980, Prössl, 1990). It occurs from the Early Cenomanian to the Middle Turonian of the

Rebecca K. Bounds core. It was also noted in the Late Cenomanian at Pueblo (ranging from beds PBC1 to just below PBC6) and at Blue Point (with a single occurrence also just below the equivalent of PBC6).

5.3.4 Early and Middle Cenomanian marker-species

A number of species, which have only been previously described from the Early to Middle Cenomanian of Canada (Singh, 1983), form important Early and Middle Cenomanian markers for the Rebecca K. Bounds core. These include *Dinopterygium reticulatum, Subtilisphaera hyalina* and *Dapsilidinium marinum.*

Dinopterygium reticulatum only occurs in the Rebecca K. Bounds core in the sample at the top of the Dakota Formation at 1119.5' (Early Cenomanian), which may have been deposited in a lagoonal environment.

Subtilisphaera hyalina occurs through the 'lower shale member' of the Graneros Shale Formation from the base (1110') to just below the Thatcher Limestone Member (1090'), and so makes an important marker for the Early Cenomanian.

Dapsilidinium marinum occurs in the 'lower shale member' and 'upper shale member' of the Graneros Shale Formation from 1110' (the base) to 1070' (Early to Middle Cenomanian). However, a single occurrence has also been noted in the Late Cenomanian of the Wahweap Wash section from just below the bentonite equivalent to PBC11, in the *Neocardioceras* Zone. This may represent reworking or may be a stratigraphic extension of this species along the western margin of the basin.

5.3.5 Late Cenomanian marker-species

Adnatosphaeridium tutulosum is a distinctive species and an important biostratigraphic marker from studies across the globe, with a restricted range from the Late Albian to the Late Cenomanian (Foucher, 1983, Marshall & Batten, 1988). In the Rebecca K. Bounds core it appears only in the uppermost two Cenomanian samples, in the uppermost Hartland Member (990') and at the base of the *Neocardioceras* Zone of the lower Bridge Creek Limestone Member (980' just below the equivalent of PBC9). At Pueblo, it also briefly occurs in the Hartland Member (sample PA1) and then through most of the *Sciponoceras* Zone (from the top of PBC1) with its last occurrence at the base of the *Neocardioceras* Zone (around PBC 8 to 9). The only occurrence in the Bunker Hill section is also at the base of the *Neocardioceras* Zone (also just below PBC9). The spot sample from the core at this level is coincidence, but the range top between Pueblo and Bunker Hill is precisely correlatable using the lithostratigraphic event marker horizons. This species was not found in the Blue Point or Wahweap Wash sections. In the Lower Saxony Basin in north Germany, Marshall & Batten (1988) also noted the rare but biostratigraphically important occurrence of this species which had its range top just below the appearance of species of *Neocardioceras*, in the Misburg section.

Chichaouadinium vestitum is also a species with a stratigraphically restricted range from the Albian, and with no recorded occurrences later than the latest Cenomanian. In this study it also forms an important biostratigraphic marker for the Late Cenomanian, although it also only occurs rarely. In the Rebecca K. Bounds core it occurs only in the Hartland Member at 990' and 1000'. At Pueblo it occurs in the Hartland Member, and a single specimen was also found in the lower Bridge Creek Limestone Member between PBC5 and PBC6 in the *Sciponoceras* Zone.

Epelidosphaeridia spinosa has a single record from the Turonian (Bujak & Williams, 1978) but is regarded by most authors (e.g. Clarke & Verdier, 1967, Foucher, 1983, Prössl, 1990, Costa & Davey, 1992) as a good marker species with a range top in the Cenomanian. In the material studied, it is extremely rare, with only two occurrences at Pueblo; one at the base of the Bridge Creek Limestone Member and *Sciponoceras* Zone (at the base of PBC1), and the other just below PBC14, near the top of the *Neocardioceras* Zone, around half a metre below the Cenomanian-Turonian boundary as defined by the macrofauna.

Ovoidinium scabrosum and *O. verrucosum* both have limited stratigraphic ranges from the Aptian/Albian and range tops in the Cenomanian (e.g. Davey & Verdier, 1973, Singh, 1983, Below, 1984, Prössl, 1990, Costa & Davey, 1992). In the Rebecca K. Bounds core they both appear in the sample from the top of the Dakota Formation (Early Cenomanian) and have last occurrences in the Hartland and Lincoln Members (Late Cenomanian), respectively. In addition, a single occurrence of *O. verrucosum* occurs in the Hartland Member at Pueblo, giving a Cenomanian age.

5.3.6 Early Turonian marker-species

Florentinia buspina has not been recorded from strata older than the Early Turonian (e.g. Davey & Verdier, 1976), and so makes a good Turonian marker species. It is rare in the studied sections but appears at the base of the *Mammites* Zone at Pueblo and Bunker Hill (around PBC23 to PBC24 in the Pueblo section, and immediately above the limestone equivalent to PBC24 at Bunker Hill). At Blue Point, it appears in the *Watinoceras* Zone (above the equivalent of PBC21). In the Rebecca K. Bounds core it was only logged in the lower half of the Fairport Chalky Shale Member (from 870' to 900') in the Middle Turonian.

5.3.7 Middle Turonian marker-species

Isabelidinium cooksoniae has mostly been recorded in Santonian to Maastrichtian strata but does have noted appearances in the Middle Turonian (Costa & Davey, 1992) and Late Turonian (Foucher, 1983). In the Rebecca K. Bounds core it appears in the Blue Hill Shale Member in the Middle Turonian (750' to 780') and so forms a good marker species for the core.

Raetiaedinium truncigerum has a variable stratigraphic record with many recorded occurrences in the Coniacian to Campanian (e.g. Clarke & Verdier, 1967, Bujak & Williams, 1978, Kirsch, 1991), and a few noted occurrences from the Turonian (Foucher, 1983, Prössl, 1990, Williams *et al.*, 1993). In addition, a couple of earlier occurrences were noted including one from the Vraconian (Below, 1982), and one from the Late Cenomanian at Pueblo (Courtinat, 1993). In this study, the species was not found at all in the Pueblo section or any other section in Cenomanian strata. The only occurrence was in the Rebecca K. Bounds core in the Fairport Chalky Shale Member (Middle Turonian) where the species forms an important biostratigraphic marker.

5.3.8 Local and basinal biostratigraphic marker-species

Membranilarnacia polycladiata has a limited occurrence in the literature, but a total recorded range from the Albian? through to the Maastrichtian (Cookson & Eisenack, 1958, Prössl, 1990, Kirsch, 1991). However, in this study it forms an excellent marker for the latest Cenomanian.

In the Rebecca K. Bounds core it only occurs in two samples (980' and 990') from the uppermost Hartland Member and lowermost Bridge Creek Limestone Member. The sample taken at 980' was taken from just below the equivalent of PBC9. In the Pueblo material, the species forms a near-perfect *Sciponoceras* Zone marker, with a first occurrence at the base of PBC1 (the base of the biozone and base of the Bridge Creek Limestone Member) and the last occurrence in the sample (PB12) including material from the top of the *Sciponoceras* and base of the *Neocardioceras* Zones (including the limestone bed PBC9 and the shale below). In the material from the Wahweap Wash section, the range top also occurs exactly at the top of the *Sciponoceras* Zone. At Bunker Hill, the species was found in only two samples (BH3 and BH4), which include the limestone bed equivalent to PBC9 and the shale below. However, at this locality these two samples, although at the same lithostratigraphic interval as the range-top at Pueblo, occur at the base of the *Neocardioceras* Zone.

At Blue Point, the species occurs in the two Dakota Formation samples (BP1 and BP2), and through the Mancos Shale Formation, as far as sample BP7, immediately below the uppermost sample from the *Sciponoceras* Zone. This uppermost occurrence is in the sample which includes the concretionary horizon equivalent to PBC7 and part of the shale bed above (sample BP7). No lithostratigraphic horizon occurs which is laterally equivalent to PBC8. The next laterally traceable, lithostratigraphic horizon above is a concretionary horizon equivalent to PBC9. However, *M. polycladiata* was not seen in either the sample including this horizon (sample BP9), or the sample solely from the shale below (sample BP8).

Effectively, the range top of *M. polycladiata* is exactly synchronous (within the limits of the sampling) across the basin in all of the sections except for the one at Blue Point, where the *Cyclonephelium compactum* acme event (as discussed below) occurred for longer than in the other sections.

Dorocysta litotes has been recorded from the Albian through to the Campanian (e.g. Nøhr-Hansen, 1993, Ioannides, 1986). However, it does not occur right through the Rebecca K. Bounds core but first appears at the top of the Hartland Member (Late Cenomanian) and disappears in the lower half of the Fairport Chalky Shale Member (Middle Turonian). It also occurs in all the other sections except the Wahweap Wash section.

Hystrichosphaeridium bowerbankii has a total recorded range from the Barremian to the Campanian (e.g. Davey, 1969, Bujak & Williams, 1978, Prössl, 1990). However, in all the boundary sections, the species only appears in the Late Cenomanian. The species has a range-top around PBC7 at Pueblo, between the equivalents of PBC9 and PBC11 at Wahweap Wash, and around PBC14 at Blue Point and Bunker Hill. In the Rebecca K. Bounds core the species was only noted in the 'upper shale member' of the Graneros Shale Formation (Middle Cenomanian). From this study, the species has an apparent range-top in the Late Cenomanian.

Impagidinium modicum has a previously recorded range only in the Albian and Cenomanian (Brideaux & McIntyre, 1975, Singh, 1983). In the Rebecca K. Bounds core it first appears in the lower Bridge Creek Limestone Member (Late Cenomanian) in the sample taken from just below the equivalent of PBC9 (980') and continues through to the sample (800') at the top of the Fairport Chalky Shale Member (Middle Turonian). At Pueblo, the species occurs from the base of the section studied in the Hartland Member (*Metoicoceras* Zone), and is intermittently found through to the *Mammites* Zone. At Bunker Hill, the species is seen from near the base of the section studied, from the *Neocardioceras* Zone, through to the *Mammites* Zone. At Wahweap Wash, the species first appears in the *Watinoceras* Zone. At Blue Point, the species does not appear until the *Mammites* Zone. This differential appearance may be a product of environmental constraints.

Kleithriasphaeridium readei has a total recorded range from the Albian to the Santonian (e.g. Davey & Verdier, 1976, Bujak & Williams, 1978, Foucher, 1983). It only occurs in the Rebecca K. Bounds core in the Middle Turonian, appearing at the base of the Fairport Chalky Shale Member (900') and continuing through to the top of the Blue Hill Shale Member (750'), thus forming an important biostratigraphic marker for the core. It was not found in any of the other sections in this study.

Microdinium ornatum has a previously recorded range from the Albian to the Maastrichtian (e.g. Cookson & Eisenack, 1960a, Morgan, 1980, Aurisano, 1989, Mohr & Gee, 1992). In the Rebecca K. Bounds core, it forms an important biostratigraphic marker, ranging from the Late Cenomanian in the Hartland Member (at 1000') through to the Middle Turonian Blue Hill Shale Member. It was also noted in the Pueblo, Wahweap Wash and Blue Point sections.

Pervosphaeridium pseudhystrichodinium has a total recorded range from the Albian to Campanian (e.g. Davey & Verdier, 1973, Foucher, 1983, Prössl, 1990, Kirsch, 1991). In the Rebecca K. Bounds core it was recorded from the 'lower shale member' of the Graneros Shale Formation (Early Cenomanian) through to the lower Bridge Creek Limestone Member (to sample 980' just below PBC9, in the Late Cenomanian). In three of the other sections it was only found in the Late Cenomanian, with a last occurrence around PBC5 at Pueblo, around the equivalent of PBC6 at Blue Point, and just below the equivalent of PBC9 at Wahweap Wash. It was not seen in the Bunker Hill section. Thus from this study, the species has a range top within the basin in the Late Cenomanian.

Rhiptocorys veligera has a total recorded range from the Albian to the Maastrichtian (e.g. Davey & Verdier, 1973, Foucher, 1983, Kirsch, 1991). The species ranges from the base of the Bridge Creek Limestone Member (Late Cenomanian) in the Rebecca K. Bounds core, through to the Blue Hill Shale Member (Middle Turonian), forming an important biostratigraphic marker for the core. At Pueblo, the species appears at the base of the Bridge Creek Limestone Member (in PBC1) in the Late Cenomanian. At Blue Point, a single specimen was noted from the Early Turonian.

Senoniasphaera microreticulata has a total recorded range from the Aptian to the Turonian (e.g. Bujak & Williams, 1978, Jarvis *et al.*, 1988, Nøhr-Hansen, 1993). This species forms an important Middle Cenomanian marker species for the Rebecca K. Bounds core, with a limited stratigraphic occurrence in the 'upper shale member' of the Graneros Shale Formation, between 1040' and 1060'. The species was not noted from any of the other sections.

5.4 EXTENSION OF PREVIOUSLY RECORDED RANGES

5.4.1 Species occurring later than previously recorded

Several species are found here to have more extensive ranges than previously have been recorded in the literature.

Apteodinium maculatum grande has only previously been recorded as late as the latest Cenomanian, but in this study occurs through to the Middle Turonian, in the Rebecca K. Bounds core.

Apteodinium reticulatum only has a limited occurrence in the literature from a few studies from the north of North America (Singh, 1971, 1983, Nøhr-Hansen, 1993) with a latest recorded occurrence of Early Cenomanian. In this study, it extends through to the Early Turonian in all five sections studied.

Other species have also only previously been described from Cenomanian and older strata, but in this study occur in the Early and even Middle Turonian. These include *Batiacasphaera granulosa* (Cookson & Eisenack, 1974, Singh, 1983, Jarvis *et al.*, 1988), *Canningia scabrosa* (Cookson & Eisenack, 1970a), *Chichaouadinium boydii* (Morgan, 1980, Prössl, 1990), *Cribroperidinium orthoceras* (Habib, 1970, Bujak & Williams, 1978, Below, 1982, 1984, Singh, 1983), *Cyclonephelium brevispinatum* (Below, 1981, 1984), *C. chabaca* (Below, 1981, 1982, 1984, Masure, 1988), *C. paucimarginatum* (Morgan, 1980, Below, 1982, 1984), *C. uncinatum* (Norvick *in* Norvick & Burger, 1976), *Ginginodinium evittii* (Singh, 1983), *Heterosphaeridium conjunctum* (Morgan, 1980), *Impagidinium modicum* (Brideaux & McIntyre, 1975, Singh, 1983), *Kiokansium williamsii* (Singh, 1983, Masure, 1988, Prössl, 1990), *Odontochitina rhakodes* (Bint, 1986), *Oligosphaeridium albertense* (Davey, 1969a, Costa & Davey, 1992), *Oligosphaeridium dividuum* (Below, 1984), *Oligosphaeridium totum* (Bujak & Williams, 1978, Below, 1984), *Pareodinia ceratophora* (Bujak & Williams, 1978, Singh, 1983), *Prolixosphaeridium parvispinum* (Morgan, 1980, Habib & Drugg, 1987, Costa & Davey, 1992), *Pseudoceratium eisenackii* (Bujak & Williams, 1978, Morgan, 1980, Below, 1981, 1982, 1984), *Pterodinium? cornutum* (Below, 1982, 1984, Singh, 1983), *Spiniferites lenzii* (Below, 1982, 1984), *Spiniferites tripus* (Singh, 1983), *Subtilisphaera inaffecta* (Singh, 1983), *Tehamadinium coummia* (Below, 1981, 1982, 1984), *Trithyrodinium dubium* (Singh, 1983), and *Xenascus plotei* (Below, 1981, 1982, 1984, Bint, 1986, Masure, 1988). The possibility of reworking is discussed at the end of the chapter.

Chatangiella granulifera tenuis previously described from the 'mid' Cretaceous of Arctic Canada (as *Deflandrea granulifera* in Manum & Cookson, 1964) and from Albian and Cenomanian strata of Saskatchewan (Davey, 1970), occurs in the Middle Turonian of the Rebecca K. Bounds core, where it is common in part of the Fairport Chalky Shale and all of the Blue Hill Shale Members.

Eurydinium glomeratum and *Isabelidinium? globosum* (which form a complex) have only been described from the Albian and Cenomanian of Canada (Davey, 1970). In this study they do not appear until the Early Turonian where they form an important and near-synchronous, correlatable range base across the basin along with *Chatangiella spectabilis*. In the Bunker Hill material, *I.? globosum* appears just below the bentonite equivalent to PBC20, while *C. spectabilis* was seen in the sample above PBC21, and *E. glomeratum* was seen from the sample above PBC23. In the Pueblo material, *C. spectabilis* appears around bentonite PBC20, *E. glomeratum* was seen from the sample including

PBC23 and PBC24, and *I.? globosum* was found around PBC26. In the Blue Point material, the only one of the three to appear is *E. glomeratum*, in the sample just below the shale equivalent to PBC23. In the Rebecca K. Bounds core, all three species are first seen in the sample from 960', which was taken from just below the limestone horizon equivalent to PBC23. None of these species were found in the Wahweap Wash section. In the Rebecca K. Bounds core both *E. glomeratum* and *I.? globosum* range in prominent numbers up to the top of the Fairport Chalky Shale Member (Middle Turonian). *Eurydinium glomeratum* also continues in limited numbers through to the top of the Blue Hill Shale Member.

Gonyaulacysta cassidata has previously been described mainly from Cenomanian or older strata, although some authors have found this species in the Turonian (Norvick *in* Norvick & Burger, 1976, Habib & Drugg, 1987). It is rare in all the sections studied but occurs in the Late Cenomanian at Pueblo and Wahweap Wash, and in the Early Turonian at Blue Point and Bunker Hill. In the Rebecca K. Bounds core it was only found in the Middle Turonian upper Fairport Chalky Shale Member.

Hapsocysta peridictya has only previously been described from the Aptian and Albian (e.g. Morgan, 1980, Below, 1984, Habib & Drugg, 1987, Prössl, 1990), apart from one record in the Late Cenomanian (Costa & Davey, 1992). This species was found in only one sample at the top of the Blue Hill Shale Member (750') in the Middle Turonian, in the Rebecca K. Bounds core, and so represents either an extension of stratigraphic range, or reworking.

Impagidinium delicatum has previously been described from Albian and Cenomanian strata (Davey, 1969a, Brideaux & McIntyre, 1975), but in this study has only been found in the Middle Turonian, where it represents an important marker in the Rebecca K. Bounds core, appearing at the top of the Bridge Creek Limestone Member and extending through to the Blue Hill Shale Member.

Bint (1986) described *Nyktericysta* sp. A from the early Late Albian of Kansas. In the present study, however, it occurs in the Dakota Formation of the Rebecca K. Bounds core, and continues up into the base of the Graneros Shale Formation (Early Cenomanian). It is also present in a single sample (W27) from the horizon including the bentonite equivalent to PBC17 in the Wahweap Wash section (Early Turonian).

Occisucysta hinzii has only been recorded from the Aptian of offshore north-west Africa (Below, 1984). Only one specimen was found in this study, in the Late Cenomanian near the top of the *Scipnonoceras* Zone, between PBC6 and PBC7 at Pueblo. It is possible that this specimen is reworked or that it represents a Tethyan transgressive pulse. This occurrence coincides with the *Cyclonephelium compactum* acme event at Pueblo.

Valensiella magna is generally regarded as a Lower Cretaceous species, with a last occurrence datum in the Barremian (e.g. Habib & Drugg, 1987, Prössl, 1990, Costa & Davey, 1992, Stover *et al.*, 1996). However, it has been recorded as late as the Cenomanian (Morgan, 1980, Below, 1984) and one study has even suggested it occurs in the Campanian (Harker *et al.*, 1990). Only a few specimens were found in the Rebecca K. Bounds core; one in the Late Cenomanian (1010'), and two in the Middle Turonian (810' and 790'). It is quite probable, however, that these are reworked.

Valensiella tazadensis has only been previously been described from the Albian (Below, 1981). However, Below noted that there was a close relationship with *V. reticulata* which has a similar appearance and a total recorded range from the Jurassic through most of the Cretaceous (e.g. Morgan, 1980, Prössl, 1990, Costa & Davey, 1992). It is possible that many previous studies have recorded occurrences of *V. tazadensis* as *V. reticulata*. In this study, both species occur from the 'upper shale member' of the Graneros Shale Formation (1050', just below the 'X' bentonite) through to the Blue Hill Shale Member in the Rebecca K. Bounds core, and in all the boundary sections (apart from *V. reticulata* at Bunker Hill).

5.4.2 Species occurring earlier than previously recorded

Acanthaulax wilsonii was originally considered to be a Senonian species, but more recent studies have found this species in the Cenomanian and Turonian of Germany (Marshall & Batten, 1988, Prössl, 1990, Kirsch, 1991). At Pueblo and Blue Point, this species occurs in Upper Cenomanian and Lower Turonian strata. It is also found in Lower Turonian strata from Bunker Hill.

Canningia senonica has not been previously recorded before the earliest Conianian (Bujak & Williams, 1978) but in the Rebecca K. Bounds core it occurs in the Fairport Chalky Shale Member in the Middle Turonian.

A number of species of *Chatangiella* occur in Turonian strata in the basin. *Chatangiella granulifera* is generally only recorded from Santonian to Campanian strata, although it has been noted in the 'mid' Cretaceous (Manum & Cookson, 1964) and from the earliest Turonian onwards (Costa & Davey, 1992). In the core, this species only occurs rarely, in the uppermost Fairport Chalky Shale and Blue Hill Shale Members in the Middle Turonian. *Chatangiella victoriensis* is similarly generally only recorded from Coniacian through Maastrichtian strata with exceptions including recordings from the Middle Turonian onwards (Foucher, 1983) and even from the Late Cenomanian onwards (Costa & Davey, 1992). In the core, this species also occurs infrequently in the Fairport Chalky Shale and Blue Hill Shale Members in the Middle Turonian. These species may form important biostratigraphic markers in the Rebecca K. Bounds core.

Chatangiella spectabilis has only one published occurrence earlier than the Santonian (Scott *et al.*, 1994). In the present study on the Rebecca K. Bounds core, the species has also been noted from 960', in the Early Turonian, and is common through to the top of the Blue Hill Shale Member. This species also occurs in the Early Turonian at Pueblo from bentonite PBC20 in the *Watinoceras* Zone, and at Bunker Hill from just above the limestone bed equivalent to PBC21. As mentioned above, this forms a near synchronous event marker for the eastern half of the basin, involving the appearance of other taxa including *Isabelidinium globosum* and *Eurydinium glomeratum*. *Chatangiella spectabilis* was not found in the Blue Point or Wahweap Wash sections.

Dinogymnium vozzhennikovae only has a limited occurrence in the literature from the Turonian (Vozzhennikova, 1967, Lentin & Vozzhennikova, 1990), with a single possible occurrence in the Cenomanian (Davey, 1970, as *Dinogymnium* sp. B). In this study, it forms a distinctive marker, ranging from the top of the Lincoln Member (Late Cenomanian) to the top of the Fairport Chalky Shale Member (Middle Turonian) in the Rebecca K. Bounds core. It also occurs through the Late Cenomanian and Early Turonian, in the Pueblo and Bunker Hill sections. It does not occur in the Blue Point and Wahweap Wash sections.

Nelsoniella aceras has only previously been described from the Late Turonian onwards (Cookson & Eisenack, 1960a). However, in this study, a single specimen which exactly matches the original description was found in the sample at the top of the Dakota Formation (Early Cenomanian) in the Rebecca K. Bounds core.

One species (*Spongidinium* sp. cf. *S. delitiense*) found at levels thought to be deposited in proximal shoreface environments in the Rebecca K. Bounds core (750' and 1110') in the Early Cenomanian and in the Middle Turonian seems very similar to *Spongidinium delitiense* which has only previously been recorded from the Late Santonian onwards (e.g. Bujak & Williams, 1978, Lucas-Clark, 1987, Kirsch, 1991, Costa & Davey, 1992, Williams *et al.*, 1993).

Subtilisphaera foliacea has previously been described from the Turonian to Senonian of Australia (Eisenack & Cookson, 1960) but in this study is found from the Late Cenomanian onwards, in the Rebecca K. Bounds core; in Late Cenomanian material from Bunker Hill; in Late Cenomanian and Early Turonian material from Pueblo; and in Early Turonian material from Wahweap Wash.

5.5 CONCLUSIONS

5.5.1 Biostratigraphically useful dinoflagellate cysts

The stratigraphic intervals studied from the Rebecca K. Bounds core, Blue Point, Wahweap Wash, Pueblo and Bunker Hill sections are verified as Cenomanian to Turonian in age, from their dinoflagellate cyst assemblages. This is based on the occurrences of *Alterbidinium emulatum*, *Batiacasphaera euteiches*, *Disphaeria macropyla*, and *Xenascus australensis*, along with a combination of *Dapsilidinium? pumilum*, *Downiesphaeridium armatum*, *Isabelidinium magnum*, *Trithyrodinium suspectum* and *Xenascus perforatus* (suggesting a Cenomanian or younger age), with *Cribroperidinium cooksoniae*, *Cyclonephelium compactum*, *Florentinia cooksoniae*, *Florentinia resex*, *Kiokansium unituberculatum*, *Leberidocysta defloccata*, *Litosphaeridium siphoniphorum*, and *Prolixosphaeridium conulum* (suggesting a Turonian or older age).

These ages can be further subdivided, using the dinoflagellate cyst assemblages and previously described stratigraphic ranges. The Early Cenomanian is defined in the Rebecca K. Bounds core by the presence of *Subtilisphaera hyalina*, and the Early to Middle Cenomanian by the presence of *Dapsilidinium marinum*.

The Cenomanian - Turonian boundary is defined for all the studied sections by the last appearances of *Adnatosphaeridium tutulosum*, *Chichaouadinium vestitum*, *Epelidosphaeridia spinosa*, *Ovoidinium scabrosum* and *Ovoidinium verrucosum*, in the Late Cenomanian, and by the first appearance of *Florentinia buspina* in the Early Turonian. The base of the Middle Turonian is defined in the Rebecca K. Bounds core by the first appearances of *Isabelidinium cooksoniae* and *Raetiaedinium truncigerum*.

In addition to the above, certain other species have local (temporary) range tops and bases which may be useful within the basin. These include the top occurrence of *Senoniasphaera* *microreticulata* which coincides with the Middle/Upper Cenomanian boundary in the Rebecca K. Bounds core.

A number of species have their lowest occurrence in the Late Cenomanian of the core. These include *Chichaouadinium boydii*, *Cyclonephelium compactum*, *Cyclonephelium membraniphorum*, *Dinogymnium vozzhennikovae*, *Disphaeria macropyla*, *Dorocysta litotes*, *Downiesphaeridium armatum*, *Hystrichostrogylon membraniphorum*, *Impagidinium modicum*, *Isabelidinium magnum*, *Microdinium ornatum*, *Palaeotetradinium silicorum*, *Rhiptocorys veligera*, *Subtilisphaera foliacea*, *Tehamadinium coummia*, *Xenascus australensis*, and *Membranilarnacia polycladiata*. In addition, *M. polycladiata* along with *Hystrichosphaeridium bowerbankii* and *Pervosphaeridium pseudhystrichodinium* have their highest occurrence within the Late Cenomanian.

In the Early Turonian, *Eurydinium glomeratum*, *Isabelidinium? globosum* and *Chatangiella spectabilis* have their lowest occurrences, while *Canningia reticulata* and *Spiniferites lenzii* have their highest occurrences. The Middle Turonian is marked by first occurrences of *Canningia senonica*, *Chatangiella granulifera*, *Chatangiella granulifera tenuis*, *Chatangiella victoriensis*, *Impagidinium delicatum* and *Kleithriasphaeridium readei*.

Rapid immigration of dinoflagellates has been noted in previous high-resolution studies from the Quaternary (de Vernal & Mudie, 1992) colonising new areas within much shorter time-spans than can be measured using the 'HIRES' chronostratigraphic framework available for the Western Interior Basin. Hence, it is not surprising that some of the species of dinoflagellate cyst have synchronous range tops or bases, between the sections, across the basin transect. Species with synchronous range tops include *Adnatosphaeridium tutulosum* and *Membranilarnacia polycladiata*. Species with synchronous range bases include *Chatangiella spectabilis*, *Eurydinium glomeratum*, *Florentinia buspina* and *Isabelidinium? globosum*. *Adnatosphaeridium tutulosum* also seems to have a near-synchronous intercontinental range-top when compared with ammonite biostratigraphy.

The depositional environments along the mid- to low-latitude transect from the Western Interior Seaway included a variety of basinal environments (from proximal to distal/off-shore). This is probably one reason for the extremely diverse dinoflagellate cyst assemblages found in this study.

5.5.2 Note on stratigraphic ranges and reworking

From the stratigraphical and palaeogeographical lists, a number of species within the material are found to have lower or higher ranges than previously described before, thus extending their previously described, total ranges. It is probable that the extension of the ranges of some species into younger material results from reworking, but it seems unlikely to be the most important reason.

Dinoflagellate cysts are hydrodynamically equivalent to fine silt particles (Dale, 1976, 1983), and hence currents are very important when considering palynomorph assemblages, as they play an significant role in mixing and distributing populations of cysts as they sink through the water column. In addition they may be responsible for localised flow from rivers into the marine basin (thus potentially transporting reworked cysts from the local catchment area), winnowing cysts from the shelf floor and eroding contemporary or relict shelf sediments (Davies *et al.*, 1982).

Some of the sediments from the Rebecca K. Bounds core (Dakota Formation, 'lower shale member' of the Graneros Shale Formation, uppermost Fairport Chalky Shale Member and Blue Hill Shale Member), from the Blue Point section (Dakota Formation and lowermost Mancos Shale Formation) and from the Wahweap Wash section (lowermost Tropic Shale formation) contain silt-sized siliciclastic particles and hence might be more likely to contain reworked dinoflagellate cysts. The main source for detrital sediment in the Western Interior Basin was from the orogenic chain to the west (Hattin, 1975).

However, the sediments of the Greenhorn Limestone Formation (deposited in the centre and eastern part of the basin) are predominantly composed of clays and pelagic carbonate, contain little siliciclastic silt and so are unlikely to contain much reworked material unless it is contemporary. Occasional and sporadic sediment reworking and winnowing is suggested to have occurred, but concentrating coarser carbonate material into biosparite horizons (e.g. Hattin, 1975, Sageman, 1985, Elder & Kirkland, 1985), particularly in the Lincoln Member, but also at intervals during deposition of the Hartland and Bridge Creek Limestone Members (e.g. during the deposition of the limestone equivalent to PBC7). Compared with the rest of the Greenhorn Limestone Formation, the Lincoln and Hartland Members contain comparatively higher proportions of terrigenous material, deposited while transgression was in progress. Maximum transgression of the Greenhorn cycle is represented by the pelagic carbonates of the Bridge Creek Limestone or Jetmore Members, which have the lowest values of terrigenous residues from the sediments of the Greenhorn cyclothem, suggesting that reworking was least likely at this time and hence not important for much of this study.

This suggests that reworking may not have been significant in extending the ranges of dinoflagellate cysts found in the Cenomanian - Turonian boundary sections, particularly in material from Pueblo (with the highest species diversities) and Bunker Hill. One reason for the extension of the stratigraphic ranges of dinoflagellate cyst species (into strata of younger and older ages) may be due to the dynamic nature of the Western Interior Seaway, with the moving and mixing of very different water masses (Boreal and Tethyan), very strongly affected by eustatic fluctuations.

CHAPTER 6

REVIEW OF RELEVANT PREVIOUS PALYNOLOGICAL WORK

PART A: ASPECTS OF DINOFLAGELLATES AND THEIR CYSTS

6A.1 INTRODUCTION

This chapter is intended as an introduction to dinoflagellates and their cysts, other marine palynomorphs and palynofacies assemblages, particularly with respect to their uses in a geological context. It is important to understand the lifestyle of dinoflagellates and the factors which affect their cyst assemblages in order to use them for palaeoenvironmental interpretations. This chapter will look briefly at dinoflagellate ecology and biology to understand the distribution of living species and the reasons for cyst production. Aspects of particular interest to this study will also be reviewed from both geological and recent work. These include the feeding strategies used by meroplanktonic dinoflagellates (for use in palaeoecological interpretations), the distribution and redistribution of dinoflagellate cysts in neritic environments and the variation in dinoflagellate cyst assemblages in reaction to environmental change (e.g. in water mass or climate). In addition, palynofacies variations in response to changing environment and sea-level will also be examined.

Dinoflagellates are an important part of the marine and freshwater biota today, and are widely distributed in Mesozoic and Cainozoic sediments with an extensive fossil record that goes back at least 220 million years.

Dinoflagellates are thought to have a systematic position near the base of the phylogenetic tree of the eucaryotes. Properties of the dinoflagellate nucleus (central organelle of cells containing the chromosomes), the mitotic apparatus (asexual reproductive apparatus) and chloroplast (cells containing the chlorophyll for photosynthesis) suggest that they are primitive. However, for primitive organisms they show a large diversity in form, habit and habitat as well as some highly specialised organelles including in some forms a light sensitive eye-type structure (Evitt, 1985).

They have been classified in the past as protists (members of the animal kingdom) since some forms are predatory, and also as pyrrhophytes (members of the plant kingdom) since many forms are holophytic (photosynthesisers). Now they are generally classified as plants in the Division Pyrrhophyta (from the Greek *pyrrhos* meaning flame coloured), and in the Class Dinophyceae. Dinoflagellates or Dinoflagellata are names still used from classification as protists.

Most fossil dinoflagellates are not the remains of dead creatures like most other fossils, but instead are the remains of cysts (protective envelopes) produced by living dinoflagellates as part of their life cycles. Since only some of today's living species produce preservable cysts, and there is no reason to think that the situation was any different in the geological past, then the fossil record is highly selective. The fossil record of dinoflagellate cysts is not a record of all the dinoflagellates that ever lived at that time (Evitt, 1985). Some of the fossil cysts are siliceous or calcareous but most are made of organic material (termed dinosporin), which is chemically very similar to the wall material of spores and pollen grains (sporopollenin).

Among living forms, meroplanktonic (cyst producing) dinoflagellates mostly live in neritic (continental shelf) environments. Both modern and ancient cysts are most typically found in shelf and upper continental slope deposits, since almost all oceanic dinoflagellates do not produce cysts. Some dinoflagellates are freshwater, but dinoflagellate cysts have only been found in freshwater deposits as far back as the Cretaceous. The cysts are most commonly found in fine grained sedimentary rocks, particularly shales and siltstones.

Like other major planktonic groups they show biogeographical provincialism, and differ in species abundance and diversity along an onshore-offshore gradient, subject to local sea floor topography and current transport.

6A.2 ASPECTS OF DINOFLAGELLATE ECOLOGY

This section is intended as a basic introduction to living dinoflagellates, to illustrate their life requirements and their place in the marine ecosystem.

6A.2.1 Lifestyles

Different species of dinoflagellates have a variety of lifestyles or ways in which they live and feed. Many are holophytic (i.e. they are autotrophs or primary producers) and photosynthesise organic materials or foods from sunlight using chlorophyll. Some are predatory (heterotrophic or phagotrophic), eating and absorbing other living things. Some are saprophytic, consuming dead or decaying things and obtaining their nutrients in solution. Some are symbiotic, living in harmony with other things to their mutual benefit, while some are parasitic, living off other creatures to their detriment. Many are more than one of the above, often at different stages of their life cycles (Evitt, 1985, Taylor, 1987).

6A.2.2 Ecological requirements

Like all living creatures, their ecological requirements are a complex interplay of chemical, physical and biological factors. Chemical factors include salinity and major and minor nutrients. Physical factors include light, temperature and hydrodynamics or circulation (Taylor, 1987). Biological factors include the relative abundance of other dinoflagellate species, other planktonic groups and even much larger biota. These affect the dinoflagellates as competitors for nutrients, and as both predators on, and prey for, the dinoflagellates.

Salinity can be very important in affecting species abundance. Generally, areas with reduced salinities tend to have fewer species occurring. However the same can occur for increased salinities (hypersaline conditions) in areas of high evaporation and low precipitation.

Nutrients are extremely important for dinoflagellates. These include oxygen, carbon dioxide, carbon, nitrogen, phosphorus and silicon. Nutrient levels will affect the distribution of the different feeding groups of dinoflagellates. It is quite possible that the major nutrients may not be that important.

Some areas with good nutrient measurements do not appear to be able to support growth. It may be that vitamins and/or trace elements control the general fertility of the waters (Taylor, 1987).

Since many dinoflagellates are at least partly holophytic, they spend a large part of their life in the photic zone, above the compensation depth. This is the depth at which the level of light becomes so reduced that respiration exceeds assimilation. This can vary from 5m to 40m in depth, increasing to 100m in the tropics. Many dinoflagellate species show vertical diurnal migration, swimming up to the surface at night, and sinking down deeper in the day, depending on their tolerance of harmful ultra-violet rays (Tappan, 1980).

Temperature affects both the life cycles and the diversities of species. Dinoflagellate blooms and dormant stages of the life cycle are often directly linked to seasonal temperature changes. On a geographical scale, as a general rule, areas of the globe that have a lower temperature tend to have less species. This may partly be a result of increases in the density and viscosity of the sea water, as a result of lowered temperatures towards the poles. A result is often dominance of an assemblage by fewer species in higher latitudes, though this is a large generalisation (Taylor, 1987).

Circulation patterns, both vertically and horizontally, affect nutrient enrichment of the photic zone (either upwelling nutrients from the deep ocean or carrying them in from river sources) and thus affect the distribution of dinoflagellates, other microplankton and other biota.

6A.2.3 Nutrients and food sources

As mentioned above, the level and source of nutrients affects the different groups of dinoflagellates. Where nutrient levels are high enough, the autotrophs require only sunlight to create the organic compounds that they need. Some dinoflagellates photosynthesise but require additional vitamins (auxotrophs) and some (myxotrophs) photosynthesise but may also ingest other organisms. Examples of myxotrophs with chromoplasts have been found with the remains of partly digested bacteria, blue-green algae and diatoms. It is thought that where other biotic groups, particularly diatoms, have the upper hand in numbers, removing essential nutrients from the waters, the numbers of holophytic dinoflagellates are often reduced. However in these conditions, phagotrophic dinoflagellates that feed on the diatoms make up a larger proportion of the dinoflagellate population (Tappan, 1980).

Generally only non-thecate or naked dinoflagellates lack chloroplasts and are completely phagotrophic or saprophytic. Some saprophytic dinoflagellates, for example species of *Amphidium* live in the spaces between sand grains in substrates immediately overlying black muds, taking their nutrition from the decaying organic matter below. Many dinoflagellates are parasites, both externally and internally. Often in the parasitic stage of their life cycle they do not even resemble dinoflagellates, and have only been recognised when seen in their motile stages (Tappan, 1980).

Some dinoflagellates have symbiotic algae or bacteria assisting them. Many more are symbiotic themselves and have been collectively placed in the Order Zooxanthellae. They are the most widely occurring marine algal symbiont. They are characteristic of nutrient deficient waters and are common in e.g. planktonic foraminifera, radiolaria, other dinoflagellates, corals, anemones and molluscs, particularly in nutrient deficient tropical waters and reefs. In return for protection, nitrogen, phosphorus and carbon dioxide supplied by their hosts, they provide oxygen and photosynthetic products as food (Tappan, 1980).

6A.2.4 Habitats

Dinoflagellates live in a wide range of environments which include extreme ranges in temperature and salinity. These include rivers; bogs; salty, brackish and freshwater lakes; neritic, coastal and estuarine waters, the open ocean and between sand grains on the beaches of lakes and seas. Red snow and ice at high latitudes or altitudes results from the accumulation of dinoflagellates or their cysts (Williams, 1971, Wall *et al.*, 1977, Dale, 1983).

Almost all fossil dinoflagellate cysts have been found in facies from marine environments. Some dinoflagellates are cosmopolitan, having a wide distribution through a variety of marine habitats. Other species are more restricted by temperature, water depth and distance from the shore-line.

Many meroplanktonic (cyst-producing) species are neritic while holoplanktonic species (not producing resting cysts) are oceanic. If the hypnozygotes passed out of the photic zone, as they would in an oceanic environment, then they would die. However, some meroplanktonic species may still live in the oceanic environments, re-invading or spreading there from shelf waters, after excystment. Oceanic living dinoflagellates commonly have elongate horns or ornate wings, to increase surface area and hence assist with buoyancy and nutrient uptake. Neritic dinoflagellates more typically have simple morphologies (e.g. Dale, 1983).

Some dinoflagellates are euryhaline, tolerating a wide salinity variation, while others are more sensitive. However, virtually all marine species studied have an optimal growth in salinities well below that of the open sea. As many peridinioids seem to prefer reduced salinities near shore, and gonyaulacoids prefer more open marine environments, the ratio of g:p in cyst assemblages has been used as a salinity indicator (e.g. Wall *et al.*, 1977). However, it is highly possible that the species are responding to other environmental parameters. Extending the environmental preferences of living forms beyond the marine realm, fresh water living dinoflagellate assemblages today are also dominated by peridinioids.

Many dinoflagellates have a wide temperature tolerance range. Others are more temperature sensitive and can be restricted to polar or tropical waters. Many modern species of *Ceratium* have tropical or polar temperature restrictions. Generally, warmer waters have lower nutrient concentrations (of nitrogen and phosphorus, for example) and some modern species are adapted to lower nutrient levels. Many dinoflagellates adapted to lower nutrient conditions have blooms that follow the diatom blooms in the spring when nutrients are seasonally depleted and there is less competition (Taylor, 1987).

6A.2.5 Productivity

Dinoflagellates are very important primary producers, second only to the diatoms in the production of marine organic matter across the globe, with both groups together forming the base of the marine and freshwater food webs. Productivity can fluctuate on local to regional scales depending on many oceanographic factors. Temporary high phytoplankton productivity is referred to as a bloom.

Productivity can be increased on a local scale by many factors. One of the most important ones is nutrient levels. If these increase, for example by seasonal discharge changes off river mouths or by seasonal changes in vertical mixing of the water column, then the plankton generally shows a rapid increase in diatoms and ebriids while dinoflagellate populations increase more slowly reaching a peak later on.

Seasonal changes in nutrients are normally driven by seasonal temperature changes in mid to high latitudes, linked to wind and insolation patterns. Studies in the Mediterranean show a massive increase in March/April to May/June with nearly 200 times as many dinoflagellates than in the previous winter. As the waters then become thermally stratified through the summer, the nutrients become depleted at the surface, and the maximum is followed by a gradual decline in the summer. A second, smaller maximum occurs in the autumn (from renewed vertical mixing) before dinoflagellate production trails off into winter (Taylor, 1987).

Vertical changes also occur in assemblages at one geographical location, as different species are at their productive optimum at different depths in the water column, due to decreasing light intensity with depth.

The characteristic reddish-brown pigment of dinoflagellates can result in the discolouration of the seas when living dinoflagellates reach massive numbers. This phenomenon is known as a red-tide. The patches are generally only small and last a few days but sometimes can reach kilometres in size and last for weeks. This may result in fish mortality, particularly of the bottom feeders as their gills become clogged. Some species are toxic and even release some of their toxins into the surrounding waters. Most species do not normally kill directly but the toxins can accumulate in shellfish and consumption of these can kill. The death and decay of huge numbers of cells after a bloom can result in high bacterial populations and oxygen depletion which may also be fatal to some marine organisms. In Florida, red tides are normally associated with unusually heavy rains, with the influx of nutrients triggering the expansion in populations. This is not always the case however. Sometimes red tides can be triggered by changing current patterns or upwelling (Taylor, 1987).

Despite their small size, dinoflagellates play a major part in ecosystems and not just as an important base of the food chain. The zooxanthellae are photosynthetic symbionts of other protists and invertebrates, notably corals and hence play a major role in the ecosystems of modern reefs (Tappan, 1980). Some estuarine and marine species produce toxins which can cause shellfish and fish poisoning (in humans). For some species the toxins are produced in large quantities by blooms and used to kill massive shoals of fish as a direct food source (Burkholder *et al.*, 1992).

6A.3 ASPECTS OF DINOFLAGELLATE BIOLOGY

6A.3.1 Cell organisation and wall composition

Dinoflagellates are complicated and variable. A typical dinoflagellate is a free-living, photosynthetic, biflagellate. It swims in a spiral motion through the water column with two flagella which extend from two pores and lie in two grooves, one in the cingulum (transverse, equatorially around the cell) and the other hanging down in the sulcus (longitudinally on the ventral surface).

However, not all dinoflagellates are like this. Some have a sulcus which is wound around the cell. The Prorocentrales which are thought to be more primitive, have both flagella extending through pores in the apex. Others do not have flagella: some have a tentacle and others (parasitic dinoflagellates) have a sucker-like stalk (Tappan, 1980).

The centre of the protoplast is the nucleus, the main organelle which contains the chromosomes. The nucleus is considered primitive for the eucaryotes with some features that are procaryotic and some that are eucaryotic. Among other things, the protoplasm also contains plastids that contain the chlorophyll for the photosynthesisers, as well as pyrenoids for producing the starch/food (Tappan, 1980).

The dinoflagellate cells are usually bounded by the cell membrane. The outer region, including the wall, is called the amphiesma. It is normally complex and is made up of several layers or membranes. Within the amphiesma, some taxa have thecal plates (composed of cellulosic material) and are termed armoured or thecate. These plates have a distinctive number and arrangement and are unique for each genus and in some cases each species. Taxa that do not possess thecal plates are athecate and termed unarmoured or naked. Some unarmoured taxa (for example the Gymnodinioids) may have a separate layer beneath the outer amphiesma called a pellicle which normally consists of cellulose but may have a dinosporin content and so is potentially geologically preservable (Evitt, 1985).

An important distinction to make is the difference between the theca and the cyst, as both are important, distinct but closely related structures produced by some dinoflagellates, as containers for the cell protoplast.

The theca is constructed of thecal plates which are fitted together along linear junctions called sutures. These are thin units made of cellulosic material and are easily destroyed by bacteria, so they are short lived and not preserved in the fossil record. Living dinoflagellates that have thecae are classified using their thecal architecture (the number and arrangement of the plates) as well as their shape, distribution and sculpture (Evitt, 1985). The cysts of modern dinoflagellates have only recently begun to be used in distinguishing taxa.

Fossil dinoflagellate cysts are classified using the cyst morphology which is often very dissimilar to the thecal morphology. Tabulation is often poor or incomplete or only hinted at by the shape of the archaeopyle. These fossil cysts are usually made of dinosporin which is highly resistant and geologically long lived. Other fossilisable cysts are calcareous or (rarely) siliceous.

The cysts are grown inside the theca (with the probable exception of species of *Palaeoperidinium*). Proximate cysts are grown immediately inside the theca with no large extrusions and approximate the shape of the original motile cell. Proximochorate and chorate cysts have large crests or processes thought to be grown on the cyst after the release of the theca, with growth that may even help the break-up of the theca (Wall, 1970, 1971, Fensome *et al.*, 1993).

6A.3.2 The life cycle

The known life-cycles of dinoflagellate species can be simple or extremely complex and may include coccoid, cyst, multicellular or amoeboid stages. Typically, however, the dinoflagellates occur as motile, biflagellate cells, and in almost all cases these form part of the life-cycle. The life cycle may involve stages of vegetative (asexual) reproduction and sexual reproduction as well as times of non-motility or dormancy when the cell is enclosed by the cyst wall (Evitt, 1985).

The complete life cycles are only known for some dinoflagellates. For some species, the dinoflagellates reproduce by asexual fission in times favourable for rapid population growth, although at times sexual reproduction may occur. Eventually, following this, the flagella are lost and the dinoflagellate becomes non-motile. The protoplast (cell contents) shrink and pull away from the theca, and one or more membranes that will become the cyst walls, form in the space created between the protoplast and theca. Once the cyst has formed, the thecal plates break apart and fall off or are destroyed by bacteria in situ, exposing the cyst, which behaves as a sedimentary particle. It is subject to currents and depending on turbulence will settle through the water column and land on the sediment/water interface. After a period of dormancy, which may vary from a matter of hours to months, the protoplast excysts through a specialised opening (called the archaeopyle) leaving the cyst behind. This archaeopyle is a genetically controlled, regular shaped opening. The protoplast then splits into numerous new cells each of which develops flagella and a theca (Evitt, 1985).

6A.4 THE SELECTIVITY OF THE FOSSIL RECORD: INTERPRETATIONS OF DINOFLAGELLATE CYSTS ASSEMBLAGES

All fossil records are selective, since the fossils that are found are only ever a tiny proportion of the individuals that once lived. Any fossil assemblage is affected by the life habits and habitat; by the size, shape and composition of preservable parts; by the nature of the enclosing sediment; by the post depositional history at the site of deposition; and by chance of discovery. Fossil dinoflagellate cyst assemblages are affected by these factors as much as any other fossil group, but they are also affected by further selectivity.

The main reason for this further selectivity is that the cysts today are only produced by a minority of species of living (meroplanktonic) dinoflagellates, and are only produced at certain stages of the life cycle, under certain conditions. Effectively, large numbers of living dinoflagellates in the water column do not necessarily mean that large numbers of cysts are produced. To further complicate the situation, some of the different species of living dinoflagellates are known to produce identical dinosporin cysts, while some single species of living dinoflagellates are known to produce morphologically different dinosporin cysts, which if found in the fossil record would be interpreted as different species. There is no reason to think that the situation would have been any different back in the geological past. The extension of this is that many holoplanktonic (non-cyst producing) dinoflagellate species probably lived in the geological past without leaving any form of fossil record (Evitt, 1985).

However, the fossil record of dinoflagellate cysts is not considered to be any less complete than that of any other fossil group (Bujak & Davies, 1983, Fensome *et al.*, 1993).

The variability of the proportions of meroplanktonic to holoplanktonic dinoflagellates has probably varied through geological time. The number of species of described dinoflagellate cysts counted per stage through the Mesozoic and Cainozoic (Bujak & Williams, 1979) fluctuates greatly. Although affected by variable amounts of research concentrated on different parts of the stratigraphic column, this curve is still likely to be a product of both the proportions of dinoflagellate species that were meroplanktonic at that time and (probably to a lesser extent) of dinoflagellate productivity. This curve has also been noted by other authors in long-ranging biostratigraphic studies, with a maximum species diversity in the Albian, shortly before a global first-order maximum transgression (Bujak & Williams, 1978, Habib & Drugg, 1987). The curve also follows general trends in global sea-level and as such, the times of maximum cyst diversity coincide with times of high sea level, and hence with the times of largest epicontinental shelf sea areas (Habib & Drugg, 1987). Perhaps it is not surprising that since the highest proportions of cyst producing dinoflagellates occur in continental shelf seas today, that through geological time the greatest diversity of cyst species are found at times of greatest continental shelf sea areas. The Cenomanian/Turonian is thought to be the time of highest eustatic levels in the Mesozoic. The extremely diverse assemblages noted in this study confirm this idea.

Modern quantitative studies of waters and substrates show that there is no simple or constant relationship that exists between the absolute number of living dinoflagellates in the water column, and the number of resting cysts on the bottom, at any one time. The production of preservable cysts is a quantitatively variable phenomenon. Any hypotheses about the numbers of cysts in a sample cannot be extrapolated back to interpret the numbers of dinoflagellates that were living at that time. Modern oceanic environments contain a relatively diverse number of species, but almost all are holoplanktonic. In contrast, high latitude, neritic waters contain far fewer species but a much higher proportion are cyst producers.

However, it is very important to note that various studies (e.g. Dale, 1976, Wall *et al.*, 1977) have noted that the abundances of cysts within the assemblages may reasonably accurately reflect the abundances of living cysts from the corresponding meroplanktonic dinoflagellates, at least in shallower water. Furthermore, cyst production over the year, decade, century, etc. will of course be averaged out in the fossil record, providing one advantage for the palaeontologist.

Comparisons based on counts of individuals or species of cyst may be useful in localised sections or over short stratigraphic intervals, but wider correlations increase the problems in interpretation. It is equally valid to suggest that ecological interpretations will be reasonably valid based on individual species and assemblages of cysts in localised sections or over short stratigraphic intervals. Increasing the stratigraphic and geographic range of these interpretations will increase the variables and therefore decrease their validity.

6A.5 FACTORS AFFECTING DINOFLAGELLATE CYST PRODUCTION

The distribution of dinoflagellate cysts (as with motile dinoflagellates) in modern sediments are clearly controlled by many interrelated oceanographic and biological factors, which result in variations in cyst production and deposition. Variations in assemblages of meroplanktonic dinoflagellates also depend on different nutritional strategies.

The environment exerts a strong influence on the number of cyst-producing dinoflagellates within the population. The meroplanktonic dinoflagellate assemblages are then further influenced by oceanographic factors including surface water temperature, nutrient supply, shoreline proximity, climate and salinity.

Once the dinoflagellate cysts are produced they are then known to be strongly influenced by other factors including preservation, and current and sediment redistribution.

All of the above factors have been studied in recent environments and sediments and have also been applied to palaeoecological and palaeoenvironmental studies.

6A.5.1 Biological variations in cyst production

The cysts of dinoflagellates that are found in the fossil record are not the remains of dead dinoflagellates. These preservable cysts are mostly thought to be the resistant housings of hypnozygotes or zygotic cells in a resting stage as a period of dormancy following sexual reproduction.

It is probable that the fossil record may include dinoflagellate remains that were associated with various stages of the life cycle, since any wall layer produced with enough dinosporin would be preservable. Dinoflagellate cells can be non-motile for a number of reasons and can possess a cell wall and hence be considered as cysts. Hence, cysts produced from a single living species may be of more than one type in terms of morphology, function and resistance to degradation (Dale, 1983).

As mentioned above, the resting cells may form cysts after sexual fusion. Temporary cysts may be formed in short periods of adverse conditions by thecate dinoflagellates, involving the loss of the thecal plates, cell membrane and flagella (termed ecdysis), leaving the pellicle to become the wall layer of the temporary cyst. If the cell then has to escape from the remaining pelliculate layer, it does so through a predetermined aperture leaving the empty pellicle and forming a temporary cyst.

Vegetative cysts are metabolically and/or reproductively active non-motile cells surrounded by a continuous wall and forming the principle life-cycle stage of the dinoflagellate (for example in parasitic and symbiotic taxa). Some rare taxa may produce a digestion cyst after feeding. Some cysts may be the pellicles of motile cells.

The resistant and geologically preservable cyst is only produced by certain species. Other dinoflagellate life cycles do not form a resting cyst or form one from less resistant material. It has been suggested by some, that cysts are only produced as a result of the onset of adverse conditions. However, it is most likely that the production of resting cysts represents an adaptive coupling between sexual reproduction and survival during periods (or seasons) when conditions favouring prolific vegetative growth are temporarily diminished.

As an example from the New England Atlantic coast, a species of *Protogonyaulax* produces non-preservable cysts (dinosporin free) as part of a series of successive blooms throughout the year. Cysts are produced at the end of the spring bloom, and germinate in a relatively short time to yield further schizonts for later blooms in the summer. Cysts produced at the end of the summer have much longer dormancy periods to last through winter until the coastal waters begin to warm and stabilise again in the next spring (Evitt, 1985).

It is very important to remember when interpreting the fossil record, that the majority of living dinoflagellate species today, thrive without ever producing resting cysts. Dale (1983) reports that at least 170 dinosporin cyst morphotypes are known to be formed today, produced by over 200 species. This accounts for only 10% of all known species. Cyst producing species today are concentrated within a few major taxonomic groups, particularly families of the Peridiniales and Gonyaulacales.

6A.5.2 Distribution of dinoflagellate groups related to feeding strategies

Modern gonyaulacacean dinoflagellates are mostly photosynthetic, and thrive in stratified water conditions, with high abundances usually related to lower productivity (Harland, 1988, Lewis *et al.*, 1990, Eshet, 1994). Almost all peridiniacean dinoflagellates are heterotrophic. They are common in waters rich in dissolved nutrients, such as upwelling regions, where they are associated with high diatom productivity and usually become abundant immediately following the spring bloom of diatoms on which they feed (Jacobson & Anderson, 1986, Taylor, 1987, Lewis *et al.*, 1990, Eshet, 1994). The heterotrophic dinoflagellates may at times dominate the heterotrophic plankton populations in marine waters, as effective grazers of nannoplankton (Schnepf & Elbrachter, 1992).

This is supported by multivariate statistical analyses of the geographical distribution of thecate dinoflagellates and their cysts from the northeast Atlantic and North Sea (Dodge, 1994). These have shown that the distribution of gonyaulacoid species was clearly influenced by temperature, and that the distribution of peridinioid cysts showed very similar patterns to the distribution of gonyaulacoid cysts suggesting that the conditions for cyst formation were very similar for both groups of organisms. However, the distribution of peridinioid species was noted to be more related to the availability of food organisms than to other environmental factors.

Water column turbulence also has a dominant controlling factor on the plankton (Margalef, 1978). Diatoms dominate the plankton in turbulent conditions (needed to maintain their position within the water column) with a good nutrient supply (Landry, 1977, Margalef, 1978), and consequently peridinioid dinoflagellates would also be expected to be more common in turbulent areas. Dinoflagellates themselves dominate the plankton in non-turbulent conditions with a poor nutrient supply. The net effect of increased stability and decreased nutrients in the water column is to shift the advantage from diatoms to dinoflagellates, which are able to maintain their vertical position in the water column and more efficiently utilise the lower concentrations of nutrients (Landry, 1977).

Natural processes drive ecosystems to oligotrophy, and eutrophic systems only exist where large inputs of external energy periodically occur. Ecosystems based on high productivity (indicated by diatoms and heterotrophic dinoflagellates) are dependant on the input of external energy as turbulence and nutrients (from upwelling). This system is not internally stable, as the lack of this input drives the ecosystem to oligotrophy and creates a plankton succession driven towards other phytoplankton (particularly autotrophic dinoflagellates) as the stability of the water column increases and the nutrient levels dwindle.

It is possible that it is easier for heterotrophic dinoflagellates to get their energy from preying on other plankton where the environment is variable and unstable. Where the environment is more stable the autotrophic species find it easier to take energy from their surroundings.

High relative amounts of cysts from heterotrophic dinoflagellates occur in areas which are often enriched in nutrients. These include upwelling areas (e.g. Wall *et al.*, 1977, Bujak, 1984, Lewis *et al.*, 1990, Powell *et al.*, 1990), coastal areas (Wall *et al.*, 1977, Bint, 1988), neritic environments close to a deltaic source (Bint, 1988), other high productivity or high turbulence areas such as at high latitudes or in cool waters (Balech & El-Sayed, 1965, Bujak, 1984), Arctic ice margins (Aksu *et al.*, 1992, Versteegh, 1994), and fronts between water masses (e.g. Wall *et al.*, 1977, Versteegh, 1994). Thus changes in productivity are now thought to influence the ratio between peridinioid and gonyaulacoid cysts.

In studies of upwelling off the coast of Peru, Lewis *et al.* (1990) stated that the agreement between the P:G proportions of living dinoflagellates in the water column and cysts from the sediment was surprisingly good. Changes in proportions of cysts reflect changes in the populations producing them. In effect, the P:G cyst ratio was found to be a good measure of the proportions of living autotrophic and heterotrophic dinoflagellates, and hence of productivity.

Some of the gonyaulacoid species (notably those forming red-tides in massive blooms) were seen to dominate at times of high nutrients but low turbulence. Other species generally dominated in stratified conditions (Powell *et al.*, 1992). Thus it may be possible that in fossil assemblages with high proportions of gonyaulacoid cysts (suggesting at least seasonal periods of stratification), dominance by different species of gonyaulacoid cysts may also reflect variable nutrient levels.

High proportions of peridinioid cysts are also found in waters at high latitudes, where levels of turbulence are often high, and seasonally low light levels place autotrophic dinoflagellates at a disadvantage.

6A.5.2.1 Dinoflagellate Cysts and upwelling

Upwelling areas are formed by the upward circulation of deep-sea, nutrient-rich currents, along continental or basin margins, which are then characterised by high productivity levels in the photic zone.

Davey & Rogers (1975) noted from studies along transects from the continental shelf and slope off southwest Africa that dinoflagellate cysts were most abundant in sediments below areas of strong upwelling and where terrigenous detritus was a minor constituent. High numbers of protoperidiniacean species were not noted in the upwelling areas in their study. However, high numbers of protoperidiniacean species were noted off southwest Africa by Wall *et al.*, 1977, and were suggested to be limited to upwelling waters in the nearshore inner neritic areas.

Powell *et al.*, 1992, reviewed the subject of upwelling and palynological expressions in terms of amorphous organic matter, foraminiferal test linings and dinoflagellate cysts. The most significant contribution to the palynofacies from upwelling and high productivity is amorphous organic matter (AOM) though its preservation is most strongly influenced by oxygen levels within the water column (Tyson, 1987). This AOM tends to overwhelmingly dominate the palynological assemblage. A lack of terrestrial material almost entirely indicates a marine origin for this material. Deposition in such massive amounts suggests high palaeoproductivity.

Foraminiferal test linings represent the inner organic layer of benthic and planktonic individuals (Davey, 1978, Powell *et al.*, 1992). They have been related to several environmental parameters including water depth, salinity and shoreline proximity. Powell *et al.*, 1990, in studies from offshore Peru, suggested that increased upwelling was the most significant factor in determining greater abundances of test linings but owing to preservational factors, the abundances were probably also related to the numbers of foraminifera reaching adulthood (and hence growing a test lining thick enough to be preserved).

6A.5.2.2 Dinoflagellate cysts as a measurement of palaeoproductivity

The ratios of peridinioid to gonyaulacoid cysts can be effectively used as a measure of productivity (Bujak, 1984, Powell *et al.*, 1992, Eshet *et al.*, 1994). Some of the peridinioid cysts are probably the product of autotrophic dinoflagellates, but nevertheless, it is thought that proportions of peridinioid cysts represent a close approximation to proportions of heterotrophic dinoflagellates in pre-Neogene studies (Dale & Fjellsa, 1994), and so may be used to record productivity. Previous work has always been able to relate upwelling (with associated high nutrient levels and high productivity) to high P:G ratios. Some studies have also shown a relationship between high P:G ratios and shoreline proximity, but this has not always been the case. It seems likely therefore that ratios that do demonstrate high numbers of peridinioids close to shorelines, are actually picking up higher nutrient levels which are often found in nearshore environments.

One major factor for identifying high productivity areas is often missing, as diagenesis and dissolution commonly remove diatoms from pre-Quaternary sediments.

A number of studies have used the proportions of peridinioid to gonyaulacoid cysts to measure various environmental parameters related to palaeoproductivity. Two methods have been used for calculating peridinioid:gonyaulacoid ratios (P:G ratios). Harland (1973) used the ratios of the number of peridinioid and gonyaulacoid species. A number of other studies have used the ratios of the numbers of individual peridinioid and gonyaulacoid cysts (e.g. Bujak, 1984, Powell *et al.*, 1990, Mao & Mohr, 1992, Versteegh, 1994).

Harland (1973) looked at the ratio of gonyaulacoid to peridinioid cyst species in a study from the Late Cretaceous of Alberta, Canada, and found that the ratio of gonyaulacoid species was higher in more open marine environments, and lower in near-shore environments.

Bujak (1984), in a study of Eocene to Pleistocene sediments from the Bering Sea showed that before the Upper Miocene, the cyst assemblages were dominated by gonyaulacoid species. In the Upper Miocene, the assemblages change to a dominance in peridinioid species (gonyaulacoid species still being locally common but generally a minor constituent) at the same time as high diatom productivity started in the northern North Pacific, as a result of changes in palaeoceanographic conditions.

The P:G ratios used in Brinkhuis & Zachariasse (1988) have been interpreted as responding to regional productivity changes, and are not related to the shoreline proximity. The highest P:G ratios occur at a time of regional transgression (i.e. deepening water) in the earliest Palaeocene, and coincide with a decrease in sporomorph:dinoflagellate cyst values as the environment changes to from proximal to distal offshore.

Palynological studies of the upwelling areas off the coast of Peru were carried out for the Late Neogene to Pleistocene by Powell *et al.* (1990) and the Pleistocene by Lewis *et al.* (1990). Very little terrestrially derived material was found in the palynological assemblages. The P:G ratios were shown to have no relationship to changes in sea level (Lewis *et al.*, 1990). The sedimentary structures of the lithologies alternated between bioturbated and laminated horizons. Increases in the proportions of peridinioid cysts in these ratios were interpreted as changes in the intensity of upwelling. The G cysts were most common in the bioturbated strata, thought to represent times of decreased upwelling. Studies of palaeotemperatures of the surface waters (Lewis *et al.*, 1990) show that the periods of strong upwelling were also periods of relatively cool surface waters.

6A.5.2.3 A Late Cretaceous palaeoproductivity study

Eshet *et al.* (1994) presented a study of a past upwelling system from the Coniacian to Maastrichtian of Israel. The reconstruction based on palynological evidence was verified using other evidence including planktonic foraminifera, carbon and oxygen isotopes and organic geochemistry.

The lithologies mainly consist of organic rich (10-15%) carbonates. The palynofacies were found to be dominated by marine amorphous organic matter, with an abundance of dinocysts and a trace (less than 1%) of terrestrial palynomorphs. Organic geochemistry confirmed the amorphous matter as dominantly marine, of algal origin (Bein *et al.*, 1990), while the palynofacies and geochemistry suggested only minor terrestrial input. The palaeogeography, palaeontology and petrography/geochemistry also support the upwelling model.

The most common peridinioid taxa found were species of *Andalusiella*, *Palaeocystodinium*, *Palaeoperidinium*, *Manumiella* and *Chatangiella*. Other peridinioid taxa included species of *Isabelidinium* and *Trithyrodinium*. The most common gonyaulacoid taxa found were species of *Spiniferites*, *Achomosphaera* and *Hystrichosphaeridium*. Some nearly monogeneric assemblages were found, dominated by *Andalusiella*, *Chatangiella* and *Palaeocystodinium*. Almost monogeneric gonyaulacoid assemblages were also found, dominated by *Spiniferites* and *Achomosphaera* species.

The intervals of highest productivity were dominated by peridinioid species, while the lower productivity intervals were found to be dominated by gonyaulacoid cysts. The accuracy of the P:G ratios was supported by changes in the planktonic foraminiferal assemblages (independently associated with productivity changes), the petrography and geochemistry. The P:G ratios were also found to be higher in the inner part of the upwelling system (more landward of the two sections studied), where the productivity was greatest, and lower toward the outer part of the system.

Comparison with this study: Many processing problems were found to be common to the material in this study (particularly from the Bunker Hill and much of the Pueblo sections) and the material processed by Eshet *et al.* (1994). The problematical samples were dominated by marine amorphous organic matter, which is resistant to oxidation methods (unlike terrestrially derived amorphous organic matter). Palynomorphs were few in number and very difficult to find in the material. The presence of many thin and fragile-walled peridinioid cysts in the samples meant that only limited amounts of oxidation treatment could be used to tidy up the sample. As a result, the palynological residue was still swamped with amorphous organic matter making the counting procedure arduous and time-consuming.

6A.5.3 Environmental influence on cyst production

Cysts probably fulfil a number of functions (Wall, 1971). These include part of the sexual cycle, as protection (against conditions adverse to the motile forms), for propagation (allowing species to extend their ranges into climatic regions where motile forms would seasonally not survive) and for dispersion (from transportation as sedimentary particles into new geographical areas).

6A.5.3.1 Cyst production in neritic environments

The motile stage of dinoflagellates is adapted to stably stratified water columns (Landry, 1977). The relatively small proportions of dinoflagellates that produce cysts are meroplanktonic forms which are adapted to the unstable waters of shelf seas (Wall *et al.*, 1977, Margalef *et al.*, 1979, Tyson, 1987). The seasonal breakdown of hydrographic stability during the winter months or times of overcrowding cause the cyst producing motile dinoflagellates to encyst and sink to the sea floor. Thus cyst formation in many species is at least partly as protection through the winter season, when waters are too cold and/or too turbulent for the survival of the motile dinoflagellates (Dale, 1983). This ecological function has meant that dinocysts are globally most abundant in temperate shelf seas (Harland, 1973, Wall *et al.*, 1977).

The cysts therefore represent a survival strategy for planktonic dinoflagellates in a benthic environment as part of their life cycle. This is far from a unique situation as other organisms (e.g. copepods, tintinnids) also use this strategy (Dale, 1983). In other taxonomic groups the situation may be reversed as benthic organisms produce planktonic larvae for similar reasons.

6A.5.3.2 Cyst production in oceanic environments

While it is considered that the abundances of cysts within the assemblages may reasonably accurately reflect the abundances of living cysts from the corresponding meroplanktonic dinoflagellates in shallower water, studies from deep-ocean sediments suggest that cyst assemblages do not reflect the living cyst distribution, but are more affected by offshore transport in these environments. Most oceanic dinoflagellates do not produce cysts as part of their life cycle, and those that do presumably have cysts designed to stay in suspension within the mixed layer (seasonally affected layer of the ocean) until excystment has occurred. A known exception is the genus *Impagidinium* which has an oceanic distribution in Quaternary and recent sediments. Maximum abundances of dinocysts are usually found on continental slope and rise sediments, due mostly to oceanward deposition from species living on the continental shelves (Wall *et al.*, 1977). Pelagic sediments rarely hold abundant dinocysts except where there are indications of redeposition (Tyson, 1987).

6A.5.3.3 Cyst production and stratification

Permanent stratification in a basin would result in the offshore population of living dinoflagellates switching to non cyst-forming species (since dinocysts are predominantly produced by meroplanktonic dinoflagellates in unstable water conditions). Consequently, the only dinocysts suggested to be present in permanently stratified basins would be those redeposited from the less hydrographically stable basin margins (Tyson, 1987). Prasinophycean algae however are generally conspicuous in these situations, as they probably thrived in permanently stratified conditions. Consequently, permanent stratification would be indicated by high prasinophyte to dinocyst ratios and high proportions of morphologically current-sorted dinocysts carried in from the basin margins.

Dinocysts are generally rare in black shales, even from neritic environments and are only significant where there is evidence of redeposition or brief periods of improved oxygenation associated with bioturbation or benthic recolonisation (Tyson, 1987). It is suggested that this is due to a decrease in supply of dinocysts rather than an increase in terrestrial influences.

As the oceans are permanently stratified, the use of prasinophytes and dinocysts as indicators of vertical stability are only of value in neritic sediments. In oceanic sediments, dinocysts represent resedimentation.

6A.5.4 Oceanographic factors affecting cyst assemblages

As already discussed, nutrient levels greatly affect the dinoflagellate populations and hence the cyst assemblages produced. Some of the other factors affecting cyst assemblages include salinity and shoreline proximity which are dealt with in later sections. Water masses are characterised by distinctive temperatures, salinities etc. and also exert a strong influence on dinoflagellates and hence on cyst populations. Consequently the changes in dinoflagellate assemblages with temperature can also be used to study climatic change, and give indications for the rates at which dinoflagellate populations can migrate with changes in water-mass.

6A.5.4.1 Distribution affected by water temperature and water mass

Major boundaries in recent cyst assemblages are noted to coincide with hydrodynamic frontal systems in the overlying waters (Wall *et al.*, 1977, Tyson, 1987).

Multivariate statistical analyses of the geographical distribution of thecate dinoflagellates and their cysts from the northeast Atlantic and North Sea (Dodge, 1994) have suggested that although the cyst forming species seemed to share similar characteristics as they were tightly clustered, the distribution of gonyaulacoid species was clearly influenced by temperature. The distribution of peridinioid cysts showed very similar patterns to the distribution of gonyaulacoid cysts suggesting that the conditions for cyst formation were very similar for both groups of organisms. However, the distribution of peridinioid species was noted to be more related to the availability of food organisms than to other environmental factors.

Habib & Drugg (1987) discussed the palaeogeographical distribution of several dinocyst species from the Lower Cretaceous in respect to boreal and tethyan water-masses, re-iterating the work of de Reneville & Raynaud (1981), but failed to expand the work further up the column in their long-ranging study into the Late Cretaceous.

Davey (1970) considered Cenomanian assemblages from Texas to be very similar to those from the Anglo-Paris Basin, due to the open Tethyan connection between the two areas. However, assemblages from the material from Saskatchewan, Canada were considered to be very different from the assemblages in the material from the Anglo-Paris Basin, with common acritarchs and prasinophytes. One reason for the difference between the assemblages is probably the boreal nature of the water masses in Canada at this time, compared with the Tethyan influences in the other sections studied. The abundant taxa found in Saskatchewan were species of *'Deflandrea'* (now *Eurydinium* and *Isabelidinium* species) which Davey attributed to boreal connections and cooler waters.

6A.5.4.2 Assemblage reaction to climatic cycles

Mudie (1992) noted that dinocyst, acritarch and chlorophyte assemblages responded to Milankovitch cyclicity through the Quaternary and Recent of the Arctic Ocean and northwest Atlantic. The ratio of gonyaulacoid to peridinioid cysts gave an index of temperature and ice cover as gonyaulacoid cysts were found in summer open-water (with salinities >27%) while peridinioids increased with ice thickness and with reduced salinities (17 - 27%). The dinocysts showed more sensitivity to glacial-interglacial changes than did the foraminifera. Acritarchs and chlorophytes dominated in areas greatest affected by stratified glaciofluvial and seasonal meltwater environments.

Versteegh (1994) looked at the patterns of cysts in the Pliocene of the Mediterranean and compared them with Milankovitch cyclicity linked to environmental changes. The patterns of cyst assemblages, palynofacies and $\delta^{18}O$ were used to suggest that at times of minima in precession, the salinity levels were at a minimum, and coincided with maximum terrestrial input (higher sporomorph to dinocyst ratios and higher amounts of reworking), increased proportions of inner neritic to outer neritic cysts, increased proportions of outer neritic to oceanic cysts, higher productivity (from higher peridinioid to gonyaulacoid ratios), and in extreme cases with the formation of sapropelic layers (due to increased surface productivity and increased stratification). The productivity increases at this time are thought to be due to increased land-derived nutrients and not from upwelling. The changes in orbital precession are thought to have affected precipitation levels and hence run-off, at times decreasing surface salinity, increasing the neritic influence on the cyst assemblages and increasing the input of river-borne nutrients. The increasing levels of neritic cysts and inner neritic cysts were probably due to increased basinward transport of the neritic cysts and perhaps from increased stratification with a lowered salinity surface-layer with coastal water properties and hence a basinward extension of the neritic water mass and its inhabitants.

Dinoflagellates have been noted to be able to quickly disperse and invade marine basins. High resolution studies from the Late Quaternary of the Labrador Sea and from Pleistocene and Holocene sediments in cores from Greenland (de Vernal & Mudie, 1992) have shown that cyst assemblages were noted to react to changes in oceanographic conditions and colonise new areas over distances of hundreds of miles within extremely short geological time spans (less than a few hundred years).

6A.5.5 Post-depositional effects on cyst assemblages

6A.5.5.1 Cyst production and preservation

Dale (1976) noted from studies of recent sediments from Trondheimsfjord (Norway) that approximately 20% of the locally recorded dinoflagellate species contributed cysts which would eventually become incorporated in bottom sediments. He also noted that 30% of the cyst morphotypes, including most of the representatives of *Peridinium*, were much less resistant to degradation, and would not be preserved in the fossil record. This suggests that the fossil record is further restricted by preservational factors.

Cysts are able to withstand various adverse environmental conditions. Living cysts are known to have survived the acid (including hydrofluoric acid) digestion of recent sediments, followed by the permanent mounting procedure on microscope slides, only to die on excystment when placed close to a radiator (K. Farr, *pers. comm.*, 1993). Anoxic conditions (including hydrogen sulphide in the sediments) seem to pose no threat to the cysts during normal resting periods, and hence should not have affected resting cysts at times of oxygen depletion.

6A.5.5.2 Cyst redistribution and sedimentation

Once formed, the cysts behave as fine silt particles, in sedimentation, and may be transported by currents. The fate of the cysts depends very much on the environment. In shallower, neritic waters, the cysts often sink quickly through the water column and land at the sediment-water interface. They increase in abundance as the amount of finer sediment increases, usually with increased water depth, and may become gradually concentrated in the deeper parts of sedimentary basins. Open ocean cysts probably either complete their function before sinking too deeply in the water column (perhaps with only a short resting period) or they may be equipped to remain within a depth from which they are able to return their motile stages to the plankton after excystment (perhaps by density regulation) (Dale, 1976, 1983).

Cysts may be less subject to redistribution than previously thought. Many cysts reach the sea floor in faecal pellets (commonly seen in palynological preparations). When compared to individual cysts, cysts within faecal pellets will behave differently within the water column both by being larger and heavier and hence less subject to movement by currents, and also by sinking much faster and hence spending less time in the water column to be affected by currents. The degree to which dinoflagellates use the strategy of cysts within faecal pellets, for reaching the sea-floor is unknown. Bioturbation on the sea floor is liable to disaggregate faecal pellets at the sediment-water interface. Faecal pellets are also probably commonly broken up by palynological preparation techniques.

However, currents are still very important when considering assemblages and interpreting environments as they play an important role in mixing and distributing populations of cysts as they sink through the water column (Davies *et al.*, 1982). These include: localised flow from rivers into the marine basin; intrusion of marine waters into estuaries through tidal subsurface currents; wind-driven and other seaward movements; winnowing from the shelf floor; erosion of present or relict shelf sediments; mixing, sinking and basal inflow of oceanic waters into shelf waters across the continental slope and outer shelf; bathymetric contour currents; and outer-shelf currents and turbidity movements.

6A.5.5.3 Effect of cyst morphology on distribution and redistribution

Davey & Rogers, 1975 noted from studies of recent sediments from offshore southwest Africa that oceanic and warmer-water dinocysts tended to have longer and more delicate processes than nearshore forms. This variation was also seen to occur within the cysts of a single dinoflagellate species depending on where the encystment took place.

Studies in palaeopalynology have noted a larger number of robust, simple proximate cysts in near-shore environments, while distal assemblages are characterised by chorate cysts with long and complex processes. This is probably more to do with the differential sorting of morphotypes by currents, as chorate cysts may be carried further offshore. Theories on the chorate morphotype as one to help keep the cyst suspended in the water column are probably incorrect. The processes probably catch faecal or other descending material, thus enabling the cyst to sink faster and hence to leave the turbulence of the water column more quickly. The processes may also help in greater dispersment of the hypnozygotes during the resting phase of the life-style.

Impagidinium species as known oceanic species from Quaternary and present sediments, do not possess processes. Instead they have paratabular muri or flanges, which would probably not assist in catching organic debris, but which might decrease the hydrodynamic properties of the cyst, thus enabling it to remain in the mixed layer of the water column for greater lengths of time.

6A.6 USE OF DINOFLAGELLATE CYSTS FOR PALAEOENVIRONMENTAL INTERPRETATIONS

Davies *et al.*, 1982, summarised four methods for using dinoflagellate cysts in palaeoenvironmental studies, outlined as: 1) the absolute abundance of cysts per volume of sediment; 2) the relative abundance of cysts compared with other palynomorphs; 3) cyst species diversity and dominance; and 4) the abundance of individual species, groups of associated species or morphotypes, characterising an assemblage. However, it is important to note that these are all interlinked and hence cannot easily be discussed separately.

6A.6.1 Cyst abundance and species diversity

Cyst abundance and species diversity are often linked though they do not necessarily correlate. Cyst abundance is related to many factors including primary productivity, latitude, shoreline proximity and water turbulence. However, measurement of the absolute abundance of cysts within the sediment is difficult to achieve satisfactorily. Quaternary pollen methods involve the addition of known quantities of palynological spikes (e.g. *Lycopodium* spores) to measure the relative abundances of palynomorphs. However, in this study, this method did not prove satisfactory.

Cyst species diversity can also be related to many factors. Davies *et al.* (1982), discussed the work of Odum & Copeland (1974) on the classification of ecosystems for coastal environments in the U.S.A. and its applications to marine palaeopalynology. This work suggests four main components for an ecological system: the populations of organisms; the flows of water; the pathways of chemicals; and the organisational mechanisms. Diversity is suggested as a useful indicator for the levels of stress in the environment. More energy is suggested to be used up dealing with the stress (e.g. fluctuating salinities) and is reflected in lower diversities. Highly-adaptive indicator species were also suggested as important in identifying stressed ecosystems. In diversified ecosystems, any one of a number of species may have local dominance as conditions alter slightly.

Wall *et al.* (1977) applied these theories to cyst assemblages across the globe. Low latitude, offshore assemblages show a maximum diversity with much of the energy available for organisation, specialisation and diversification. Higher latitude assemblages would display lower diversities as they would need to expend more energy on seasonal programming and hence would have less energy available for diversification and specialisation. Similarly, in inshore environments, energy would also be expended coping with the greater variability of the environment, and hence the species diversities would be lower.

6A.6.1.1 Variation with shoreline proximity and bathymetry

Studies of plankton diversity and dominance have shown high abundances of individuals in estuarine environments (due to high nutrient levels) but very low diversities. Diversities in shelf and deep ocean waters are much higher but may be dominated by a few forms, depending on seasonal differences (Hulburt, 1963).

McKee *et al.* (1959) examined bottom sediments from a lagoonal environment near New Guinea, in the southwest Pacific and found an increase in abundance of cysts with water depth. However, cysts were not found in sediments shallower than 45 metres depth. Diurnal migration patterns of the living dinoflagellates in this study showed that while at night they rose to within 15 metres of the surface, during the day, they were seen to migrate downwards away from bright sunlight, to depths as great as 45 metres. The need to escape from the bright sunlight meant that few living dinoflagellates were found in waters less than 45 metres deep. This critical depth, of course, would greatly vary with latitude and (in mid to high latitudes) with season. The species distribution may well have also been affected by temperature stratification.

In studies along transects across the continental shelf and slope offshore southwest Africa, Davey & Rogers (1975) noted that fine-grained, nearshore sediments were often devoid of dinocysts, particularly in the vicinity of a river mouth, due to the paucity of cyst-forming dinoflagellates and transport by the oceanward currents from the river mouth. This was followed by an initial increase in the absolute abundance of dinocysts away from the shore, followed by a second increase further offshore corresponding to upwelling on the continental slope in areas of nutrient concentration. The sediments from high areas of upwelling were found to have low diversities, probably due to the strong upwelling currents. The greatest species diversities were found in the continental slope sediments where sediment deposition was slowest and hence a greater length of time was represented in a sediment sample. The living dinoflagellates increased shorewards apart from anomalous concentrations in places of intense upwelling, where they were most abundant. Hence the numbers of motile dinoflagellates were not necessarily reflected by larger numbers of cysts in the sediment. Beyond the inner shelf, water depth was no longer considered to be important in affecting the distribution of cysts.

Wall *et al.* (1977) concluded from cyst studies from recent material from inshore-offshore transects that species diversity increased in offshore assemblages. Species abundance was also noted to increase in an offshore direction, due mainly to the addition of offshore species not found in near-shore environments. Other reasons included the seaward transport of estuarine and inner-neritic cysts, and the possible addition of reworked cysts.

Multivariate statistical analyses of the geographical distribution of thecate dinoflagellates and their cysts from the northeast Atlantic and North Sea (Dodge, 1994) have clearly shown that the greatest abundances and diversities of dinocysts is on the northwest European shelf. Here, the sea depth is no greater than 200 metres, is under strong influence from the land (in the way of nutrient supply and sediment input) and the water column is mixed through most of the year. The high productivity of dinocysts here confirms that thecate dinoflagellates from neritic areas produce cysts as a means of coping with extremes of temperature and the inhospitably turbid water through the winter season.

Masure (1988) used species dominance and diversity to track changes in sea levels in the Albian and Cenomanian of the Bahamas. Inner neritic assemblages were seen to have high species dominance and low diversities, while as the environment changed to outer neritic, the diversities increased.

Palynological studies of transgressive and regressive sediments from the Late Cretaceous of the eastern United States (Habib & Milner, 1989), also suggest that species diversity is related to depositional environment and so also to palynofacies. Offshore shallow-shelf assemblages are more diverse than near-shore assemblages and are dominated by different species. Multiple occurrence datums with marine amorphous debris were considered to be evidence of initial marine transgression. A rapid change to high species diversity and high ratios of dinoflagellates to sporomorphs are considered to be evidence of a rapid transgression in facies overlying a sequence boundary.

Tocher & Jarvis (1994) noted that compared with elsewhere in the Anglo-Paris Basin, cyst abundances and diversities were lower in the Middle and Late Cenomanian at Fumichon, Normandy, France due to the marginal location of the section at that time.

6A.6.2 Relative cyst abundance

The abundance of cysts can be compared with the abundance of other palynomorphs and phytoclasts. Often it is compared with sporomorph (pollen and spore) numbers, but can also be compared with palynofacies assemblages. Davey & Rogers (1975) noted that the ratio of sporomorphs to dinocysts within the sediment normally decreased oceanwards, in transects offshore of southwest Africa.

Morzadec-Kerfourn (1977) compared the percentages of dinocysts with the rest of the palynological content, in transect studies from offshore Brittany. The cyst content in the oceanic zone (with water depths greater than 100m) was around 50%. In the coastal zone, the cyst content varied between 3.5% and 8%. In the estuarine zone, the cyst content varied between 20% in the lower part and 90% in the upper part of the tidal zone, where the dinocyst assemblage was almost monospecific.

Mebradu (1978) compared the changing ratios of microplankton (mostly dinocysts), tasmanitids, foraminiferal test linings and sporomorphs from the Jurassic of Dorset, and concluded that relative abundances in dinocysts were linked to transgressive-regressive cycles. The distributions of the categories were not controlled by lithology but by environmental factors such as shoreline proximity, depth of the basin, directional changes in transporting currents, and the rate of production and availability of miospores.

Brinkhuis & Zachariasse (1988) used the ratios of sporomorphs to dinocysts across a Cretaceous-Tertiary boundary section in northwest Tunisia. The boundary is characterised by a large and sudden increase in the proportion of sporomorphs, suggesting a major regression, followed by a more gradual decrease with subsequent transgression. This is paralleled within the dinocyst assemblages by large increases in *Spiniferites/Achomosphaera* and *Cyclonephelium/Glaphyrocysta* groups of cysts and decreases in *Impagidinium* species taken to indicate a switch from deeper-water/offshore to shallower-water/nearer-shore environments. The proportions of peridinioid species increase shortly before the proportions of sporomorphs decrease, and are not thought to indicate deeper-water environments, but to indicate regional productivity increases associated with increased water circulation from transgression. The return to stable and optimum environmental conditions after the sea-level fluctuations at the boundary, was thought to have been reflected by later, well-balanced dinocyst assemblages.

6A.6.3 Abundance and Distribution of Dinoflagellate Cyst Taxa and Groups

Different species of cyst, in studies of recent material, have shown a number of environmental preferences, which may be applicable to taxa from the Cretaceous. Numerically more abundant cysts within an assemblage may represent cosmopolitan species, while often biogeographical and palaeoenvironmental information may be obtained from species that are numerically less important (Dale, 1976).

Wall *et al.* (1977) classified the species of cysts from recent sediments into four main groups, according to their inshore - offshore distributions. These included estuarine, estuarine-neritic, neritic and oceanic. The assemblages were then further split into categories based on their latitudinal distribution (e.g. temperate, tropical etc.). The distribution of individual taxa was primarily related to water depth, but also controlled by latitudinal and climatic factors. The overall distribution of cysts is considered to be related to water-mass characteristics (Reid, 1975, Wall *et al.*, 1977, Dale, 1983).

6A.6.3.1 Specific taxa

***Spiniferites* taxa:** Many different trends have been recognised with species of *Spiniferites* from both recent and ancient sediments.

Spiniferites ramosus was associated with cold, upwelling water from samples along transects offshore southwest Africa as it was found to be most abundant in nearer-shore shelf areas where upwelling was strongest (Davey & Rogers, 1975). High numbers of *Spiniferites ramosus* along with other species of *Spiniferites* were found in the oceanic (water-depth greater than 100 metres) and coastal zones, along transects from offshore Brittany (Morzadec-Kerfourn, 1977). *Spiniferites ramosus* has also been found in high productivity assemblages dominated by peridinioid cysts (Bujak, 1984). *Spiniferites* species have been used as outer neritic species (e.g. Versteegh, 1994), or as inner neritic species (Davey & Rogers, 1975, Wall *et al.*, 1977, Brinkhuis & Zachariasse, 1988) or as both (Bint, 1988). Edwards & Andrle, 1992 suggested that species of *Spiniferites* showed no clear trends with either temperature or depth and that other species of cyst including *S. ramosus* showed numerous and various trends, probably due to taxonomic problems (suggesting that the cysts from more than one species were being grouped as the same taxa).

***Cyclonephelium* taxa:** Species of *Cyclonephelium* have been taken to indicate nearshore, shallow-water environments (Brinkhuis & Zachariasse, 1988) or open-marine neritic environments (Downie *et al.*, 1971).

***Operculodinium* taxa:** Different species of *Operculodinium* from recent sediments have been associated with different environmental conditions. *Operculodinium centrocarpum* was associated with warmer water masses from samples along transects offshore southwest Africa and increased in numbers offshore (Davey & Rogers, 1975). *Operculodinium israelianum* has been used as an inner neritic and warmer water indicator (Edwards & Andrle, 1992).

***Impagidinium* taxa:** In Quaternary and Recent studies, species of *Impagidinium* are considered to be from deep-water offshore or oceanic environments (Reid, 1975, Dale, 1976, Morzadec-Kerfourn, 1977, Wall *et al.*, 1977, Davies *et al.*, 1982, Harland, 1983, Powell *et al.*, 1990, Lewis *et al.*, 1990, Edwards & Andrle, 1992). This oceanic-centred distribution has meant that species of *Impagidinium* have been successfully used as deep-water indicators in pre-Quaternary studies (e.g. Brinkhuis & Zachariasse, 1988, Versteegh, 1994) in respect to low tolerance of nutrient and salinity variations. A number of new species of *Impagidinium* were described by Bujak (1984) from the Cenozoic of the Bering Sea, and since they were previously undescribed from areas further south, they were suggested to represent cold water species. Other species of *Impagidinium* from modern sediments are thought to be related to warmer waters (Edwards & Andrle, 1992).

Nematosphaeropsis **taxa:** *Nematosphaeropsis labyrinthus* has maximum abundances in outer-neritic to oceanic sediments (Davey & Rogers, 1975, Dale, 1976, Lewis *et al.*, 1990).

Protoperidinium **taxa:** Cysts corresponding to *Protoperidinium* species are suggested to be most abundant in a variety of situations and environments. These include upwelling areas (e.g. Wall *et al.*, 1977, Bujak, 1984, Lewis *et al.*, 1990, Powell *et al.*, 1990), neritic environments over a range of water temperatures (Edwards & Andrle, 1992), coastal areas (Wall *et al.*, 1977, Bint, 1988), at high latitudes or in cool waters (Balech & El-Sayed, 1965, Bujak, 1984, Dale, 1985, Powell, 1992), and along fronts between water masses (e.g. Wall *et al.*, 1977, Versteegh, 1994). This is due to a combination of variation in nutrient levels, feeding strategies and the more environmentally tolerant and euryhaline character of the living peridinioid species. Edwards & Andrle (1992), in a study of modern sediments (mostly from the North Atlantic) found that cysts corresponding to *Protoperidinium* species occur most abundantly in neritic environments over a range of water temperatures.

6A.6.3.2 Further Pre-Quaternary examples

Goodman (1979) studying the Lower Eocene of Maryland, noted that trends in species dominance also indicated environmental preferences, for example with high numbers of *Wetzeliella* type cysts and other peridinioids indicating shallow-water marine to estuarine environments.

Downie *et al.* (1971) also looked at assemblage compositions from the Lower Eocene of England. Assemblages dominated by *Spiniferites* along with *Achomosphaera*, *Hystrichosphaeridium* and other species and assemblages dominated by *Areoligera* and *Glaphyrocysta* were interpreted as representative of open-marine neritic environments. Assemblages dominated by acritarchs such as *Micrhystridium* were interpreted as indicating inner-neritic environments. Assemblages dominated by species of *Wetzeliella* and *Deflandrea* were interpreted as indicative of lagoonal, estuarine or brackish water environments.

Nearshore/coastal environments in the Campanian to Maastrichtian of New Jersey (Habib & Milner, 1989) were represented by high P:G ratios, including species of *Chatangiella* (e.g. *C. victoriensis*), *Gillinia*, *Palaeoperidinium* (*P. pyrophorum*), and *Dinogymnium*, and dominated by *Palaeohystrichophora infusorioides*. The offshore environments were generally dominated by species of *Areoligera*, *Glaphyrocysta* and *Exochosphaeridium*, with a higher species diversity. The distribution of *Palaeohystrichophora infusorioides* was considered difficult to interpret as it was abundant in coastal and nearshore facies but also found to be abundant at multiple occurrence datums (sudden increases in diversity) representing episodes of transgression. This species consequently occupied a wide range of habitats.

Wilpshaar & Leereveld (1994) used dinocyst associations to reflect environmental changes and palaeobathymetries from the Valanginian to Lower Cenomanian of the Vocontian Basin in south-eastern

France. The '*Muderongia* group' (also including *Odontochitina* and *Phoberocysta*) in high abundances were suggested to indicate restricted shallow marine conditions. However for the '*Muderongia* group', transport into the basin was considered to play an important part in the distribution of the cysts resulting in a consistent and frequent presence of this group (though why this basinward transport did not seem to affect the other inner-neritic groups is not explained). High abundances of the '*Systematophora* group', the '*Cribroperidinium* group' (also including *Apteodinium*), and the '*Circulodinium* group' (also including *Aptea*, *Cyclonephelium*, *Cerbia* and *Sentusidinium*) were suggested to be associated with inner neritic and restricted marine environments. High abundances of the '*Oligosphaeridium* group' (also including *Kleithriasphaeridium* and *Hystrichosphaeridium*) and the '*Spiniferites* group' (also including *Achomosphaera*) were suggested to be indicative of open marine neritic conditions. The '*Pterodinium* group' were suggested to be morphologically comparable with modern *Impagidinium* species and the occurrence of this group was suggested to indicate the influence of oceanic waters.

Palaeohystrichophora infusorioides was found to the most abundant species in the majority of horizons from the Cenomanian from sections in the Anglo-Paris Basin (Davey, 1970). Peaks in abundance were successfully correlated between sections across the basin using macrofossil biostratigraphy. The graphs of *P. infusorioides* from the sections at Compton Bay, Isle of Wight and Fetcham Mill, Surrey also showed the largest increase in abundance at the top of the Cenomanian, just below the base of the Turonian. The other most common species include *Dapsilidinium ambiguum* (as *Cleistosphaeridium huguonotii*), subspecies of *Spiniferites ramosus* and species of *Micrhystridium*.

Aurisano (1989) discussed the morphological variability of *Palaeohystrichophora infusorioides* in his study from the Cenomanian to Maastrichtian of New Jersey and Delaware, U.S.A.. He suggested two end member forms (Variant A and Variant B) represented in this study by the *P. infusorioides* and *Subtilisphaera cheit* complex. These were noted to vary in proportions with *P. infusorioides* (Variant A) dominating during transgressive phases of deposition and *S. cheit* (*P. infusorioides* Variant B) dominating during regressive phases of deposition, when it dominated the dinocyst assemblages.

PART B: PALAEOENVIRONMENTAL INTERPRETATIONS FROM OTHER PALYNOLOGICAL TAXA

6B.1 Acritarch taxa

Acritarchs are by definition, fossils from organisms of unknown origin. Dinoflagellates in modern ecosystems represent a major part of the base of the marine food web and it is likely that the situation was no different back through the geological time. This, along with their primitive cell biology suggests that they probably evolved far back in the Palaeozoic or even Precambrian. However, no fossil record (apart from one potential species in the Late Silurian) exists for dinoflagellates until the Triassic. Either the dinoflagellates did not produce preservable cysts at all until then, or the cysts that they did produce are not recognisable as dinoflagellate remains and have been grouped with the polyphyletic acritarchs (Evitt, 1985).

Some cysts from both modern and ancient sediments are more dinoflagellate-like than others. Some cysts known to be produced by living dinoflagellates, show no dinoflagellate characteristics and if they were found in the fossil record, they would be interpreted as acritarchs. Hence there is a potential overlap between non-descript dinoflagellate cysts and acritarchs.

The modern dinoflagellate order Prorocentrales (with apical projected flagella) are considered to be the most primitive of the dinoflagellates. None are known to produce preservable cysts, but if they did then they would not be recognised as dinoflagellate cysts, and hence grouped with the acritarchs. It seems probable that some acritarchs (with a fossil record back into the Precambrian) may in fact be dinoflagellate cysts (Evitt, 1985).

6B.2 Prasinophyte taxa

The phycomas of prasinophycean algae (e.g. *Tasmanites*, *Leiosphaeridia*, *Crassosphaera*, *Cymatiosphaera*, *Pterospermella*) do not represent the resting stage in the life cycle of prasinophytes, nor are they benthic (Tappan, 1980, Tyson, 1987). They represent a pelagic distribution since the phycoma is only sedimented after the contents are released or it is ingested by zooplankton and included in faecal pellets. These algae flourish in permanently stratified conditions (Tyson, 1987).

Davey (1978) noted that assemblages from the Aptian from offshore southwest Africa were unusual in that the acritarchs (meaning prasinophytes) were abundant and even outnumbered the dinocysts. The taxa included *Pterospermella*, *Cymatiosphaera* and *Eyrea*, the former two noted to be consistently associated with organic-rich sediments through the Mesozoic. The samples were also dominated by amorphous organic matter though with large amounts of terrestrially derived debris or sporomorphs. Dinocysts were low in abundance (<5%) but high in diversity. Davey suggested that the assemblage was probably a result of large run-off from the African landmass with restricted circulation in the basin.

Changes in Pliocene surface currents were strongly affected by fluctuations in surface run-off and topographic changes in Greenland, and were reflected in dinocyst and prasinophyte assemblages (de Vernal & Mudie, 1992). Acritarchs and chlorophytes were found to dominate in areas greatest affected by stratified glaciofluvial and seasonal meltwater environments (Mudie, 1992).

PART C: PALAEOENVIRONMENTAL INTERPRETATIONS FROM PALYNOFACIES DATA

6C.1 Factors affecting palynofacies assemblages

The organic carbon content of marine sediments is controlled by six main factors. These are sediment texture (particularly grain-size), water depth, primary productivity, rates of allochthonous organic matter supply (terrestrial and marine), rates of sediment accumulation and bottom water oxygen levels (Tyson, 1987).

Oxidation within the sediment combined with biological activity and chemical degradation (in alkaline conditions) will break down and destroy organic matter. Different types of particulate organic matter are more or less susceptible to degradation. In particular the amount of AOM is greatly affected by oxygen levels within the sediment, and hence its presence characterises low-energy, stagnant, oxygen-depleted environments. Bioturbation related to macrobenthic activity is probably the most important factor in affecting the preservation of organic matter as well as affecting the quality of the palynomorphs. Large amounts of bioturbation increase the levels of oxygen within the sediment as well as causing physical degradation of the organic material. Infauna also consume the organic matter as food.

Particulate organic matter behaves physically like other sedimentary particles. Most organic particles are hydrodynamically similar to clay and silt (Tyson, 1987), and hence can be sedimentologically used in terms of their grain-size, sorting and angularity. The presence of particulate organic matter is greatly affected by the grain-size of the sediment. Well-sorted, coarse-grained sediments deposited under comparatively higher-energy conditions, hold little organic matter as it is generally either not laid-down, removed by winnowing and/or destroyed by normal (oxic) oxygen levels. However fine-grained sediments from marine shelf environments are generally rich in particulate organic matter.

The buoyancy of the relative terrestrially derived phytoclasts is affected by the composition, grain size and shape. Of the different types of phytoclast (without taking into account the shape of the particles), the most buoyant is supposed to be the membranous material, followed by brown wood with black wood as the least buoyant (Steffen & Gorin, 1993). However, the buoyancy is greatly affected by size and shape. As with any sedimentary particle the size that can be transported is directly affected by the transportational energy available. Larger fragments are indicative of higher energy currents and hence normally, in a shelf environment, of nearer-shore conditions. The shape of the grains also greatly affects the buoyancy. Flat or blade-shaped particles take longer to settle out of the water column and hence are likely to be transported further. The shape of fragments is probably of greater importance than their composition in respect to buoyancy (Steffen & Gorin, 1993).

However the palynofacies composition in a marine shelf environment is probably most affected by the biodegradability of the phytoclasts and palynomorphs. Degraded material of terrestrial origin and most membranous material (partly due to its more fragile nature) are more susceptible to physical and chemical degradation and decrease in number in an offshore direction. The least susceptible to chemical degradation is the black wood which is comparatively inert although can be physically fragile. Degradation is affected by the physical, chemical and biological activity in the water column and by the length of time that particles take to settle out (in turn a function of turbulence and water-depth). The chance of preservation is also improved by lowered oxygen levels upon burial (dysoxic to anoxic conditions) which lower or remove fungal activity allowing more delicate phytoclasts to be preserved (Tyson, 1995).

Primary productivity also affects the palynofacies, although the relationship is not a simple one. Organic-rich sediments will not accumulate under areas of high primary productivity unless other factors (in particular reduced benthic oxygen levels) allow preservation. In many circumstances the level of primary productivity is strongly influenced by the degree of nutrient recycling within an ecosystem. The removal of organic carbon (and other nutrients) from the system, by sedimentation, will lower primary productivity unless the system has an external source of allochthonous nutrients such as a terrestrial or an upwelling source (Tyson, 1987).

6C.2 Palynofacies variation with sea-level change

The relationships between palynofacies assemblages and sea-level changes in a sequence stratigraphic context as illustrated in Steffen & Gorin, 1993, are summarised below. The lowstand systems tract involves a basinward shift in deposition following sea-level fall with subsequent erosion, sediment bypass and the reworking of shallow shelf sediments into deeper basinal areas, resulting in a prograding lowstand succession. The palynofacies of lowstand systems tracts are characterised by large, angular woody fragments and/or degraded terrigenous fragments, by an increase in the proportions of transported fragments and by a decrease in the abundance of dinocysts. For application to this study on a smaller scale, an increase in larger sized woody fragments and terrestrial-sourced amorphous organic matter can indicate deposition closer to shore.

Transgressive systems tracts are marked at the base by an initial flooding surface followed by a retrograding succession of sediments resulting from a progressive landward shift in sediment accommodation due to rising sea-levels. Their palynofacies are characterised by an upward decrease in the abundance, size and angularity of terrigenous fragments, and by an upward increase in blade-shaped black-wood fragments and in the diversity and abundance of marine palynomorphs including dinoflagellate cysts, which peak at the maximum flooding surface.

Highstand systems tracts mark a return to prograding sedimentation as rates of sea-level rise slow and eventually halt and the environment of deposition shoals upwards. The highstand systems tract reverses the above patterns in palynofacies with a decrease in dinocysts and blade-shaped black wood fragments, and by an increase in other fragments of terrestrial origin. However the proportions of large phytoclasts and of terrestrial amorphous matter observed in large quantities in the lowstand systems tract are not as numerically important in the highstand systems tract except towards the top as progradation of the shoreline continues in late highstand. The sequence boundary, often marked by an erosional unconformity, indicates the top of the highstand systems tract.

The major changes in palynofacies related to sea-level change as noted by Steffen & Gorin (1993), were recorded from a third order cycle. However they also noted that the distribution of organic matter was affected by smaller scale (fourth to sixth order) and larger scale (first and second order) fluctuations.

Different depositional environments will alter to different degrees, in response to the same sea-level fluctuation. Small scale sea-level fluctuations in a shallow water setting may result in drastic changes in depositional environment and consequently marked changes in lithology and palynofacies, while the same fluctuations in a deep water, pelagic environment will have comparatively little effect. The shallow-water sections in this study (Blue Point, Wahweap Wash and Bunker Hill) are consequently far more likely to show palynofacies changes in response to sea-level change.

Different authors have noted conflicting patterns in the distribution of increased proportions of blade-shaped fragments. As mentioned above, Steffen & Gorin (1993), noted an increase in proportions with rising sea-level. However, Tyson (1987), suggested that with increased distances from fluvial sources, prolonged reworking, exposure and oxidation, woody phytoclasts tend to become smaller, more equidimensional and darker in colour from oxidation.

Palynomorphs are generally of little use in determining palaeo-depths but may be more useful for determining distances from shore. The use of palynofacies as a shoreline proximity indicator needs to take into account a number of factors. These include the proximity of the fluvio-deltaic sources for the input of phytoclasts, the amount of discharge from the sources, the amount of terrestrial primary productivity in the source catchment area, and the length of transport between particle source and depositional site. A proximal facies is one deposited nearest to the terrestrial sources, with highest siliciclastic sedimentation rates and hence with least transport and modification of its particulate organic matter assemblages (Tyson, 1995).

Palynofacies as a shoreline proximity indicator must be used with care, as changes suggesting a shift towards more distal facies may really reflect changes towards a drier climate with a decrease in terrestrial primary productivity and run-off. Similarly changes in marine circulation patterns may also affect palynofacies assemblages, in modifying the magnitude and direction of bottom and surface currents. Water-mass stratification will confine circulation to the surface waters and so favour only the offshore transport of small, buoyant terrestrial particles that can be transported in suspension or by the wind, resulting in a seemingly distal shift in the palynofacies. Shifts from distal-marine towards proximal-marine palynofacies may result not only from eustatic fall but also from tectonic rejuvenation and from a shift towards more humid climatic conditions. Palynofacies changes may result from a complex interplay of many factors, not just relating to eustatic levels.

CHAPTER 7

'TIME-SLICE' TRANSECTS: EFFECT OF PALAEOENVIRONMENT ON PALYNOLOGICAL ASSEMBLAGES

7.1 INTRODUCTION

The high-resolution stratigraphic control available between the sections presents a unique opportunity to look at the effect of differences in depositional environment on palynological assemblages. The aim of this chapter is to use the 'HIRES' chronostratigraphic framework to pick samples from selected 'time-slices' from all of the sections, and examine the marine palynomorph and palynofacies assemblages deposited at particular times, in different basinal subenvironments.

The locations of the core and section sites used are described in Appendix A and illustrated in Figure 3.1; the samples used along with their range-chart plot depths are listed in Appendix B, and illustrated alongside the lithological logs in Figures 3.16 (Blue Point section), 3.13 (Wahweap Wash section), 3.9 (Pueblo section), 3.8 (Rebecca K. Bounds core), and 3.11 (Bunker Hill section); the authors for the dinoflagellate cyst and other palynomorph species are listed in Appendix C; the species are illustrated in Appendix D; and the occurrences/abundances of individual species and of the palynofacies assemblages are illustrated in the range charts, located in Appendix E.

7.1.1 Methods and Problems

Seventeen horizons (A to Q) were selected in relation to bentonite and limestone marker beds, that could be traced between the sections (Figure 7.1). The sample from each horizon from each of the sections was then compared with its equivalents from the other sections. The channel sampling method used meant that each horizon was averaged out with adjacent material. Effectively, however, a direct comparison can be taken across the basin for geologically 'instantaneous' moments and the relationships between the assemblages compared and contrasted.

The original sampling was not designed for this work, and hence where necessary the accuracy has been compromised. The 'time-slices' are approximations since the sampling resolution varied from section to section. In one case, with the coarser resolution sampling from the top of the western sections, the same sample (W37 from the Wahweap Wash section) was used for adjacent time-slices (Figure 7.1; 'time-slice' P and Q). Nevertheless, the channel sampling has meant that the same horizons have been included in all the examined samples.

The stratigraphic control based on bentonite and limestone horizons is better and the sampling resolution is much finer near the base of the western sections. Consequently the comparisons with the western part of the basin are much more accurate in the lower half of the sections where most samples were used.

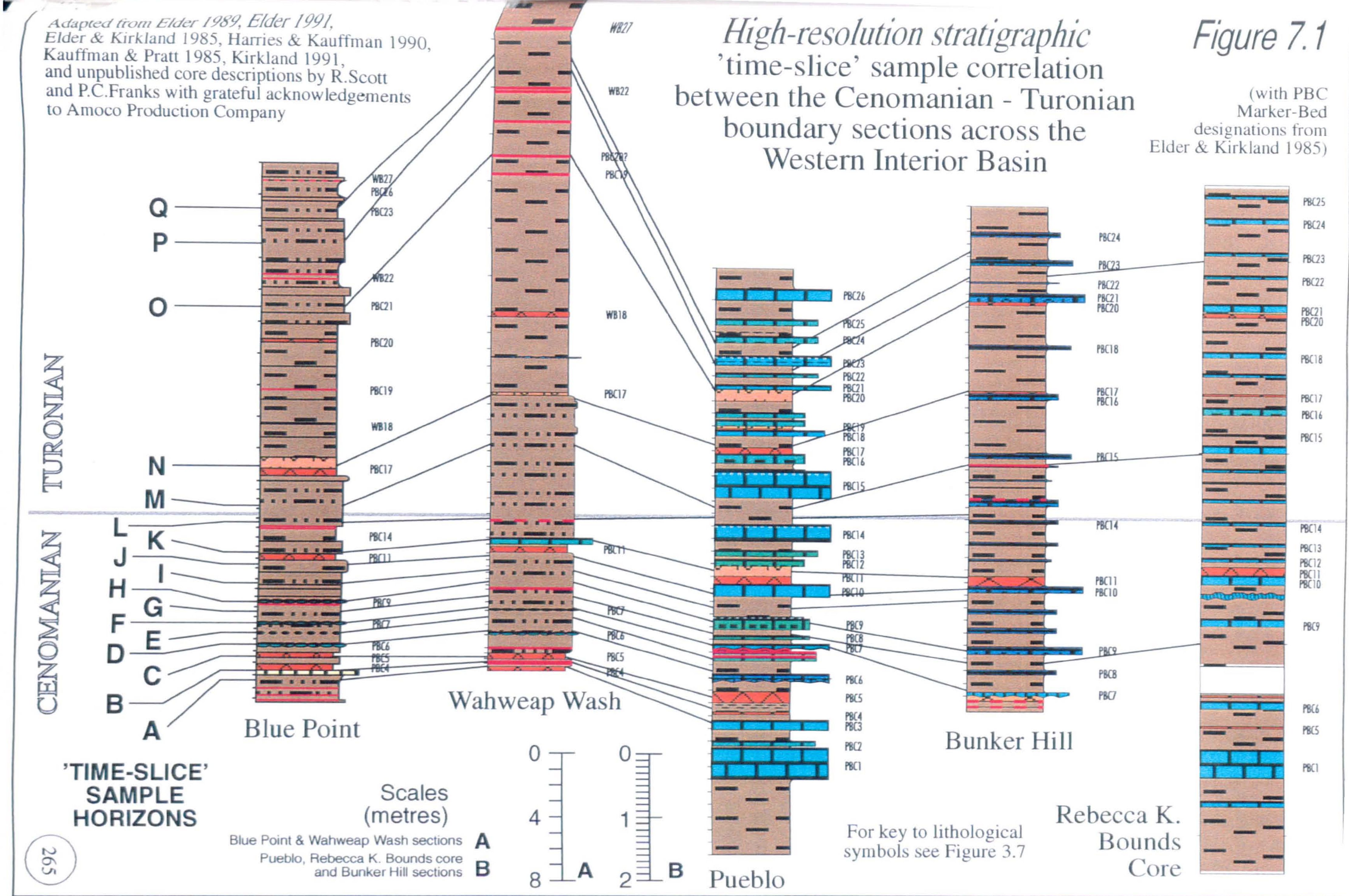
One problem in comparing water depths is that the depths given are for peak transgression.

Adapted from Elder 1989, Elder 1991, Elder & Kirkland 1985, Harries & Kauffman 1990, Kauffman & Pratt 1985, Kirkland 1991, and unpublished core descriptions by R.Scott and P.C.Franks with grateful acknowledgements to Amoco Production Company

Figure 7.1

High-resolution stratigraphic 'time-slice' sample correlation between the Cenomanian - Turonian boundary sections across the Western Interior Basin

(with PBC Marker-Bed designations from Elder & Kirkland 1985)



For key to lithological symbols see Figure 3.7

However, the sea-level was thought to fluctuate on a variety of scales and hence the depths are only comparative. The sea-levels at the base of the western sections were probably much shallower at times, than those given for peak transgression.

In addition the two western sections were located in separate, rapidly subsiding, tectonically-controlled foredeep basins and other studies (e.g. Elder, 1991) have suggested that sea-level curves were not the same for these sub-basins. At the base of the sections examined, it seems likely that the Blue Point section was the nearer-shore, shallower-water section of the two. However, as time progressed, the relative sea-levels fluctuated at different times within these two basins (due to differences in subsidence rates) and it seems likely that by peak transgression, the Blue Point section was the further-offshore of the two sections, and may also have been the deeper-water site of the two.

The Bunker Hill section is not a completely satisfactory section to use as the high amorphous organic matter content and the low abundances of dinoflagellate cysts made counting and sometimes taxonomy difficult (Chart 5C, Appendix E). The assemblages at this locality are likely to have been more affected by the high productivity than by the salinity levels, as the section was also dominated by high numbers of small peridinioid cysts and hence many other species show low abundances (in comparison with other sections). This may have lowered the occurrences of many normal-marine, shallow-water species that would have occurred at Bunker Hill. These species still occurring in the western sections in higher numbers are then reflected in this study to have a lowered-salinity preference as well as a shallow-water preference. Effectively this study may make some of the normal-salinity, shallow-water species, look like low-salinity, shallow-water species.

The palynofacies assemblages from the Rebecca K. Bounds core are unlikely to be accurately represented (though are still useful for comparison) as the palynofacies counts were taken from slides which were heavily processed (using oxidation and probably ultrasonic treatment) and do not represent the total kerogen content. The palynological assemblages from the upper half of the Pueblo section (Chart 4C, Appendix E) and all of the Bunker Hill section (Chart 5C, Appendix E) were dominated by amorphous organic matter (88 to almost 100% of the assemblage) and hence the second palynofacies count was not made for these parts/sections. For this reason, the only effective palynofacies comparisons that can be made are between the western sections (Blue Point and Wahweap Wash) and to a lesser extent, the centre of the basin (lower half of the Pueblo section and the Rebecca K. Bounds core).

7.1.2 Summary of depositional environments

The depositional environments for the localities varied in terms of distance from shore, bathymetry, nearness to terrestrial input and salinity (Figures 3.2, 3.3, 7.2). The environments of deposition are briefly discussed below and summarised in Figure 7.3. The different parts of the Western Interior foreland basin resulted from different structural controls which affected subsidence rates and bathymetry. Both the Black Mesa Basin (Blue Point site) and Kaiparowits Basin (Wahweap Wash site) were located in the western foredeep basin, which underwent the greatest subsidence but also received the greatest volume of sedimentation (Figure 3.2). Between the foredeep sub-basin and the main axial

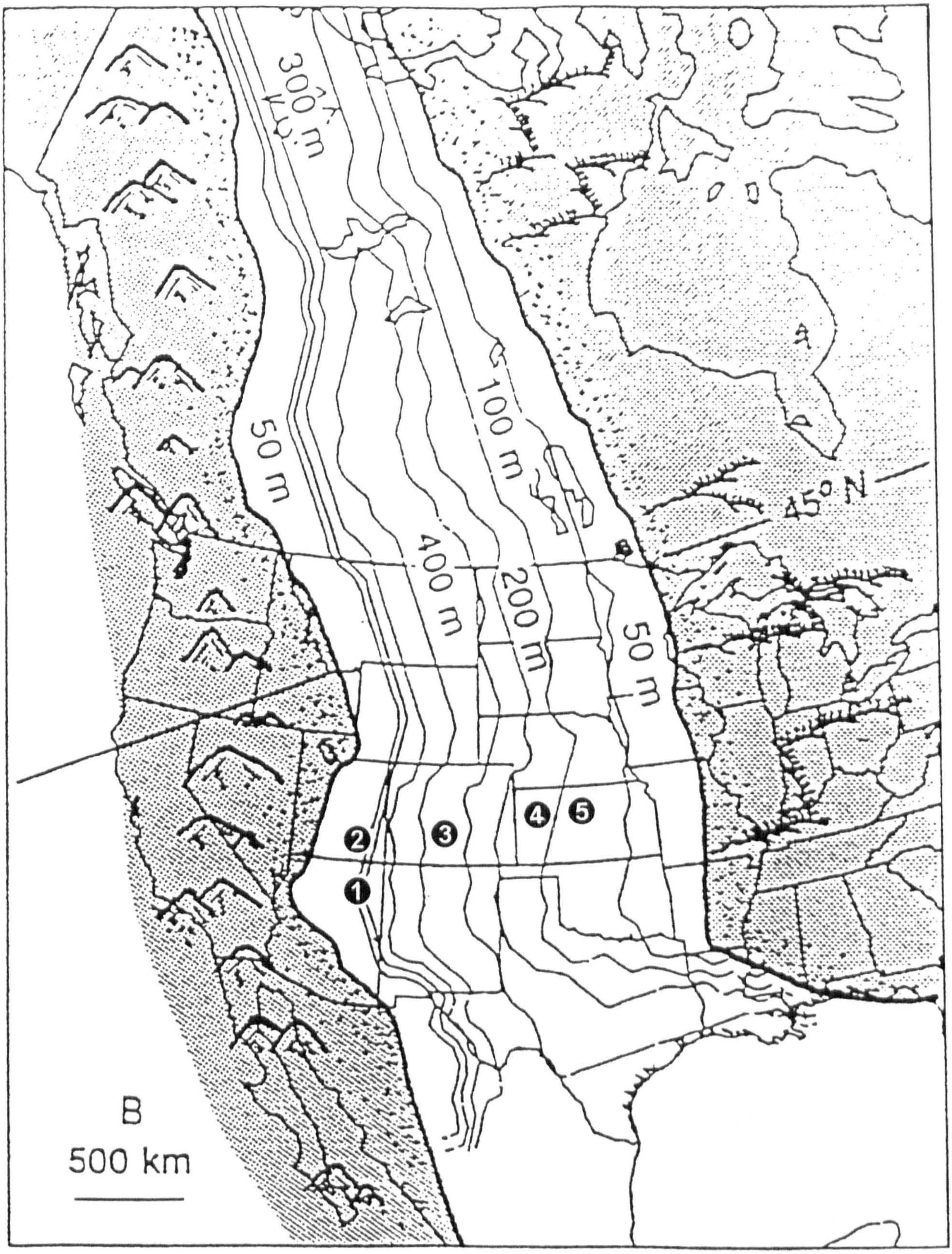


Figure 7.2

Adapted from Ericksen & Slingerland 1991

Palaeogeography and palaeobathymetry of the Western Interior Seaway during peak transgression of the Greenhorn eustatic cycle in the Early Turonian. Core and section sites marked as follows: 1. Blue Point, Arizona; 2. Wahweap Wash, Utah; 3. Pueblo, Colorado; 4. Rebecca K. Bounds core, Kansas; 5. Bunker Hill, Kansas.

SECTION LOCALITIES:
SUMMARY OF DEPOSITIONAL ENVIRONMENTS

Section	**Blue Point**	**Wahweap Wash**	**Pueblo**	**Rebecca K. Bounds Core**	**Bunker Hill**
Comparative salinity	Lower	Lower	Higher	Higher	Higher
Estimated * depth at peak transgression	Shallow <100m ∅ 50-100m ⊗	Shallow 100-200m ∇ 50-100m ⊗	Deep 200-500m ∇ 300-400m ⊗	Intermediate 200m ⊗	Shallow <100m ∇ ⊗
Estimated * ⊗ distance from west shoreline	Near 250km	Near 150km	Intermediate 700km	Far 1000km	Far 1200km
Estimated * ⊗ distance from east shoreline	Far 1500km	Far 1600km	Far 1100km	Intermediate 700km	Near 500km
Sedimentation rate	High	High	Low	Low	Low
Sediment type	Dominantly siliciclastic, some pelagic carbonate	Dominantly siliciclastic, some pelagic carbonate	Highly pelagic carbonate, some siliciclastic	Dominantly pelagic carbonate, tiny siliciclastic	Dominantly pelagic carbonate, negligible siliciclastic

* Estimates given are for peak transgression at the base of the *Mammites* Zone. Depths and distances near the base of the *Sciponoceras* Zone would have been much smaller. For example in early *Sciponoceras* times, the Blue Point locality was considered to near-shore or lagoonal and hence extremely close to shore with very shallow depths.

Figured estimates from: ∇ Harries & Kauffman, 1990, ⊗ Erickson & Slingerland, 1990, ∅ Olesen, 1991.

Figure 7.3

trough of the seaway was a forebulge zone of uplifted basement blocks, which trapped much of the siliciclastic material entering the seaway from the west. Subsidence in the main axial trough (the location of the Pueblo and Rebecca K. Bounds core sites) exceeded sedimentation resulting in the deepest environments of the basin. The eastern platform of the basin overlying the tectonically-stable craton, only subsided gently and was separated from the axial trough by a hinge zone (location of the Bunker Hill site). Very little siliciclastic material entered the seaway from the east resulting in pelagic carbonate deposition in that part of the seaway (Kauffman, 1988, Kauffman & Caldwell, 1993).

7.1.2.1 Blue Point and Wahweap Wash sections

These sites were located in different sub-basins near the western margin of the Western Interior seaway. The sites of deposition were in tectonically-active, rapidly subsiding, and rapidly sedimenting foredeep basins, just to the east of the Cordilleran fold and thrust belt. The Blue Point locality was probably closer to shore than the Wahweap Wash locality, at least at the time of deposition of the base of the sections studied. The basin received large amounts of siliciclastic sediment directly from the Mogollan Highlands to the southwest and the Sevier Highlands to the west. Sedimentation was comparatively rapid and fairly fine-grained (mostly silty clays), resulting in high turbidity and low light penetration. The input of terrestrial organic matter was comparatively high compared to further east. Nutrient levels were also probably fairly high with a terrestrial source. The bottom oxygen conditions fluctuated between moderate (dysaerobic) and episodically high (Kauffman, 1985a, Harries & Kauffman, 1990). Water depths at Blue Point are thought to have been less than 100 metres at maximum transgression (Olesen, 1991), based on the lack of keeled planktonic foraminifera which represent deeper waters (Leckie, 1987). This palaeobathymetry is confirmed by Ericksen & Slingerland (1990), who suggest depths of 50 to 100 metres (Figure 7.2). Water depths at Wahweap Wash are thought to have been between 100 and 200 metres at maximum transgression (Harries & Kauffman, 1990) or perhaps as shallow as 50 metres (Ericksen & Slingerland, 1990; Figure 7.2).

7.1.2.2 Pueblo section

This site was located near the deepest part of the seaway along the western-central axis, separated from the western fore-deep basin by tectonic structural highs. The locality received only small amounts of siliciclastic sediment, along with pelagic material from the water column. The source of the siliciclastic material, as for most of the basin, was the Sevier Highlands to the west. Sedimentation was slow and very fine-grained (clays and pelagic carbonate), with lower overall turbidity than further west. The bottom oxygen conditions fluctuated between low (anaerobic) and episodically high. The general paucity of benthic fauna (with the exception of inoceramid bivalves) suggests that the sediment-water interface was inhospitable. The section is transitional between the siliciclastic dominated western sedimentary province and the siliciclastic-starved pelagic carbonate province to the east. At maximum transgression, water depths are thought to have been between 200 and 500 metres (Kauffman, 1985a, Harries & Kauffman, 1990). The palaeobathymetry suggested by Erickson & Slingerland (1990) is around 300 to 400 metres (Figure 7.2).

7.1.2.3 Rebecca K. Bounds core and Bunker Hill section

At the time of deposition of the Bridge Creek Limestone Member, these sites were located towards the eastern side of the seaway, on the tectonically passive, cratonic eastern margin. The basin received only very small amounts of siliciclastic sediment from the Sevier Highlands to the west or from the shoreline to the east (Hattin, 1975). Rates of sedimentation were relatively low and constant. The sediment was predominantly composed of pelagic carbonate material (mostly coccoliths, often as faecal pellets, with some foraminiferal tests) and hence was fine-grained. Turbidity was fairly high, with episodically high turbulence resulting in bottom oxygen conditions fluctuating between moderate (dysaerobic) and episodically high. Nutrient levels were continuously moderate to high, resulting in high organic productivity, particularly at Bunker Hill, with abundant organic rain to the sea floor, hence the input of marine organic matter was continuously high compared to further west (Harries & Kauffman, 1990). With negligible terrestrial input, the source of nutrients must have been marine and hence (at least seasonally) from upwelling. At the Rebecca K. Bounds core site at maximum transgression, water depths are thought to have been moderate at around 200 metres (Erickson & Slingerland, 1990; Figure 7.2). At the Bunker Hill locality at maximum transgression, water depths are thought to have been relatively shallow at 100 metres or less (Figure 7.2), within the photic zone (Kauffman, 1985a, Harries & Kauffman, 1990).

7.2. MARINE PALYNOMORPH RESULTS

The results taken are intended as a comparison along an environmental transect across the Western Interior Basin (Figure 3.2), from the nearshore, shallow-water, reduced salinity environments of the west (Blue Point and Wahweap Wash sections) through the deep-water, more normal salinity environments in the centre of the basin (Pueblo and the Rebecca K. Bounds core) to the shallow-water but normal salinity environment in the east (Bunker Hill).

The preferences towards shallow or deep environments and lowered or normal salinity tolerance are almost certainly partially linked and so are often not easy to tell apart. Almost by definition the deeper-water species were probably only tolerant of more-normal salinities. The difference between shallow-water and lowered-salinity tolerant species is demonstrated by occurrences in the Bunker Hill section, where the environment was shallow-water but the site was far from terrestrial freshwater sources and hence the salinity remained comparatively normal.

7.2.1 'Lowered-salinity' preference

Examples of the abundances of some of the species from the 'time-slice' samples, showing a lowered-salinity preference, are illustrated in Figures 7.4 and 7.5. *Kiokansium williamsii* was entirely restricted to the suggested lowered-salinity environments of Blue Point and Wahweap Wash along the western margin of the basin. *Subtilisphaera zawia* was almost entirely restricted to the lowered salinity western localities with occasional occurrences in the centre of the basin.

DINOFLAGELLATE CYST 'TIME-SLICE' DATA SETS: Figure 7.4
EXAMPLES OF SPECIES WITH A 'LOWERED-SALINITY' PREFERENCE

Those species with suggested preference for comparatively
shallow-water environments with lower salinities.
See text for further details of each species.

Numbers of dinoflagellate cysts found in each 'time-slice' sample - = no equivalent sample
SLICE = 'time-slice' sample horizon BP = Blue Point section
WW = Wahweap Wash section PU = Pueblo section
RB = Rebecca K. Bounds core BH = Bunker Hill section

Coronifera oceanica

SLICE	BP	WW	PU	RB	BH
Q		3	1	-	
P		3		1	
O	1			-	1
N		3	2	-	
M	2	1	3	1	1
L	3			-	
K	3		1	-	
J	6	2	1	-	
I	6	3		-	
H	2	3	2	-	
G	3	6	1	4	
F	2	2	1	-	
E	8	1		-	-
D	3	3	2	-	-
C	4	1	1	-	-
B	4	2	5	-	-
A	2	1	1	-	-

Cribroperidinium cooksoniae

SLICE	BP	WW	PU	RB	BH
Q	1	1		-	
P	1	1		1	
O	1	2		-	
N		1	1	-	
M	2	2			
L	1	1		-	
K	2			-	
J	1			-	
I	1	2		-	
H				-	1
G	2	2	1		
F	3		1	-	
E	3	1		-	-
D	3	3	1	-	-
C	1	1		-	-
B	1	3		-	-
A	1			-	-

Cyclonephelium vannophorum

SLICE	BP	WW	PU	RB	BH
Q	1	1		-	
P	1	1			
O	4	10		-	
N		1		-	
M		2			
L	2			-	
K	8			-	
J	2	4		-	
I	1			-	2
H		3	1	-	
G	1				
F	7	1	1	-	
E	12	1		-	-
D	2		1	-	-
C	4			-	-
B	4	3		-	-
A				-	-

Exochosphaeridium phragmites

SLICE	BP	WW	PU	RB	BH
Q	3	8	5	-	1
P	3	8	6	6	1
O	2	11	7	-	
N	2	34	3	-	
M	40	29	2	1	
L	10	25		-	3
K	8	7	1	-	1
J	26	18	1	-	1
I	7	16	2	-	3
H		31	3	-	2
G	8	37	1		1
F	5	30	3	-	
E	4	11	2	-	-
D		4	3	-	-
C	1	1	2	-	-
B	1	7	1	-	-
A		1	1	-	-

DINOFLAGELLATE CYST 'TIME-SLICE' DATA SETS: Figure 7.5
FURTHER EXAMPLES OF SPECIES WITH A 'LOWERED-SALINITY' PREFERENCE

Those species with suggested preference for comparatively
shallow-water environments with lower salinities.
See text for further details of each species.

Numbers of dinoflagellate cysts found in each 'time-slice' sample - = no equivalent sample
SLICE = 'time-slice' sample horizon BP = Blue Point section
WW = Wahweap Wash section PU = Pueblo section
RB = Rebecca K. Bounds core BH = Bunker Hill section

Florentinia mantellii

SLICE	BP	WW	PU	RB	BH
Q		2	2	-	1
P		2	4	7	
O	1	1	3	-	6
N	1			-	1
M	2		3	6	7
L	1	2	1	-	1
K	3	1	5	-	
J			2	-	1
I			1	-	2
H	5	3	1	-	1
G	5	7	3	1	3
F	13	1	5	-	
E	11	5	5	-	-
D	9	4	6	-	-
C	20	14	2	-	-
B	20	20	5	-	-
A	16	1	4	-	-

Oligosphaeridium pulcherrimum

SLICE	BP	WW	PU	RB	BH
Q	4	2		-	
P	4	2			1
O	1	1		-	1
N	2	1		-	
M					2
L				-	
K	1			-	
J	1			-	
I	1	1		-	
H	1			-	
G	2				
F	2			-	
E	1			-	-
D	1	1	1	-	-
C				-	-
B				-	-
A				-	-

Palaeoperidinium cretaceum

SLICE	BP	WW	PU	RB	BH
Q	6	4		-	
P	6	4			
O	2			-	
N			1	-	
M	3				
L	3			-	
K	2	1		-	1
J	5			-	
I	2	1		-	
H	1			-	
G					1
F				-	
E			1	-	-
D				-	-
C			1	-	-
B		1		-	-
A				-	-

Pareodinia ceratophora

SLICE	BP	WW	PU	RB	BH
Q		2		-	
P		2			
O			1	-	
N	4	1		-	
M	5	2			1
L	1	2		-	
K	3	1	2	-	
J				-	
I	1	2	2	-	
H				-	
G					
F	1	3		-	
E	2	1		-	-
D		2		-	-
C		2		-	-
B				-	-
A				-	-

Based on its occurrences in the Rebecca K. Bounds core, *Nyktericysta* sp. A is thought to be a fresh- to brackish-water species as it is found in abundant numbers in monospecific populations (see Chapter 8). It was also noted in much smaller numbers in the medial shelf sediments of the lowermost Graneros Shale and hence may be used as a near-shore indicator. Two specimens were also noted from one sample in the Wahweap Wash section and may either represent a nearer-shore influence or possibly reworking.

Some species showed a strong preference for the shallow-water, lowered salinity environment in the western parts of the basin, where they occurred much more frequently or in much higher numbers (often abundantly), although they also occurred further east in much smaller numbers. These species include *Cribroperidinium cooksoniae* (Figure 7.4), *Cyclonephelium brevispinatum*, *Cyclonephelium vannophorum* (Figure 7.4), *Exochosphaeridium phragmites* (Figure 7.4) and *Florentinia resex* (though conversely, the abundance of this species also seemed to increase with increased water-depth).

Other less abundant species also occurred more frequently or in higher numbers in the western parts of the basin, in the shallow-water, lowered salinity environment, although they also occurred further east in slightly smaller numbers. These included *Atopodinium haromense*, *Coronifera oceanica* (Figure 7.4), *Cyclonephelium chabaca*, *Hystrichosphaeridium bowerbankii* (though this species may also have been affected by lowering oxygen levels as it showed progressive disappearance in the Late Cenomanian first in the centre of the basin and later further west), *Oligosphaeridium pulcherrimum* (Figure 7.5), *Palaeoperidinium cretaceum* (though its greatest abundances were towards the top of the western sections at the time of maximum transgression and hence the species was also responding to other factors; Figure 7.5) and *Pareodinia ceratophora* (Figure 7.5).

Some species are common in all of the sections but were frequent or abundant, particularly near the base of the western sections, deposited in a lowered-salinity, medial shelf environment. These species include *Canninginopsis colliveri* and *Florentinia mantellii* (Figure 7.5).

Some species had a wide distribution and seemed to show little environmental preference except slightly towards more frequent occurrences or slightly greater abundances in the western sections, with further occurrences in the centre of the basin and the smallest occurrences at Bunker Hill. These species included *Florentinia clavigera*, *Florentinia cooksoniae*, *Florentinia deaniae*, *Florentina laciniata*, *Hystrichosphaeridium recurvatum* (though this species had lower numbers through the Blue Point section), *Oligosphaeridium complex* and *Oligosphaeridium dividuum*. This may partly be a function of smaller diversities in the western parts of the basin resulting in comparatively small increases in abundance.

Odontochitina costata is common throughout all the sections but generally shows much higher abundances in the western sections (Figure 7.10). However, a few exceptions to this do occur with higher abundances at Pueblo or even at Bunker Hill, probably as a result of other changing environmental factors. However, the less common *Odontochitina operculata* shows a much less clear environmental picture and may even occur more frequently in the centre of the basin at Pueblo (Figure 7.10). This may represent a function of environmental preference or morphological adaptation between *Odontochitina* species (as a gradation exists between *O. costata* and *O. operculata*).

Species of *Xenascus* display a fairly strong environmental preference for the lowered-salinity, shallow-water western sections with far more frequent occurrences and more abundant numbers than further east. However they do show a distribution which suggests that they were more influenced by southern waters as they generally appear at times of known transgression. *Xenascus australensis* is the most widely distributed of the *Xenascus* species with occurrences in all of the boundary sections. However it occurs most commonly in the western sections at times of transgression. Outside of the western sections, *X. perforatus* only has a single noted occurrence at Pueblo at peak transgression. *Xenascus plotei* is only noted from the shallow-water sections but occurrences at Bunker Hill are limited. This suggests that the patterns are not clearly linked to either reduced-salinity or shallow-water.

7.2.2 'Shallow-water' preference

Examples of the abundances of some of the species from the 'time-slice' samples, showing a shallow-water preference, are illustrated in Figure 7.6. *Canningia reticulata* was almost entirely restricted to the shallow-water environments of Blue Point and Wahweap Wash along the western margin of the basin and Bunker Hill near the eastern margin of the basin, though it was more abundant in the western sections (Figure 7.6). *Dinopterygium cladoides* was present through all the sections but occurred in greater abundance in the shallow-water sections (Figure 7.6). *Canningia* sp. A occurred predominantly in shallow sections though with less obvious or explainable patterns. It was largely restricted to the Blue Point section, though it also had occurrences much higher-up in the Rebecca K. Bounds core and very rare occurrences at Pueblo.

The commonly appearing species *Spiniferites ramosus ramosus*, *S. ramosus gracilis* and *S. twistringiensis* are common to abundant through all of the sections studied and individually do not show particularly strong preferences, which may result from multi-specific origins for individual cyst species as suggested by Edwards & Andrle (1992). Close examination of the relative proportions of these different species, however, suggest that they do have some environmental preferences. *Spiniferites twistringiensis* has a variable abundance but seems to show some preference towards greater abundance in the shallower-water sections (Figure 7.6). Similarly *S. ramosus ramosus* also has a variable abundance through all of the sections and is also slightly more abundant in the shallower-water sections than at Pueblo, with greatest abundances towards the base of the western sections deposited in a medial shelf environment. *Spiniferites ramosus gracilis* also has a very variable abundance and also shows highest abundances towards the base of the sections studied. However, it is more abundant in the deeper sections, particularly at Pueblo. It is likely that these species of *Spiniferites* have a wide environmental tolerance across the shelf environments (as suggested by previous work e.g. Davey & Rogers, 1975, Versteegh, 1994), but may occur in slightly large numbers in a nearer-shore environment. However, the difference in morphology may be responsible for varying degrees of hydrodynamic sorting resulting in greater basinward transport of the subspecies (*S. ramosus gracilis*) with longer and more numerous processes, supporting previous suggestions (e.g. Davey & Rogers, 1975).

Spiniferites lenzii (with generally shorter processes than *S. ramosus ramosus* or *S. ramosus gracilis*) shows a complex response to a number of environmental factors, not all related to salinity or water-depth. The preference for shallow-water environments is quite strong (i.e. smallest numbers at

DINOFLAGELLATE CYST 'TIME-SLICE' DATA SETS: Figure 7.6
EXAMPLES OF SPECIES WITH A 'SHALLOW-WATER' PREFERENCE

Those species with suggested preference for comparatively shallow-water environments
but with no preference shown for lower or 'normal-marine' salinities.
See text for further details of each species.

Numbers of dinoflagellate cysts found in each 'time-slice' sample - = no equivalent sample
SLICE = 'time-slice' sample horizon BP = Blue Point section
WW = Wahweap Wash section PU = Pueblo section
RB = Rebecca K. Bounds core BH = Bunker Hill section

Canningia reticulata

SLICE	BP	WW	PU	RB	BH
Q	1	1		-	
P	1	1		1	
O	5	2		-	
N	1			-	
M					
L				-	
K	1			-	
J	1			-	
I				-	
H				-	
G	1				1
F	1	5		-	2
E	1			-	-
D	1			-	-
C				-	-
B				-	-
A				-	-

Dinopterygium cladoides

SLICE	BP	WW	PU	RB	BH
Q	2	1		-	
P	2	1	1		2
O	2	1	1	-	1
N	5	3	1	-	7
M	3	1		3	2
L	4	4		-	
K	2	1	2	-	3
J	6	1	4	-	5
I	6		2	-	2
H	3		1	-	4
G	5	2	1	1	5
F	2	1	2	-	1
E	9	1	3	-	-
D	4	10	2	-	-
C	1		1	-	-
B	1	2		-	-
A	2			-	-

Spiniferites lenzii

SLICE	BP	WW	PU	RB	BH
Q	9	5	2	-	2
P	9	5	3		
O	36	8		-	7
N	7	6		-	1
M	1	1	1	1	6
L	31	30	1	-	1
K	2	1	1	-	1
J	6	1		-	5
I	6	11	1	-	1
H			1	-	1
G	1		4	2	
F		5		-	3
E		2	1	-	-
D		6		-	-
C		1	1	-	-
B			3	-	-
A				-	-

Spiniferites twistringiensis

SLICE	BP	WW	PU	RB	BH
Q	3	9	6	-	7
P	3	9	4	4	15
O	6	3	2	-	19
N	6	7	14	-	16
M	7	5	4	8	20
L	11	2	4	-	11
K	8	2	3	-	17
J	21	3	3	-	14
I	15	8	6	-	6
H	6	2	16	-	14
G	15	4	8	4	10
F	5	5	3	-	6
E	5	2	4	-	-
D	10	4	12	-	-
C	17	1	10	-	-
B	17	5	1	-	-
A	17	3	12	-	-

Pueblo) but the species also has its greatest abundances in the western sections suggesting some preference for lowered salinities (Figure 7.6). However, this species reaches its maximum abundance with continued transgression towards the top of the western sections though it is not present at all at the base of the western sections. This in turn suggests a preference for deeper water and more-normal salinities. It is probable that the abundance peaks for this species are responding to other environmental factors in preference to its onshore-offshore distribution.

7.2.3 'Normal-salinity' preference

Examples of the abundances of some of the species from the 'time-slice' samples, showing a normal-salinity preference, are illustrated in Figure 7.7. Some species were entirely restricted to the suggested normal-salinity environments of Pueblo, the Rebecca K. Bounds core and Bunker Hill in the centre and towards the eastern margin of the basin. These were *Adnatosphaeridium tutulosum* (Figure 7.7), *Chatangiella spectabilis*, *Downiesphaeridium* sp. A (with an occurrence that may also be linked to large quantities of amorphous organic matter) and *Leberidocysta defloccata*. *Apteodinium deflandrei* was only found towards the top of the Bunker Hill locality suggesting a potential preference for shallow-water, normal-salinity environments.

Some species showed a strong preference for normal-salinity environments, mainly occurring in the Pueblo, Rebecca K. Bounds core and Bunker Hill sections although they also occurred in the western sections in much smaller abundances at times of known greater oceanic influence (for example around the equivalent of PBC6 ('time-slice' D) and PBC23 to PBC26 (P and Q)). These species include *Impagidinium modicum* (Figure 7.7), *Isabelidinium magnum*, *Pterodinium cingulatum* (Figure 7.7), *Pterodinium? cornutum*, *Subtilisphaera pirnaensis* (Figure 7.7) and *Subtilisphaera pontis-marie*.

Other species also showed a preference (though not as strong) for normal-salinity environments as they also occurred more frequently or in greater numbers in the normal-salinity localities, and occurred in the western sections in smaller numbers. These species include *Eurydinium ingramii*, *Oligosphaeridium totum* and *Subtilisphaera? inaffecta* (see below).

Florentinia radiculata had a wide distribution and seems to show little environmental preference except slightly towards more frequent occurrences or slightly greater abundances in the easternmost section, with further occurrences in the centre of the basin and only slightly smaller occurrences in the western sections.

7.2.4 'Deep-water' preference

Examples of the abundances of some of the species from the 'time-slice' samples, showing a deep-water preference, are illustrated in Figures 7.8 and 7.9. Some species were entirely (or almost entirely) restricted to the deeper-water localities of Pueblo and the Rebecca K. Bounds core. These include several rare species such as *Chichaouadinium vestitum*, *Ellipsodinium rugulosum*, *Epelidosphaeridia spinosa*, *Histiocysta palla*, *Kallosphaeridium? helbyi*, *Microdinium reticulatum* and *Occisucysta hinzii* (though this species may be reworked).

DINOFLAGELLATE CYST 'TIME-SLICE' DATA SETS: Figure 7.7

EXAMPLES OF SPECIES WITH A 'NORMAL-SALINITY' PREFERENCE

Those species with no suggested preference for comparatively shallow- or deep-water environments but with preference for 'normal-marine' salinities. See text for further details of each species.

Numbers of dinoflagellate cysts found in each 'time-slice' sample - = no equivalent sample
SLICE = 'time-slice' sample horizon BP = Blue Point section
WW = Wahweap Wash section PU = Pueblo section
RB = Rebecca K. Bounds core BH = Bunker Hill section

Adnatosphaeridium tutulosum

SLICE	BP	WW	PU	RB	BH
Q				-	
P					
O				-	
N				-	
M					
L				-	
K				-	
J				-	
I				-	
H				-	
G			1	9	1
F			1	-	
E				-	-
D			1	-	-
C				-	-
B			3	-	-
A			5	-	-

Impagidinium modicum

SLICE	BP	WW	PU	RB	BH
Q	2		1	-	1
P	2				
O				-	2
N		1		-	3
M				1	1
L				-	
K				-	1
J				-	
I				-	
H				-	1
G				5	
F				-	
E			1	-	-
D			1	-	-
C				-	-
B			3	-	-
A			1	-	-

Pterodinium cingulatum

SLICE	BP	WW	PU	RB	BH
Q			1	-	2
P			1		1
O				-	9
N		1		-	2
M		1		2	1
L				-	
K			1	-	
J			1	-	
I			1	-	
H			1	-	6
G			1	17	2
F			2	-	
E			1	-	-
D	2	1	6	-	-
C		1	5	-	-
B			3	-	-
A			4	-	-

Subtilisphaera pirnaensis

SLICE	BP	WW	PU	RB	BH
Q		1	5	-	6
P		1	2		3
O	1	1	3	-	
N		1		-	2
M		1		4	1
L	1			-	3
K				-	
J			1	-	
I			1	-	1
H				-	
G			3	3	
F			12	-	4
E			6	-	-
D		1	8	-	-
C			2	-	-
B			1	-	-
A				-	-

DINOFLAGELLATE CYST 'TIME-SLICE' DATA SETS: EXAMPLES OF SPECIES WITH A 'DEEP-WATER' PREFERENCE

Figure 7.8

Those species with suggested preference for comparatively deep-water environments with 'normal-marine' salinities.
See text for further details of each species.

Numbers of dinoflagellate cysts found in each 'time-slice' sample - = no equivalent sample
SLICE = 'time-slice' sample horizon BP = Blue Point section
WW = Wahweap Wash section PU = Pueblo section
RB = Rebecca K. Bounds core BH = Bunker Hill section

Achomosphaera ramulifera

SLICE	BP	WW	PU	RB	BH
Q	2	6	7	-	1
P	2	6	19		2
O		1	4	-	1
N		14	22	-	3
M		5	19	1	5
L		5	8	-	2
K		6	11	-	1
J		4	3	-	1
I		9	3	-	3
H		8	12	-	4
G		12	18	4	3
F	1	7	8	-	5
E	1	6	8	-	-
D		25	8	-	-
C		30	3	-	-
B		22	13	-	-
A		1	18	-	-

Chlamydophorella nyei/ Dapsilidinium ambiguum complex

SLICE	BP	WW	PU	RB	BH
Q			1	-	
P				2	
O				-	1
N				-	
M			1	5	
L				-	
K		1		-	
J			1	-	
I			4	-	5
H			3	-	
G			2	12	
F			9	-	
E			5	-	-
D			6	-	-
C		1	3	-	-
B		2	3	-	-
A			2	-	-

Circulodinium distinctum

SLICE	BP	WW	PU	RB	BH
Q		5	19	-	2
P		5	10		1
O	2	12		-	
N	1	1	2	-	1
M	3	1	13	1	1
L		5	13	-	1
K	2	3	17	-	
J	1	3	5	-	1
I			13	-	
H		2	6	-	
G		5	3	6	
F		3	1	-	
E		4	8	-	-
D		1	6	-	-
C		1		-	-
B		16	1	-	-
A				-	-

Dapsilidinium laminaspinosum

SLICE	BP	WW	PU	RB	BH
Q		1		-	
P		1			
O				-	
N		1		-	
M				1	
L				-	
K				-	
J			1	-	
I	1			-	1
H				-	1
G			1	2	
F			1	-	
E			1	-	-
D	1	1	1	-	-
C	1	1	1	-	-
B	1		2	-	-
A				-	-

DINOFLAGELLATE CYST 'TIME-SLICE' DATA SETS: Figure 7.9
FURTHER EXAMPLES OF SPECIES WITH A 'DEEP-WATER' PREFERENCE

Those species with suggested preference for comparatively deep-water environments
with 'normal-marine' salinities.
See text for further details of each species.

Numbers of dinoflagellate cysts found in each 'time-slice' sample - = no equivalent sample
SLICE = 'time-slice' sample horizon BP = Blue Point section
WW = Wahweap Wash section PU = Pueblo section
RB = Rebecca K. Bounds core BH = Bunker Hill section

Dinogymnium vozzhennikovae

SLICE	BP	WW	PU	RB	BH
Q				-	1
P				7	3
O			2	-	
N				-	
M			1	4	
L			1	-	
K				-	
J				-	
I				-	
H				-	
G				1	
F				-	
E				-	-
D			2	-	-
C				-	-
B				-	-
A				-	-

Heterosphaeridium? heteracanthum

SLICE	BP	WW	PU	RB	BH
Q			1	-	
P			2	3	
O		1	2	-	1
N			1	-	
M	3		2	1	
L				-	
K			2	-	
J			1	-	1
I			4	-	
H				-	1
G		1		1	3
F		1		-	
E		1	3	-	-
D			3	-	-
C		1	1	-	-
B		2	1	-	-
A	2			-	-

Hystrichodinium pulchrum

SLICE	BP	WW	PU	RB	BH
Q		9	39	-	
P		9	42		1
O		1	1	-	1
N		1		-	3
M	4		1		1
L	1			-	2
K			5	-	
J			3	-	1
I		1	1	-	
H		1	1	-	11
G			1		1
F		6		-	2
E		1		-	-
D		2	1	-	-
C		9		-	-
B		5	1	-	-
A	2		3	-	-

Surculosphaeridium? longifurcatum

SLICE	BP	WW	PU	RB	BH
Q			1	-	
P					
O			1	-	
N	1			-	
M		1	4		
L			1	-	
K	1	1		-	
J				-	
I				-	
H				-	
G			1	1	
F	1		2	-	
E	1		2	-	-
D	1		1	-	-
C		2		-	-
B				-	-
A				-	-

Dinogymnium vozzhennikovae was also generally restricted to Pueblo and the Rebecca K. Bounds core, though it also occurred in the Bunker Hill section at peak transgression. It did not occur at all in the western sections indicating normal-salinity preferences (Figure 7.9).

Some species were more commonly found in the deeper localities but did appear in the shallower localities at times of known greater oceanic influence, for example around the equivalent of PBC6, and PBC23 to PBC26. These include commonly occurring species, present in the shallower sections but with the highest numbers in the deepest sections, such as *Achomosphaera ramulifera* (though often also with quite high numbers at Wahweap Wash; Figure 7.8), *Achomosphaera* sp. A, the *Chlamydophorella nyei*/*Dapsilidinium ambiguum* complex (Figure 7.8), *Circulodinium distinctum* (though this species also occasionally had high numbers in the shallower, western sections suggesting that its occurrence may also be influenced by other factors; Figure 7.8), and *Hystrichodinium pulchrum* (Figure 7.9).

Also included in this category are some of the less-common species such as *Acanthaulax wilsonii*, *Chlamydophorella discreta*, *Dapsilidinium laminaspinosum* (Figure 7.8), *Heterosphaeridium? heteracanthum* (Figure 7.9), *Rhiptocorys veligera*, *Spiniferites tripus*, *Subtilisphaera foliacea*, *Tehamadinium coummia* and *Trithyrodinium dubium*.

Other species were less certain though also potential candidates and included *Achomosphaera crassipellis*, *Apteodinium reticulatum*, *Canningia* sp. B, *Cyclonephelium membraniphorum*, *Dapsilidinium? pumilum*, *Heterosphaeridium multifurcatum*, *Hystrichostrogylon membraniphorum*, *Litosphaeridium siphoniphorum*, *Microdinium ornatum*, *Microdinium setosum*, *Spiniferites wetzelii*, *Surculosphaeridium? longifurcatum* (Figure 7.9), *Systematophora* sp. A and *Valensiella tazadensis*.

7.2.5 Reworking

Some species such as *Achomosphaera neptunii* are almost certainly reworked. Other possible reworked species may include *Ginginodinium evittii*, *Nyktericysta* sp. A and *Occisucysta hinzii*.

7.2.6 No preference

Many of the species of dinoflagellate cyst showed no environmental preferences that were detectable from this transect study. Examples of the abundances of some of the species from the 'time-slice' samples, showing no preference, are illustrated in Figure 7.11. Common species displaying no detectable preference include *Alterbidinium rhombovale*, *Batiacasphaera granulosa*, *Batiacasphaera* sp. A, *Cometodinium? whitei*, *Downiesphaeridium armatum*, *Downiesphaeridium multispinosum* (Figure 7.11), *Exochosphaeridium arnace*, *Florentinia ferox*, *Fromea amphora*, *Fromea fragilis*, *Impletosphaeridium clavulum*, *Membranilarnacia polycladiata*, *Operculodinium* sp. A, *Pervosphaeridium pseudhystrichodinium*, *Pervosphaeridium truncatum* (Figure 7.11), *Prolixosphaeridium conulum*, *Pseudoceratium eisenackii*, *Tanyosphaeridium salpinx*, *Tanyosphaeridium variecalamus*, *Trichodinium castanea*, *Trithyrodinium* sp. cf. *T. evittii*, *Trithyrodinium suspectum*, *Valensiella reticulata* and *Xiphophoridium alatum*.

DINOFLAGELLATE CYST 'TIME-SLICE' DATA SETS: Figure 7.10
EXAMPLE OF POTENTIAL MORPHOLOGICAL ADAPTATION TO ENVIRONMENT

Potential adaptation shown for *Odontochitina* species with
Odontochitina costata showing preference for 'shallow-water' environments and
Odontochitina operculata showing preference for 'deep-water' environments.

Odontochitina costata

SLICE	BP	WW	PU	RB	BH
Q	4	6		-	1
P	4	6			1
O	5	8	2	-	2
N	11	3	2	-	3
M	16	5	2	3	4
L	17	32	15	-	6
K	12	8	2	-	4
J	5	35	1	-	2
I	2	3		-	6
H		21	1	-	1
G	9		2	3	2
F	7	1	3	-	1
E	45	4	5	-	-
D	19	42	8	-	-
C	8	8	2	-	-
B	8	4	8	-	-
A	5		5	-	-

Odontochitina operculata

SLICE	BP	WW	PU	RB	BH
Q	1	1	2	-	1
P	1	1	2		1
O	1	3	3	-	1
N		1	3	-	
M	3	2	6	1	3
L		27	21	-	1
K	2		3	-	1
J			1	-	3
I			2	-	1
H		3	1	-	
G	1		1	5	1
F		1	8	-	
E		3	2	-	-
D	1	3	3	-	-
C	1	7		-	-
B	1	3	9	-	-
A	4		5	-	-

EXAMPLES OF SPECIES SHOWING OTHER ENVIRONMENTAL PREFERENCES

Preferences not shown for particular water depths or salinities.

Cyclonephelium compactum

SLICE	BP	WW	PU	RB	BH
Q			3	-	
P				5	
O				-	1
N				-	
M	5	7	5	6	5
L	1	10	6	-	
K	11	5	4	-	
J	1	1	20	-	12
I		2	6	-	7
H	13		2	-	1
G	55		7	10	4
F	70	24	15	-	
E	7	117	27	-	-
D	1	2	2	-	-
C		2	2	-	-
B		11		-	-
A			6	-	-

Palaeohystrichophora infusorioides

SLICE	BP	WW	PU	RB	BH
Q	39	56	23	-	32
P	39	56	11	20	38
O	63	68	33	-	28
N	84	47	35	-	18
M	40	76	29	45	44
L	36	12	23	-	52
K	42	76	83	-	46
J	55	49	82	-	49
I	61	65	43	-	45
H	4	10	29	-	29
G	8	6	66	11	31
F	4	20	10	-	3
E	2	2	11	-	-
D	13	4	3	-	-
C		21	13	-	-
B		13	11	-	-
A	40	123	22	-	-

See text for further details of each species.
Numbers of dinoflagellate cysts found in each 'time-slice' sample - = no equivalent sample
SLICE = 'time-slice' sample horizon BP = Blue Point section
WW = Wahweap Wash section PU = Pueblo section
RB = Rebecca K. Bounds core BH = Bunker Hill section

DINOFLAGELLATE CYST 'TIME-SLICE' DATA SETS: Figure 7.11

EXAMPLES OF SPECIES WITH NO VISIBLE ENVIRONMENTAL PREFERENCE

Those species with little or no shown preference for environments
along the basin transect.
See text for further details of each species.

Numbers of dinoflagellate cysts found in each 'time-slice' sample - = no equivalent sample
SLICE = 'time-slice' sample horizon BP = Blue Point section
WW = Wahweap Wash section PU = Pueblo section
RB = Rebecca K. Bounds core BH = Bunker Hill section

Downiesphaeridium multispinosum

SLICE	BP	WW	PU	RB	BH
Q	7	3	2	-	1
P	7	3	3	5	4
O	4	1	1	-	3
N		1	1	-	3
M	4	1	2	4	1
L	1	1		-	1
K	2		1	-	6
J	6	1	2	-	7
I	5	4	4	-	
H	2		3	-	7
G	7		1	7	3
F	4	2	4	-	1
E	5		5	-	-
D	5	1	5	-	-
C	6	11	6	-	-
B	6	10	12	-	-
A	4	1	6	-	-

Pervosphaeridium truncatum

SLICE	BP	WW	PU	RB	BH
Q			1	-	2
P			2		
O			1	-	4
N	1	2	2	-	2
M	1	2	2		1
L	2		1	-	1
K	2		4	-	
J				-	
I				-	
H	1	6	2	-	5
G	1	5	2	6	1
F	2	1	1	-	2
E	1	1		-	-
D	4	1	1	-	-
C	1	2	1	-	-
B	1	3	1	-	-
A	2	1	1	-	-

Tenua hystrix

SLICE	BP	WW	PU	RB	BH
Q	3	5	12	-	1
P	3	5	6	18	3
O	1	1	13	-	1
N	2	7	4	-	
M	9	9	20	8	1
L	7	15	39	-	1
K	12	6	5	-	2
J	8	24	10	-	1
I	1	3	22	-	4
H	1	4	5	-	1
G	10	9	4	3	2
F	18	11	7	-	
E	28	6	9	-	-
D	15	11	3	-	-
C	26	2	6	-	-
B	26	5	3	-	-
A	8		2	-	-

**VARIATION IN
DINOFLAGELLATE CYST DIVERSITY →
WITH ENVIRONMENT**

Dinoflagellate cyst species diversity

SLICE	BP	WW	PU	RB	BH
Q	35	45	45	-	33
P	35	45	41	46	32
O	37	43	31	-	43
N	34	48	48	-	40
M	42	44	39	64	39
L	34	30	35	-	34
K	50	29	44	-	32
J	43	28	52	-	38
I	36	43	46	-	30
H	22	31	51	-	40
G	39	32	61	62	38
F	41	43	65	-	22
E	49	38	68	-	-
D	58	49	67	-	-
C	38	60	45	-	-
B	38	48	56	-	-
A	38	16	64	-	-

Tenua hystrix is a species that is common to abundant through all of the sections in variable numbers and displays patterns which relate to the environmental transects but which must also be controlled by other, more important factors (Figure 7.11). Towards the base of the sections it displays higher abundances in the western sections suggesting a tolerance to lowered salinities and a preference towards shallow-water environments. However, through the upper half of the sections the species switches to greater abundances in the Pueblo section with increases in abundance in the Bunker Hill section, suggesting a preference for more-normal salinities and perhaps deeper-water environments. It is another example of a species with important environmental implications that cannot be simply linked to shoreline proximity, water depth or salinity. Other examples of species showing other environmental preferences are illustrated in Figure 7.10.

Palaeohystrichophora infusorioides (Figure 7.10) and *Subtilisphaera cheit* are common to dominant in most of the samples reaching abundance peaks in different places at different times. These species do not regularly follow preferences for any of the environmental factors under study in the transect, but clearly respond to other influences. These may be fluctuations in productivity. *Subtilisphaera? inaffecta* also is common to dominant in most of the samples, but in this case does show higher numbers in the Pueblo and particularly in the Bunker Hill sections and hence may have had some preference for normal-salinity and perhaps shallow-water conditions.

Cyclonephelium compactum is also a species that demonstrates no transect-environmental preferences for water-depth or salinity (Figure 7.10). However, in the sections at intervals (which are correlatable across the basin) it rises to very large numbers of individuals, responding to other environmental factors. However, the acme events occur in the same samples as increased proportions of 'lowered-salinity' and sometimes 'shallow-water' indicator species at Blue Point, Wahweap Wash and Pueblo and at the same time as increased proportions of 'shallow-water' indicator species at Bunker Hill. The greatest peaks occur at the top of the *Sciponoceras* Zone in the western sections. Further peaks also occur around PBC10 and PBC14 at Pueblo and Bunker Hill. Similarly *Cyclonephelium uncinatum* also seems to show little transect-environmental preference and also produces correlatable peaks in abundance across the basin, again in response to other environmental factors, often in the same samples as *Cyclonephelium compactum* and also marking the Cenomanian - Turonian boundary.

Other species that do have environmental preferences (discussed above) also show correlatable acme events particularly in the western sections. *Spiniferites lenzii* has smaller acme peaks at times through the *Neocardioceras* Zone and then much larger ones near the top of the *Watinoceras* Zone. *Exochosphaeridium phragmites*, *Cyclonephelium brevispinatum* and *Hystrichodinium pulchrum* also show large correlatable acme events.

7.2.7 Dinoflagellate cyst species diversity

In eleven out of seventeen cases, the highest species diversities were found at Pueblo in the deepest part of the basin (Figure 7.11). However, in some of the other cases the highest diversity was found in the western sections, particularly in the upper part of the section studied. This may partly be due to the wider stratigraphic coverage of the samples from the top of the Blue Point and Wahweap Wash sections. It may also be a product of the levels of amorphous organic matter in the Pueblo and

Bunker Hill sections which prevented scanning for additional species. Bunker Hill often had among the lowest diversity counts, probably for this reason. The Rebecca K. Bounds core, located at one of the deeper sites, always had the highest diversities, probably due to greater species counts from this section.

7.2.8 Prasinophytes

The prasinophytes generally showed no environmental preference along the transect, though numbers varied between sections, responding to other variables such as stratification. Leiospheres were ubiquitous and occurred in variable though often large numbers through all of the sections. Species of *Pterospermella*, *Pterosphaeridia* and *Tasmanites* also occurred through all of the sections though in much smaller numbers. *Crassosphaera papillata* was not found in the western, lowered-salinity sections, though this may be due to generally low numbers.

7.2.9 Acritarchs and chlorophytes

Acritarchs were generally rare through the sections, but many were still subject to some environmental restrictions.

Many species almost always occurred in the shallow-water, reduced-salinity western sections. These included Acritarch sp. A, *Eyrea nebulosa*, *Leiofusa jurassica*, and *Micrhystridium minutispinum*. *Baltisphaeridium crameri* was generally restricted to shallow water environments (Blue Point, Wahweap Wash and Bunker Hill sections).

Some species were generally only found in the higher salinity environments of Pueblo, the Rebecca K. Bounds core and Bunker Hill. These included *Micrhystridium stellatum* and *Scuticabolus lapidaris*. Other species were generally restricted to the deeper-water environments of the Rebecca K. Bounds core and particularly Pueblo. These included Acritarch sp. B, *Tetraporina* sp. A and *Wuroia* sp. A.

Species of *Veryhachium* generally showed little environmental preference and occurred sporadically through the various sections. The only exception to this was *V. formosum* which occurred in much greater numbers in the western sections.

7.2.10 Foraminiferal test linings

The foraminiferal test linings seemed to show no clear relationship with either water-depth or salinity, and may have responded to other environmental parameters such as benthic oxygen levels. The test linings generally (though not always) occurred in smaller numbers in the Blue Point section which may be partly to do with salinity. However, the Wahweap Wash section frequently held the largest numbers of linings, particularly through the *Neocardioceras* Zone. The highest numbers at Pueblo were found through the *Watinoceras* Zone.

7.2.11 Statistical analysis and justification for the associations of indicator species

7.2.11.1 Method

The data was analysed by multivariate statistical analysis using M.V.S.P. (version 2.1j). The data from the time-slice horizon samples from the boundary sections (Blue Point, Wahweap Wash, Pueblo and Bunker Hill) was combined to give the largest possible data set and hence provide the best opportunity to identify potential correlation.

Two types of agglomerative hierarchical cluster analysis were carried out on the taxa to try to confirm the environmental species associations. The first calculated a similarity matrix for the normal abundances of the species based on squared euclidean distances. The data was then clustered using the minimum variance method. The resultant dendrogram is illustrated in Figure 7.12b. The second calculated a similarity matrix using Spearman's Rank Order correlation coefficients to emphasise the rarer taxa, as many of those which are thought to have shown an environmental preference occur in small numbers. The cluster analysis then used the unweighted average linkage (UPGMA) method. The resultant dendrogram is illustrated in Figure 7.12c.

7.2.11.2 Results of cluster analyses

Normal abundance data analysis: Cluster analysis with the minimum variance method on the squared euclidean distances clearly separates those species with higher abundances from those with lower abundances (Figure 7.12b). *Palaeohystrichophora infusorioides* and *Subtilisphaera inaffecta* are grouped away from the other species as they have the highest abundances. Other common, clearly segregated species include *Subtilisphaera cheit*, *Spiniferites ramosus* subspecies and the foraminiferal test linings. All of the species with lower abundances are suggested to be very similar, although some degree of clustering of species from the same association is shown.

Effectively, most significance is attached to larger differences in species abundance while little significance is attached to presence. As the assemblages in many samples are frequently dominated by large numbers of relatively few species, this method would only offer limited support for the associations of indicator species.

Rare occurrence data analysis: The cluster analysis to emphasise the rarer taxa shows extremely good support for the associations of indicator species (Figure 7.12c). Furthermore, other possible indicator species suggested from the time-slice comparisons are also suggested in the cluster analysis.

All of the 'deep-water' indicator species are clearly separated in the upper half of the dendrogram along with almost all of the 'normal-salinity' indicator species. Within this, several of the clusters show particularly strong affiliations of indicator species. The 'normal-salinity' indicators *Adatosphaeridium tutulosum*, *Pterodinium cingulatum*, *?P. cornutum* and *Isabelidinium magnum* seem to group closely with some of the 'deep-water' species (e.g. *Chlamydophorella discreta*, *C. nyei*/*Dapsilidinium ambiguum*, *Dapsilidinium laminaspinosum*, *Ellipsodinium rugulosum*, *Rhiptocorys veligera*, *Tehamadinium coummia* and *Trithyrodinium dubium*). This suggests that these

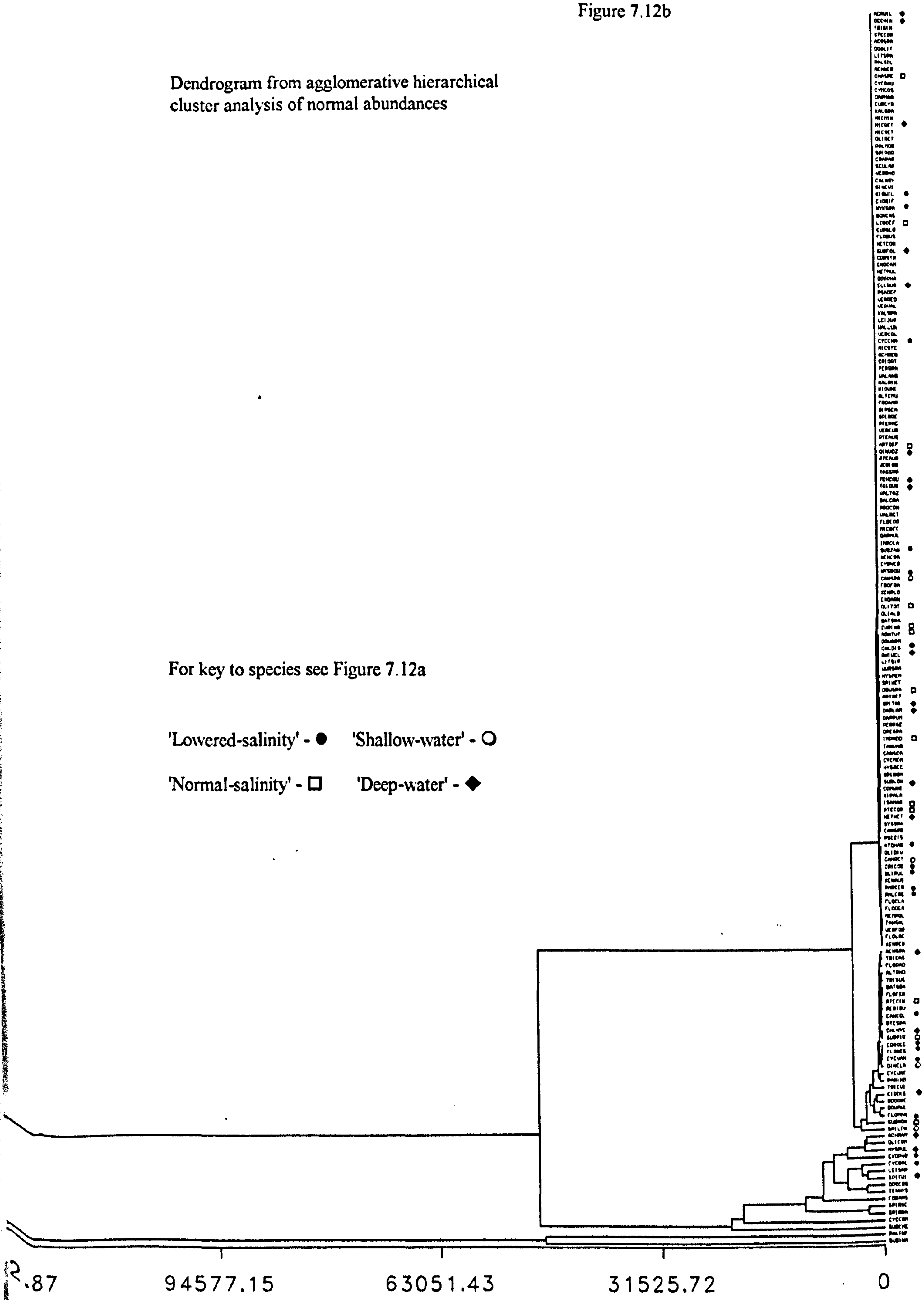
Figure 7.12a

Key to species used in the cluster dendrograms from multivariate statistical analysis of the 'time-slice' comparisons

ACAWIL	- Acanthaulax wilsonii	KIOWIL	- Kiokansium williamsii
ACHCRA	- Achomosphaera crassipellis	LEBDEF	- Leberidocysta defloccata
ACHNEP	- Achomosphaera neptunii	LEIJUR	- Leiofusa jurassica
ACHRAM	- Achomosphaera ramulifera	LEISPP	- Leiosphaeridia spp.
ACHREG	- Achomosphaera regiensis	LITSIP	- Litosphaeridium siphoniphorum
ACHSPA	- Achomosphaera sp. A	LITSPA	- Litosphaeridium sp. A
ACRSPA	- acritarch sp. A	MEMPOL	- Membranilarnacia polycladiata
ADNTUT	- Adnatosphaeridium tutulosum	MICMIN	- Micrhystridium minutispinum
ALTEMU	- Alterbidinium emulatum	MICREC	- Micrhystridium recurvatum
ALTRHO	- Alterbidinium rhombovale	MICSTE	- Micrhystridium stellatum
APTDEF	- Apteodinium deflandrei	MICRET	- Microdinium reticulatum
APTRET	- Apteodinium reticulatum	MICSET	- Microdinium setosum
ATOHAR	- Atopodinium haromense	NYKSPA	- Nyktericysta sp. A
BALCRA	- Baltisphaeridium crameri	OCCHIN	- Occisucysta hinzii
BATGRA	- Batiacasphaera granulosa	ODOCOS	- Odontochitina costata
BATSPA	- Batiacasphaera sp. A	ODOOPE	- Odontochitina operculata
CALASY	- Callaiosphaeridium asymmetricum	ODORHA	- Odontochitina rhakodes
CANRET	- Canningia reticulata	OLIALB	- Oligosphaeridium albertense
CANSCA	- Canningia scabrosa	OLICOM	- Oligosphaeridium complex
CANSPA	- Canningia sp. A	OLIDIV	- Oligosphaeridium dividuum
CANSPB	- Canningia sp. B	OLIPUL	- Oligosphaeridium pulcherrimum
CANCOL	- Canninginopsis colliveri	OLIRET	- Oligosphaeridium reticulatum
CHASPE	- Chatangiella spectabilis	OLITOT	- Oligosphaeridium totum
CHLDIS	- Chlamydophorella discreta	OPESPA	- Operculodinium sp. A
CHLNYE	- Chlamydophorella nyei/Dapsilidinium ambiguum	PALINF	- Palaeohystrichophora infusorioides
CIRDIS	- Circulodinium distinctum	PALCRE	- Palaeoperidinium cretaceum
COMWHI	- Cometodinium whitei	PALSIL	- Palaeotetradinium silicorum
COROCE	- Coronifera oceanica	PALMOR	- Palambages morulosa
CORSTR	- Coronifera striolata	PARIND	- Paralecaniella indentata
CRAPAP	- Crassosphaera papillata	PARCER	- Pareodinia ceratophora
CRICOO	- Cribroperidinium cooksoniae	PERPSE	- Pervosphaeridium pseudhystrichodinium
CRIORT	- Cribroperidinium orthoceras	PERTRU	- Pervosphaeridium truncatum
CYCBRE	- Cyclonephelium brevispinatum	PROCON	- Prolixosphaeridium conulum
CYCCHA	- Cyclonephelium chabaca	PSADEF	- Psaligonyaulax deflandrei
CYCCOM	- Cyclonephelium compactum	PSEEIS	- Pseudoceratium eisenackii
CYCMEM	- Cyclonephelium membraniphorum	PTECIN	- Pterodinium cingulatum
CYCPAU	- Cyclonephelium paucimarginatum	PTECOR	- Pterodinium cornutum
CYCUNC	- Cyclonephelium uncinatum	PTEAUR	- Pterospermella aureolata
CYCVAN	- Cyclonephelium vannophorum	PTEAUS	- Pterospermella australiensis
CYMCOS	- Cymatiosphaera costata	PTESPA	- Pterospermella sp. A
DAPLAM	- Dapsilidinium laminaspinosum	PTEPAC	- Pterosphaeridia pachytheca
DAPMAR	- Dapsilidinium marinum	RHIVEL	- Rhiptocorys veligera
DAPMUL	- Dapsilidinium multispinosum	SCULAP	- Scuticabolus lapidaris
DAPPUM	- Dapsilidinium pumilum	SPILEN	- Spiniferites lenzii
DINVOZ	- Dinogymnium vozzhennikovae	SPIPOR	- Spiniferites porosus
DINCLA	- Dinopterygium cladoides	SPIRGC	- Spiniferites ramosus gracilis
DIPGEA	- Diplofusa gearlensis	SPIRGM	- Spiniferites ramosus granomembranaceous
DORLIT	- Dorocysta litotes	SPIRRA	- Spiniferites ramosus ramosus
DOWARM	- Downiesphaeridium armatum	SPIRRE	- Spiniferites ramosus reticulatus
DOWMUL	- Downiesphaeridium multispinosum	SPITRI	- Spiniferites tripus
DOWSPA	- Downiesphaeridium sp. A	SPITWI	- Spiniferites twistringiensis
ELLRUG	- Ellipsodinium rugulosum	SPIWET	- Spiniferites wetzelii
ENDCAM	- Endoscrinium campanula	STECOR	- Stephodinium coronatum
EUREYR	- Eurydinium eyrensis	SUBCHE	- Subtilisphaera cheit
EURGLO	- Eurydinium glomeratum	SUBFOL	- Subtilisphaera foliacea
EURING	- Eurydinium ingramii	SUBINA	- Subtilisphaera inaffecta
EXOARN	- Exochosphaeridium arnace	SUBPIR	- Subtilisphaera pirnaensis
EXOBIF	- Exochosphaeridium bifidum	SUBPON	- Subtilisphaera pontis-marie
EXOPHR	- Exochosphaeridium phragmites	SUBZAW	- Subtilisphaera zawia
EYRNEB	- Eyrea nebulosa	SURLON	- Surculosphaeridium longifurcatum
FLOBUS	- Florentinia buspina	SYSSPA	- Systematophora sp. A
FLOCLA	- Florentinia clavigera	TANSAL	- Tanyosphaeridium salpinx
FLOCOO	- Florentinia cooksoniae	TANVAR	- Tanyosphaeridium variecalamus
FLODEA	- Florentinia deanei	TASSPP	- Tasmanites spp.
FLOFER	- Florentinia ferox	TEHCOU	- Tehamadinium coummia
FLOLAC	- Florentinia laciniata	TENHYS	- Tenua hystrix
FLOMAN	- Florentinia mantellii	TEPSPA	- Tetraporina sp. A
FLORAD	- Florentinia radiculata	TRICAS	- Trichodinium castanea
FLORES	- Florentinia resex	TRIGIN	- Trigonopyxidia ginella
FORAMS	- Foraminiferal test linings	TRIEVI	- Trithyrodinium sp. cf. T. evittii
FROAMP	- Fromea amphora	TRIDUB	- Trithyrodinium dubium
FROFRA	- Fromea fragilis	TRISUS	- Trithyrodinium suspectum
GINEVI	- Ginginodinium evittii	VALRET	- Valensiella reticulata
GONCAS	- Gonyaulacysta cassidata	VALTAZ	- Valensiella tazadensis
HETCON	- Heterosphaeridium conjunctum	VERCOL	- Veryhachium collectum
HETHET	- Heterosphaeridium heteracanthum	VEREUR	- Veryhachium europeum
HETMUL	- Heterosphaeridium multifurcatum	VERFOR	- Veryhachium formosum
HYSPUL	- Hystrichodinium pulchrum	VERIRR	- Veryhachium irregulare
HYSBOW	- Hystrichosphaeridium bowerbankii	VERRED	- Veryhachium reductum
HYSREC	- Hystrichosphaeridium recurvatum	VERRHO	- Veryhachium rhomboideum
HYSMEM	- Hystrichostrogylon membraniphorum	VERVAL	- Veryhachium valiente
IMPMOD	- Impagidinium modicum	WALANG	- Wallodinium anglicum
IMPCLA	- Impletosphaeridium clavulum	WALLUN	- Wallodinium luna
ISAMAG	- Isabelidinium magnum	WURSPA	- Wurola sp. A
KALGRA	- Kallosphaeridium granulatum	XENAUS	- Xenascus australensis
KALRIN	- Kallosphaeridium ringnesiorum	XENPER	- Xenascus perforatus
KALSPA	- Kallosphaeridium sp. A	XENPLO	- Xenascus plotei
KIOUNI	- Kiokansium unituberculatum	XIPALA	- Xiphophoridium alatum

Figure 7.12b

Dendrogram from agglomerative hierarchical cluster analysis of normal abundances



For key to species see Figure 7.12a

'Lowered-salinity' - ● 'Shallow-water' - ○

'Normal-salinity' - □ 'Deep-water' - ◆

species associations are closely linked. The 'deep-water' association for the acritarch *Wuroia* sp. A is also confirmed as it also clusters closely with these.

Some of the species that show a less-clear 'deep-water' association but occur in larger numbers also cluster closely. These include *Achomosphaera ramulifera*, *Achomosphaera* sp. A, *Circulodinium distinctum*, *?Heterosphaeridium heteracanthum* and *Hystrichodinium pulchrum*. As some of these species also show higher abundances in some of the samples from the Wahweap Wash section, it is likely that they also responded to other environmental factors.

Apteodinium deflandrei, *Impagidinium modicum* and *Leberidocysta deflocatta* (with a 'normal-salinity' preference) cluster together but away from the 'deep-water' species. They also cluster close to *Gonyaulacysta cassidata* and *Eurydinium eyrensis* suggesting that these may also share the same preference.

Subtilisphaera pirnaensis and *S. pontis-marie* ('normal-salinity' indicators) are clustered together along with the foraminiferal test linings. This would indicate that the foraminifera producing the organic linings had a preference for 'normal-marine' salinities and higher-productivity conditions.

All of the 'lowered-salinity' and 'shallow-water' indicator species are grouped in the lower half of the dendrogram. The 'shallow-water' indicator species do not closely cluster themselves but generally group in with the 'lowered-salinity' species, suggesting that this group may have less validity than the others. This may also suggest that salinity had greater control on species distribution than water depth. The most notable cluster includes *Canningia reticulata*, *Canningia* sp. A, *Canninginopsis colliveri*, *Coronifera oceanica*, *Cribroperidinium cooksoniae*, *Cyclonephelium brevispinatum*, *C. vannophorum*, *Dinopterygium cladoides*, *Florentinia resex*, *Oligosphaeridium pulcherrimum* and *Pareodinia ceratophora*. Other species which also closely cluster with these and may also have responded to the same environmental changes include *Florentinia clavigera*, *Tenua hystrix* and *Xenascus plotei*.

The suggested morphological adaptation of *Odontochitina costata* and *O. operculata* is further supported by the statistical analysis as the former is clustered with the greatest concentration of 'lowered-salinity' species while the latter is clustered with the 'deep-water' indicators. A similar pattern may also occur with species of *Xenascus* as *X. australensis* is clustered with the 'normal-salinity' and 'deep-water' indicators while as mentioned, *X. plotei* is clustered with the greatest concentration of 'lowered-salinity' indicators.

7.2.11.3 Conclusions

A close relationship is noted between the 'normal-salinity' and 'deep-water' indicator species and between the 'lowered-salinity' and 'shallow-water' indicator species in the cluster dendrogram based on Spearman's Rank Order correlation coefficients. It is possible that some of the species included in the 'normal-salinity' association (e.g. *Adnatosphaeridium tutulosum* and the *Pterodinium* species) could equally be placed in the 'deep-water' association. Similarly, several of the species in the small 'shallow-water' association are clustered with the 'lowered-salinity' association, which may suggest that the group is not valid. It is likely that salinity had greater control than bathymetry on the distribution of the meroplanktonic dinoflagellates.

7.2.12 Marine palynomorph conclusions

These should only be taken as preliminary results which ideally need further work to confirm or redress the findings, with an expansion of the data sets, the number of sections studied and the number of time slices used. It is quite possible that some or many of the species listed are reacting to other environmental factors, and not to those under study using the transect. The results may also be distorted by other factors ensuing from the less than ideal sampling and counting procedures. However, many of the species under study show variably clear environmental preferences which may be used for subsequent environmental interpretations.

Many of the species of dinoflagellate cyst showed a clear response to lateral changes in water depth (e.g. species of *Canningia*, *Dinopterygium*, *Dinogymnium*, *Chlamydophorella*, *Achomosphaera* etc.) and salinity (e.g. species of *Kiokansium*, *Cyclonephelium*, *Exochosphaeridium*, *Impagidinium*, *Pterodinium*, *Subtilisphaera* etc.). Those species with relatively good environmental preference shown are listed in Figure 7.12. Associations of these species are used in subsequent chapters for palaeoenvironmental interpretations. Many other species, however, (e.g. *Cyclonephelium compactum*, *Cyclonephelium uncinatum*, *Tenua hystrix*, *Palaeohystrichophora infusorioides*, *Subtilisphaera cheit*, and species of *Spiniferites*, *Odontochitina*, *Xenascus* etc.) showed patterns responding to other environmental changes.

Some of the environmental preferences for cyst species show some accordance with previous work. Differences in suggested preferences by species of *Cyclonephelium* for shallow-water environments (Brinkhuis & Zachariasse, 1988) or offshore-shelf environments (Downie *et al.*, 1971) are demonstrated by some species with 'lowered-salinity' preferences (e.g. *C. brevispinatum* and *C. vannophorum*) and others with 'deep-water' or alternative preferences (e.g. *C. paucimarginatum* and *C. compactum*, respectively). This also demonstrates the advantages of this study, with comparatively good palaeoenvironmental control already available, and the problems of other studies which can only refer to environmental parameters (e.g. shoreline proximity or bathymetric differences) in subjective or qualitative terms.

Some murochorate or morphologically similar dinoflagellate cysts are suggested to have a deeper water or oceanic preference from contemporary and pre-Quaternary studies. These include species of *Impagidinium* (Reid, 1975, Davies *et al.*, 1982), *Pterodinium* (Brinkhuis & Zachariasse, 1988, Wilpshaar & Leereveld, 1994) and *Nematosphaeropsis* (Davey & Rogers, 1975, Lewis *et al.*, 1990). This is supported by species in this study which show a 'normal-salinity' or 'deep-water' preference such as *Impagidinium modicum*, *Pterodinium cingulatum*, and *Adnatosphaeridium tutulosum* (which is morphologically very similar to species of *Nematosphaeropsis*).

The cyst assemblages appear to have been affected by hydrodynamic sorting but this is probably not the principal control on dinoflagellate distribution. The different species and subspecies of *Spiniferites* seem to have greater numbers of species with longer-processes in the deeper parts of the basin. Many of the proximate species (e.g. *Atopodinium haromense*, *Cribroperidinium cooksoniae*, *Canningia* and *Canninginopsis* species, and some species of *Cyclonephelium*) showed a preference for 'shallow-water' or 'lowered-salinity' environments. However many of the chorate and murochorate

DINOFLAGELLATE CYST SPECIES WITH SUGGESTED ENVIRONMENTAL PREFERENCES

Figure 7.12d

'Lowered-salinity' indicator species are those with preferences for comparatively shallow water environments with lower salinities.

'Shallow-water' indicator species are those with preferences for comparatively shallow water environments but with no preference for lower or 'normal-marine' salinities.

'Normal-salinity' indicator species are those with no preferences for shallow or deep environments but with preferences for 'normal-marine' salinities.

'Deep-water' indicator species are those with preferences for comparatively deep water environments with 'normal-marine' salinities.

'Lowered-salinity' Indicator Species

Atopodinium haromense
Canninginopsis colliveri
Coronifera oceanica
Cribroperidinium cooksoniae
Cyclonephelium brevispinatum
Cyclonephelium chabaca
Cyclonephelium vannophorum
Exochosphaeridium phragmites
Florentinia mantellii
Florentinia resex
Hystrichosphaeridium bowerbankii
Kiokansium williamsii
Nyktericysta sp. A
Oligosphaeridium pulcherrimum
Palaeoperidinium cretaceum
Pareodinia ceratophora
Subtilisphaera zawia

'Shallow-water' Indicator Species

Canningia reticulata
Canningia sp. A
Dinopterygium cladoides
Spiniferites lenzii
Spiniferites twistringiensis

'Normal-salinity' Indicator Species

Adnatosphaeridium tutulosum
Apteodinium deflandrei
Chatangiella spectabilis
Downiesphaeridium sp. A
Eurydinium ingramii
Impagidinium modicum
Isabelidinium magnum
Leberidocysta defloccata
Oligosphaeridium totum
Pterodinium cingulatum
?Pterodinium cornutum
Subtilisphaera pirnaensis
Subtilisphaera pontis-marie

'Deep-water' Indicator Species

Acanthaulax wilsonii
Achomosphaera ramulifera
Achomosphaera sp. A
Chichaouadinium vestitum
Chlamydophorella discreta
Chlamydophorella nyei
Circulodinium distinctum
Dapsilidinium ambiguum
Dapsilidinium laminaspinosum
Dinogymnium vozzhennikovae
Ellipsodinium rugulosum
Epelidosphaeridia spinosa
?Heterosphaeridium heteracanthum
Histiocysta palla
Hystrichodinium pulchrum
?Kallosphaeridium helbyi
Microdinium reticulatum
Occisucysta hinzii
Rhiptocorys veligera
Spiniferites tripus
Subtilisphaera foliacea
?Surculosphaeridium longifurcatum
Tehamadinium coummia
Trithyrodinium dubium

species also showed a 'shallow-water' or 'lowered-salinity' preference (e.g. *Coronifera oceanica, Dinopterygium cladoides, Exochosphaeridium phragmites* and species of *Florentinia* and *Oligosphaeridium*), while many proximate species showed a 'deep-water' preference (e.g. *Histiocysta palla, Kallosphaeridium? helbyi* and *Chlamydophorella discreta*). It seems likely that biological factors played a more important role in dinoflagellate cyst distribution than sedimentological ones. However, dinoflagellate cyst species diversity was found to be generally related to water-depth, with the greatest diversity of species found in the sections from deeper sites in the basin, supporting previous studies (e.g. Wall *et al.*, 1977).

Many species of acritarch were rare but showed some environmental preference, whether to lowered salinities, shallower or deeper waters. Many others however, such as species of *Veryhachium* generally showed little preference. The distribution of species of prasinophyte generally showed no environmental preference along the transect, but probably reflect other environmental factors such as stratification in the water column.

7.3 PALYNOFACIES RESULTS

7.3.1 Variations in palynomorphs and phytoclasts with environment

The proportions of palynomorphs were compared across the basin transect along the 'time-slices' (Figure 7.1) to pick out any trends relating to shoreline proximity, water-depth and transport, and also to note general up-section changes across the basin. Three transects allowed a comparison with the Rebecca K. Bounds core, from below PBC9 ('time-slice' G), below PBC15 ('time-slice' M) and between PBC22 and PBC23 ('time-slice' P). Eleven transects for comparing Blue Point, Wahweap Wash and Pueblo ran from below the bentonite PBC4 through to above the bentonite PBC11 ('time-slices' A to K). Apart from the two 'time-slices' with the Rebecca K. Bounds core, the remainder of the comparisons are then restricted to the Blue Point and Wahweap Wash sections ('time-slices' L to Q). The 'time-slice' data-sets for the palynofacies variations are illustrated in Figures 7.13 to 7.17.

Amorphous organic matter: The amounts of AOM preserved are thought to be primarily a function of the benthic oxygen levels at the time of sedimentation. Between PBC4 and PBC10 ('time-slices' A to I) the levels of AOM were affected by shoreline proximity. The amounts at Blue Point were much lower than in the other sections, where the levels increased up-section (Figure 7.13). Fluctuating increases in the amounts of AOM recorded below PBC10 at Pueblo and at Wahweap Wash generally occurred at the same time though the amounts recorded were normally higher in the centre of the basin.

This suggests that water depth may have affected the amount of AOM preserved, with shallower depths allowing much greater benthic oxygenation at Blue Point and slightly better oxygenation at Wahweap Wash compared with Pueblo. The increase in levels up-section suggests a gradual decrease in benthic oxygenation, particularly in deeper parts of the basin.

Above PBC10 ('time-slices' J to Q), the levels of AOM are similar between all the sections, suggesting that a critical water-depth may have been reached at Blue Point and that onshore-offshore

Figure 7.13

PALYNOFACIES 'TIME-SLICE' DATA SET ENVIRONMENTAL VARIATIONS: MARINE-DERIVED AMORPHOUS ORGANIC MATTER AND MARINE PALYNOMORPHS

See text for further details.

Palynofacies 'time-slice' data set environmental variations

Marine amorphous matter

SLICE	BP	WW	PU	RB
Q	160	157	-	-
P	160	157	-	165
O	154	132	-	-
N	90	83	-	-
M	91	147	-	125
L	114	169	-	-
K	51	173	107	-
J	104	180	101	-
I	85	129	175	-
H	3	98	175	-
G	1	130	99	113
F	1	38	20	-
E		60	145	-
D	2	20	30	-
C	1	13	4	-
B	1	24	2	-
A	2	4	12	-

Dinocysts & acritarchs

SLICE	BP	WW	PU	RB
Q	34	33	-	-
P	34	33	-	54
O	58	68	-	-
N	41	52	-	-
M	30	73	-	62
L	44	39	-	-
K	31	32	58	-
J	56	31	50	-
I	35	42	45	-
H	4	12	43	-
G	28	31	58	19
F	62	49	42	-
E	58	56	37	-
D	63	27	25	-
C	39	29	53	-
B	39	48	12	-
A	39	31	30	-

Foraminiferal test linings

SLICE	BP	WW	PU	RB
Q	4	14	-	-
P	4	14	-	
O	2	24	-	-
N	9	1	-	-
M		17	-	
L	4	12	-	-
K	3	20	2	-
J		22	3	-
I	1	10	9	-
H		11	1	-
G		10	7	
F		6	3	-
E		4	5	-
D		1	1	-
C		2		-
B		2		-
A				-

Prasinophytes

SLICE	BP	WW	PU	RB
Q	2	1	-	-
P	2	1	-	34
O	3	1	-	-
N	7	2	-	-
M	5	2	-	24
L	5	6	-	-
K	8	5	1	-
J	10	4	11	-
I	8	5	12	-
H		1	4	-
G	9	2	7	2
F	2	11	3	-
E	3	3	2	-
D	6	1	2	-
C	4	8	2	-
B	4	2		-
A	1	1	1	-

Numbers of palynofacies particles found in each 'time-slice' sample

- = no equivalent sample

SLICE = 'time-slice' sample horizon BP = Blue Point section

WW = Wahweap Wash section PU = Pueblo section RB = Rebecca K. Bounds core

gradients no longer affected the amounts of AOM preserved in the sections studied. Alternatively, some other factor (perhaps an expanded oxygen-minimum zone) then controlled the oxygen levels equally across the basin.

The amount of AOM in the Rebecca K. Bounds core was noted to be as high as in the other sections and so does not seem to have been affected by different laboratory preparation techniques.

Dinoflagellate cysts and acritarchs: The relative proportions of dinoflagellate cysts and acritarchs varied between sections across the basins (Figure 7.13). At different times, each of the three main sections studied had more cysts in comparison to other palynomorphs than the other sections. This is due to the comparative enrichment of other palynomorphs for different reasons, at different times and in different places. No simple or easily explainable pattern could be determined between the sections. Below PBC11 ('time-slices' A to J), the overall highest relative abundances were found in the Blue Point section at times of oceanic influence (suggested by geochemical, macrofaunal and microfaunal data), around the equivalents of PBC6 and PBC7 ('time-slices' D to F). The lowest relative abundances were found in the sample from the equivalent of PBC9 ('time-slice' H) at both Blue Point and Wahweap Wash.

Foraminiferal test linings: The material from the Wahweap Wash section almost exclusively contained the greatest comparative proportions of foraminiferal test linings in comparison to the other sections (Figure 7.13). Within this section, numbers were comparatively lower up to 'time-slice' G (below the equivalent of PBC9), and so may have been affected by water depth or shoreline proximity. In the palynofacies counts, the Blue Point material yielded none until 'time-slice' I (just below the equivalent of PBC10), perhaps restricted by shoreline proximity. A small number was recorded fairly consistently through the interval studied from the Pueblo section. Fluctuations in numbers could not be readily correlated between sections. The environmental preferences for organic lining-producing foraminifera at the Wahweap Wash section are unknown but may have been related to water-depth and/or benthic oxygen levels.

No foraminiferal test linings were seen in the Rebecca K. Bounds core material. The reason for this is unknown but it is possible that they were all destroyed by the heavy processing techniques. The Rebecca K. Bounds core contains abundant calcareous foraminifera at this stratigraphic interval (Scott *et al.*, 1994) and it seems unlikely that species with organic linings inhabited Colorado and central Kansas but were excluded from western Kansas.

Prasinophytes: The numbers of prasinophytes are variable within and between sections (Figure 7.13). Their presence was apparently not simply related to shoreline proximity and water-depth. One correlatable distinctive increase in numbers occurred in 'time-slices' I and J (below PBC10 and PBC11) in both the Blue Point and Pueblo sections, but this increase was not as obvious in the Wahweap Wash section.

Figure 7.14

PALYNOFACIES 'TIME-SLICE' DATA SET ENVIRONMENTAL VARIATIONS: 'PROXIMITY' PHYTOCLASTS

See text for further details.

Membranous material

SLICE	BP	WW	PU	RB
Q	4	10	-	-
P	4	10	-	2
O	6	3	-	-
N	7	9	-	-
M	8	1	-	5
L	3		-	-
K	4	2		-
J	7	3	3	-
I	8	2	1	-
H	7	3	2	-
G	9	3	3	3
F	17	4	5	-
E	33	11	2	-
D	14	14	2	-
C	13	4		-
B	13	12	4	-
A	7	2	3	-

Terrestrial amorphous matter

SLICE	BP	WW	PU	RB
Q		2	-	-
P		2	-	
O	2	1	-	-
N	3		-	-
M	1		-	
L	2	3	-	-
K	2	1		-
J	2	3	1	-
I	10	1	1	-
H	2	3	1	-
G	5	1	1	
F		1		-
E	2	3	1	-
D	1	1		-
C	2	2		-
B	2	2		-
A	3	1		-

Wood-brown-very large

SLICE	BP	WW	PU	RB
Q		5	-	-
P		5	-	
O		1	-	-
N	3	1	-	-
M	2		-	
L	3	2	-	-
K	2	3		-
J	3	1	1	-
I	8	1	1	-
H	3	4		-
G	8	3	1	
F	4	2		-
E	6	1		-
D	10		1	-
C	7	1		-
B	7	6		-
A	9	4		-

Wood-black-very large

SLICE	BP	WW	PU	RB
Q		1	-	-
P		1	-	
O		1	-	-
N	1		-	-
M	1		-	
L	1	1	-	-
K				-
J	1			-
I	2		1	-
H	3			-
G		1		
F		1	1	-
E		1		-
D	1	1		-
C	1			-
B	1	2	1	-
A		1	1	-

Numbers of palynofacies particles found in each 'time-slice' sample

- = no equivalent sample

SLICE = 'time-slice' sample horizon BP = Blue Point section

WW = Wahweap Wash section PU = Pueblo section RB = Rebecca K. Bounds core

Figure 7.15

PALYNOFACIES 'TIME-SLICE' DATA SET ENVIRONMENTAL VARIATIONS: WOODY PHYTOCLASTS

See text for further details.

Wood-brown-elongate

SLICE	BP	WW	PU	RB
Q	24	35	-	-
P	24	35	-	3
O	26	16	-	-
N	39	32	-	-
M	38	19	-	4
L	39	41	-	-
K	38	23	35	-
J	27	22	33	-
I	37	8	50	-
H	51	53	37	-
G	21	27	31	19
F	29	24	34	-
E	35	22	46	-
D	27	17	29	-
C	30	21	19	-
B	30	16	11	-
A	20	23	10	-

Wood-brown-equidimensional

SLICE	BP	WW	PU	RB
Q	62	55	-	-
P	62	55	-	45
O	63	59	-	-
N	56	49	-	-
M	56	33	-	37
L	50	46	-	-
K	83	35	59	-
J	64	60	54	-
I	64	66	33	-
H	100	35	40	-
G	98	48	47	136
F	73	43	76	-
E	50	32	51	-
D	65	38	82	-
C	83	37	60	-
B	83	47	25	-
A	104	82	43	-

Wood-black-elongate

SLICE	BP	WW	PU	RB
Q	11	15	-	-
P	11	15	-	2
O	4	6	-	-
N	6	21	-	-
M	21	3	-	2
L	17	16	-	-
K	5	9	15	-
J	4	7	10	-
I	6	16	15	-
H	7	17	6	-
G	3	25	8	1
F	3	14	12	-
E	2	19	13	-
D	2	17	19	-
C	8	20	17	-
B	8	17	19	-
A	3	9	10	-

Wood-black-equidimensional

SLICE	BP	WW	PU	RB
Q	37	19	-	-
P	37	19	-	11
O	16	8	-	-
N	18	20	-	-
M	14	18	-	24
L	13	11	-	-
K	9	16	29	-
J	11	11	31	-
I	9	26	26	-
H	23	32	52	-
G	9	27	32	19
F	5	31	18	-
E	3	43	35	-
D	2	80	34	-
C	7	66	42	-
B	7	38	125	-
A	12	45	99	-

Numbers of palynofacies particles found in each 'time-slice' sample

- = no equivalent sample

SLICE = 'time-slice' sample horizon   BP = Blue Point section

WW = Wahweap Wash section   PU = Pueblo section   RB = Rebecca K. Bounds core

Figure 7.16

PALYNOFACIES 'TIME-SLICE' DATA SET ENVIRONMENTAL VARIATIONS: MIOSPORES

See text for further details.

Pollen grains				
SLICE	BP	WW	PU	RB
Q	21	10	-	-
P	21	10	-	45
O	20	14	-	-
N	10	12	-	-
M	24	33	-	38
L	19	24	-	-
K	15	53	1	-
J	14	37	3	-
I	12	24	6	-
H		29	13	-
G	10	21	5	1
F	5	12	6	-
E	8	5	4	-
D	8	5	5	-
C	5	10	5	-
B	5	8	3	-
A	3	1	3	-

Spore grains				
SLICE	BP	WW	PU	RB
Q		1	-	-
P		1	-	4
O	1	1	-	-
N		1	-	-
M		1	-	4
L			-	-
K		1		-
J				-
I				-
H			1	-
G		1		1
F				-
E				-
D	1			-
C			1	-
B				-
A				-

SELECTED 'TIME-SLICE' PALYNOFACIES RATIO VARIATIONS WITH ENVIRONMENT

See text for further details.

Dinoflagellate cysts:Miospores				
SLICE	BP	WW	PU	RB
Q	61.8%	75.0%	-	-
P	61.8%	75.0%	-	52.4%
O	73.4%	81.9%	-	-
N	80.4%	80.0%	-	-
M	55.6%	68.2%	-	59.6%
L	69.8%	61.9%	-	-
K	67.4%	37.2%	98.3%	-
J	80.0%	45.6%	94.3%	-
I	74.5%	63.6%	88.2%	-
H	100%	29.3%	75.4%	-
G	73.7%	58.5%	92.1%	90.5%
F	92.5%	80.3%	87.5%	-
E	87.9%	91.8%	90.2%	-
D	87.5%	84.4%	83.3%	-
C	88.6%	74.4%	89.8%	-
B	88.6%	85.7%	80.0%	-
A	92.9%	96.9%	90.9%	-

Marine palynomorphs:Terrestrial palynomorphs and phytoclasts				
SLICE	BP	WW	PU	RB
Q	20.1%	23.9%	-	-
P	20.1%	23.9%	-	44.0%
O	31.3%	45.8%	-	-
N	28.5%	27.5%	-	-
M	17.5%	46.0%	-	43.0%
L	26.5%	28.4%	-	-
K	21.0%	28.5%	30.5%	-
J	33.2%	28.4%	32.0%	-
I	22.0%	28.4%	33.0%	-
H	2.0%	12.0%	24.0%	-
G	18.5%	21.5%	36.0%	10.4%
F	32.0%	33.3%	24.0%	-
E	30.5%	31.5%	22.4%	-
D	34.5%	14.4%	14.0%	-
C	21.6%	19.5%	27.6%	-
B	21.6%	26.0%	6.0%	-
A	19.9%	16.0%	15.5%	-

Numbers and ratios (%) of palynofacies particles found in each 'time-slice' sample
- = no equivalent sample
SLICE = 'time-slice' sample horizon BP = Blue Point section
WW = Wahweap Wash section PU = Pueblo section RB = Rebecca K. Bounds core

Membranous material: A clear onshore-offshore trend was noticeable in the proportions of membranous material (Figure 7.14). The proportions are generally highest in the near-shore deposits at Blue Point below the equivalent of PBC15 ('time-slices' A to M). At Wahweap Wash the proportions are also high below the equivalent of PBC7 ('time-slices' A to E), but they are consistently low through the Pueblo section. The trend between the western sections reversed around PBC17 ('time-slice' N), where the proportions in the Wahweap Wash section increased in comparison to those at Blue Point. This confirms suggestions (e.g. Steffen & Gorin, 1993) that membranous material is an effective indicator of shoreline proximity and/or terrestrial input.

Spores: The proportions of spores are extremely low, only comprising 'trace' quantities through the western sections and the Pueblo section (Figure 7.16). They were noticeably higher in the Rebecca K. Bounds core. This may be due to a vegetational difference between the east and west coasts of the seaway, but palaeocurrent directions in the basin (predominantly from the west) suggest that it is more probably due to the greater resistance of the thick spore walls to the heavy laboratory processing of the Rebecca K. Bounds core material.

Pollen: Generally between 'time-slices' A and F (the equivalents of below PBC4 to PBC7) the numbers are low in all of the sections (though lowest at Pueblo and highest at Wahweap Wash; Figure 7.16). From the equivalent of below PBC9 and above, the numbers greatly increase in the western sections but remain low at Pueblo. Between 'time-slices' G and M (the equivalents of below PBC9 to below PBC15), the proportions of pollen grains are generally higher at Wahweap Wash than at Blue Point. However above 'time-slice' M (the equivalent of below PBC15), the proportions are generally higher at Blue Point, while they decrease at Wahweap Wash. Clearly a relationship exists between pollen proportions and shoreline proximity but it is not a simple one. It seems likely that the proportionate numbers of pollen within a sample reach their maximum at a certain distance off-shore, presumably due to hydrodynamic sorting, as the amount of woody and cuticular/membranous material decreases. In nearer-shore environments the pollen grains were swamped by other terrestrial debris but up to a point, as shoreline proximity decreases, the relative proportions of pollen increase.

'Time-slice' G (the equivalent of below PBC9) in the Rebecca K. Bounds core contains only a very small proportion of pollen, much less than elsewhere further west. However, the higher two samples compared contain very high proportions of pollen (much higher than elsewhere), perhaps suggesting an eastern source for the pollen grains or perhaps again suggesting greater resistance of miospores to laboratory processing.

Terrestrially derived amorphous organic matter: The amorphous matter resulting from the degradation of woody and cuticular material occurs most commonly in the western sections where it makes-up a very small but regular proportion of the palynofacies (Figure 7.14). The proportions at Pueblo are much lower where it is extremely rare if present at all. None was noted from these intervals from the Rebecca K. Bounds core. Consequently the proportions are a good indication of shoreline proximity.

Elongate black wood: The proportions of elongate black wood are lowest in the sediments of the lower half of the Blue Point section, deposited in the nearer-shore environment (Figure 7.15). The proportions are variable but roughly equal through remainder of the Blue Point and all of the Wahweap and Pueblo sections in sediments deposited in deeper-water environments.

Equidimensional black wood: The pattern is very similar to that of the elongate black wood with comparatively small quantities in the lower half of the Blue Point section and variable though larger quantities through the rest of the sections (Figure 7.15).

Large black wood: Large pieces of black wood are generally scarce in all of the sections but particularly in the Pueblo section, suggesting a slight preference for an on-shore distribution (Figure 7.14). No large wood was found in the Rebecca K. Bounds core, which may be due to sieving during processing.

Elongate brown wood: The distributions of elongate brown wood do not seem to follow any pattern but show roughly similar proportions between all of the sections (Figure 7.15). This however suggests that elongate brown wood is more common in the centre of the basin in comparison with other types of wood fragments which were deposited in greater comparative numbers in the western sections. The transporting currents appear to have been as effective at carrying the elongate fragments to the centre of the basin as to the nearer-shore sections. Hence in shelf sediments the proportions of elongate fragments to non-elongate fragments are only likely to be of limited use in determining shoreline proximity.

Equidimensional brown wood: The proportions of equidimensional brown wood, as a rule, were generally larger in the western sections but proved to be very variable throughout all of the sections (Figure 7.15). Often the numbers were greater at Pueblo than in one of the western sections. On its own the proportions are of little value and could not be used as a shoreline proximity indicator.

Very large brown wood: The very large fragments of brown wood are more numerous than the very large black wood fragments. They show a clear signal with much larger numbers in the western sections (deposited in nearer-shore environments) than at Pueblo, where numbers are very small and infrequent (Figure 7.14). In the lower half of the Blue Point section ('time-slices' A to J, below PBC11) the numbers are higher than in the Wahweap Wash section. However this trend reverses in the upper half of the sections, particularly above the equivalent of PBC20 ('time-slices' O to Q).

7.3.2 Variation in palynofacies ratios with environment

The palynomorph and phytoclast ratios were also compared across the 'time-slice' horizons to look at variations with shoreline proximity. The 'time-slice' data-sets for the palynofacies ratios are illustrated in Figures 7.16 and 7.17.

Figure 7.17

SELECTED 'TIME-SLICE' PALYNOFACIES RATIO VARIATIONS WITH ENVIRONMENT

See text for further details.

Elongate wood:Equidimensional wood

SLICE	BP	WW	PU	RB
Q	26.1%	38.5%	-	-
P	26.1%	38.5%	-	8.2%
O	27.5%	24.2%	-	-
N	36.6%	43.1%	-	-
M	44.7%	30.1%	-	9.0%
L	45.5%	48.7%	-	-
K	31.4%	37.2%	36.2%	-
J	28.2%	28.7%	33.3%	-
I	34.1%	20.5%	51.6%	-
H	31.0%	49.6%	31.9%	-
G	17.3%	39.7%	32.8%	11.4%
F	28.1%	33.0%	32.6%	-
E	38.5%	34.7%	40.7%	-
D	27.1%	22.2%	29.1%	-
C	27.9%	28.3%	26.1%	-
B	27.9%	26.2%	16.6%	-
A	15.5%	19.5%	12.3%	-

Black wood:Brown wood

SLICE	BP	WW	PU	RB
Q	35.8%	26.9%	-	-
P	35.8%	26.9%	-	21.3%
O	18.3%	16.5%	-	-
N	20.3%	33.3%	-	-
M	27.3%	28.8%	-	38.8%
L	25.2%	23.9%	-	-
K	10.2%	29.1%	31.9%	-
J	14.5%	17.8%	31.8%	-
I	13.5%	35.9%	33.3%	-
H	17.6%	34.8%	43.0%	-
G	8.6%	40.5%	33.6%	11.4%
F	7.0%	40.0%	22.0%	-
E	5.2%	53.4%	33.1%	-
D	4.7%	64.1%	32.1%	-
C	11.8%	59.3%	42.8%	-
B	11.8%	45.2%	80.1%	-
A	10.1%	33.5%	67.5%	-

Large wood:Small wood

SLICE	BP	WW	PU	RB
Q	0.0%	4.6%	-	-
P	0.0%	4.6%	-	0.0%
O	0.0%	2.2%	-	-
N	3.3%	0.8%	-	-
M	2.3%	0.0%	-	0.0%
L	3.3%	2.6%	-	-
K	1.5%	3.5%	0.0%	-
J	3.6%	1.0%	0.8%	-
I	7.9%	0.9%	1.6%	-
H	3.2%	2.8%	0.0%	-
G	5.8%	3.1%	0.8%	0.0%
F	3.5%	2.6%	0.7%	-
E	6.3%	1.7%	0.0%	-
D	10.3%	0.7%	0.6%	-
C	5.9%	0.7%	0.0%	-
B	5.9%	6.3%	0.6%	-
A	6.1%	3.0%	0.6%	-

'Proximity' phytoclasts:Terrestrial phytoclasts and palynomorphs

SLICE	BP	WW	PU	RB
Q	2.5%	11.8%	-	-
P	2.5%	11.8%	-	1.8%
O	5.8%	5.5%	-	-
N	9.8%	6.9%	-	-
M	7.3%	0.9%	-	4.4%
L	6.1%	4.2%	-	-
K	5.1%	4.2%	0.0%	-
J	9.8%	4.9%	3.7%	-
I	17.9%	2.8%	3.0%	-
H	7.7%	5.7%	2.0%	-
G	13.5%	5.1%	3.9%	1.7%
F	15.4%	6.1%	3.9%	-
E	29.5%	11.7%	2.0%	-
D	19.8%	9.2%	1.7%	-
C	14.7%	4.3%	0.0%	-
B	14.7%	14.9%	2.7%	-
A	11.8%	4.8%	2.4%	-

Ratios (%) of palynofacies particles found in each 'time-slice' sample

- = no equivalent sample

SLICE = 'time-slice' sample horizon BP = Blue Point section

WW = Wahweap Wash section PU = Pueblo section RB = Rebecca K. Bounds core

Marine to terrestrial: The proportions of marine palynomorphs to terrestrial palynomorphs and phytoclasts often proved to be biased towards the marine-derived palynomorphs in the centre of the basin (Figure 7.16). However this was not always the case. The situation was reversed at approximately the same stratigraphic level as the equivalents of PBC6 and PBC7 ('time-slices' D to F). The proportions are also variable within each section with no clear overall pattern. It does not appear to be a particularly reliable shoreline proximity indicator.

Dinocysts to miospores: Again the ratio of dinocysts to miospores is variable both within and between sections and hence is not clearly or obviously related to shoreline proximity (Figure 7.16).

Prasinophytes to dinocysts: There is no reason for this ratio to show any relation to shoreline proximity. The ratio is variable within and between sections. However the fluctuations are reasonably synchronous between the sections suggesting a relatively basin-wide control on the production of prasinophyte phycomas. This might suggest synchronous basin-wide variations in water-column stratification.

Spores to pollen: The numbers of spores are far too few for this ratio to have any meaning in comparison within and between the boundary sections.

Black to brown wood: The ratio of black wood to brown wood showed a fairly good relationship to shoreline proximity, with the proportions of black wood generally higher in the more distal deposits (Figure 7.17). The ratios are generally lowest through the lower half of the Blue Point section ('time-slices' A to K) below the equivalent of above PBC11. Above the equivalent of PBC20 ('time-slices' O to Q) the ratios alter to lower numbers in the Wahweap Wash section. In some of the comparable samples, the proportions of black wood are highest in the Pueblo section. However, in many of the 'time-slices' the proportions are highest in the Wahweap section, particularly at times of transgression. This suggests that in nearer-shore sections sediment baffling may increase the proportions of black wood.

Elongate to equidimensional wood: The proportions of elongate woody phytoclasts (black and brown) to equidimensional woody phytoclasts are extremely variable and show little pattern in relation to shoreline proximity (Figure 7.17).

Large to small wood fragments: The proportions of large wood to small wood, as with the individual abundances of large wood particles, proved to be extremely good for determining shoreline proximity (Figure 7.17). With one exception, the ratios are consistently smallest in the Pueblo section, often by a large difference. As noted with other abundances and ratios, the ratios were greatest in the lower part of the Blue Point section ('time-slices A to N, as far as the sample from the equivalent of PBC17). In the upper parts of the sections ('time-slices O to Q, from above the equivalent of PBC20) the proportions are higher at Wahweap Wash, suggesting that from this time onwards, this section was closer to shore than the Blue Point locality.

'Proximity phytoclasts' to phytoclasts: The proportions of phytoclasts with clear higher abundances in the nearer-shore sections (membranous material, terrestrially derived amorphous matter, large black wood and large brown wood) are contrasted here with the remaining terrestrial phytoclasts and palynomorphs (Figure 7.17). The combination of these phytoclasts in increasing the numbers within the group used, are likely to have decreased the minor fluctuations in numbers of individual types of phytoclast producing a steadier and clearer shoreline proximity signal.

When compared along the synchronous time-lines this ratio proved to be extremely successful in indicating shoreline proximity. In all but one case, the ratios are clearly lower in the Pueblo section, and often the differences are comparatively large. The ratios are consistently higher in the Blue Point section up as far as 'time-slice' N, around the equivalent of PBC17. Above this level, the ratios are higher from the Wahweap Wash section, again suggesting that from this time onwards, this section was closer to shore than the Blue Point locality.

7.3.3 Palynofacies conclusions

The synchronous time-lines provide a valuable testing-ground for palynofacies variations between different proximal to distal shelf environments. Many of the palynomorph and phytoclast abundances and ratios traditionally used to determine shoreline proximity proved to be worthless using the synchronous 'time-slices' across the basin. The relative production and preservation of marine palynomorphs seem to be largely independent of shoreline-proximity and water-depth but responded to other factors. The proportions of terrestrial palynomorphs and phytoclasts are related to shoreline proximity and terrestrial input but the relationship is not a simple one. Only some of the terrestrial phytoclasts form good shoreline proximity indicators. These are the large wood fragments, the membranous material and the terrestrial amorphous matter. It seems likely that these ratios would be of more use in stratigraphically longer, less high-resolution studies across much greater fluctuations in sea-level. However, the difference in palaeoenvironment between the section sites generally was not great enough to produce good correlations or patterns within the palynofacies studies. Other oceanographic changes rather than shoreline proximity are likely to have affected the results.

However, some of the ratios proved to be useful to varying degrees. In particular the ratio of larger phytoclasts, membranous material and terrestrially derived amorphous organic matter (all found in greater quantities in the near-shore sections) to total counts of terrestrially derived phytoclasts and palynomorphs proved to be most useful, along with (to a lesser extent) the proportions of black wood to brown wood.

It seems likely that palynofacies composition may help in deducing the relative subsidence rates of the western sections. At the time of deposition of the sediments in the *Sciponoceras* and *Neocardioceras* Zones, the Blue Point section was closer to shore and to terrestrial source input. The proportions of black wood to brown wood entering the western part of the basin were much lower and the proportions of nearshore phytoclasts were much higher. However, the Black Mesa Basin probably subsided faster than the Kaiparowits basin and by *Watinoceras* and *Mammites* times, the Blue Point site of deposition was further off-shore or further from terrestrial source input than the Wahweap Wash site. At this time the proportions of pollen and black wood to brown wood began decreasing while the proportions of nearshore phytoclasts were increasing through the Wahweap section, and it seems likely that here subsidence had slowed and the shoreline had started prograding or that terrestrial input into the Kaiparowits basin had increased.

CHAPTER 8

THE GREENHORN EUSTATIC CYCLE: PALYNOLOGICAL VARIATIONS AND INTERPRETATIONS FROM THE REBECCA K. BOUNDS CORE

8.1 INTRODUCTION

One of the main slants of the thesis is to study the Cenomanian-Turonian boundary event. However, the subject of this chapter is the longer-term transgressive-regressive Greenhorn cycle. This has been studied to look at longer term changes in the Western Interior Basin and to help try to differentiate between short and long term changes at local and regional scales. The aims of this chapter are to relate the palynological data (marine palynomorph and palynofacies counts) with the available information from previous work on a time scale spanning most of a second-order transgressive-regressive marine cycle. The objectives will include a study of the reactions of the dinoflagellate cysts and palynofacies to changes in sea level, salinity, productivity and circulation, and the use of the palynology to try and solve some of the questions arising from previous work on the basin.

The extensive literature published on many facets of the geology of the Western Interior Basin has meant that much geological information and many interpretations are already available for the stratigraphy studied for this chapter. The aspects of the geology involve many topics in lithostratigraphy, palaeontology and geochemistry and have led to many theories on the palaeoecology and palaeoceanography from the basin, which can be used in the palynological studies. However little work has yet been published on the sequence stratigraphy of the Greenhorn cyclothem and the aim of this chapter is not to work out, in detail, the lithostratigraphy in terms of sequence stratigraphic events. Only basic sequence stratigraphic concepts will be referred to in this chapter. Kauffman & Caldwell (1993) suggest that the Greenhorn cycle is a second-order transgressive-regressive eustatic cycle and also suggest a pattern of third- and fourth- order cycles but without outlining the precise resultant lithostratigraphy (Figure 1.1). The generalised overall patterns of sedimentation for the Greenhorn marine cyclothem are illustrated in Figure 8.1.

The palaeoenvironmental, palaeoecological and palaeoceanographical information for the depositional history of the Greenhorn cyclothem for Kansas is described in detail by Hattin (1975). However, where the depth of information is insufficient, the more thoroughly studied sections at the Rock Canyon Anticline at Pueblo, Colorado have also been used. The flat topography of the sea floor and uniform deposition across Colorado and Kansas has been consistently proved from the numerous studies, and hence differences between the sections are likely to be only minor.

The foraminiferal data available for the Rebecca K. Bounds core comes solely from unpublished poster material from Bergen *et al.*, 1990, which cannot be reproduced in diagram form in this thesis. No text is available which describes or interprets the foraminiferal assemblages from the Rebecca K. Bounds core samples.

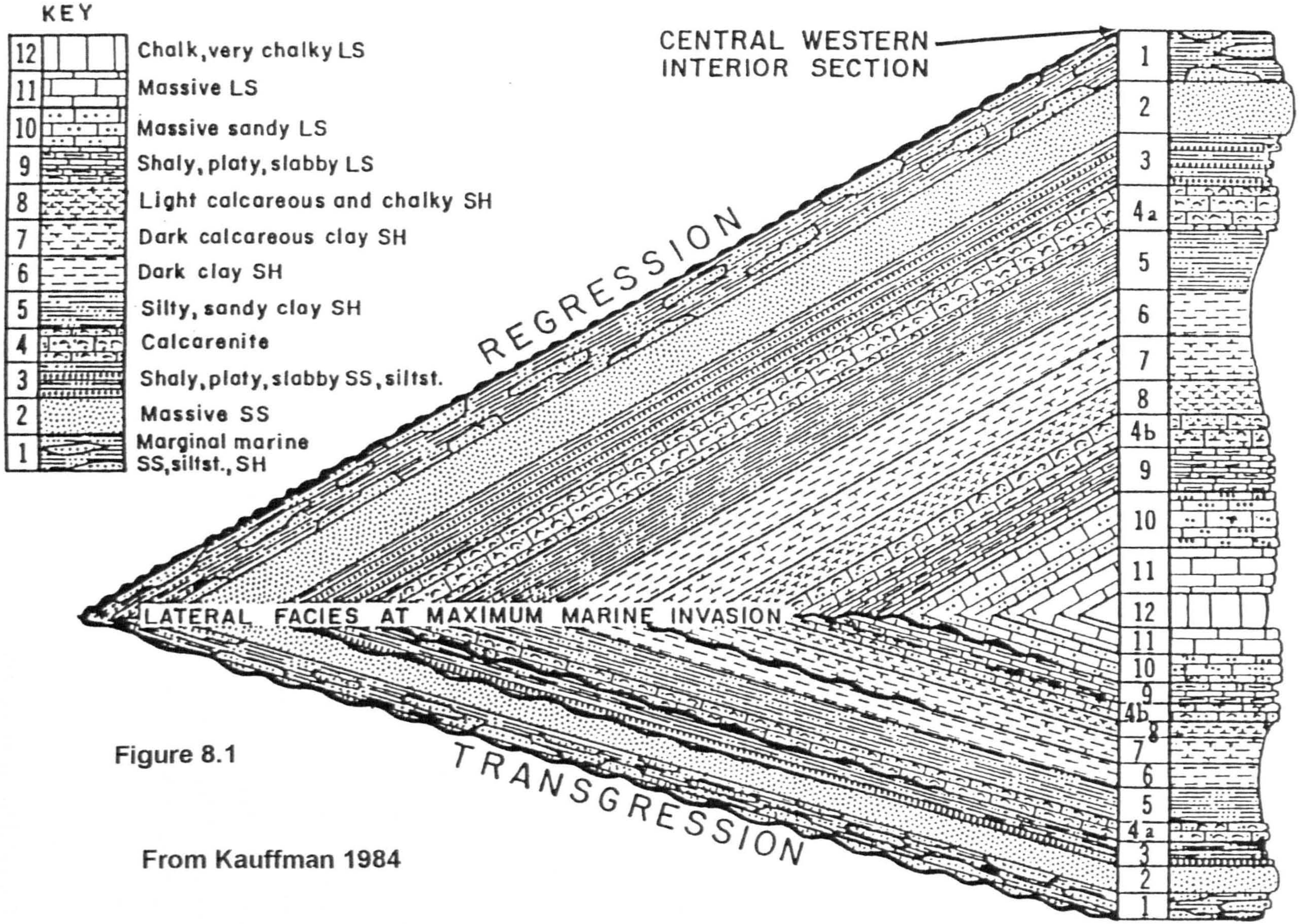


Figure 8.1

From Kauffman 1984

Generalised model of a symmetrical cyclothem, reflecting deposition during a second-order tectono-eustatic fluctuation, in the centre (right) and shallow marginal platform (left) of a hypothetical epicontinental sea (based on a centre to eastern margin transect of the Cretaceous Western Interior Basin). The upward-fining transgressive facies (1-12) and upward-coarsening regressive facies (12-1) are defined in detail as preserved in the axial part of the Western Interior Basin (e.g. at the Pueblo and Rebecca K. Bounds core sites). Note shoreward-basinward diachronism of facies during transgression-regression, bounding disconformities, and concentration of intra-cycle disconformities on transgressive hemicycle.

The sampling resolution through the Rebecca K. Bounds core is very low compared with the boundary section studies. Consequently it is hard to really compare or effectively use the core material for palaeoenvironmental comparisons with other sections. When considering how much change has been noted to occur through the much shorter boundary sections, the validity of the results and conclusions drawn must be questioned as they are surely affected by the low resolution. Many of the palaeoenvironmental changes through the Greenhorn cyclothem will have been missed. Nevertheless some environmental changes may be inferred and tested from the samples, particularly in relation to comparatively large-scale changes such as the second-order sea-level fluctuation.

For detailed comparison of stratigraphic occurrences of taxa and palynomorphs alongside the lithostratigraphy, the chart plot depths are included against the lithological log of the core in Chapter 3 (Figures 3.6 and 3.8). The location of the core site is described in Appendix A. The dinoflagellate cyst and other palynomorph species are listed along with their authors in Appendix C and illustrated in Appendix D.

8.1.1 Marine palynomorph results

The stratigraphic occurrences and abundances of individual species (in order of first appearance datum) referred to in this chapter, are illustrated in Appendix E: Chart 1A. The dinoflagellate cyst species diversities, proportions of dinoflagellate cyst indicator species (plotted out against each other), peridinioid/gonyaulacoid proportions and levels of marine amorphous organic matter (AOM) from the palynofacies counts referred to in this chapter, are plotted out alongside the lithostratigraphy of the Rebecca K. Bounds core in Figure 8.2. The proportion of each association of dinoflagellate cyst indicator species is calculated as a ratio of the number of individual cysts from the species from that indicator association to the total number of cysts from all the species from all four associations. The peridinioid/gonyaulacoid ratios are calculated as the ratio of the number of individual peridinioid cysts to the total number of gonyaulacoid and peridinioid cysts per sample.

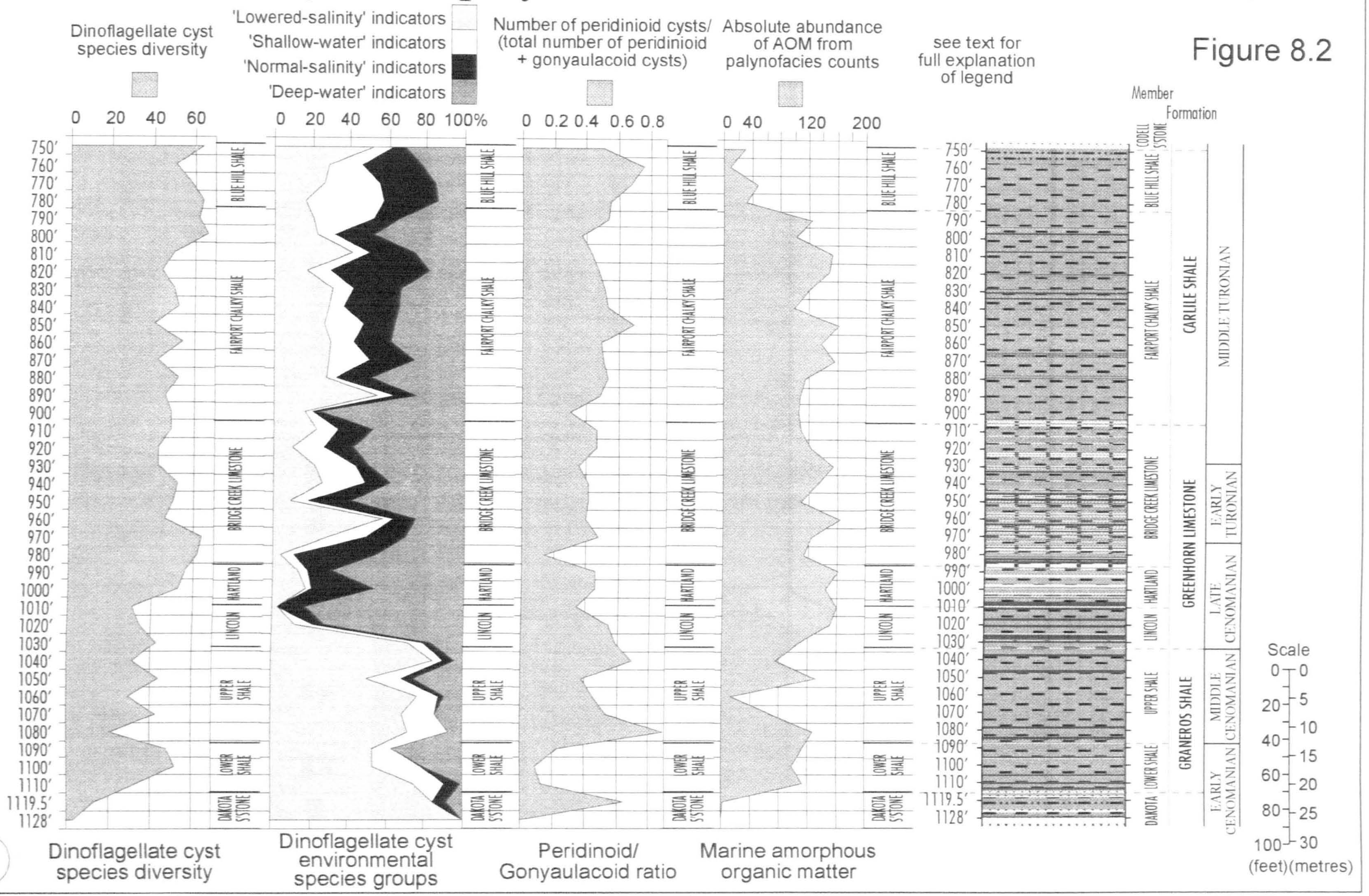
The following points need to be considered for interpreting these results:- (1) The species of dinoflagellate cyst suggested to have environmental preferences from the results of the 'time-slice' studies are listed in Figure 7.12. 'Deep-water' species are also by definition normal-salinity species. 'Lowered-salinity' species are also by definition shallow water ones. The 'shallow-water' species are tolerant of ranges of salinity. 'Normal-salinity' species show little preference for differences in water depth. (2) The curves from the dinoflagellate cysts are obviously linked. Through the samples, the dinoflagellate cyst species diversity curve is affected by the P/G ratio, particularly in those samples which are strongly dominated by marine amorphous organic matter (which made counting procedures difficult), and contain larger numbers of peridinioid cysts.

8.1.2 Palynofacies results

The stratigraphic occurrences and abundances of individual palynofacies types referred to in this chapter, are illustrated in Appendix E: Chart 1C (including marine amorphous organic matter (AOM) counts) and 1D (excluding AOM counts). Selected curves for the proportions of palynofacies types and groups referred to in this chapter, are illustrated in Figure 8.3. Generally, only the results

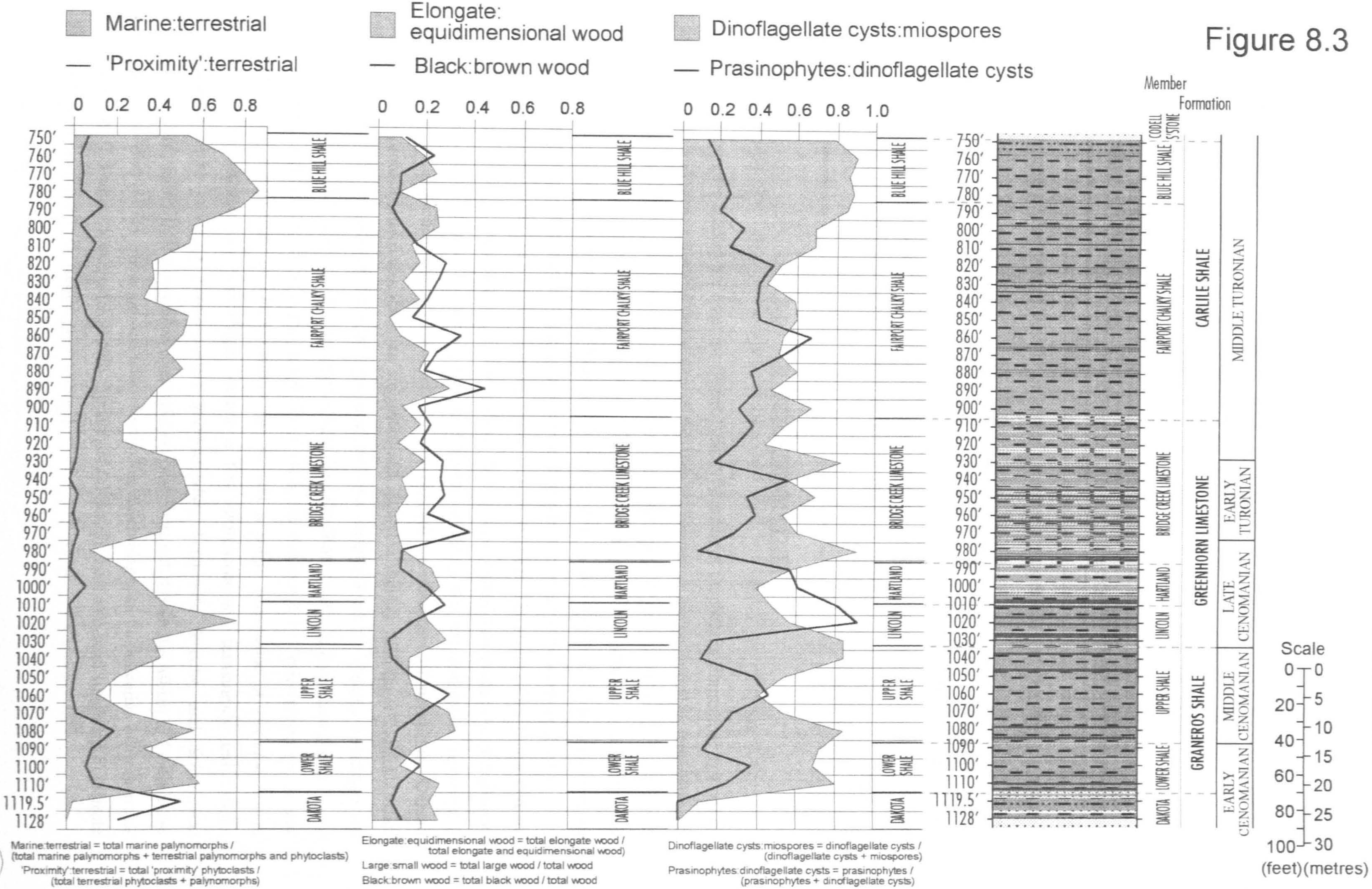
Dinoflagellate cyst and palynofacies data: Rebecca K. Bounds Core

Figure 8.2



Selected palynofacies ratios: Rebecca K. Bounds Core

Figure 8.3



Marine:terrestrial = total marine palynomorphs / (total marine palynomorphs + terrestrial palynomorphs and phytoclasts)

'Proximity':terrestrial = total 'proximity' phytoclasts / (total terrestrial phytoclasts + palynomorphs)

Elongate:equidimensional wood = total elongate wood / total elongate and equidimensional wood)

Large:small wood = total large wood / total wood

Black:brown wood = total black wood / total wood

Dinoflagellate cysts:miospores = dinoflagellate cysts / (dinoflagellate cysts + miospores)

Prasinophytes:dinoflagellate cysts = prasinophytes / (prasinophytes + dinoflagellate cysts)

from those groups/ratios that proved more useful and reliable in the 'time-slice' comparisons, will be discussed in this chapter.

In this study the proportions of palynomorphs and phytoclasts recovered from all sections are given as percentages. The abundance values of marine amorphous organic matter (AOM) given are the proportions from the entire palynofacies counts, and the proportions for all the palynomorphs and phytoclasts given are the values from the palynofacies counts excluding the abundance of AOM.

The validity of the results of the palynofacies investigations for the Rebecca K. Bounds core material must be questioned as the slides used for the palynofacies counts are not kerogen slides. The material in them has clearly been heavily processed (particularly oxidised) and consequently the less resistant palynomorphs and phytoclasts are likely to have disappeared. No foraminiferal test linings were counted from any of the samples, probably as a result of having been destroyed during processing. Consequently any references to marine palynomorphs only include the dinoflagellate cysts and prasinophytes. In addition, no very large wood fragments were counted (black or brown) which perhaps suggests that the material has also been sieved to remove the large fraction.

8.2 DAKOTA FORMATION

The samples studied are from the Upper Dakota Member of the Dakota Formation. In Kansas, the sediments and environment of deposition of the Dakota Formation are suggested to have changed from fluviatile sandstones and mudstones to estuarine and other marginal marine sediments in the 'upper few feet' (metre) of the formation (Hattin, 1964, 1967). The environments of deposition of the Dakota and Graneros Shale Formations are illustrated in Figure 8.4. In the Rebecca K. Bounds core an unconformable sequence boundary is suggested for the lithological contact at the core depth of 1171.2', separating the Lower Dakota Member from the Upper Dakota Member. The strata of the Lower Dakota Member are thought to represent an estuarine-delta plain system within transgressive and highstand systems tracts. The strata of the Upper Dakota Member overlying this are thought to represent a brackish, upper shoreface system. However, the depositional environments of the Upper Dakota Member are probably more complex than suggested and involve a number of fresh to brackish water environments. The palynological assemblages from the two samples from the Dakota Formation are very distinctive yet different to each other and to those from the Graneros Shale Formation above.

The dinoflagellate cysts in the sample from 1128' are dominated by *Nyktericysta* sp. A, but include a few occurrences of *Odontochitina* sp. A, and a single occurrence of *Pseudoceratium eisenackii*. In addition the assemblages include a few leiospheres and tasmanitids and various chlorophyte algae including *Petalosporites quadrangulus*, *Lecaniella foveata*, and *Schizocysta laevigata*. Large numbers of thin-walled ceratioid-type cysts were noted from the Albian to Cenomanian of Kansas by Bint (1986) and suggested when dominating assemblages to be indicative of fresh-water environments (J. Lentin, *pers. comm.*, 1993). Species of *Lecaniella* have also been suggested to indicate non-marine environments (D. Batten, *pers. comm.*).

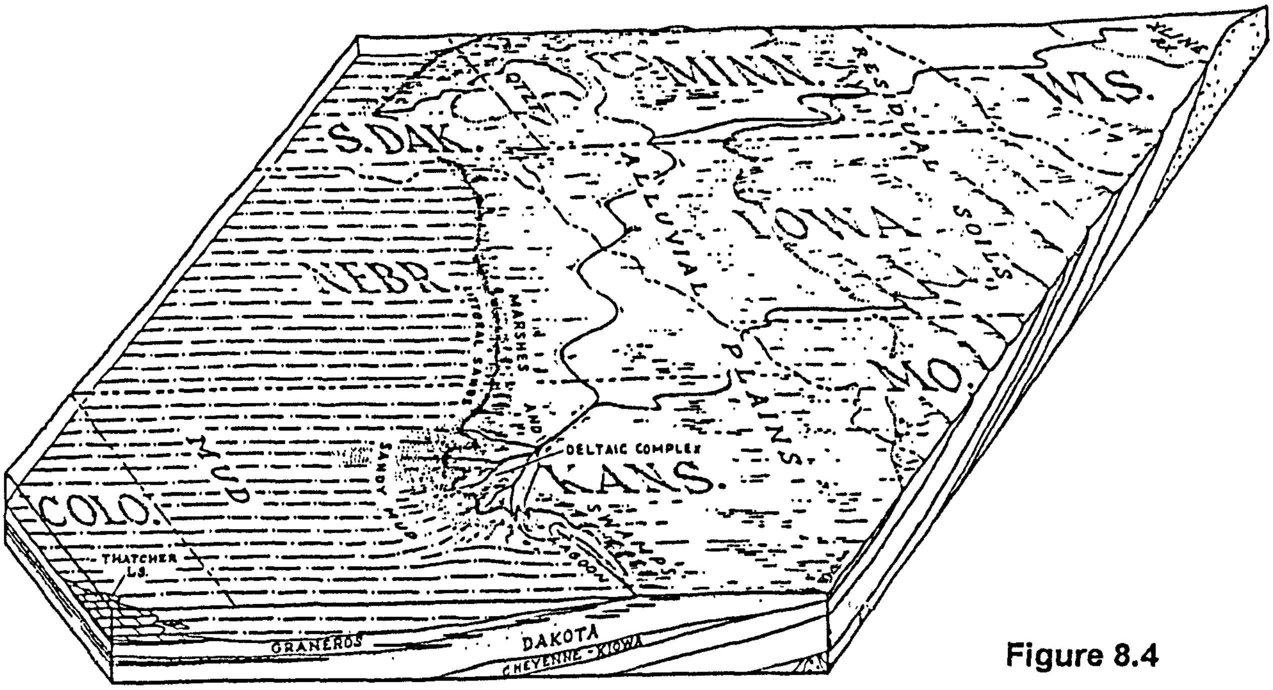


Figure 8.4

Adapted from Hattin 1967
Lithostratigraphic interpretation of the overall environments of deposition for the Dakota and Graneros Shale Formations (Cenomanian) for the eastern margin of the Western Interior Basin.

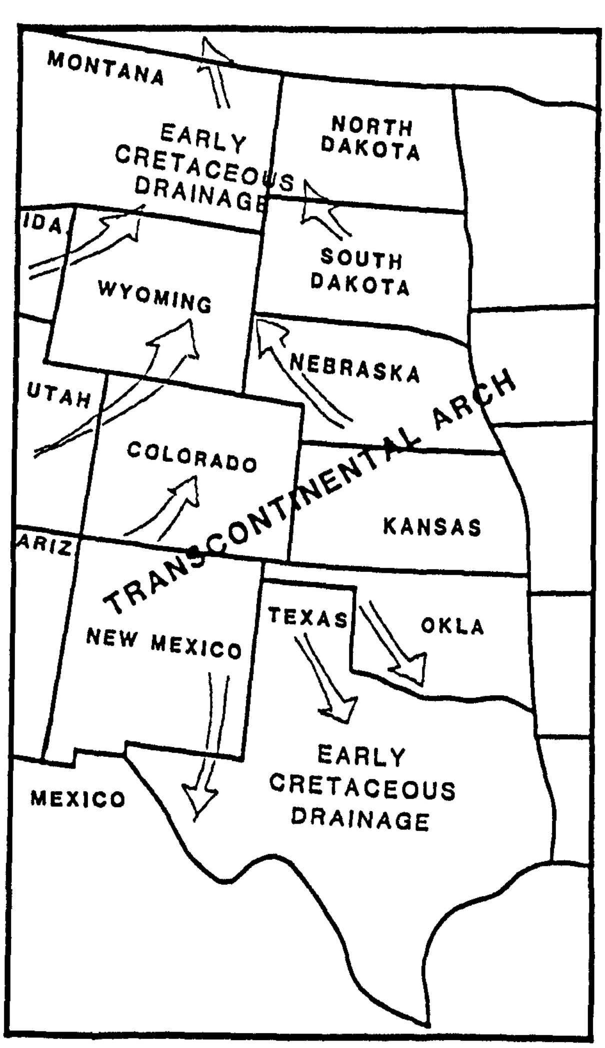


Figure 8.5

From Gustason & Kauffman 1985
Regional map of the Western Interior showing the probable position of the transcontinental arch and fluvial drainage patterns during Lower Cretaceous time. The transcontinental arch formed a barrier between the Boreal and Tethyan oceans during deposition of the Dakota Formation.

The sample also contains high levels of membranous material and very high levels of miospores (with twice as many spores as pollen), low levels of woody phytoclasts and no marine derived AOM, dinoflagellate cysts, acritarchs, chlorophytes or prasinophytes in the 200 palynofacies counts.

The sample was taken from a silty shale horizon with sparse carbonised leaf and plant imprints on some laminae, suggesting extremely low-energy, brackish or even freshwater conditions with vegetation close-by to allow the preservation of leaf prints. The very low diversity, high dominance palynological assemblage reinforces the brackish or even fresh-water conditions with its extremely distinctive group of species.

The sample from 1119.5' contains a more diverse though still limited assemblage of dinoflagellate cysts (13 species) which represent an extremely eurytopic flora. The assemblage is strongly dominated by *Ovoidinium verrucosum*. Additional common species include *Nyktericysta* sp. A, *Ginginodinium evittii*, *Dinopterygium reticulatum*, *Oligosphaeridium complex* and species of *Florentinia*. Prasinophyte assemblages include small numbers of leiospheres and large numbers of tasmanitids suggesting some stratification (perhaps due to low surface salinities).

The very high proportion of peridinioid cysts suggests a high productivity environment in nutrient-rich near-shore waters. The presence of *Nyktericysta* sp. A in fairly large quantities suggests a continued brackish-water environment (or significant terrestrial input) though the higher diversities of dinoflagellate cyst species suggest that the water was not fresh. The sample was taken from a clay-rich siltstone horizon with thin silty laminations and small horizontal and inclined burrows. A brackish lagoonal, estuarine or restricted bay environment is suggested for this strata from the low diversity and highly dominated assemblages.

A single occurrence of *Pterodinium? cornutum* is problematical as the occurrence of the genus *Pterodinium* is considered to represent an oceanic influence. The next occurrence of this species was a single specimen in the 'lower shale member' of the Graneros Shale Formation at 1100'. It was also recorded at 1060', as was the first appearance of *Pterodinium cingulatum*. However, it is quite possible that the occurrence of this species in the Dakota Formation and even in the 'lower shale member' of the Graneros Shale Formation, is due to reworking.

The sample (from 1119.5') contains extremely high levels of membranous material, high levels of miospores (as many spores as pollen), low levels of woody phytoclasts, and only a trace of marine derived AOM and marine palynomorphs.

The sample is from a horizon overlain by the uppermost sands of the Dakota Formation. These are thought to represent lower shoreface deposits and are conformably overlain by the deeper shelf shales of the Graneros Shale Formation (Figure 8.4).

None of the beds of the Dakota Formation of Kansas have any ammonite or inoceramid remains and hence are thought to be brackish (Hattin, 1975). The macrofauna and microfauna of the Dakota Formation in Colorado suggest a low diversity, highly stressed community. The environments were probably in brackish water, with high turbidity and low-oxygen benthic conditions. Marine circulation at this time was severely restricted, particularly from the south by shallow sills on the Transcontinental Arch (across southern Colorado) and central Texas Platform (Figure 8.5). This acted as a physical and biogeographical barrier between the discrete northern Cool-Temperate and southern Warm-Temperate to Subtropical arms of the seaway with their distinctive biotas (Gustason & Kauffman, 1985). Effectively, the fauna and flora in the upper part of the Dakota Formation of the Rebecca K. Bounds core were entirely Boreal. The initial connection of the two water-masses occurred at the base of the Graneros Shale Formation in the Greenhorn cyclothem.

8.3 GRANEROS SHALE FORMATION

The Graneros Shale Formation represents the first offshore marine sedimentation in the central part of the seaway, during early transgression of the Greenhorn marine cycle. The diversity of the dinoflagellate cyst assemblages is much higher through the formation than in the samples from the Dakota Formation. Since the connection to the Tethyan ocean opened at the time of deposition of the material at the base of the Graneros Shale Formation, it is not possible to clearly divide the dinoflagellate cyst assemblages into Boreal and Tethyan species. The dinoflagellate cyst assemblages are clearly dominated by 'lowered-salinity' dinoflagellate cyst indicator species through all of the samples from the Graneros Shale Formation.

The proportions of miospores decrease rapidly in the sample from the base of the Graneros Shale and generally maintain low levels throughout the formation. In the samples from the Graneros Shale Formation, the ratio of spores to pollen is low (in comparison to those from the Dakota Formation), and the levels of brown wood generally increase from around 20% at the base to around 50% near the top, suggesting that the relative abundance of brown wood increases in a medial-shelf environment. The levels of black wood are generally very low throughout the Graneros Shale Formation (< 5%), suggesting low levels of phytoclast degradation throughout the formation.

The basal 0.30m (1') of the Graneros Shale in the Rebecca K. Bounds core contains silt and fine sand laminae and may represent proximal offshore deposits within reach of storm wave base (Kauffman, 1985b). In Kansas, the lower part of the Graneros Shale Formation has very few inoceramids and lacks any cephalopods, and has been lithologically and faunally linked with brackish water environments (Hattin, 1965). The lowest sample studied from the Graneros Shale Formation is from 1110', above the level of the first inoceramid fragments, which suggest fully marine conditions as far down as 1113'.

The basal unit grades up into soft shales representing medial offshore deposits from deeper, quiet water environments, with oxygen-depleted, soft substrates, below storm wave base (Figure 8.4). Occasional silty intervals through the rest of the 'lower shale member', may still reflect the distal edges of storm-wave reworking (Kauffman, 1985b). The levels of AOM are high in all of the samples from the 'lower shale member' of the Graneros Shale Formation, suggesting low benthic oxygen levels.

Most samples from the Graneros Shale Formation at Pueblo yield small numbers of arenaceous benthic foraminifera with Boreal affinities (Figure 8.6). This indicates that the first seas to invade this part of the basin were from the north. The poor assemblages suggest that the waters were sub-saline and that the bottom water was poorly oxygenated. Occasional occurrences of *Hedbergella* in the Graneros Shale Formation suggest that the seaway was connected with the Tethyan ocean, but in the lower half of

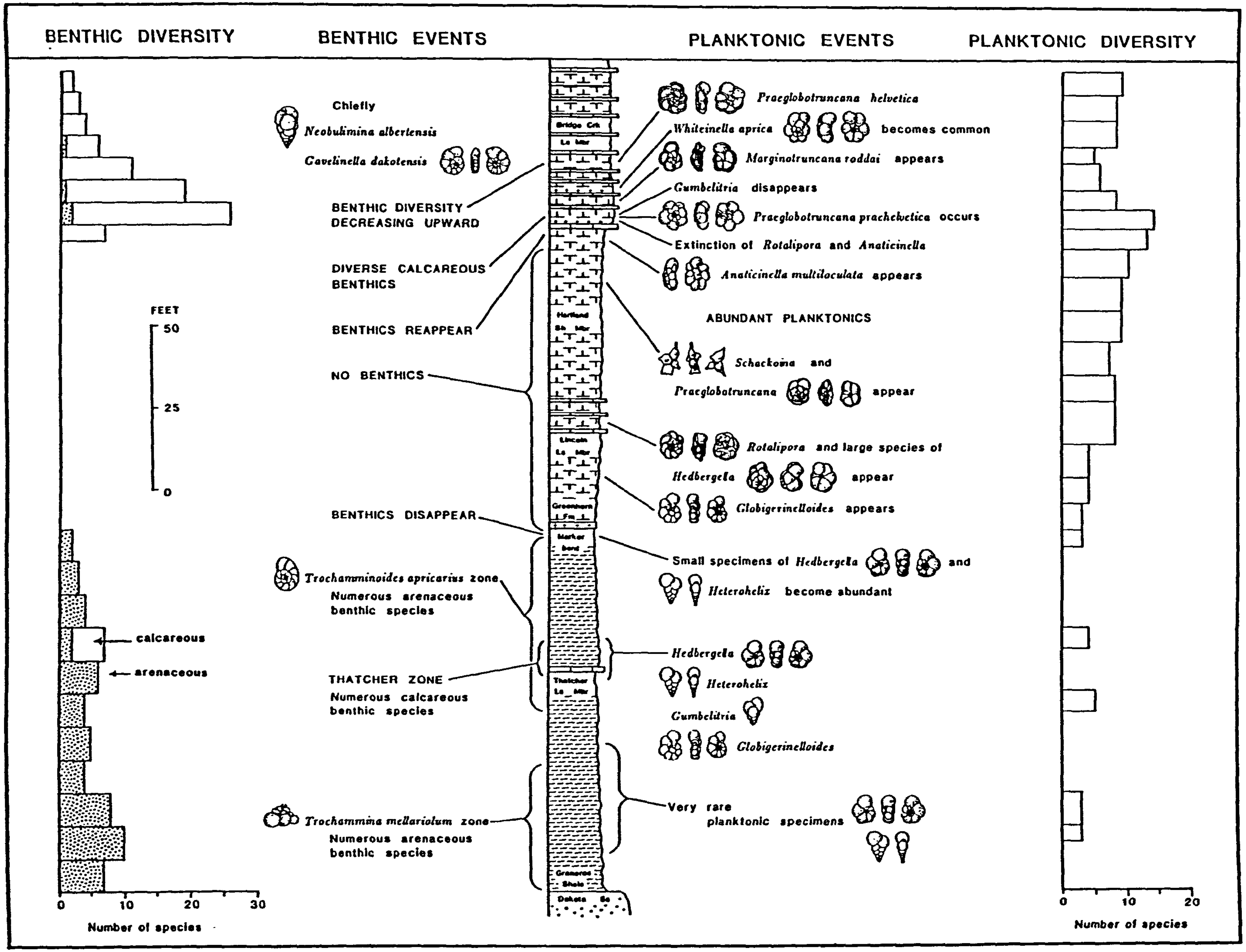


Figure 8.6

Overview of the occurrences of foraminifera in the Graneros Shale and Greenhorn Limestone Formations at the Rock Canyon Anticline, near Pueblo.

From Eicher & Diner 1985

the formation (below the Thatcher Limestone Member), the Tethyan connection was weak and most of the time the currents probably flowed southwards out of the seaway. Salinities were probably too low for the planktonic foraminifera to proliferate (Eicher & Diner, 1985). No planktonic or benthonic species were noted in the 'lower shale member' of the Graneros Shale Formation of the Rebecca K. Bounds core (unpublished poster material from Bergen *et al.*, 1990). However, the connection with the Tethyan ocean means that the assemblages of dinoflagellate cyst in the 'lower shale member' are not necessarily entirely Boreal. This interval contains quite high ratios of prasinophytes to dinoflagellate cysts suggesting water column stratification at this time.

At Pueblo, fluctuations in benthic oxygen levels affected the abundance of the agglutinated benthic foraminifera (Figure 8.6; Eicher & Diner, 1985). A lack of carbonate in the sediment of the lower shale member reflects unfavourable conditions for the coccolithophores and calcareous planktonic foraminifera probably due to either relatively cool water temperatures or more likely due to lowered surface salinities (Kauffman, 1985b). This is supported by high proportions of 'lowered-salinity' dinoflagellate cyst indicator species in the samples. Dinoflagellate cyst species diversity rapidly increases in and through the samples of the 'lower shale member' of the Graneros Shale Formation as the environment of deposition deepened, despite lowered surface salinities which excluded the calcareous microfauna/flora. The base of the formation is also marked by a large increase in the proportions of marine palynomorphs although this then gradually decreases through the samples of the 'lower shale member' of the Graneros Shale Formation, perhaps suggesting increased terrigenous input or progradation of the shoreline after initial transgression.

The Thatcher Limestone Member was deposited at the time of a short transgressive pulse causing a rapid incursion of warm subtropical, oxygenated, normal-salinity, Tethyan waters, oxygenating the sea floor and bringing an associated moderately to highly diverse warm-water benthic and pelagic biota (including epifaunal and infaunal filter-feeders). At Pueblo, the shales 1 to 2 metres above and below the Thatcher Limestone Member are calcareous. They include a southern macro-fauna characteristic of Texas and Mexico, as well as a warm-water (Caribbean) assemblage of numerous planktonic foraminifera, several calcareous benthonic foraminifera (Figure 8.6) and sparse calcareous nannofossils (Eicher & Diner, 1985, Kauffman, 1985b, Watkins, 1985).

In the Rebecca K. Bounds core marine nannofossils first appear in the Graneros Shale Formation around the Thatcher Limestone Member (Scott *et al.*, 1994) and indicate this increase in salinity to 'normal-marine' levels. The sample (1090') from 5'/1.5m below the base of the Thatcher Limestone Member in the Rebecca K. Bounds core has no benthic or planktonic foraminifera recorded (unpublished poster material from Bergen *et al.*, 1990). However, the increasing dinoflagellate cyst species diversity curve reaches a peak (around 50 species) in this sample, and also shows an increase in the number of 'deep-water' dinoflagellate cyst species, suggesting that the dinoflagellates may have reacted faster than the foraminifera to this transgressive event. The sample (1080') from 3'/0.9m above the Thatcher Limestone Member contains a fairly large diversity of planktonic foraminifera but no benthic species (unpublished poster material from Bergen *et al.*, 1990). This sample also shows a very large increase in the proportion of peridinioid species (the first major increase during the deposition of fully marine sediments), perhaps as salinities normalised and productivity increased or as water-column stability decreased. The ratios of prasinophytes to dinoflagellate cysts shows a large decrease above and below the Thatcher Limestone Member, also suggesting a decrease in water column stratification associated with this transgressive event. The samples above and below the Thatcher Limestone Member show an increase in the ratio of elongate to equidimensional phytoclasts supporting decreased shoreline proximity. The sample from above the Thatcher Limestone Member shows a temporary decrease in levels of brown wood and an increase in the proportions of marine palynomorphs, probably also in reaction to the transgression.

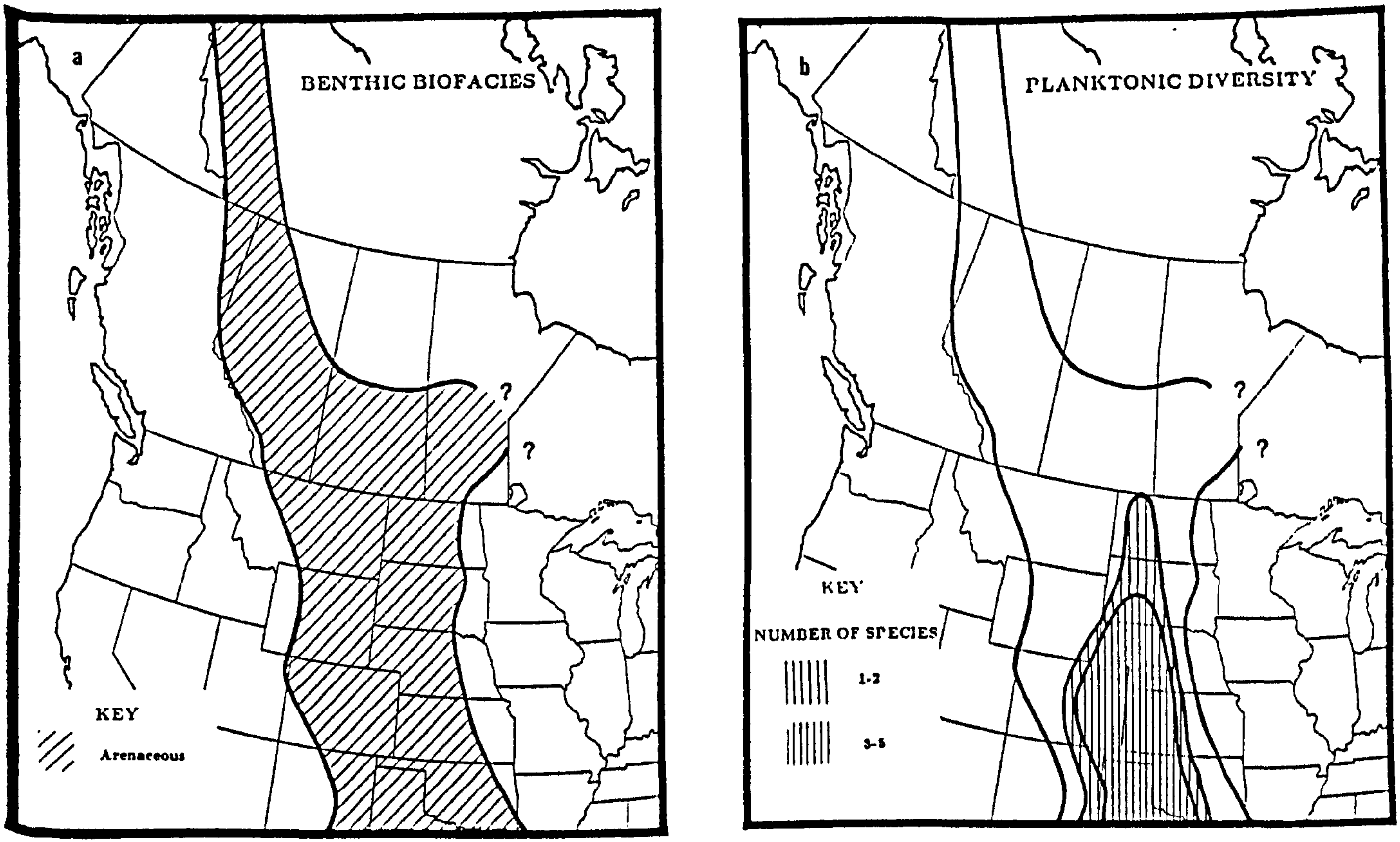
The Thatcher Limestone Member has been interpreted as the maximum flooding interval for the Greenhorn marine cyclothem (Figure 3.5; Scott *et al.*, 1994). However, the geographically limited extent of the Thatcher Limestone Member (Eicher & Diner, 1985) suggests otherwise. It seems more likely that the bed was deposited following a third- or fourth-order transgressive event.

The shales of the 'upper shale member' represent a return to medial-offshore, quiet waters, with a dysaerobic benthic environment. At Pueblo, the calcareous benthic foraminifera disappear due to the return of oxygen depleted conditions at the sea floor and do not re-appear until just below the base of the Bridge Creek Limestone Member, while the arenaceous forms re-established themselves after an absence during deposition of the Thatcher Limestone Member suggesting further circulation of Boreal waters (Figure 8.6; Eicher & Diner, 1985). The palaeogeographic distribution of foraminifera during the time of deposition of the 'upper shale member' of the Graneros Shale is illustrated in Figure 8.7. In the Rebecca K. Bounds core, the planktonic species are continuously recorded from above the Thatcher Limestone Member (unpublished poster material from Bergen *et al.*, 1990), and their presence through the upper member suggests that surface salinities remained normal (or near-normal) to the top of the Graneros Shale Formation in western Kansas.

The first samples from the 'upper shale member' of the Graneros Shale Formation above (1070' and 1060') show a large decrease in AOM and a temporary increase in the proportion of black wood, suggesting increased oxygen levels in the water column at this level. However, the ratios of prasinophytes to dinoflagellate cysts are higher in these samples suggesting increased water column stratification at this time. The ratios of marine palynomorphs to terrestrial palynomorphs and phytoclasts decreases through the 'upper shale member' of the Graneros Shale Formation, which may indicate increasing terrigenous input.

Towards the top of the Graneros Shale Formation of Kansas, the shales become increasingly chalky and rich in foraminifera, and contain proportionately more planktonic rather than benthonic species. This suggests a gradual transition to 'normal-marine' salinities as open-sea conditions were established with further transgression and improved connection with the Tethys, ultimately reaching normal or near-normal salinity in the uppermost part with abundant inoceramids, ammonites, oysters and planktonic foraminifera (Hattin, 1975).

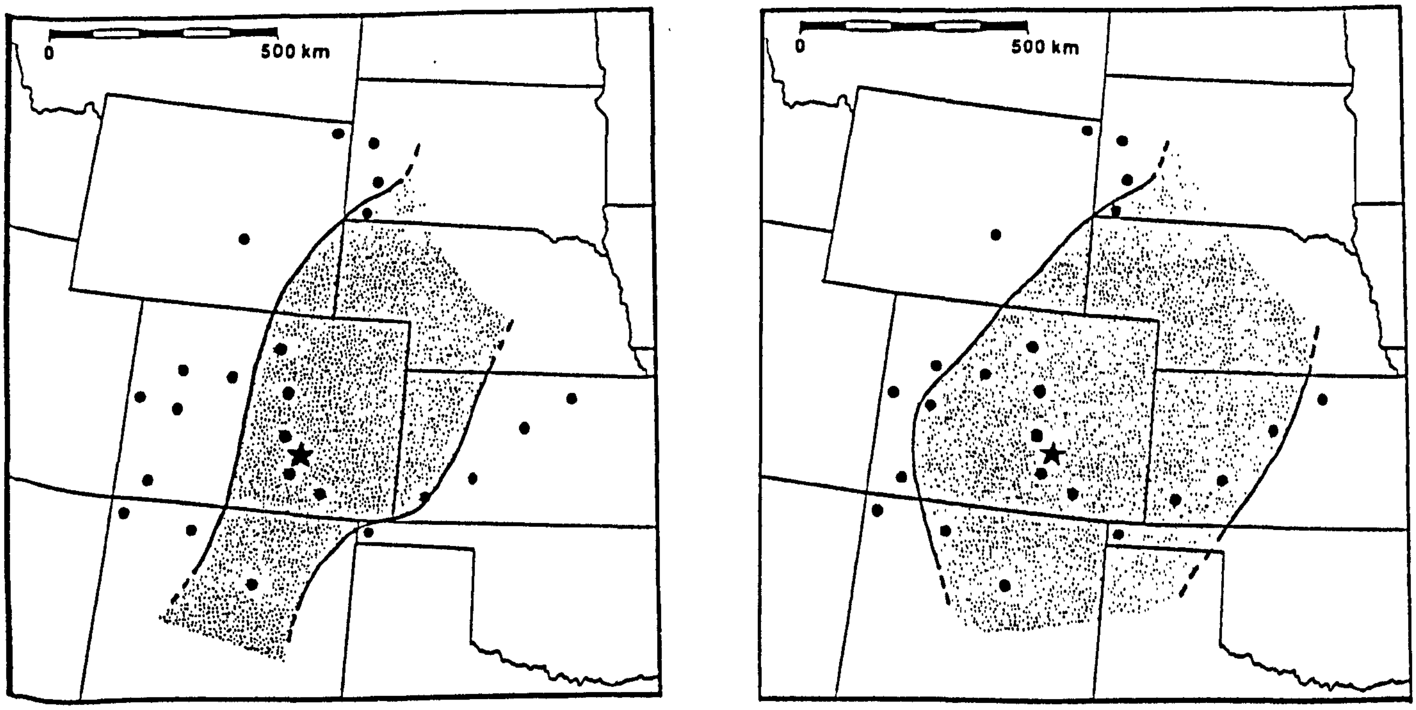
The shift from the dominantly siliciclastic sedimentation of the Graneros Shale Formation to the dominantly carbonate sedimentation of the Greenhorn Limestone Formation is a product of the distance from the shoreline (Hattin, 1975) and so occurs at different chronostratigraphic levels at Pueblo and in Kansas. At Pueblo, the top of the Graneros Shale Formation (marked by the 'X' bentonite) again shows an increase in the calcareous content of the shales, and evidence of a recirculation event in the seaway



Distribution of foraminifera in the Western Interior during deposition of the uppermost Graneros Shale, (a) benthic biofacies, (b) planktonic diversity.

Figure 8.7

From Eicher & Diner 1985



Nannofossil presence/absence in the below X bentonite time-slice. Nannofossil-bearing samples are enclosed by stippled field. The Pueblo, Colorado locality is denoted by the star.

Nannofossil presence/absence in the above X bentonite time-slice. Nannofossil-bearing samples are enclosed by stippled field. The Pueblo, Colorado locality is denoted by the star. Note the significant increase in the size of the nannofossil filed within the study area.

Figure 8.8

From Watkins 1985

associated with the incursion of warm, southern waters, an increase in salinity and oxygen to 'normal-marine' levels, and the diversification of foraminifera (Figure 8.6) and benthic fauna (e.g. molluscs) marking the first phase of pelagic deposition that characterised the Greenhorn Limestone Formation (Kauffman, 1985b). In the Rebecca K. Bounds core, the sample (1050') from 1.2m (4') below the 'X' bentonite has the first benthic foraminifera recorded and also shows a significant increase in the abundance and diversity of planktonic species. However, no further benthic species were then noted until the Bridge Creek Limestone Member (unpublished poster material from Bergen *et al.*, 1990). This sample also contains an increase in the proportions of 'deep-water' and 'normal-salinity' dinoflagellate cyst species and an increase in the proportions of marine palynomorphs and levels of AOM, which suggests a Tethyan transgressive pulse with associated decreasing benthic oxygen levels.

The uppermost Graneros Shale Formation of western Kansas (equivalent to the lower Lincoln at Pueblo), following the transgressive pulse around the 'X' bentonite, is thought to represent an oxygen-deficient stillstand stage (progradational phase) with a high content of organic carbon (at Pueblo) and a moderately low faunal diversity (Sageman & Johnson, 1985). In the Rebecca K. Bounds core, the sample at 1040' contains decreased abundances and diversities of planktonic foraminifera compared to the samples above and below (unpublished poster material from Bergen *et al.*, 1990), probably resulting from this highstand event, with perhaps greater influence from the Boreal water to the north. This sample also contains an increase in the proportions of 'low-salinity' dinoflagellate cyst indicators. However, a fall in abundance of AOM suggest improved oxygen levels, and low ratios of prasinophytes to dinoflagellate cysts suggest improved vertical circulation. The P/G ratio and the proportions of marine palynomorphs to terrestrial palynomorphs and phytoclasts increase in this sample suggesting increased productivity.

The nannofossils appear in small quantities within 4m (13') of the base of the 'X' bentonite at Pueblo and across Western Kansas though their occurrence is sporadic. This may reflect fluctuations in clastic input or occasional incursions of oceanic surface waters, perhaps as a response to climatic fluctuations. The palaeogeographical distribution of nannofossils from a centimetre below the 'X' bentonite show a geographical spread restricted to the centre of the basin, where environmental conditions were suitably stable and oceanic in character to support significant numbers of nannoplankton. The transgression associated with the base of the Greenhorn Limestone Formation was rapid. Samples taken from a centimetre above the 'X' bentonite show a much wider distribution of nannofossils (over twice the geographical area), though still with the greatest diversities in the central trough of the basin (Figure 8.8). The distribution of nannofossils was thought to be restricted to the central trough of the basin by the influx of freshwater from the basin margins (Watkins, 1985).

Generally the patterns of dinoflagellate cyst indicator species and palynofacies reinforce the ideas of fluctuations in sea level through the deposition of the Graneros Shale Formation as suggested by the lithostratigraphy and patterns of foraminifera, with transgressive events at the base of the formation, at the Thatcher Limestone Member and just below the 'X' bentonite, each followed by probable stillstand (progradational) events.

8.4 GREENHORN LIMESTONE FORMATION

Lithostratigraphically, the base of the Lincoln Member is taken at the base of the first calcarenitic bed, above which lies persistently calcareous shale and other calcarenites (Hattin, 1975, Sageman & Johnson, 1985). In the Rebecca K. Bounds core, the first calcarenite horizon lies 4.39m (14.4') above the 'X' bentonite. The base of the Lincoln Member is characterised by abundant calcareous nannofossils in rock-forming quantities, and signifies the establishment of free and open communication between the Western Interior Basin and oceanic surface waters to the south (Watkins, 1985).

The depositional conditions of the Greenhorn Limestone Formation are thought to be in a low-energy, far-offshore, pelagic environment. Alternating shale and limestone beds suggest alternating periods of quiet-water, oxygen-deficient benthic conditions and periods of well-circulated, well-oxygenated benthic environments and water mass mixing, as periodically, the influx of terrigenous material either waned in absolute or comparative terms resulting in layers of purer carbonate which were extensively bioturbated and subsequently lithified (Hattin, 1975, Sageman & Johnson, 1985).

The Lincoln Member contains numerous calcarenite beds, particularly in the middle and upper parts of the member, which are thought to have formed from occasional and sporadic sediment reworking and winnowing, causing a concentration of coarser bioclastic material. These are only preserved progressively further eastward up through the Lincoln Member as transgression continued and water deepened to the west. The sedimentation of the Hartland Member contains fewer calcarenitic beds and suggests conditions further offshore than represented by the Lincoln Member (Hattin, 1975).

The Bridge Creek Limestone Member records the peak transgression of the Greenhorn cyclothem (Hattin, 1975, Kauffman, 1977a) and the maximum extent of the Western Interior Seaway during the Cretaceous (Figures 1.2 and 7.2). The lack of calcarenites in the lower part of the Bridge Creek Limestone Member indicate that the sea was too deep to allow the currents to scour the sea floor at that time. Hence they are pelagic carbonates with few, if any, current induced structures (Sageman, 1985). The lower half of the middle part of the Bridge Creek Limestone Member has the most laterally continuous limestones occurring in the seaway (Hattin, 1975, Elder & Kirkland, 1985, Cobban, 1985, Glenister & Kauffman, 1985). This marks the peak eustatic rise of the Greenhorn marine cycle, represents a switch from dominantly retrograding sedimentation to dominantly prograding sedimentation and thus by definition is the second-order maximum flooding interval. In the upper part of the Bridge Creek Limestone Member, the rocks become predominantly calcareous shale, with progressively thinner and more calcarenitic limestones, reflecting greater benthic current activity during a time of progradation (Elder & Kirkland, 1985), in the earliest stages of the second-order highstand systems tract.

Virtually all of the Greenhorn Limestone Formation contains ammonites and inoceramids suggesting waters of normal salinity. The broad, nearly-flat shape of the inoceramid bivalves allowed them to live on the soft substrates of the sea floor, and they were tolerant of the low benthic oxygen levels. Many of the species of macrofauna from the Greenhorn Limestone Formation have a global distribution, indicating free communication of the Western Interior Seaway with the worlds oceans (Hattin, 1975).

The diversities of dinoflagellate cyst species are fairly moderate through the Greenhorn Limestone Formation (30-50 species) though they reach a peak through the Hartland Member and lower part of the Bridge Creek Limestone Member (at around 65 species) just below the maximum flooding interval. The proportions of peridinioid cysts remain moderate and fairly stable throughout the samples from the formation.

The environmental signals from the palynological samples are often quite conflicting through the samples of the Greenhorn Limestone Formation, in comparison with the Graneros Shale Formation beneath, perhaps as a result of a variety of different fluctuating environmental parameters and a pelagic/hemipelagic environment of deposition further from sources of terrestrial input.

8.4.1 Lincoln and Hartland Members

The foraminifera of the Lincoln and Hartland Members consist solely of planktonic forms at Pueblo (Figure 8.6), also recording the large-scale Tethyan incursion into the seaway at this time. Originally they simply consisted of small specimens of *Hedbergella* and *Heterohelix*, but the diversity increases in the upper Lincoln and Hartland, due to increasingly open circulation from the southern Tethyan waters. In the Greenhorn Limestone Formation, the generally large imbalance between numbers of planktonic species and numbers of benthonic species within the foraminiferal assemblages is due to the low oxygen levels at the sea floor (Eicher & Diner, 1985). The lack of benthic foraminifera through the Lincoln and Hartland Members suggests that the oxygen levels at the sea-floor were continually low; the levels of AOM in the samples of the Greenhorn Limestone Formation are high, particularly in the Lincoln and Hartland Members.

A significant increase in diversity and abundance of planktonic foraminifera in the Rebecca K. Bounds core is noted in the two samples (1030' and 1020') from the base of the Lincoln Member (unpublished poster data from Bergen *et al.*, 1990). The sample from 1030' shows some increase in the proportions of 'deep-water' dinoflagellate cyst indicator species. However, the sample from 1020' shows a huge change in the dinoflagellate cyst assemblages with a massive increase in 'deep-water' and 'normal-salinity' dinoflagellate cyst indicators. The dinoflagellate cyst assemblages generally remain dominated by these indicator species through the rest of the samples from the Greenhorn Limestone Formation, recording the dominantly pelagic depositional period in the 'Greenhorn sea'. The sample from 1020' contains small numbers of keeled foraminifera, which reoccur in the Hartland Member at 1000' (unpublished poster data from Bergen *et al.*, 1990), and are suggested to indicate palaeobathymetries of greater than 100m deep (Leckie, 1987) although their presence may also have been affected by oxygen levels in the water column (Jarvis *et al.*, 1988). The sample at the base of the Lincoln Member also shows an increase in the ratio of elongate to equidimensional phytoclasts suggesting decreased shoreline proximity.

An alternating transgressive pulse/stillstand (highstand) model is suggested to account for the cyclic patterns of sedimentation and faunal distribution through the Lincoln and Hartland Members at Pueblo (Sageman, 1985, Sageman & Johnson, 1985). These third- and fourth-order cycles from the

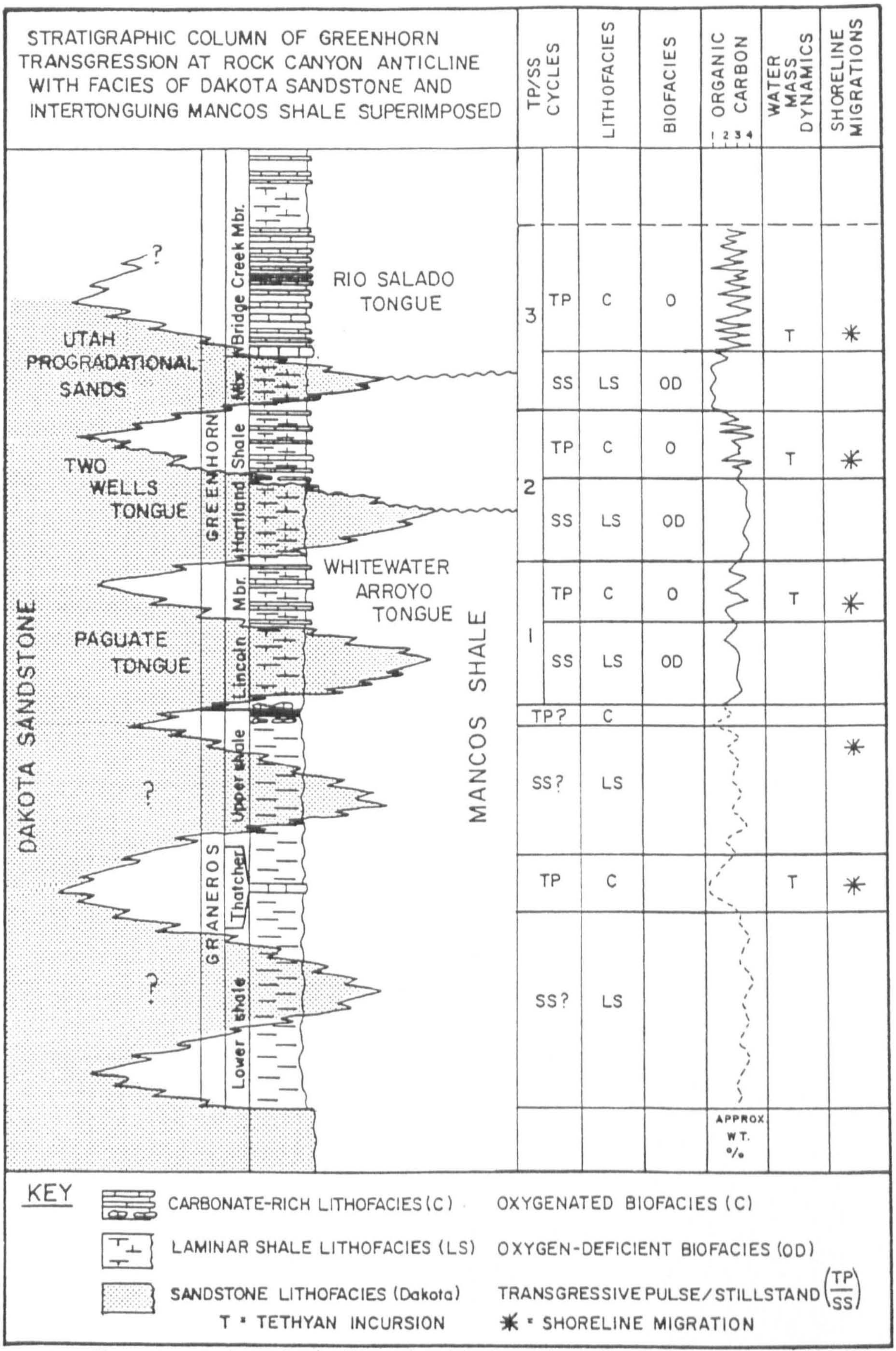
Lincoln upwards have been successfully correlated to prograding sandstone tongues of the Dakota Formation and Mancos Shale in west-central New Mexico and southern Utah (Figure 8.9), supporting this sequence stratigraphic model (Sageman & Johnson, 1985).

These third- and fourth-order sea-level fluctuations have involved periodical changes in benthic oxygen levels. Explanations for this have included an expanded oxygen-minimum zone (Frush & Eicher, 1975) and a brackish-water surface layer producing density stratification (Pratt, 1984, Kauffman, 1984) affected by the sea level changes. However, the levels of AOM increase through the Lincoln Member from around 50% in the sample at the base to 75-80% in the top samples, and remain very high through the Hartland Member (around 75-80%). The ratio of prasinophytes to dinoflagellate cysts rises from low at the base of the Lincoln Member (with around 1 prasinophyte to 4 dinoflagellate cysts) to very high in the upper part of the member (over 4 prasinophytes for every dinoflagellate cyst). The levels in the samples of the Hartland Member are slightly lower but still high (at almost 2 prasinophytes per dinoflagellate cyst). This suggests a high degree of water column stratification in the Lincoln and Hartland Members supporting the theory of density stratification through this period.

The transgressive pulses (third- and fourth-order) represented times of more carbonate-rich deposition with the incursion of oxygen depleted water masses, sediment trapping at the basin margins, and fluctuations in energy levels, oxygen content and faunal assemblages. The alternation of shales and limestones, suggests an alternation of typically quiet-water oxygen-deficient benthic conditions (with a high organic carbon content, and epifaunal bivalve-dominated macrofaunal assemblages) with periods of significant current activity and oxygenation of the benthic zone (with a decrease in organic carbon deposition, peaks in benthic taxa and appearances of diverse assemblages of warm temperate and subtropical bivalves and ammonites) (Sageman & Johnson, 1985). Strata deposited during these intervals include the lower Lincoln Member and the lower Hartland Member of western Kansas. However, all the material studied was sampled from the shales and not from the limestone beds. Samples from these strata (e.g. 1030', 1020', 1000') contain increased abundances and diversities of planktonic foraminifera suggesting greater influences of Tethyan waters from the south. The palaeogeographic distribution of foraminifera during the time of deposition of the lower Hartland Member (equivalent to the middle Hartland Member at Pueblo) is illustrated in Figure 8.10.

The stillstand periods represent progradational phases with a higher clastic sediment input to the centre of the basin, a decrease in bottom current energy, and perhaps the development of salinity stratification. They are characterised by laminated to micro-bioturbated shales, with low-diversity, low-abundance, inoceramid-dominated, epifaunal macrofossil assemblages and preservation of high levels of organic carbon and are thought to represent a sustained periods of oxygen depletion in the Western Interior Seaway (Sageman, 1985, Sageman & Johnson, 1985). Strata deposited during these intervals include the upper Lincoln Member, and upper Hartland Member of western Kansas. The sample from the upper Lincoln Member (1010') contains decreased abundances and diversities of planktonic foraminifera compared with those from the lower Lincoln and lower Hartland members, perhaps suggesting greater influence from Boreal waters from the north.

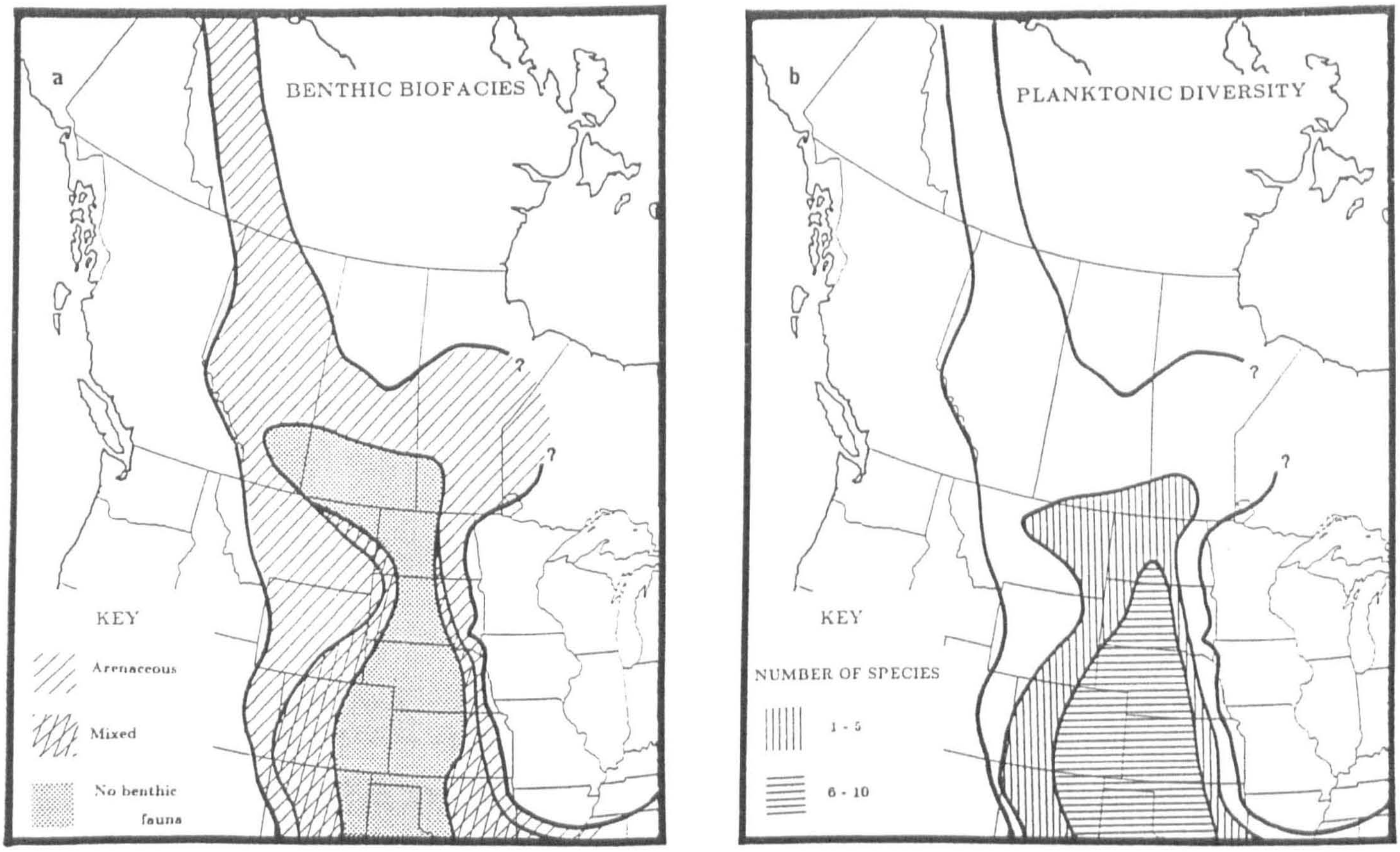
In contrast to the Graneros Shale Formation and Bridge Creek Limestone Member assemblages, the smaller-scale fluctuations in dinoflagellate cyst and foraminiferal assemblages in the samples of the



The transgressive pulse/stillstand model of cyclic sedimentation and oxygen-deficient biofacies distribution -- Greenhorn transgression. Dakota lithofacies of the seaway's western margin are superimposed over the Rock Canyon section. Shoreline migrations are based on Cobban and Hook(1984); geochemical curves for the Graneros Shale are inferred and for the Bridge Creek Member are generalized from Pratt(1983).

Figure 8.9

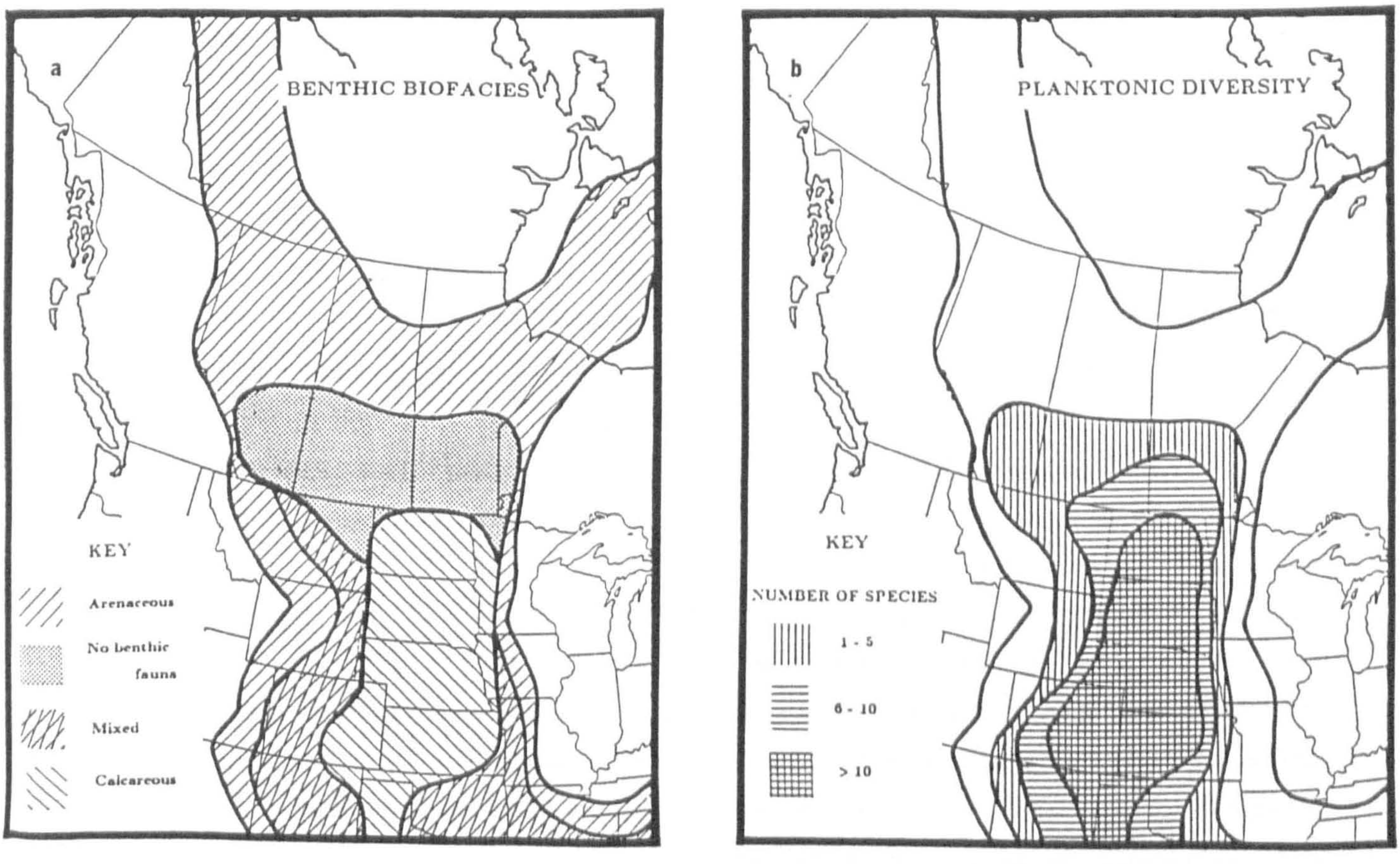
From Sageman 1985



Distribution of foraminifera in the Western Interior during deposition of the middle part of the Hartland Shale Member of the Greenhorn Formation, (a) benthic biofacies, (b) planktonic diversity.

Figure 8.10

From Eicher & Diner 1985



Distribution of foraminifera in the Western Interior during deposition of the lowermost part of the Bridge Creek Limestone Member of the Greenhorn Formation, (a) benthic biofacies, (b) planktonic diversity.

Figure 8.11

From Eicher & Diner 1985

Lincoln and Hartland members have contrary implications. Those with increased diversities and abundances of foraminifera (suggesting increased salinity and water-depth at the time of the transgressive pulses) also contain slightly larger proportions of 'lowered-salinity' and 'shallow-water' dinoflagellate cyst indicator species. However, this may be because the samples were taken from shale horizons.

The levels of brown wood show a sharp fall through the lower half of the Lincoln Member (from around 50% to just above 10%) followed by a large but fairly steady increase through the upper half of the Lincoln, through the Hartland and into the Bridge Creek Limestone Member. The dinoflagellate cyst to miospore, and marine palynomorph to terrestrial palynomorph and phytoclast ratios decrease through the Lincoln and into the Hartland Member suggesting increased terrigenous input. This might support suggested transgression in the lower part and regression in the upper part of the Lincoln Member, but not the transgression in the Hartland Member. In support of the transgression-stillstand model, the samples from 1020' and 1000' contain lower abundances of woody phytoclasts and higher ratios of elongate to equidimensional wood than the samples from 1010' and 990'.

The upper of the two samples from the Hartland Member in the Rebecca K. Bounds core (990') is taken from 0.91m (3') below the base of the Bridge Creek Limestone Member and may not reflect this stillstand event. The sample contains a high abundance and diversity of planktonic foraminifera (unpublished poster material from Bergen *et al.*, 1990), which may result from the transgressive event which occurred just below the base of the Bridge Creek Limestone Member, with greater influence from the Tethyan water to the south. Alternatively the foraminifera from the sample simply do not show this stillstand event.

8.4.2 Bridge Creek Limestone Member

The lower part of the Bridge Creek Limestone Member at Pueblo, reflects a rapid decrease in detrital input into the central seaway from eustatic rise and shoreward migration of the strand-line. The faunas at the base of the 'lower' Bridge Creek Limestone Member contain mixed warm-temperate and subtropical components of the *Sciponoceras* Zone reflecting the incursion of warm southern water masses and increase in salinity to 'normal-marine' levels (Kauffman, 1984, Elder & Kirkland, 1985) at a time of rapid transgression. The palaeogeographic distribution of foraminifera during the time of deposition of the lowermost Bridge Creek Limestone Member is illustrated in Figure 8.11.

The first sample from the Bridge Creek Limestone Member (980') in the Rebecca K. Bounds core, from just below PBC9 at the base of the *Neocardioceras* Zone, shows lower abundances and diversities of planktonic foraminifera than the samples from the Hartland Member (unpublished poster material from Bergen *et al.*, 1990). However, at this stratigraphic level at Pueblo, the planktonic foraminiferal assemblages have already been affected by some of the Cenomanian-Turonian boundary events and have already lost a number of their forms (Figure 8.6), including the keeled taxa, perhaps due to the expanding mid-water oxygen minimum zone (see Chapter 9 for details). In the Rebecca K. Bounds core, some keeled taxa are noted at 980' (unpublished poster material from Bergen *et al.*, 1990) though in lower numbers than in previous samples (990' and 1000'). This indicates that the disappearance of the keeled taxa was not synchronous between localities, perhaps due to the progression of depleted oxygen conditions through the basin. The basinal position of the Rebecca K. Bounds core site represented a shallower depositional environment than Pueblo, along the basinal hinge zone (Kauffman, 1985a) and hence would not have been affected by oxygen depletion deep within the water column until slightly later. The sample from 980' also shows a limited occurrence of benthic foraminifera (not noted in the Rebecca K. Bounds core since the Tethyan transgressive pulse just below the 'X' bentonite at 1050'), suggesting better oxygenation at the sea floor than had previously occurred during deposition of the Greenhorn Limestone Formation. The P/G ratio is fairly stable through the Greenhorn Limestone Formation but the proportion of peridinioid cysts in this sample are much lower than in any other sample studied from the formation, suggesting lower surface productivity at the time of deposition of this horizon.

The levels of brown wood are very high (just under 80%) in the sample from 980', possibly due to the suggested increased run-off in the shale between PBC8 and PBC9 (see Chapter 9). However, the proportions of prasinophytes are very low in this sample (approximately 1 prasinophyte for 10 dinoflagellate cysts) which suggests that water column stratification was not important at this time. The levels of brown wood are much lower through the middle of the Bridge Creek Limestone Member (around 20%) and then increase again through the upper part of the Bridge Creek Limestone Member to around 40% at the top, perhaps from progradation following the maximum flooding interval. The samples from the base of the Bridge Creek Limestone Member (980' and 970') contain some of the highest dinoflagellate cyst species diversities from the Greenhorn cyclothem perhaps suggesting a large influence from both the Tethyan and Boreal water masses. These samples also contain lower abundances of AOM than other samples in the Greenhorn Limestone Formation, which is unusual considering their stratigraphic position so close to the Cenomanian-Turonian boundary with its associated oxygen depletion event.

In the Rebecca K. Bounds core the benthic foraminifera are absent from 970' (the sample from just below the equivalent of PBC15) near the base of the *Watinoceras* Zone in the Early Turonian but noted at 960' (unpublished poster material from Bergen *et al.*, 1990) at the top of the zone suggesting improved benthic oxygen conditions at this time. However, no benthic taxa were then noted again until 890' in the Fairport Chalky Shale Member. A continued decline in benthic foraminiferal abundance and diversity through the middle and upper parts of the Bridge Creek Limestone Member of the Pueblo section was also noted by Eicher & Diner (1985).

In the basal Turonian at Pueblo, the diversity of planktonic foraminifera increases with the radiation of new taxa, including deeper-water keeled forms (Figure 8.6), suggesting improvement in the mid-water oxygen levels (Eicher & Diner, 1985). However, in the samples from the Rebecca K. Bounds core, the decline in planktonic abundance and diversity preceding the end of the Cenomanian continues into the Turonian and on into the middle part of the Bridge Creek Limestone Member (samples 970' and 960') (unpublished poster material from Bergen *et al.*, 1990). The two samples in the lower half of the Bridge Creek Limestone Member (970' and 960') are very different to the other samples from the Greenhorn Limestone Formation in terms of their dinoflagellate cyst assemblages, containing much larger numbers of 'low-salinity' and 'shallow-water' indicator species. Lowered-salinity surface waters might explain the continued decline in planktonic foraminifera at this stratigraphic level.

The *Mammites* Zone of the middle part of the Bridge Creek Limestone Member reflects the peak eustatic rise of the Greenhorn Limestone Formation and contains very high faunal diversities with the largest influx of subtropical to tropical and cosmopolitan taxa around PBC23 to PBC26 at Pueblo (Figure 1.3; Kauffman, 1984). This again reflects open communication with the Tethyan ocean with an increase in salinity and oxygen to 'normal-marine' levels. In the Rebecca K. Bounds core the benthic foraminifera re-appear in the sample from 960', just below the equivalent of PBC23 (unpublished poster material from Bergen *et al.*, 1990), perhaps as a result of increasing benthic oxygen levels. The sample at 950' (near the equivalent of PBC28) shows a slight increase in abundance and diversity of planktonic forms, possibly as a result of the transgressive pulse at the maximum flooding interval. The sample at 950' also contains some keeled planktonic taxa suggesting improved conditions at mid water-column depths. These appearances occur after the re-appearances of the benthic foraminifera suggesting as other authors have done for other localities (e.g. Harries & Kauffman, 1990) that oxygen conditions improved on the sea-floor before they improved higher-up in the water column. The dinoflagellate cyst to miospore and marine palynomorph to terrestrial palynomorph and phytoclast ratios increase from the lower to the middle part of the Bridge Creek Limestone Member supporting the suggestions of transgression.

The sample at 940' (from the middle part of the Bridge Creek Limestone Member) shows both a decline in planktonic abundances and diversities as well as a temporary absence of keeled forms, perhaps suggesting a highstand event with deteriorating oxygen conditions or a decrease in surface salinities. The levels of prasinophytes increase in the samples through the Bridge Creek Limestone Member reaching a maximum at 940' with around equal proportions of prasinophytes and dinoflagellate cysts suggesting increased water column stratification perhaps related to lowered surface salinities. The levels of prasinophytes then fall again in the samples from the upper part of the Bridge Creek Limestone Member.

In the upper part of the Bridge Creek Limestone Member at Pueblo, the warm, normal marine conditions continued to favour high levels of pelagic carbonate production at a time of high productivity and preservation of organic carbon. The stable oxygen isotope signatures show a slight decrease in $\delta^{18}O$ towards the top of the member, associated with a decrease in diversity and abundance of planktonic foraminifera and coccoliths (Elder & Kirkland, 1985).

This is reflected by a significant decrease in the proportions of marine palynomorphs and the ratio of dinoflagellate cysts to miospores in the samples from 920' and 910'. These samples also contain higher proportions of prasinophytes (perhaps suggesting increased stratification from decreased surface salinities), a large increase in the levels of woody phytoclasts (suggesting increased terrigenous input or increased shoreline proximity) and a decrease in the ratio of black to brown wood (suggesting less degradation of the phytoclasts in the water column perhaps from decreased transport time). However, the changes at Pueblo are not noted in the foraminiferal or dinoflagellate cyst assemblages in the samples from the Rebecca K. Bounds core.

The samples from the top of the middle part of the Bridge Creek Limestone Member (930') and from the upper part of the member (920' and particularly 910') show increased planktonic foraminiferal abundances and diversities as well as the presence of keeled forms, suggesting further transgressive pulses with re-oxygenation of the water column (unpublished poster material from Bergen *et al.*, 1990). In the samples through the middle and upper parts of the Bridge Creek Limestone Member, the dinoflagellate cyst indicator species also suggest similar increases in salinity and water-depth with greater proportions of 'deep-water' and 'normal-salinity' dinoflagellate cyst indicator species from 930' upwards into the base of the Fairport Chalky Shale Member. These samples also contain decreasing levels of AOM suggesting improved oxygen levels.

8.5 CARLILE SHALE FORMATION

8.5.1 Fairport Chalky Shale Member

In the Rebecca K. Bounds core and at Pueblo, the Fairport Chalky Shale Member consists of calcareous and chalky shale with thin calcarenite and occasional limestone beds, and is more closely allied in facies and faunas to the Greenhorn Limestone Formation than it is to the Blue Hill Shale Member of the Carlile Shale Formation. The diversity and abundance of planktonic foraminifera and coccoliths shows a decrease towards the top of the Bridge Creek Limestone Member, but increases again at the base of the Fairport Chalky Shale Member (Figure 8.12; Glenister & Kauffman, 1985).

Samples from the Fairport Chalky Shale Member contain greater proportions of 'normal-salinity' dinoflagellate cyst indicator species than those from the Bridge Creek Limestone Member. The fewer 'deep-water' dinoflagellate cyst indicators suggest that sea-levels may have been lower (although keeled planktonic foraminifera occur through much of the Fairport Chalky Shale Member) and the comparatively small increase in 'lowered-salinity' and 'shallow-water' dinoflagellate cyst indicators suggests that salinities remained fairly near to 'normal-marine' levels.

At Pueblo, the sediments of the lower part of the Fairport Chalky Shale Member suggest normal marine conditions in warm, well circulated seas near the basin centre, with moderately oxygenated substrates and high levels of winnowing producing numerous calcarenite horizons. The warm, normal marine conditions continued to favour high levels of pelagic carbonate production at a time of high productivity and preservation of organic carbon. Oxygen levels below the sediment-water interface were still poor with little bioturbation, although the lower part of the Fairport Chalky Shale Member is richly fossiliferous, particularly with ammonites and bivalves (Glenister & Kauffman, 1985). The levels of AOM are fairly high through the member but fluctuate between lower values of around 50 to 60% and higher values of around 80%. Fluctuating stable isotope values have been interpreted (Pratt, 1983, 1984, 1985) as slight changes in surface salinity. The alternating limestone/calcarenite and chalky shale/shale beds suggest a continuation in visible expression of Milankovitch cycles. The levels of woody phytoclasts are comparatively low through much of the lower half of the Fairport Chalky Shale Member suggesting decreased terrigenous input during this period.

Planktonic foraminifera remain abundant through the Fairport Chalky Shale Member, though diversity falls off rapidly above the lower 20 metres (at Pueblo), leaving only small specimens of *Hedbergella* and *Heterohelix* (Figure 8.12). Only a few hardy species of benthic foraminifera remain through the lower two-thirds of the member. These assemblages are very similar to those in the Lincoln

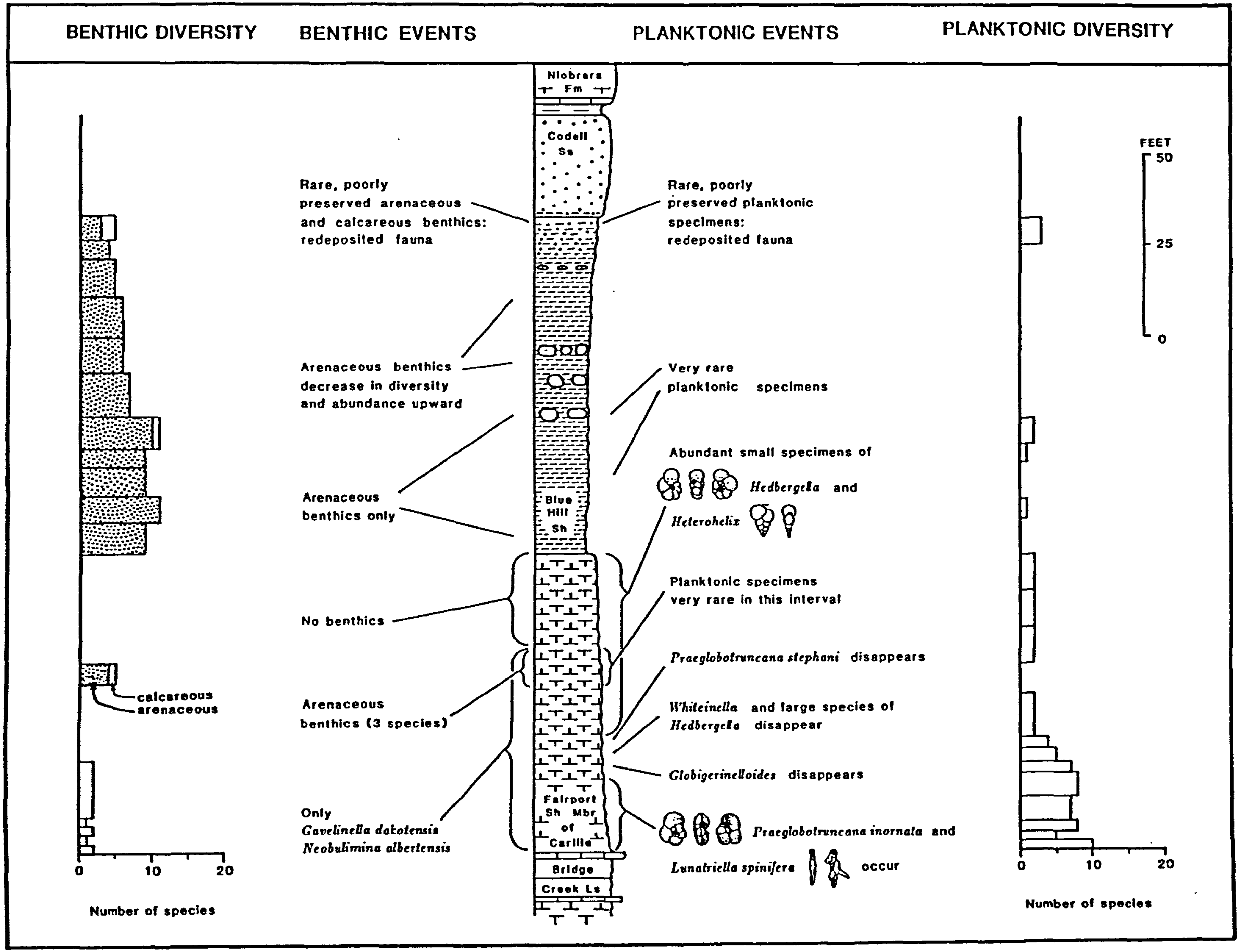


Figure 8.12

Overview of the occurrences of foraminifera in the Carlile Shale Formation at the Rock Canyon Anticline, near Pueblo.

From Eicher & Diner 1985

and much of the Hartland Members and suggest that oxygen became too depleted to support the benthic forms and the seas became too shallow for all but the most broadly distributed planktonics.

The distribution pattern of planktonic foraminifera through the Fairport Chalky Shale Member in the Rebecca K. Bounds core is one of general decline in diversity, after initial increases. The lowest sample (900') from the member shows a large decrease in abundance and diversity of the planktonic forms compared with the uppermost sample from the Bridge Creek Limestone Member, probably due to a regressive trend with shoaling of the seaway. This is further supported by the disappearance of the keeled taxa (present at the top of the Bridge Creek Limestone Member) perhaps suggesting water depths of less than 100m (Leckie, 1987). Alternatively, the lack of keeled taxa may be due to lower oxygen levels in the water column. By contrast, this sample also shows an increase in the proportion of 'deep-water' dinoflagellate cyst indicator species, particularly the *Chlamydophorella nyei/Dapsilidinium ambiguum* complex.

The abundance and diversity of the planktonic foraminifera increased further into the lower Fairport Chalky Shale Member (890', 880' and 870') with small occurrences of benthic taxa at 890' and 870' and small occurrences of keeled taxa at 880', suggesting improved oxygen conditions and/or increased water depths, possibly from small transgressive pulses in the lower part of the member. These samples also show an increase in the ratio of elongate to equidimensional wood fragments suggesting a further-offshore environment of deposition. However, the dinoflagellate cyst and foraminiferal assemblages in the sample from 890' again have contrasting environmental implications, with increases in 'lowered-salinity' dinoflagellate cyst indicator species (in particular *Canninginopsis colliveri* and *Cyclonephelium brevispinatum*). The sample from 880' shows a return to foraminiferal and dinoflagellate cyst assemblages with compatible environmental implications as the proportions of 'deep-water' and 'normal-salinity' dinoflagellate cyst indicator species increase significantly.

The lower three samples (900' to 880') of the Fairport Chalky Shale Member have comparatively lower levels of AOM suggesting increased levels of oxygen in the water column, while the ratios of black to brown wood increase at 890' suggesting increasing degradation of the phytoclasts at this level. The dinoflagellate cyst to miospore ratios and marine palynomorph to terrestrial palynomorph and phytoclast ratios have very similar curves, fluctuating through the lower part of the member though with slight increases in dinoflagellate cyst/marine ratios at 880' and 850', suggesting transgressional pulses around the time of deposition of these horizons.

The ratio of prasinophytes to dinoflagellate cysts is fairly high through much of the Fairport Chalky Shale Member (with over 1 prasinophyte per 2 dinoflagellate cysts). This ratio increases at 870' and at 860' reaches approximately 2 prasinophytes per dinoflagellate cyst, suggesting an increase in water column stratification at this time. The levels of AOM in the samples 870' to 850' are comparatively high, perhaps as a result of increased water column stratification. However, the ratios of black to brown wood also increase around 860' suggesting increasing degradation of the phytoclasts at this level. The sample at 870' shows the highest abundances of foraminifera recorded from the Greenhorn cyclothem of the Rebecca K. Bounds core. After this the abundance and diversity of planktonic foraminifera show a general decline, punctuated by temporary increases, with peaks at 850' and 830' perhaps representing Tethyan pulses, though each showing decreasing magnitude. The samples at 860', 850' and 830' contain small numbers of keeled taxa (unpublished poster material from Bergen *et al.*, 1990), suggesting that at the time of deposition of these horizons, the depths remained above 100 metres.

The upper part of the Fairport Chalky Shale Member records the first major effects of shoaling (shallowing) and sea-level fall in the seaway with an increase in silt content, and a decrease in the warm-water faunal elements. An increase in restriction of benthic oxygen levels at this time, led to a depauperate benthic macrofauna, a highly depleted benthic foraminiferal assemblage and increased organic matter preservation, and may signal the re-establishment of a constricted southern aperture for the seaway, preventing open-ocean circulation. Glenister & Kauffman (1985) also suggest that a brackish-water surface layer was re-established on the seaway, causing salinity stratification and thus preventing vertical circulation. At the top of the member, a further increase in silt content suggests a continued shoaling of the seaway, with increasing current activity and hence oxygenation of the seafloor.

The horizon at 840' shows a general decline in planktonic foraminiferal abundance and no keeled taxa, and may represent deposition during a regressive phase. The levels of woody phytoclasts increase in this sample. The samples from both 840' and 830' show a comparative decrease in the levels of AOM suggesting increased oxygen levels in the water column.

The levels of woody phytoclasts gradually decrease through the upper half of the member to less than 10% at the top suggesting decreased terrigenous input over this period. The ratios of black to brown wood increase from 830' to 820' suggesting increasing degradation of the phytoclasts at this level. Above 830' the dinoflagellate cyst to miospore ratios and marine palynomorph to terrestrial palynomorph and phytoclast ratios start to increase in the upper part of the Fairport Chalky Shale Member and reach a peak at the base of the Blue Hill Shale Member.

A short interval at Pueblo (around two-thirds of the way up the Fairport Chalky Shale Member), contains a few arenaceous foraminifera but few planktonic forms (Figure 8.12) suggesting a temporary influence of the Boreal water mass, or indicating that the influence of the southern water-mass was temporarily diminished. The absence of planktonic species in the sample from 820' in the Rebecca K. Bounds core, may represent this temporary Boreal influx. This sample contains a decrease in the proportions of 'deep-water' dinoflagellate cyst indicator species but not an increase in the proportions of 'lowered-salinity' forms. This sample is, however, marked by an increase in the levels of prasinophytes. Above 820' the ratio of prasinophytes to dinoflagellate cysts drops fairly gradually through the remainder of the member, suggesting decreasing water column stratification. The samples 820' and 810' show a comparative increase in the levels of AOM, perhaps from increased stratification.

The sample from 810' contains a larger proportion of 'lowered-salinity' dinoflagellate cyst indicator species. However, the planktonic foraminifera increase in abundance and diversity from 810' to 790', perhaps resulting from a final transgressive pulse in the uppermost Fairport Chalky Shale Member. This is followed by a decline in the Blue Hill Shale Member at 780', with a last occurrence of planktonic taxa recorded at 770' (unpublished poster material from Bergen *et al.*, 1990). The diversity of dinoflagellate cyst species is fairly stable (at around 50 species) through the formation, but reaches a peak (around 65 species) just below the top of the Fairport Chalky Shale Member, at 800'. This sample also shows an increase in 'deep-water' dinoflagellate cyst indicator species and an increase in the ratio of elongate to equidimensional phytoclasts (both suggesting a transgressive pulse), but a comparative decrease in the levels of AOM (suggesting increased oxygen levels). The ratios of black to brown wood decrease at the top of the Fairport Chalky Shale Member suggesting less degradation of the phytoclasts at this level.

8.5.2 Blue Hill Shale Member

The Blue Hill Shale Member is an example of a gradational regressive marine sequence from proximal offshore to lower distal shoreface environments. The filling and shoaling of the basin continued with recirculation and reoxygenation of the benthic zone at the beginning of Blue Hill Shale Member deposition. Oxygen levels in the benthic zone were high, supporting a diverse burrowing and shelly fauna and preventing organic matter preservation. Current circulation also increased up section with shoaling. The levels of AOM in the member are much lower than in the Fairport Chalky Shale Member and generally decrease in the samples through to the top of the member, suggesting continually improving benthic oxygen levels.

The Blue Hill Shale Member is lithostratigraphically equivalent in the Pueblo section and the Rebecca K. Bounds core but not chronostratigraphically equivalent as the member was probably deposited earlier in western Kansas than in Colorado. The member is also much thinner in the Rebecca K. Bounds core than at Pueblo, probably due to the flatness and shallow gradient of the cratonic shelf over the eastern margin of the basin.

At Pueblo, foraminiferal assemblages from the Blue Hill Shale Member consist of arenaceous benthic specimens similar to those in the Graneros Shale Formation, as well as some calcareous benthic foraminifera (Figure 8.12). The lower part of the member contains rare planktonic forms (*Hedbergella* and *Heterohelix*) suggesting that a weak connection remained with the southern ocean. The variety and abundance of arenaceous benthic species increases up into the Codell Sandstone Member (Eicher & Diner, 1985). In the Rebecca K. Bounds core, the planktonic foraminifera show a decline in diversity and abundance through the lowermost Blue Hill Shale Member (samples at 780' and 770') with final appearances at 770'. This suggests greater connection with the Tethys at the time of deposition of the Blue Hill Shale Member in Kansas compared with the time of deposition of the member in Colorado. Benthic foraminifera first appear in the Blue Hill Shale Member at 770' as arenaceous taxa, and increase in abundance and diversity as shoreline proximity increased in samples 760' and 750' (unpublished poster material from Bergen *et al.*, 1990), mirroring the patterns recorded from the Pueblo section (Eicher & Diner, 1985).

The sample at the base of the Blue Hill Shale Member (780') shows a large decline in 'deep-water' dinoflagellate cyst indicator species and an increase in 'shallow-water' and 'normal-salinity' species. An increase in 'lowered-salinity' dinoflagellate cyst indicator species only occurs in the sample from 770'.

The lower part of the Blue Hill Shale Member contains no macrofossils, but the blocky nature of the shale suggests intense micro-bioturbation. High benthic turbidity is thought to have precluded suspension-feeding bivalves. The concretionary layers in the middle part of the member at Pueblo contain a diverse molluscan assemblage, including infaunal and epifaunal forms characteristic of normal marine, lower shoreface and proximal offshore environments (Glenister & Kauffman, 1985).

The upper part of the Blue Hill Shale Member represents the lower shoreface transition unit into the Codell Sandstone Member above and is highly bioturbated (with abundant and diverse trace fossils), except for a few thin beds representing the distal edges of storm deposits. One septarian concretionary layer contains sparse oyster lenses. Towards the top of the Blue Hill Shale Member, the seafloor came within reach of storm wave base and rapid sedimentation.

The presence of ammonites and inoceramids indicates normal marine conditions near the top of the Blue Hill Shale Member at 761.8' and 760.9'. The sample from 750', from the top of the Blue Hill Shale Member maintains a high dinoflagellate cyst species diversity, but it contains greater proportions of 'lowered-salinity' dinoflagellate cyst indicator species than the sample from below.

The peridinioid proportions within the samples are reasonable steady through the Carlile Shale Formation but show an increase in the Blue Hill Shale Member. This is probably due to increasing nutrient levels at the site of deposition from increasing shoreline proximity as sea-levels regressed.

The levels of membranous material are unexpectedly low in the Blue Hill Shale Member (lower than through the Graneros Shale Formation) and only increase slightly in the sample from just below the base of the Codell Sandstone Member. The levels of brown wood remain steady through much of the Blue Hill Shale Member, only increasing in the top two samples, but even then are still in much lower proportions than in most samples studied. Miospore levels are low throughout the member, with only a slight increase in the uppermost sample. The spore:pollen ratio is quite variable through the Carlile Shale Formation, but the most noticeable (though still small) increase occurs in the top sample of the Blue Hill Shale Member. The proportions of marine palynomorphs decrease steadily through the member, but are much higher in the Blue Hill Shale Member than in most of the sediments of the Greenhorn cyclothem: the levels at the top of the member are very similar to those found at the base of the Graneros Shale Formation but much higher than any ratios noted from the Dakota Formation. This suggests that either conditions were further offshore than suggested by Glenister & Kauffman (1985) or that terrigenous input was very low, perhaps due to drier climatic conditions, or that productivity was high enough to overwhelm the terrigenous palynomorphs and phytoclasts. Whatever the reason, the palynofacies and proportions of dinoflagellate cyst indicator species suggest that the environment at the time of deposition of the Blue Hill Shale Member was quite different to that of the 'lower shale member' of the Graneros Shale Formation.

8.5.3 Codell Sandstone Member

The Codell Sandstone Member represents the final shoaling of the seaway within the Greenhorn cyclothem. It was deposited under shallow water, wave and current agitated, fully oxygenated marine conditions. At Pueblo, the lower part of the Codell Sandstone Member is thought to represent lower shoreface environments, below fair-weather wave base but in reach of storm waves. The middle part of the Codell Sandstone Member represents middle shoreface, trough-bedded, highly bioturbated sands. The upper part of the Codell Sandstone Member represents the middle to upper shoreface transition with bioturbated storm beds. There is no upper shoreface and foreshore sequence at Pueblo (Glennister

& Kauffman, 1985), presumably removed (if they existed) by subsequent erosion in the terminal regression of the Greenhorn cycle. The top of the Codell Sandstone Member is marked by a major regional unconformity at 675', and is overlain by the transgressive systems tract of the Niobara transgressive-regressive cyclothem (second-order).

8.6 CONCLUSIONS

The strata of the Greenhorn cyclothem represent a series of changing depositional environments in response to a second-order transgressive-regressive eustatic cycle (Figure 8.1). In western Kansas, the depositional environments of the transgressive systems tract changed from non-marine and marginal marine (Dakota Formation) to proximal and medial marine shelf (Graneros Shale Formation) to pelagic marine distal shelf (Greenhorn Limestone Formation) in a suite of facies displaying a general fining upward of siliciclastic material and increasing carbonate-content (Figure 8.1). The regressional depositional environments of the highstand systems tract returned through pelagic marine distal shelf (Greenhorn Limestone Formation and Fairport Chalky Shale Member of the Carlile Shale Formation) to medial and proximal marine shelf (Blue Hill Shale Member) and finally to proximal shoreface (Codell Sandstone Member) in a suite of facies displaying general coarsening upward of siliciclastic material and decreasing carbonate-content. The second-order sequence boundaries lie at the base of the upper Dakota Member and at the top of the Codell Sandstone Member (Figure 3.5). The second-order maximum flooding interval at the peak of rising sea-level rates occurred in the middle of the Bridge Creek Limestone Member of the Greenhorn Limestone Formation, and represents a switch from dominantly retrograding sedimentation to dominantly prograding sedimentation.

The fluctuating eustatic levels changed shoreline proximities and bathymetries and hence also the salinity of the water, which is particularly noted by the changing assemblages of calcareous microfossils. The Western Interior Seaway extended between the Boreal ocean to the north and the Tethyan ocean to the south (Figure 1.2), and hence was affected by very different water masses from each end. The foraminifera suggest that the seaway of Colorado and Kansas was originally filled by cooler, lower-salinity water from the Boreal ocean, with subsequent transgression bringing in warmer, higher-salinity water from the south. Hence the deposition of the Dakota Formation and part of the Graneros Shale Formation along with part of the Blue Hill Shale Member and the Codell Sandstone Member was dominated by the Boreal water mass with its characteristic fauna and flora. Similarly the Greenhorn Limestone Formation and Fairport Chalky Shale Member were largely affected by the Tethyan water mass.

Over this pattern produced by the second-order sea-level fluctuations, the patterns of third- and fourth-order fluctuations have also been noted, particularly through the Greenhorn Limestone Formation (e.g. Sageman, 1985). The sampling resolution from the Rebecca K. Bounds core (at 10' intervals) has generally picked up the environmental fluctuations at this scale, but the resolution is probably not fine enough to record these fluctuations with complete conviction.

8.6.1 Variations from sea level change

A number of general patterns may be picked out from the palynological proportion and ratio curves in reaction to the second-order transgressive-regressive marine cycle.

The dinoflagellate cyst species diversity curve often shows significant increases in the samples deposited at the time of transgressive pulses. The highest overall diversities occur both before the maximum flooding interval and also at the top of the Fairport Chalky Shale Member. The samples deposited at the time of the Thatcher Limestone Member resulting from transgression during deposition of the Graneros Shale Formation also contains very high diversities. This suggests that perhaps in the Western Interior Basin, highest species diversity occurred at times of greatest water mass mixing.

The proportions of dinoflagellate cyst indicator species very clearly suggest a history for the Greenhorn cycle. The Graneros Shale Formation is dominated by 'low-salinity' indicator species at a time of deposition in a medial to distal shelf environment dominated by the Boreal water mass. The Greenhorn Limestone Formation is marked by a large switch to dominance by 'deep-water' indicators at a time of deposition in a pelagic/hemipelagic distal shelf environment at a time of greatest Tethyan influence. The Carlile Shale Formation is marked by a fairly even mix of indicator species suggesting that compared to the time of deposition of the Greenhorn Limestone Formation, the sea was shallower with lower salinities but not as shallow or brackish as during deposition of the Graneros Shale Formation.

Despite the low sampling resolution available for the Rebecca K. Bounds core, the proportions of dinocyst indicator species are able, with some confidence, to pick up the third- and fourth-order transgressive pulses. Transgressive pulses are most clearly suggested around the Thatcher Limestone Member and the 'X' bentonite in the Graneros Shale Formation; at the base of the Lincoln Member and at the base, middle and top of the Bridge Creek Limestone Member of the Greenhorn Limestone Formation; and at the base, middle and top of the Fairport Chalky Shale Member of the Carlile Shale Formation.

The peridinioid/gonyaulacoid ratio suggests higher productivity at a number of times in a number of different environments. Higher productivity is suggested in the brackish environment at the top of the Dakota Formation and also in the proximal shelf environment of the Blue Hill Shale Member. Higher peaks in productivity also are suggested in the samples following the transgressive pulses of the Thatcher Limestone Member and above the 'X' bentonite. Productivity was generally fairly high throughout the Greenhorn cycle except in the 'lower shale member' of the Graneros Shale Formation and in the sample from the base of the Bridge Creek Limestone Member.

The abundance of AOM is generally high through most of the sediments of the Greenhorn cyclothem. The main exceptions are the samples from the Dakota Formation and the Blue Hill Shale Member which were deposited in near-shore/marginal marine environments and hence had well-oxygenated substrates.

The ratio of marine palynomorphs to terrestrial palynomorphs and phytoclasts and the ratio of dinoflagellate cysts to miospores have fairly similar curves through the Greenhorn cyclothem but neither show a clear overall sea-level curve for the samples studied. The largest anomaly is the high proportion of the marine palynomorph/dinocyst fraction in the Blue Hill Shale Member, perhaps due to very high productivity.

The ratio of elongate to equidimensional woody phytoclasts did not reflect changes in sea level in near-shore or proximal shelf environments of the Dakota Formation, 'lower shale member' of the Graneros Shale Formation and Blue Hill Shale Member. It also showed little change through the Bridge Creek Limestone Member in a distal pelagic environment. However in medial to distal shelf environments the curve frequently showed an increase in the proportion of elongate fragments at times of transgressive pulses, particularly around the Thatcher Limestone Member, at the base of the Lincoln and Hartland Members, and at the base and top of the Fairport Chalky Shale Member. It is possible that in proximal environments the off-shore transport of woody phytoclasts may not have been sufficient to allow suitable hydrodynamic differentiation of the phytoclasts; however, this is not particularly convincing.

The ratio of prasinophytes to dinocysts is interesting in suggesting very high levels of water column stratification during deposition of the Lincoln and Hartland Members, but also high levels during deposition of the lower and 'upper shale member' of the Graneros Shale Formation, and the middle part of the Bridge Creek Limestone Member and middle Fairport Chalky Shale Members.

Conclusions from the combined dinocyst and palynofacies results along with those from previous work are mutually supportive on a general level. However, in some instances discrepancies occur, particularly in the pelagic sediments of the Greenhorn Limestone Formation. This may result from a number of situations perhaps due to a combination of: 1) greater distances from the source of terrigenous input and the production of many of the dinoflagellate cysts; 2) highly fluctuating conditions at the meeting point of different water masses; and/or 3) deep-sea current activity leaving no signal of its own.

8.6.2 Comparison of dinoflagellate cyst and foraminiferal data

The good overall agreement between conclusions from the foraminiferal data and from changes in proportions of dinocyst indicator species add further support for the 'time-slice' results and their use in the high resolution boundary studies for detecting environmental change.

In some cases, for example in the sample from below the Thatcher Limestone Member, the dinoflagellate cysts show a faster reaction to sea level and water mass change than the foraminifera. The high abundance and diversities of dinoflagellate cysts in samples with very restricted foraminiferal and nannofossil assemblages confirms that meroplanktonic dinoflagellates were far less restricted by lowered salinities and oxygen levels than the calcareous microplankton, and hence were probably able to invade new areas much faster.

8.6.3 Boreal and Tethyan affiliations

Studies of both recent and pre-Quaternary material have shown that dinoflagellate cysts are affected by different water masses (e.g. Wall *et al.*, 1977, de Reneville & Raynaud, 1981, Dodge, 1994). The foraminiferal and nannofossil assemblages have been successfully used to trace Boreal and Tethyan water mass movements in the Western Interior Basin (e.g. Eicher & Diner, 1985, Watkins, 1985, 1986). As mentioned, however, the meroplanktonic dinoflagellates are far less restricted by lowered salinities and hence do not show such a clear relationship with different water masses. Nevertheless, it is still possible to try and differentiate between some Boreal and Tethyan species.

Of all the sediments studied from the Rebecca K. Bounds core, only those from the Dakota Formation are considered to have been deposited under a water mass of entirely Boreal origin (Gustason & Kauffman, 1985). The transgression at the base of the Graneros Shale Formation opened up a weak connection with the Tethyan ocean, but owing to the rapid migration of meroplanktonic dinoflagellates and their comparative tolerance of low-salinity conditions, it is not possible to say that the assemblages of the Graneros Shale Formation were entirely Boreal although the assemblages are likely to have been Boreal-dominated, particularly at the base of the formation. Likewise the connection to the Tethyan ocean was not thought to have entirely closed until the deposition of the Codell Sandstone Member (Glennister & Kauffman, 1985), hence the assemblages of the Blue Hill Shale Member may also have Tethyan components, although they are likely to have become increasingly Boreal dominated towards the top. However, no samples from this study can be said to be entirely Tethyan as an open connection always existed to the north. Hence only very tentative suggestions can be made for any species with Tethyan affiliations.

Some species seem to show strong Boreal affiliations. These include *Dapsilidinium marinum*, *Dinopterygium reticulatum*, and *Subtilisphaera hyalina* described from the Lower and Middle Cenomanian of Alberta (Singh, 1983) and found in the Lower and Middle Cenomanian of the Rebecca K. Bounds core. *Senoniasphaera microreticulata*, also described from Canada (Brideaux & McIntyre, 1975), appears near the top of the Graneros Shale Formation but only in two samples which have decreased numbers of planktonic foraminifera suggesting increased Boreal influence. *Spongodinium* sp. cf. *S. delitiense* also only appears in two samples from the Rebecca K. Bounds core, one of them from the base of the Graneros Shale Formation (1110') and the other from the top of the Blue Hill Shale Member (750') although this could be due to environmental restrictions. However this species is not found in the boundary sections from the western localities (deposited in nearer-shore environments).

Differences in Cenomanian assemblages from Canada and Texas were attributed to differences in water temperature (Davey, 1970), with abundant species of *Eurydinium* and *Isabelidinium* associated with a boreal water mass. *Eurydinium glomeratum* and *Isabelidinium? globosum* are a major part of the dinoflagellate cyst assemblages from the middle of the Bridge Creek Limestone Member to the middle of the Fairport Chalky Shale Member and may indicate Boreal surface waters at this time. A number of peridinioid species also become important in the upper part of the Fairport Chalky Shale Member and Blue Hill Shale Member (*Alterbidinium rhombovale*, *Chatangiella granulifera tenuis*, *C. spectabilis*, *C. victoriensis* and *Isabelidinium cooksoniae*) at a time of decreasing abundance and diversity of planktonic foraminifera (Eicher & Diner, 1985, unpublished poster material from Bergen *et al.*, 1990). Again this may be attributable to an increase in the dominance of the Boreal water mass.

Species that might show Tethyan affiliations (not just from the Rebecca K. Bounds core samples but also from the boundary sections) include *Achomosphaera regiensis*, *Adnatosphaeridium tutulosum*, *Ellipsodinium rugulosum*, *Leberidocysta defloccata*, *Membranilarnacia polycladiata*, *Occisucysta hinzii*, *Stephodinium coronatum*, and *Tehamadinium coummia*. These species are generally only those that occur at times of known greater Tethyan influence, although it is quite possible that many of them are reacting to the deeper-water or more 'normal-salinity' conditions at the time. However, some of them have only been described from localities that would have been 'in' the Tethys at the time of deposition.

Some species from the 'time-slice' study (e.g. *Cyclonephelium paucimarginatum*, *Disphaeria macropyla*, *Endoscrinium campanula*, *Kiokansium unituberculatum*, *Operculodinium* sp. A, *Psaligonyaulax deflandrei* and *Spiniferites wetzellii*) do not show any preferences for differences in environment. However they do show associations with other comparatively scarce species with 'deep-water' or 'normal-salinity' environmental preferences. This may be attributable to increases in importance of the Tethyan water mass. Species of *Operculodinium* have been associated with warmer water masses from studies of recent material (e.g. Davey & Rogers, 1975, Edwards & Andrle, 1992).

However, the relationship between 'deep-water' or 'normal-salinity' species and water mass is not clear cut. For example species of *Pterodinium* and *Impagidinium* are suggested from pre-Quaternary studies to indicate an oceanic influence (e.g. Wall *et al.*, 1977, Harland, 1983, Wilpshaar & Leereveld, 1994) and in this study are found to have 'normal-salinity' (though not particularly 'deep-water') preferences. However *Pterodinium cingulatum* and *Impagidinium modicum* are unlikely to be entirely Tethyan as they have been recorded as far north as Canada and the Arctic (Brideaux & McIntyre, 1975, Singh, 1983, Ioannides, 1986). Species of *Impagidinium* have been noted with colder water affinities (Bujak, 1984) and it may be that *I. modicum* may represent a Boreal influence though at times of transgression.

At this stage, it does not seem possible to reliably separate the different palaeoenvironmental parameters affecting meroplanktonic dinoflagellates and their cyst assemblages. The potential is very good for using dinoflagellate cysts to separate water masses of different character, but a basin-wide (both longitudinal as well as latitudinal) palaeogeographical study of a particular chronostratigraphic horizon would be needed, equivalent to the nannofossil study of Watkins (1986).

CHAPTER 9

THE CENOMANIAN - TURONIAN BOUNDARY EVENT: PALYNOLOGICAL VARIATIONS AND INTERPRETATIONS

9.1 INTRODUCTION

Marine strata from many sites from a variety of basinal settings across the globe, deposited in Late Cenomanian and Early Turonian time, contain high levels of organic carbon suggesting a period of oxygen deficiency based on lithological, faunal and geochemical characteristics. High $\delta^{13}C$ values in sediments across the boundary are suggested to result from an enrichment of $\delta^{13}C$ in the oceans as a result of the preferential extraction of $\delta^{12}C$ by the marine plankton with its increased subsequent burial and diminished levels of recycling. One suggested reason for this is an expansion and intensification of the oxygen minimum zone (e.g. Schlanger & Jenkyns, 1976, Schlanger *et al.*, 1987, Arthur *et al.*, 1987) which occurred at a time of transgression, approaching a combined first- and second-order eustatic highstand (Kauffman & Caldwell, 1993). A further model suggested for the Western Interior Basin (Arthur *et al.*, 1987) is one of stable water mass stratification under a lowered salinity lid in periods of wetter climate as a result of Milankovitch driven wet and dry cycles reflected in the limestone-shale bedding couplets.

Much geological data is available for the sections studied from the extensive literature published on facets of the Western Interior Basin and the Cenomanian-Turonian boundary event. The aspects of the geology involve many topics in lithostratigraphy, palaeontology and geochemistry and have led to many theories on the palaeoecology and palaeoceanography of the basin. The aims of this chapter are to compare, in detail, the palynological assemblage variations with the published data to suggest reasons for- or reactions to the 'Cenomanian - Turonian boundary oceanic anoxic event' in the Western Interior Basin.

The locations of the section sites studied are described in Appendix A and illustrated in Figure 3.1; the samples used along with their range-chart plot depths are listed in Appendix B, and illustrated alongside the lithological logs in Figures 3.16 (Blue Point section), 3.13 (Wahweap Wash section), 3.9 (Pueblo section), 3.8 (Rebecca K. Bounds core), and 3.11 (Bunker Hill section); the authors for the dinoflagellate cyst and other palynomorph species are listed in Appendix C; the species are illustrated in Appendix D; and the occurrences/abundances of individual species and of the palynofacies assemblages are illustrated in the range charts, located in Appendix E.

9.1.1 Palynological method

The pattern of distribution of dinoflagellate cysts, marine palynomorphs and palynofacies through the sections in response to palaeoenvironmental change will have been affected by the channel sampling. This will have averaged down any assemblage fluctuations resulting from environmental changes, but it also means that none of the shorter-term fluctuations will have been lost.

As with the analysis of the Rebecca K. Bounds core, the environmental significance for the proportions of dinoflagellate indicators are as follows: 'the deep-water' species are by definition also normal-salinity species; the 'lowered-salinity' species are by definition also shallow-water species; the 'shallow-water' species are tolerant of ranges of salinity; and the 'normal-salinity' species show little preference for differences in water depth. The species of dinoflagellate cyst suggested to have these environmental preferences are listed in Figure 7.12.

The curves from the dinoflagellate cysts (Figures 9.1, 9.12, 9.15 and 9.24) are obviously linked. Through the samples, the species diversity curve is affected by the P/G ratio, particularly in those samples which are strongly dominated by marine amorphous organic matter (making counting procedures difficult) and which contain larger numbers of peridinioid cysts. These samples are also likely to affect the reliability of the proportions of indicator species, in particular in affecting the numbers of rarer taxa counted, which often have a 'deep-water' association and tend to increase at times of transgression.

9.1.2 Dinoflagellate cysts assemblages: General comparisons

The sections each show distinctive patterns of peridinioid/gonyaulacoid ratios, dinoflagellate species diversity and environmental indicator species.

The peridinioid/gonyaulacoid ratios are calculated as the ratio of the number of individual peridinioid cysts to the total number of gonyaulacoid and peridinioid cysts per sample. The Bunker Hill section has very high P/G ratios in all of the samples, averaging around 66% (66 peridinioid cysts per 100 peridinioid and gonyaulacoid cysts). The samples from the Rebecca K. Bounds core averaged 46%; although the results are not strictly comparable as they are an average over the Greenhorn cyclothem, rather than just across the Cenomanian-Turonian boundary. The western sections have lower values with the Wahweap Wash section at 40% and the Blue Point section at 38%. Pueblo has the lowest overall P/G ratios at around 35%.

The Bunker Hill site is suggested to have had moderate to high nutrient levels resulting in much higher organic productivity (Harries & Kauffman, 1991), compared with the other sites. The much higher P/G ratios for the samples from this section confirm suggestions that these ratios can be used in pre-Quaternary studies as a measurement of palaeoproductivity (e.g. Eshet *et al.*, 1994; see Chapter 6 for full review of previous work). The productivity across the transect suggests that nutrient levels were lowest in the centre of the Western Interior Basin, perhaps away from a terrestrial or upwelling source of nutrients.

The diversity of dinoflagellate cyst species is greatest in the centre of the basin with the Pueblo and Rebecca Bounds sites averaging around 46 species per sample. The western sites had lower species diversities (averaging 41 and 39 species per sample for Wahweap Wash and Blue Point respectively) and the Bunker Hill site had the lowest diversities (averaging 34 species per sample). This confirms the previous suggestions that deeper-water, further-offshore sites within a shelf environment contain greater species diversities, probably due to off-shore cyst transport. The nearer-shore localities contained generally lower species diversities probably due to lowered surface salinities. The low diversities in the samples from the Bunker Hill section may in part be due to the difficulty in counting procedures.

However if this site was a site of upwelling, then water-column stability would have been lower at the time of deposition, restricting the numbers of autotrophic dinoflagellate species able to live in the water column.

The proportion of each association of dinoflagellate cyst indicator species is calculated as a ratio of the number of individual cysts from the species from that indicator association to the total number of cysts from all the species from all four associations. The proportions of dinoflagellate cyst indicator species reinforce previous information about the environments of deposition when comparing each of the sections as a whole, which is not surprising as the sections were used to pick the indicator species. The Blue Point and Wahweap Wash samples are strongly dominated by 'lowered-salinity' and 'shallow-water' indicator species, although the latter section contains fewer 'shallow-water' species and slightly larger proportions of 'normal-salinity' and 'deep-water' species. The samples from the Greenhorn Limestone Formation of the Rebecca K. Bounds core and the Pueblo samples are dominated by 'deep-water' indicator species. The Bunker Hill section is dominated by 'normal-salinity' and 'shallow-water' species.

9.1.3 Palynofacies assemblages: General comparisons

In this study the proportions of palynomorphs and phytoclasts recovered from all sections are given as percentages. The abundance values of marine amorphous organic matter (AOM) given are the proportions from the entire palynofacies counts (Appendix E: Charts 2C, 3C, 4C and 5C), and the proportions for all the palynomorphs and phytoclasts given are the values from the palynofacies counts excluding the abundance of AOM (Appendix E: Charts 2C, 2D, 3C, 3D, 4C, 4D, 5C and 5D).

The palynofacies relationships are not simple ones, suggesting a complex interplay of various factors. Some of the trends in the palynofacies proportions suggest conflicting interpretations. Discrepancies between signals from different palynomorph and phytoclast abundances and ratios may be due to changes in sea level and surface waters which operated independently. For example, sometimes the trends in the proportions of 'proximity phytoclasts' suggest environmental changes very different from those indicated by other abundances and ratios. The trends in proportions of 'proximity phytoclasts' proved to be the most reliable of the shoreline proximity trends shown in the synchronous time-slice study, although statistically they are less reliable as they are based on smaller numbers. Generally, only the results from those groups/ratios that proved more useful and reliable in the 'time-slice' comparisons, will be discussed in this chapter.

Blue Point palynofacies: The trends through the Blue Point section include a large increase in the abundance of AOM, a general decrease in the abundance of brown wood and in the proportions of proximity indicating phytoclasts, fluctuations in the abundance of black wood, a general increase in the numbers of pollen, and a fluctuating but general increase in the numbers of marine palynomorphs. This indicates an overall distal shift environment for the site with a large increase in the preservation of AOM from depletion of oxygen levels.

Wahweap Wash palynofacies: Trends in palynofacies assemblages through this section include increasing levels of AOM and marine palynomorphs (particularly dinoflagellate cysts), decreasing levels of black wood, and variable levels of brown wood (with maxima in the *Sciponoceras* and *Mammites*

Zones), shoreline proximity-indicating phytoclasts, and pollen (with a maximum in the *Neocardioceras* Zone). This section contains larger overall proportions of foraminiferal linings than any of the others studied. This also suggests a distal shift in environment through much of the section studied with perhaps a proximal shift at the top. Again oxygen levels decreased through the interval studied.

Pueblo palynofacies: The first palynofacies count including the abundance of AOM was carried out through the whole of the section studied. However, the levels through the *Watinoceras* and *Mammites* Zones were so high that the second counts were not continued above PBC15. The general levels of AOM were high through the interval studied in the Hartland Member, fluctuated between low and high in the *Sciponoceras* and *Neocardioceras* Zones and were almost permanently very high through the *Watinoceras* and *Mammites* Zones.

The other palynofacies counts referred to in this chapter are solely taken from the top 1.2 metres of the Hartland Member, from the *Sciponoceras* Zone, from all but the top 20 cm of the *Neocardioceras* Zone, and from a single sample in the middle of the limestone horizon PBC15.

A number of general palynofacies trends include low abundances of foraminiferal test linings through the interval studied, although they increase slightly through the *Neocardioceras* Zone. The 'proximity phytoclasts' are extremely low through the entire interval studied, so their proportions compared to other phytoclasts are probably worthless. The proportions of brown wood and black wood fluctuate through the interval but are fairly constant throughout. Pollen proportions are quite variable as are the proportions of marine palynomorphs. This suggests a sufficiently distal and deep environment for changes in sea level to have a less clear effect on the palynofacies assemblages. The ratio of prasinophytes to dinoflagellate cysts is extremely high in the Hartland Member but much lower through the Bridge Creek Limestone Member.

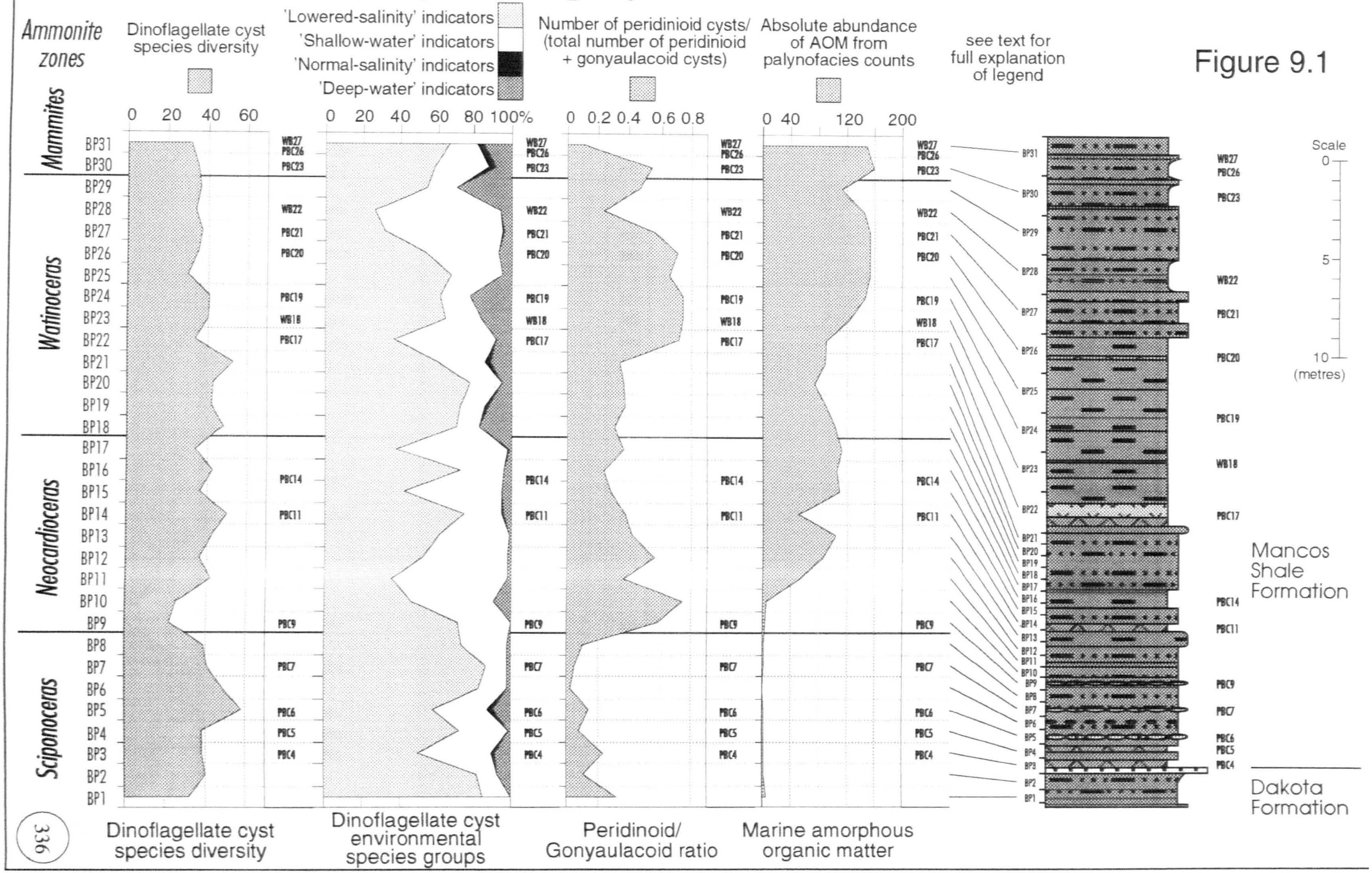
Bunker Hill palynofacies: As mentioned above, the only palynofacies count available for this section is the absolute abundance of AOM, which is extremely high in all of the samples from the section (95% to 100% of the counts).

9.2 BLUE POINT SECTION

The stratigraphic occurrences and abundances of individual species in the Blue Point section (in order of first and last appearance datum) are illustrated in Charts 2A and 2B in Appendix E. The dinoflagellate cyst species diversities, proportions of dinoflagellate cyst indicator species (plotted out against each other), peridinioid/gonyaulacoid proportions and levels of marine amorphous organic matter (AOM) from the palynofacies counts referred to in this chapter, are plotted out alongside the lithostratigraphy of the section in Figure 9.1. The stratigraphic occurrences and abundances of individual palynofacies types referred to in this section are illustrated in Chart 2C (including marine amorphous organic matter (AOM) counts) and Chart 2D (excluding AOM counts) in Appendix E. Selected curves for the proportions of palynofacies types and groups referred to in this chapter, are plotted out alongside the lithostratigraphy of the section in Figure 9.2. The detailed lithostratigraphy is illustrated in Figure 3.16.

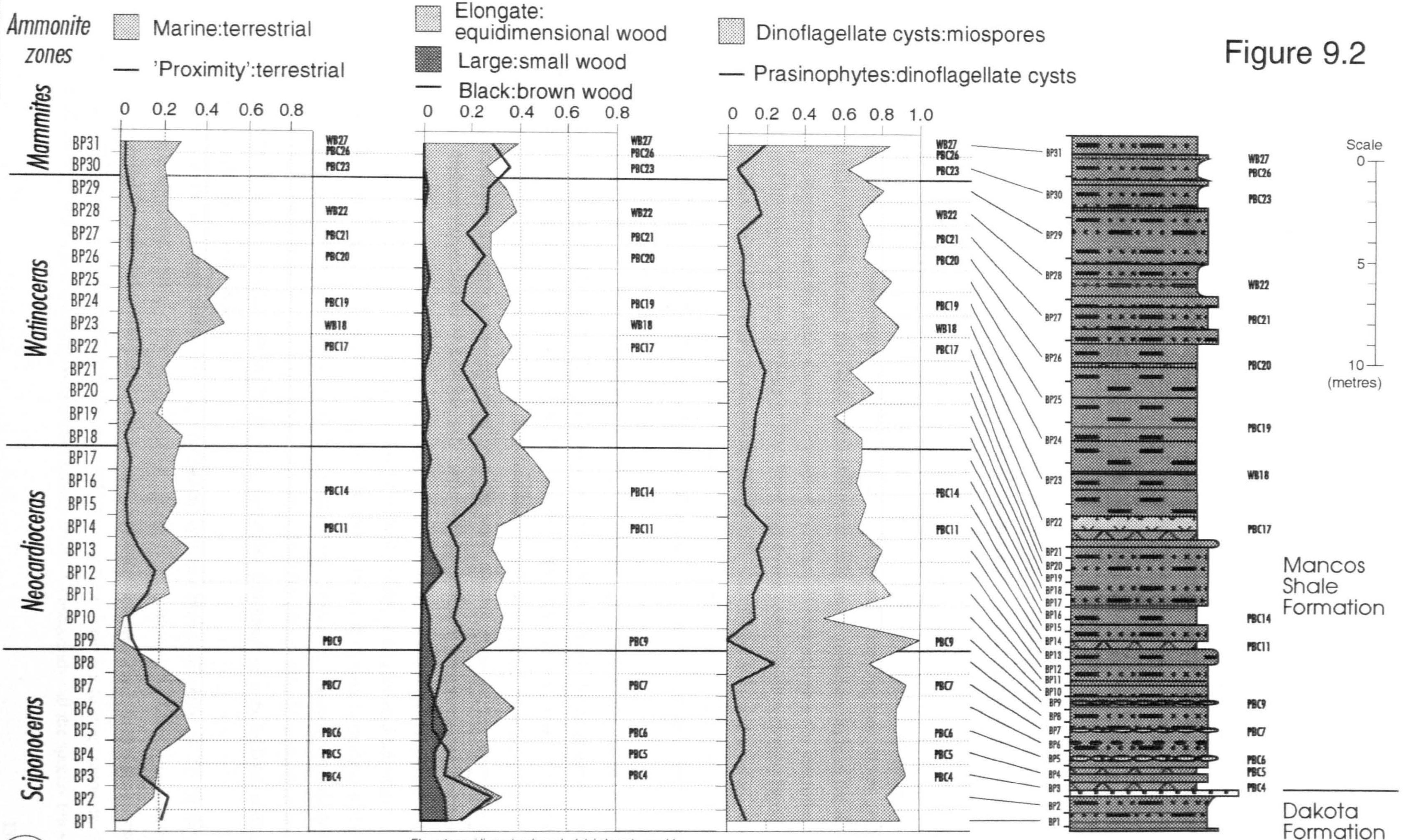
Dinoflagellate cyst and palynofacies data: Blue Point Section

Figure 9.1



Selected palynofacies ratios: Blue Point Section

Figure 9.2



Marine:terrestrial = total marine palynomorphs / (total marine palynomorphs + terrestrial palynomorphs and phytoclasts)

'Proximity':terrestrial = total 'proximity' phytoclasts / (total terrestrial phytoclasts + palynomorphs)

Elongate:equidimensional wood = total elongate wood / total elongate and equidimensional wood)

Large:small wood = total large wood / total wood

Black:brown wood = total black wood / total wood

Dinoflagellate cysts:miospores = dinoflagellate cysts / (dinoflagellate cysts + miospores)

Prasinophytes:dinoflagellate cysts = prasinophytes / (prasinophytes + dinoflagellate cysts)

9.2.1 Dakota Formation

The deposition of the Dakota Formation is thought to have been diachronous across the Western Interior Basin as a result of continued transgression progressively driving the coastline further towards the southwest. The lower sandstone member of the Dakota Formation is suggested to be of fluvial origin and is generally only preserved across the Black Mesa Basin in palaeo-valleys. Sediments of the middle carbonaceous member were deposited following a sea level rise which resulted in an elevated water table and the development of extensive coal-forming swamps adjacent to brackish-water lagoons. These lay behind a system of barrier beaches emplaced by longshore-drift from the southeast suggested to have been caused by currents from the east striking a northwest-southeast trending coastline. As transgression continued, the fine-grained sediments of the upper sandstone member were superimposed, and are thought to have been deposited in a lagoonal environment to the landward side of barrier bars overlying slight northwest-southeast structural topographical highs (Kirkland, 1991).

Fürsich & Kirkland (1986) suggest that the sedimentology and macrofaunal assemblages of the upper sandstone member in the Black Mesa Basin, are indicative of a lagoonal environment of deposition, with soft, muddy substrates in quiet conditions with low salinities. The bulk of this study was based on other sections around the Black Mesa Basin with only minor reference made to the Blue Point section. Compared with the other sections, Fürsich & Kirkland (1986) note that the macrofaunal assemblages and lithologies are very different at Blue Point and do not conform well with their lagoonal model. At Blue Point the shales contain an abundant monospecific assemblage of lucinid bivalves, with little bioturbation and a high organic carbon content suggesting low oxygen levels at the sediment-water interface. However, the levels of AOM in the palynological preparations from the Dakota Formation are very small, suggesting a fairly well oxygenated water column.

Fürsich & Kirkland (1986) suggest that the Blue Point site was located in the deepest part of the lagoon or in a restricted arm of the lagoon, as similar conditions are commonly found in deeper parts of lagoons where circulation is restricted by salinity stratified water masses, well below storm-wave base (suggested to be deeper than 10 metres). The bivalves suggest near-marine salinities although a lack of ammonites also suggests a brackish-water lid in the water column. However, the prasinophytes in the upper Dakota Formation at Blue Point only occur in low numbers suggesting that the water column was not permanently stratified. No foraminiferal linings were recorded in the palynofacies counts (only a trace was noted in the marine palynomorph counts) perhaps due to lowered salinities.

The dinoflagellate cyst assemblages from the two samples from the Dakota Formation at Blue Point are far more diverse than the sample from the Dakota of the Rebecca K. Bounds core which is thought to be from lagoonal sediments, and as diverse as many from the whole of the Blue Point section. This suggests that these samples are probably from sediments deposited in a near-shore marine environment rather than a lagoonal one.

The lowermost sample (BP1) has a dinoflagellate cyst assemblage diversity of 32. Several species occur in abundant numbers. The most dominant species is *Palaeohystrichophora infusorioides* with very high numbers of *Tenua hystrix*, *Spiniferites* spp. and *Subtilisphaera cheit*. In this near-shore (proximal shelf) environment the nutrient levels are likely to have been high due to large amounts of terrestrial run-off which would also have lowered the salinity levels. Consequently, all the species found in the Dakota Formation are likely to have been eurytopic species. The high nutrient levels are suggested by the abundance of small peridinioid cysts. The large proportions of *Spiniferites* species and *Tenua hystrix* may also have resulted from high nutrient levels. *Spiniferites* species have previously been associated with high productivity levels (Davey & Rogers, 1975, Bujak, 1984) and their large abundances in this sample may also indicate high productivity levels rather than near-shore environments as along shelf transects they have been associated with a number of environments from the inner-shelf (Wall *et al.*, 1977, Brinkhuis & Zachariasse, 1988) to the outer-shelf (e.g. Versteegh, 1994). As noted from studies of time-slice transects, *Tenua hystrix* is an oddity that neither conforms to changes in salinity levels or water-depth and perhaps may also indicate high nutrient levels.

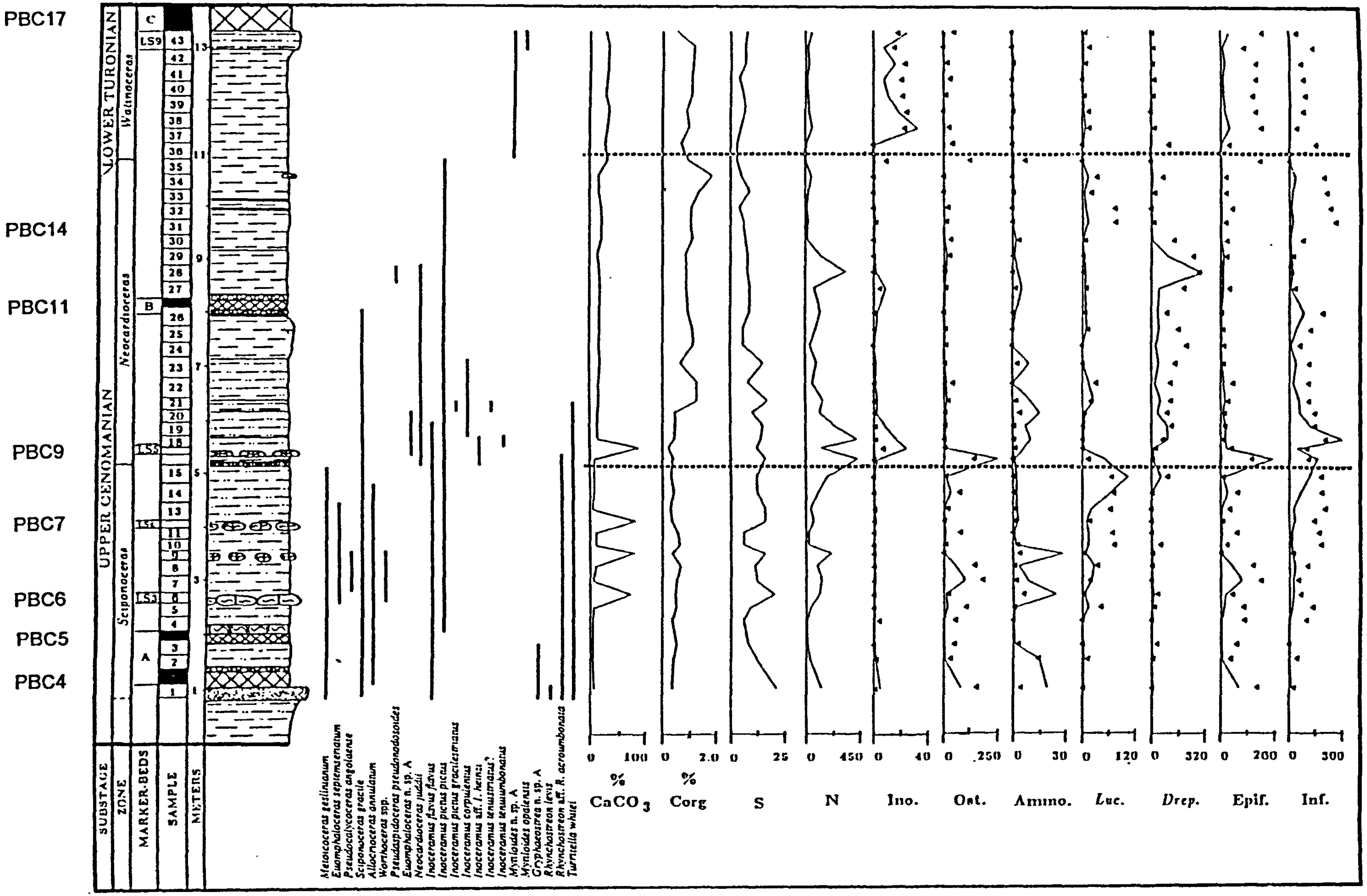
The palynofacies assemblages contain comparatively high abundances of woody phytoclasts and 'proximity phytoclasts'. In comparison with the samples from the Dakota Formation of the Rebecca K. Bounds core, however, the assemblages contain much higher abundances of woody phytoclasts in the basal sample from the Blue Point section while the abundance of membranous material is much lower. This may indicate greater degradation of the phytoclasts suggesting a more off-shore or open-marine environment.

The second sample from the base of the section (BP2) has an increased diversity of dinoflagellate cyst species (40) and may indicate increased (though still low) salinity levels. This sample also shows an increase in the proportion of marine palynomorphs to terrestrial palynomorphs and phytoclasts suggesting a deeper or more distal environment.

The uppermost sandstone bed of the Dakota Formation is thought to represent the relict bar sands redistributed by storm-generated currents (Kirkland, 1991), as the lagoon was inundated by the open sea (Fürsich & Kirkland, 1986). This bed is dominated by epifaunal suspension feeders with some infaunal suspension feeders (Kirkland, 1991), including fully-marine benthic molluscs along with trace fossils indicative of moderate to high energy conditions (e.g. *Ophiomorpha*). The disconformity below the base of the Mancos Shale Formation lies at the base of this transgressive lag.

9.2.2 Mancos Shale Formation

The Mancos Shale Formation represents fully-marine, proximal to medial shelf sedimentation below storm wave-base, deposited following basin-wide transgression. The base of the Mancos Shale Formation across the Black Mesa Basin is disconformable (Figure 3.18) due to shoreward migration of the strandline with on-going transgression and sediment trapping at the basin margins associated with a decrease in sedimentation rates through the seaway (Elder, 1991). The detailed macrofossil biostratigraphy and various macrofossil biozonation schemes for the Blue Point section are described by Elder, 1987, 1991 and Kirkland, 1991. The pattern of geochemical and macrofaunal variation across the Cenomanian - Turonian boundary at Blue Point (from Elder, 1991) is illustrated in Figure 9.3. The macrofaunal species used in this diagram (and subsequent diagrams from Elder, 1985, 1989 and 1991) are listed with their authors in Figure 9.4. The key to the lithological and taxonomic plot symbols in Figure 9.3 is illustrated in Figure 9.5. The geochemical data from the section has also been plotted against the lithological log in Figure 9.6.



with PBC marker bed
equivalent designations
from Elder & Kirkland 1985

Figure 9.3

Adapted from Elder 1991

Blue Point, Arizona: Geochemical and macrofaunal variation with ranges of biostratigraphically useful taxa plotted against stratigraphy across the Cenomanian - Turonian boundary interval.

Figure 9.4

List of macrofaunal species and their authors used in the figures

From Elder 1989

Moremanoceras scotti (Moreman)
Sumitomoceras conlini Wright and Kennedy
Calycoceras naviculare (Mantell)
Pseudocalycoceras angolaense (Spath)
Euomphaloceras septemseriatum (Cragin)
Metoicoceras geslinianum (d'Orbigny)
Neocardioceras juddii (Barrois and Guerne)
Euomphaloceras costatum Kennedy, Cobban, Hancock and Hook
Pseudaspidoceras pseudonodosoides (Choffat)
Pseudaspidoceras flexuosum Powell
Watinoceras cf. *W. praecursor* Wright and Kennedy
Quitmaniceras aff. *Q. reaseri* Powell
Watinoceras coloradoense coloradoense (Henderson)
Watinoceras reesidei Warren
Watinoceras thompsoni Cobban
Watinoceras devonense flexuosum Cobban
Vascoceras diartianum (d'Orbigny)
Vascoceras gamai (Choffat)
Vascoceras cauvini Chudeau
Fegasia catinus (Mantell)
Nigericeras scotti Cobban
Paravascoceras angermani (Bose)
Vascoceras birchbyi Cobban and Scott
Neoptychites cephalotus (Courtiller)
Metaptychoceras reesidei (Cobban and Scott)
Sciponoceras gracile (Shumard)
Baculites yokoyamai Tokunaga and Shimizu
Collingnoniceras woollgari (Mantell)
Mammites nodosoides (Schlüter)
Metoicoceras mosbyense (Cobban)
Inoceramus aff. I. heinzi (Sornay)
Mytiloides submytiloides (Seitz)

Allocrioceras annulatum (Shumard)
Scaphites brittonensis Moreman
Scaphites delicatulus Warren
Puebloites corrugatus (Stanton)
Puebloites spiralis Cobban and Scott
Inoceramus pictus Sowerby
Inoceramus flavus flavus Sornay
Inoceramus flavus pictoides Sornay
Inoceramus corpulentus McLearn
Inoceramus ginterensis Pergament
Inoceramus tenuistriatus? Nagao and Matsumoto
"*Inoceramus*" aff. "*I.*" *crippsi* Mantell
Mytiloides opalensis (*non* Bose, *sensu* Kauffman)
Mytiloides aff. *M. duplicostatus* (Anderson)
Mytiloides cf. *M. latus* (Sowerby)
Mytiloides mytiloides (Mantell)
Mytiloides cf. *M. labiatus* (Schlotheim)
Lima utahensis Stanton
Entolium aff. *E. membranaceum* (Nillson)
Nemodom sulcatinus? (Evans and Shumard)
Pycnodonte newberryi (Stanton)
Rhynchostreon levis (Stephenson)
Rhynchostreon aff. *R. acroumbonata* (Kellum)
Pseudoperna bentonensis (Logan)
Plicatula aff. *P. goldenana* Stephenson
Corbula aff. *C. truncata* Sowerby
Liopistha elongata Stanton
Yoldia aff. *Y. septariana* Cragin
Turritella whitei Stanton

Figure 9.5

Adapted from Elder 1991

Key to lithological and taxonomic plot symbols used in diagrams of stratigraphy with macrofaunal and geochemical data from Elder (1989, 1991).

- ☒ Bentonite
- ☰ Bentonite or Limonite Band
- ▧ Bentonitic Clay
- ▭ Limonite Nodule Bed
- ▒ Silty Sandstone
- ▤ Calcareous, Silty Shale or Claystone
- ▤ Calcareous Shale or Claystone
- ▦ Shaly Marlstone
- ▦ Marlstone
- ▭ Limestone Bed
- ⊖ Limestone Concretion
- ⊛ Septarian Limestone Concretion
- ⊖ Chalky Limestone Concretion
- ▤ Calcarenite or Calcisiltite Bed
- ▭ Starved Calcarenite Ripple Bed
- ▤ *Pycnodonte* Shell Bed

TAXONOMIC PLOT SYMBOLS

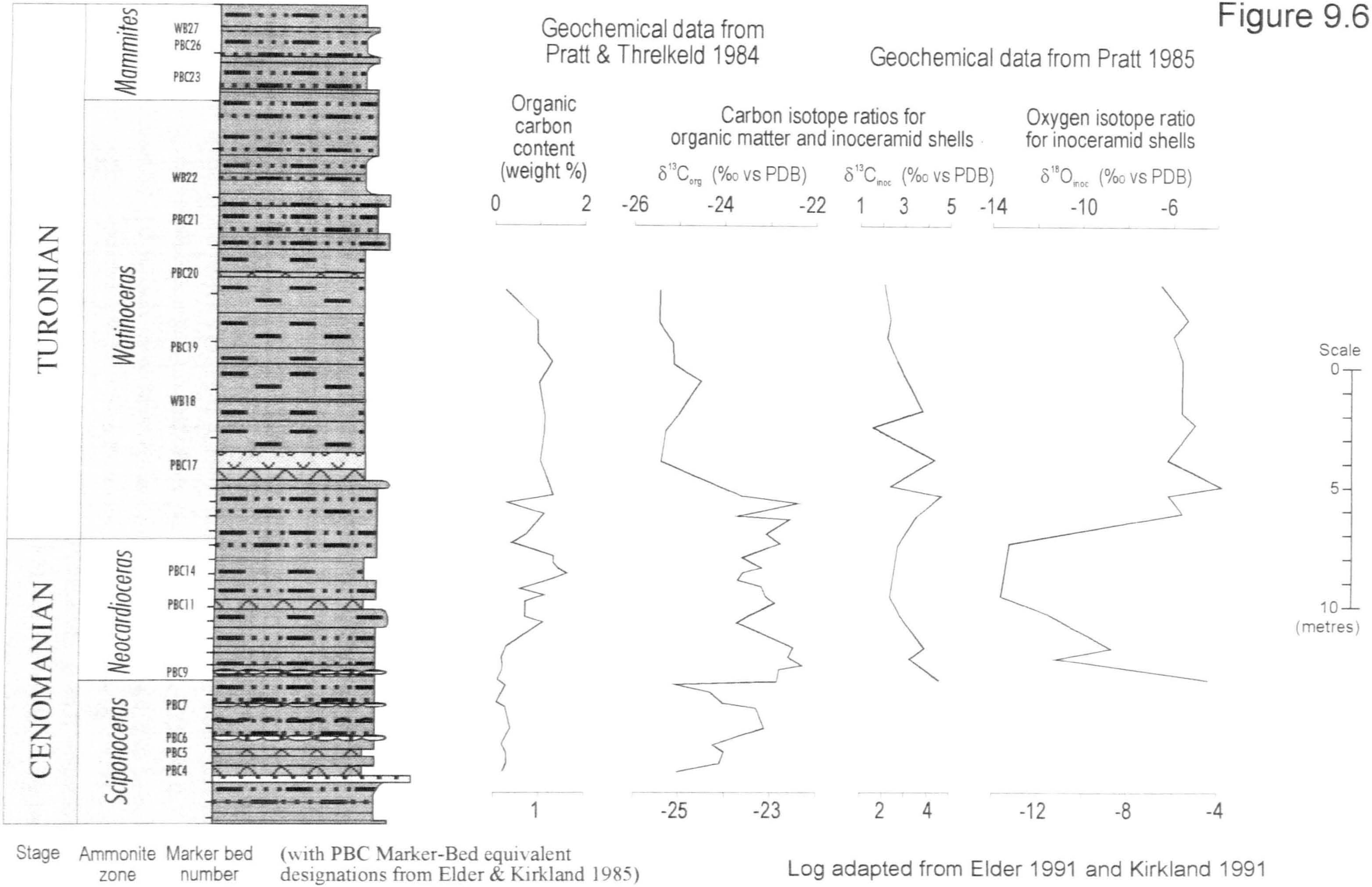
◂ = Plot point showing percent of taxa falling within the taxonomic group being plotted. Percentages are relative to all specimens tallied within each sample (Scale bar = 100%).

| = Plot line showing the number of specimens identified in each sample that fall in the group being plotted. The number of specimens represented by the scale bar is shown below the bar for each group.

Variable abbreviations are as follows: $CaCO_3$ = Calcium carbonate, C_{org} = organic carbon, S = simple diversity or species richness per sample, N = total number of specimens identified per sample, Ino. = inoceramids, Ost. = ostreids, Ammo. = ammonites, *Luc.* = *Lucina*, *Drep.* = *Drepanochilus*, Epif. = epifaunal bivalves, Inf. = infaunal bivalves, PECTIN = pectinid bivalves, PHEL = *Phelopteria*, LAMINATION = subjectively determined index of lamination. Triangles on taxonomic plots indicate percentage (scale-bar = 0 to 100 percent) of that group relative to all other groups, and solid plot lines equal total number of individuals in group identified per sample (numbers of individuals indicated on each scale bar). Note that the epifaunal and infaunal bivalves essentially make up the filter-feeding trophic group, the ammonites basically compose the carnivore group, and *Drepanochilus* composes the preserved deposit-feeding trophic group.

Selected geochemical and isotopic profiles from Blue Point, Arizona

Figure 9.6



(with PBC Marker-Bed equivalent designations from Elder & Kirkland 1985)

Log adapted from Elder 1991 and Kirkland 1991

The planktonic foraminiferal assemblages in the upper Cenomanian (*Sciponoceras* and *Neocardioceras* Zones) of the lower shale member display a low diversity of dominantly epicontinental shallow-water fauna, indicating a shallow marine depositional environment, while also indicating a warm Tethyan influence (Figure 9.7). However, the percentage of planktonic species fluctuates between 0% and 70% of the total foraminiferal population, indicating a stressful environment (Figure 9.8). These variations may be due to fluctuating support from the Tethyan water mass, and probably reflect generally lowered surface salinities rather than extremely shallow water-depths (Olesen, 1991).

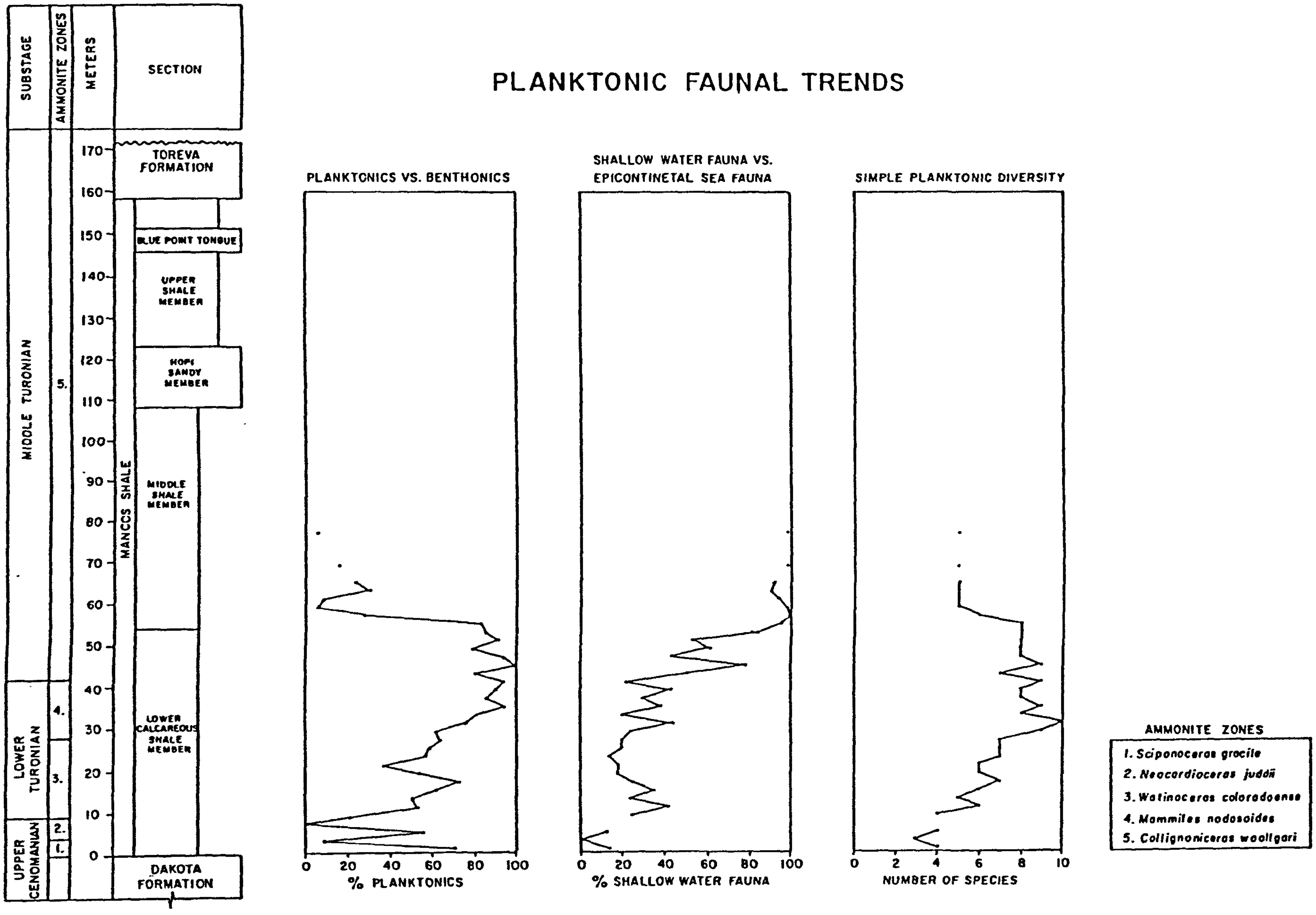
The proportions of arenaceous and calcareous benthic foraminifera are also a useful indicator for water depth and salinity (Figure 9.8). The proportions of the arenaceous to calcareous benthic foraminifera vary in the samples, in concurrence with fluctuations in planktonic abundances; also suggesting that periodically hyposaline conditions existed in the Late Cenomanian, at times of greater arenaceous proportions, alternating with periods of increased salinity at times of greater calcareous proportions (Olesen, 1991).

9.2.2.1 *Sciponoceras* **Zone:** The strata of the *Sciponoceras* Zone are thicker in more offshore sections elsewhere at Black Mesa due to current and storm induced offshore sedimentary transport leaving the nearer-shore localities (such as Blue Point) with more condensed and winnowed sections (Figure 3.18). The thinning of these strata in an onshore direction may also be partially due to their erosional truncation during basal *Neocardioceras* times. Progressively higher silt contents in the near-shore direction may also indicate winnowing and transport of fine clays in an offshore direction. The decrease in silt content through the zone suggests a general decrease in the energy of deposition from eustatic rise and increased water-depths, or from reduced current activity or from increased clay supply relative to offshore transport (Elder, 1987).

The base of the Mancos Shale Formation represents the start of deposition below storm-wave base, as water depth increased with continued transgression. At Blue Point, this was preceded by a warming of the waters and increase in salinity to 'normal' levels, across the basin due to sea-level rise from a major Tethyan transgressive pulse at the base of the *Sciponoceras* Zone. Normal salinities have been supported by the presence of bryozoa and echinoids at Black Mesa (Elder, 1987).

The transgression/tethyan pulse at the base of the formation is marked by a large fall in the abundance of 'proximity phytoclasts' (very large wood, terrestrially derived amorphous matter and membranous material) suggesting a decrease in shoreline proximity. It is also marked by a peak in 'normal-salinity' and 'deep-water' indicator dinoflagellate cyst species and by a small peak in the P/G ratio suggesting a temporary increase in productivity. The more dominant species in the lower half of the zone include species of *Spiniferites*, *Tenua hystrix*, *Florentinia mantellii*, and the 'small peridinioid group' of *Palaeohystrichophora infusorioides*, *Subtilisphaera cheit*, and *Subtilisphaera? inaffecta*.

At the same time as climatically forced limestone-shale couplets were deposited in the centre of the seaway, the couplets were also induced at Blue Point to a lesser extent, forming concretionary horizons in the calcareous shale. These concretionary horizons contain the greatest macrofaunal diversity, including stenotopic macrofauna e.g. echinoids (Figure 9.3), and are thought to have been caused by short-term sediment by-pass or hiatus events, leading to decreased sedimentation rates,



From Olesen 1991

Figure 9.7 Faunal trends in planktonic foraminifera from the Mancos Shale Formation at Blue Point, Arizona. Ammonite zones from Kirkland (1991).

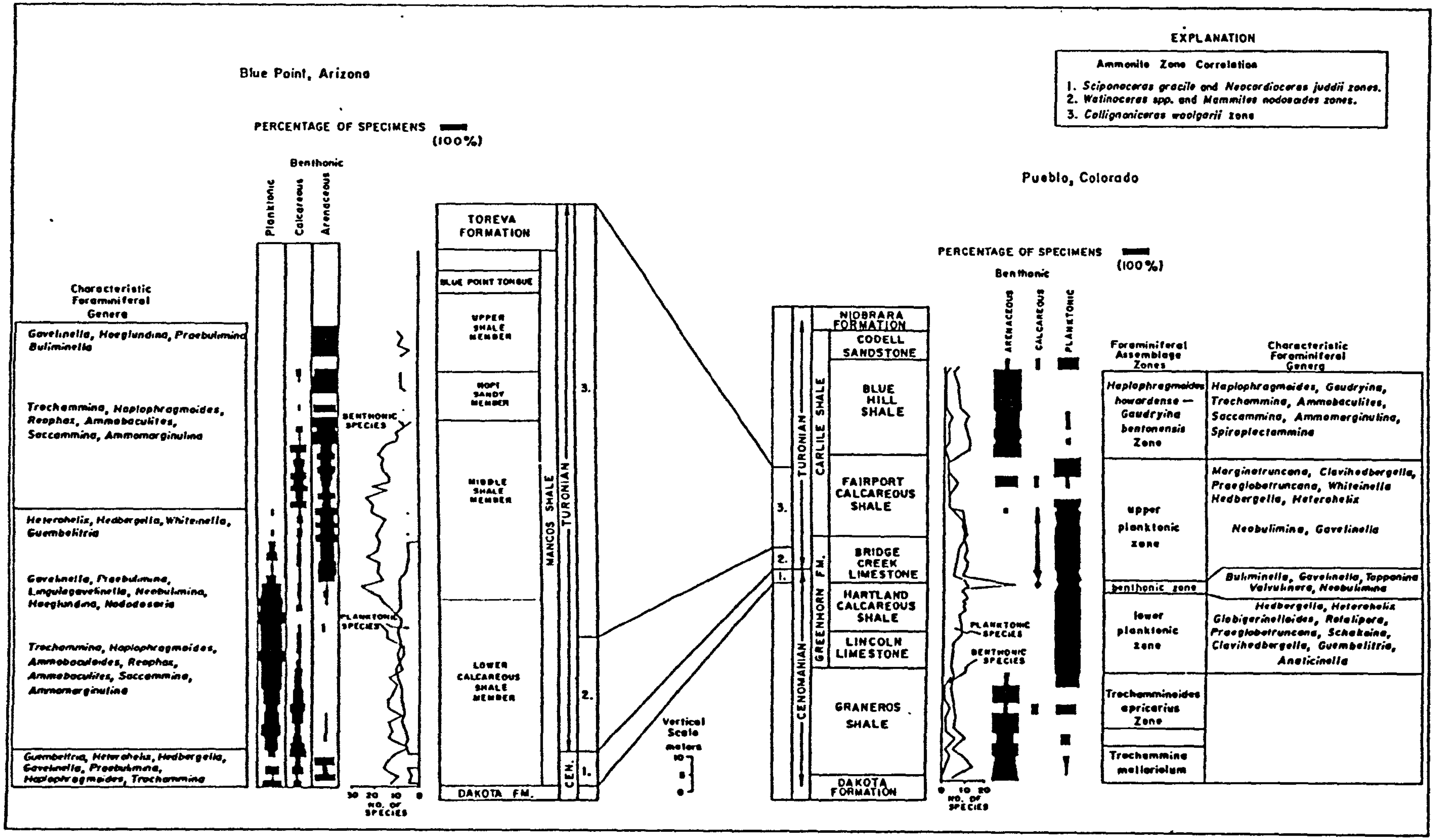


Figure 9.8

From Olesen 1991

Correlation of the Mancos Shale Formation at Blue Point, Arizona, with strata near Pueblo, Colorado, with comparison of foraminiferal assemblages. Foraminiferal data for Pueblo from Eicher (1969) and Eicher & Diner (1985). Ammonite zones from Kauffman & Pratt (1985) and Kirkland (1991).

increased benthic oxygenation and increased calcareous plankton productivity due to the influx of warmer, normal marine waters with associated fauna, from the south (Elder, 1987). Increased salinity levels from a sample in the lower half of the *Sciponoceras* Zone are also suggested by the foraminiferal assemblage (Figures 9.7 and 9.8) which contains a high abundance of planktonic species and a high ratio of calcareous to arenaceous benthonic species (Olesen, 1991). However, no foraminiferal linings were recorded in the palynofacies counts.

The pattern from the palynofacies counts through the *Sciponoceras* Zone is a relatively simple one suggesting a probable rise in sea-level (from a smoothly decreasing abundance of woody phytoclasts and rise in the proportions of marine to non-marine palynomorphs and phytoclasts) with peak transgression at around the equivalent of PBC6 and PBC7. This is followed by a regressional or progradational event through to the top of the zone suggested by a reversed pattern. The smooth curves suggest that environmental changes were gradual or that the sampling has averaged out any smaller fluctuations.

The transgression/tethyan pulse is also suggested around PBC6 by a peak in 'normal-salinity' and 'deep-water' dinoflagellate cyst indicator species and also by a small peak in the P/G ratio suggesting temporary increases in productivity. Across the basin, the most diverse macrofauna are developed in the horizon equivalent to PBC6, indicating that the most widespread 'normal' marine conditions were developed in the basin at that time (Elder, 1987, 1991). This horizon also contains the highest dinoflagellate cyst species diversities found in the section.

Macrofossil extinction episodes occurred in the shales above the equivalents of PBC6 and PBC7 (Figure 9.3), both associated with increased sedimentation rates, decreased substrate firmness and decreasing benthic oxygen levels (Elder, 1987, 1991). The interval between PBC6 and PBC7 also shows a major increase in the proportions of 'proximity phytoclasts' suggesting a potential progradational event or increase in terrigenous input.

The upper *Sciponoceras* Zone is suggested, on lithological and faunal evidence, to represent a highstand event with progradation of the shoreline after the basal transgression (Elder, 1991). The foraminiferal assemblages from a sample in the upper half of the *Sciponoceras* Zone contain lower abundances of planktonic taxa and higher proportions of arenaceous to calcareous benthic taxa (Figures 9.7 and 9.8; Olesen, 1991). This interval also contains a large increase in 'low-salinity' dinoflagellate cyst indicator species, a decrease in species diversity and a decrease in the proportion of peridinioid cysts. The more dominant species include *Cyclonephelium brevispinatum* and a correlatable acme of *Cyclonephelium compactum*.

A period of faunal demise and community restructuring occurred preceding the extinction event at the top of the zone, marked by the extinction or turnover of most common upper Cenomanian ammonites and many bivalves (Elder, 1987, 1991), and coinciding with a sharp negative $\delta^{18}O$ excursion (Figure 9.6). The top of the *Sciponoceras* Zone is also marked by a temporary increase in prasinophyte numbers and by a large and rapid decrease in the proportions of marine palynomorphs to terrestrial palynomorphs and phytoclasts, suggesting a regression or large increase in terrigenous input, perhaps with an increase in water column stratification.

Throughout the *Sciponoceras* Zone, the levels of AOM remain very low (<5%) suggesting a fairly well oxygenated water column.

9.2.2.2 *Neocardioceras* **Zone:** A second transgressive pulse has been postulated by an onshore shift in the depositional centre of the basin (the strata in the near-shore sections become thicker than those from further offshore), and from a slight disconformity, indicated by shell-beds at Blue Point (and by siltstone and calcarenite elsewhere in the Black Mesa Basin) suggesting sediment by-pass or hiatus conditions at the base of the *Neocardioceras* Zone (Elder, 1991). The shell lag at Blue Point has also been suggested to represent storm reworking (Olesen, 1991).

Once again, water temperature is supposed to have increased as new taxa entered the seaway, marked by an influx of cosmopolitan and subtropical ammonites and of inoceramids which first become abundant at the base of the *Neocardioceras* Zone. Faunal evidence suggests firmer substrates and lowered sedimentation rates in the lower half of the zone (Elder, 1987, 1991). A major fluctuation in environmental conditions occurred at the top of the *Sciponoceras* Zone which reached a maximum in the sample including PBC9 and the sample above. This environmental fluctuation is characterised by a massive increase in the abundance of woody phytoclasts, and a large drop in shoreline proximity-indicators and the proportions of marine palynomorphs (from low abundances of both dinoflagellate cysts and prasinophytes), which does not corroborate the idea of a transgression/tethyan pulse. However, the base of the zone is marked by a very large increase in the proportion of peridinioid species (particularly the 'small peridinioid group') and by a linked, large decrease in dinoflagellate cyst species diversity. No increase in 'deep-water' indicator species was noted in this sample.

Both macrofossil abundance and diversity decrease through the *Neocardioceras* Zone. Many species of ammonite became extinct and highly stenotopic fauna were also excluded, with an extinction event immediately overlying the equivalent of PBC9 and a subsequent increase in detritus-feeding gastropods indicating an increase in organic carbon levels within the sediment (Elder, 1987, 1991). This coincides with a large and sharp decrease in $\delta^{18}O$ values (Figure 9.6), considered to indicate an unusual fresh-water influx (Pratt, 1985). The sample above PBC9 shows an increase in 'deep-water' indicator species suggesting the transgressive pulse and also an increase in the number of leiospheres which may indicate an increase in the degree of stratification of the water column, supporting the theory of a subsaline cap across the basin at this time. Following the initial peak, however, the numbers are only slightly higher through the rest of the *Neocardioceras* Zone as in the samples from the *Sciponoceras* and *Watinoceras* Zones. In contrast to the Hartland Member samples from the Pueblo section (see below: Figure 9.16), the numbers of leiospheres recorded are comparatively small and no other prasinophytes are recorded in significant numbers. The levels of AOM remain fairly low (<5%) at the base of the zone but increase rapidly in the samples above the equivalent of PBC9 and remain fairly stable through to the top of the zone. In the palynofacies counts, the foraminiferal test linings appear in the sample with the first rapid increase of AOM but maintain low numbers through the zone.

The greatest negative shift in the $\delta^{18}O$ curve occurs around the bentonite equivalent to PBC11, immediately followed by a slight faunal recovery indicated by an increase in the numbers of Tethyan ammonites, suggesting an increase in the circulation of southern waters due to a transgressive pulse.

The recovery ended with another macrofaunal extinction event, particularly affecting the ammonites, probably resulting from further deterioration in benthic oxygen levels and substrate firmness (Elder, 1987, 1991). The samples around PBC11 are marked both by fluctuating alternations in the proportions of 'low-salinity' and 'shallow-water' indicator species (caused mainly by fluctuations in the amount of *Exochosphaeridium phragmites* and *Spiniferites lenzii* respectively) as well as by an increase in 'deep-water' indicator species. The sample including the base of PBC11 contains increased proportions of marine palynomorphs. The sample above PBC11 shows a temporary drop in the levels of AOM and also contains increased abundances of woody phytoclasts and decreased proportions of marine palynomorphs suggesting a progradational event or a period of increased terrigenous input.

The ratio of black to brown wood increases by a significant amount in the upper half of the zone, reaching a maximum above PBC14 and then decreasing again across the Cenomanian-Turonian boundary. This suggests increased degradation of the woody phytoclasts at the top of the zone, although the levels of AOM in these samples are consistently high.

Macrofaunal diversity decreases through this zone with a decline in environmental conditions through to the end of the Cenomanian, including increased sedimentation rates and decreased substrate stability in the upper half of the zone. These changes may have resulted from increased run-off or from sea-levels at highstand or even in slight regression. The boundary is marked by a depauperate, low diversity assemblage of eurytopic macrofauna and a short term peak in organic carbon levels (Elder, 1987, 1991).

The diagrams from Olesen (1991), show only a very low resolution for the foraminiferal data through the Cenomanian-Turonian boundary interval. However, the patterns are similar to those of the *Sciponoceras* Zone, with a high abundance of planktonic species and a high ratio of calcareous to arenaceous benthonic species in the lower half of the *Neocardioceras* Zone, followed by a reversal in the trend in the upper half of the *Neocardioceras* Zone with lower abundances of planktonic taxa and higher proportions of arenaceous to calcareous benthic taxa. This may again be indicative of the general fourth-order transgressive and highstand systems tracts for the *Neocardioceras* Zone or of different levels of dominance by different water masses.

Generally the proportions of peridinioid cysts decrease through the *Neocardioceras* Zone after the initial huge increase at the base of the zone. The top of the zone is marked by the correlatable occurrence of *Cyclonephelium uncinatum* which continues into the base of the Turonian. The Cenomanian-Turonian boundary at Blue Point is not marked by particularly large fluctuations in palynofacies.

The abundance of benthic foraminifera across the Cenomanian-Turonian boundary interval suggests that substrates were continuously oxygenated (Olesen, 1991), which is in marked contrast to the assemblages at Pueblo (Eicher & Diner, 1985, Leckie, 1985).

9.2.2.3 ***Watinoceras* Zone:** A third transgressive pulse is perhaps indicated near the beginning of the Turonian, by sediment condensation and a sharp increase in carbonate content in other sections further offshore in the Black Mesa area. The base of the zone at Blue Point is marked by a decrease in organic carbon preservation and a marked increase in percentage carbonate associated with a positive shift in

$\delta^{18}O$, indicating an increase in carbonate production and increased mixing of the water column providing better benthic oxygenation (Elder, 1987); perhaps also reflecting the break-up of the brackish-water cap suggested for the *Neocardioceras* Zone (Pratt, 1985). The base of the zone is also marked by an increase in 'deep-water' and 'normal-salinity' indicator dinoflagellate cyst species (which also suggest a transgressive pulse) although also by continued changes in the proportions of 'low-salinity' to 'shallow-water' indicator species.

Just below the PBC17-equivalent bentonite marker, macrofaunal (particularly inoceramid) abundance increases, following increased substrate stabilisation and suggesting possible higher salinity and oxygen levels (Elder, 1987). This sample is marked by a slight increase in 'deep-water' and 'normal-salinity' dinoflagellate cyst indicator species. The sample including the bentonite equivalent to PBC17 shows a large increase in the proportions of peridinioid cysts suggesting a further increase in primary productivity.

The levels of AOM decline through the lower part of the zone and do not increase until above the bentonite equivalent to PBC17. The increases are then large, reaching a maximum below PBC20 at almost 80% of the total palynofacies counts. These levels remain steady through the zone apart from a brief drop (to just below 60%) at the very top of the zone above the bentonites WB22. The levels then increase again (to 80%) into the *Mammites* Zone. The levels of foraminiferal test linings are generally higher through the *Watinoceras* Zone than in the previous zones and to a certain extent mimic the proportions of AOM through the section.

The *Watinoceras* Zone continues to show fluctuations in the palynofacies but these are generally less variable than in the previous zones. The middle of the zone is different from the top and base in having much smaller brown and black wood proportions and much larger marine palynomorph and AOM proportions, perhaps suggesting a transgressive pulse from around the bentonite WB18 to above the bentonite equivalent to PBC19. This is also supported by an increase in the proportion of 'deep-water' dinoflagellate cyst indicator species. The 'proximity phytoclasts' also fluctuate slightly through the *Watinoceras* Zone but are generally lower than in the previous zones.

Macrofaunal diversity at Blue Point was greater than further offshore (in Black Mesa and in other sections, for example Pueblo), probably due to better mixing of the water column in shallower parts of the seaway. Macrofaunal diversity increases slowly through the lower part of the zone, followed by a more rapid increase further up, though the low abundances of the infauna continue to indicate low oxygen levels within the sediments. Increases in abundance of the epifauna suggest increasing substrate firmness. Ammonite immigration in the western part of the basin (in comparison with further east) was poorly developed, perhaps due to continued lower than normal marine salinities (Elder, 1987, 1991).

The planktonic foraminifera increase in abundance and diversity up through the Early Turonian, suggesting continually increasing water depths. However, calcareous benthic foraminifera while increasing in abundance, maintain relatively low diversities (Olesen, 1991).

The data from Olesen (1991) shows only a very low resolution for the foraminiferal data through the Cenomanian-Turonian boundary interval. The patterns again are similar to those of the *Sciponoceras* and *Neocardioceras* Zones, with a greatly increased abundance of planktonic species and a very high ratio of calcareous to arenaceous benthonic species in the lower half of the *Watinoceras*

Zone. This trend generally continues through the *Watinoceras* Zone but in the upper half of the zone, a temporary and relatively small decrease in the abundance of planktonic taxa occurs. This may be indicative of a general fourth-order transgressive and highstand systems tract pattern for the *Watinoceras* Zone as well. The samples from upper half of the zone again show a decrease in 'normal-salinity' and 'deep-water' indicator species (at least partly caused by an acme of *Spiniferites lenzii*) and some decrease in the proportions of peridinioid cysts.

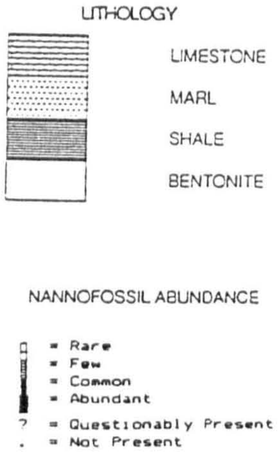
9.2.2.4 ***Mammites* Zone:** A transgressive event is suggested for the base of the zone by a slight decrease in brown wood and 'proximity phytoclasts', by an increase in the proportions of black to brown wood, an increase in 'deep-water' and 'normal-salinity' indicator species, by a further increase in the P/G ratio and by an increase in AOM. The top sample studied is strongly dominated by an acme occurrence of *Odontochitina costata*.

Maximum abundance and diversity of planktonic foraminifera occur in the *Mammites* Zone with an increase in the percentages of shallow-water oceanic forms. This suggests more normal oceanic salinities and an increase in water depth that continued into the lower *Collignoniceras* Zone. However, the absence of keeled planktonic forms still suggests that the waters in this offshore environment were less than 100 metres deep. The diversity of calcareous benthic taxa also increases significantly suggesting more 'normal' salinities at this time (Olesen, 1991). The patterns of planktonic and benthonic foraminifera at Blue Point suggest that peak transgression occurred in the *Mammites* and into the lower part of the *Collignoniceras* Zones. This is in contrast to the Pueblo section, where the maximum flooding interval is suggested at the base of the *Mammites* Zone, with transgression rates slowing down through the remainder of the zone and into the *Collignoniceras* Zone. This suggests more rapid basinal subsidence along the western margin of the seaway in comparison to sites (e.g. Pueblo) from the centre of the seaway. The macrofauna through the remainder of the lower shale member is dominated by epifaunal species of bivalve (Kirkland, 1991).

9.2.3 Blue Point nannofossil data

Bralower (1988) studied the nannofossil assemblages from both the Blue Point and Pueblo sections. The material from Blue Point studied by Bralower and for this work was subsampled from the same material (collected by Elder & Kirkland and stored at the University of Colorado, Boulder, Colorado). The sampling for the nannofossil study from Pueblo was very widely spaced and hence is of little use in this comparative study.

Eprolithus floralis ((Stradner, 1962) Stover, 1966) is one species particularly noted and discussed by Bralower as a major component of the assemblages. At Pueblo, the wide sampling resolution, coupled with little change in the abundance of this species through the section means that this species is of little use for environmental interpretations. The high enrichment of this species in the sections studied was noted to be at least partly of diagenetic origin, as the species shows a particular resistance to alteration from diagenesis. In the Blue Point section more than any other, Bralower noted a very close correlation between poor relative preservation (of other species) and high abundances of *Eprolithus floralis* (Figure 9.9). At Blue Point, the abundance curve of this species (Figure 9.10) shows



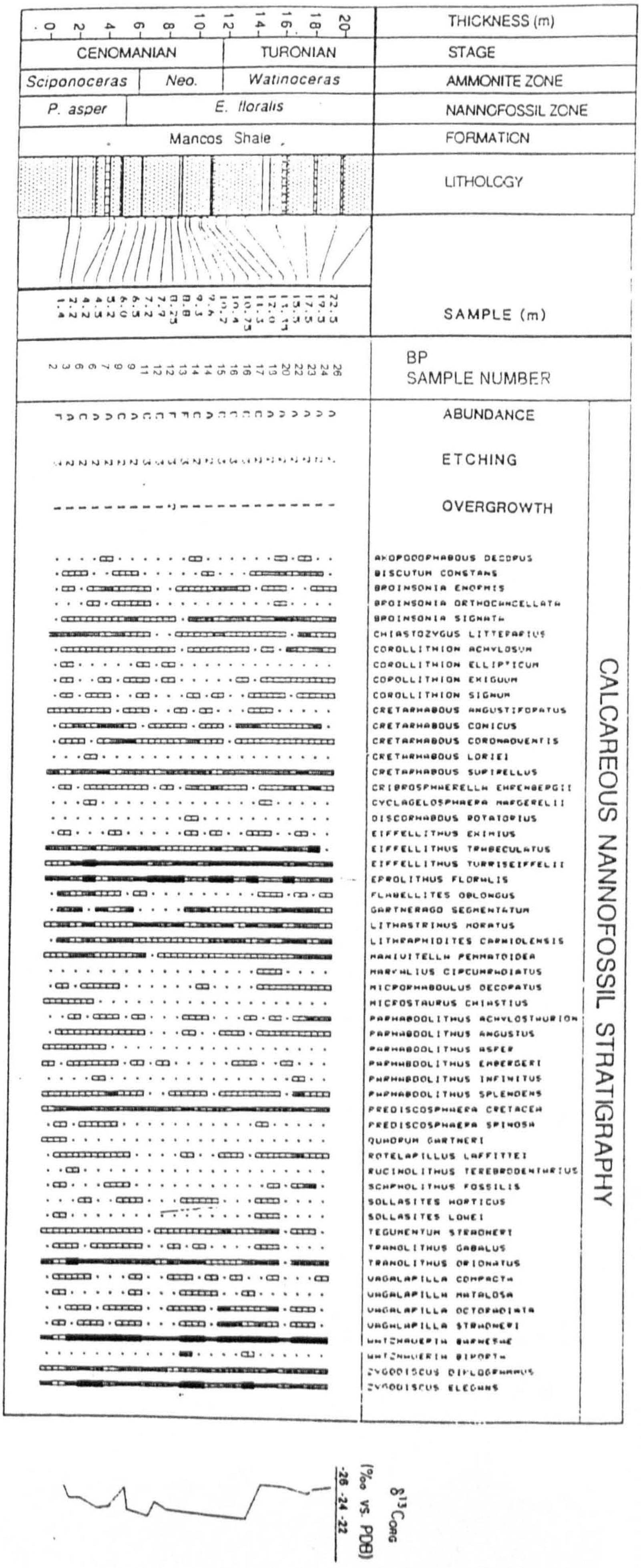


Figure 9.9

Adapted from Bralower 1988 Nannofossil stratigraphy of the Blue Point section.

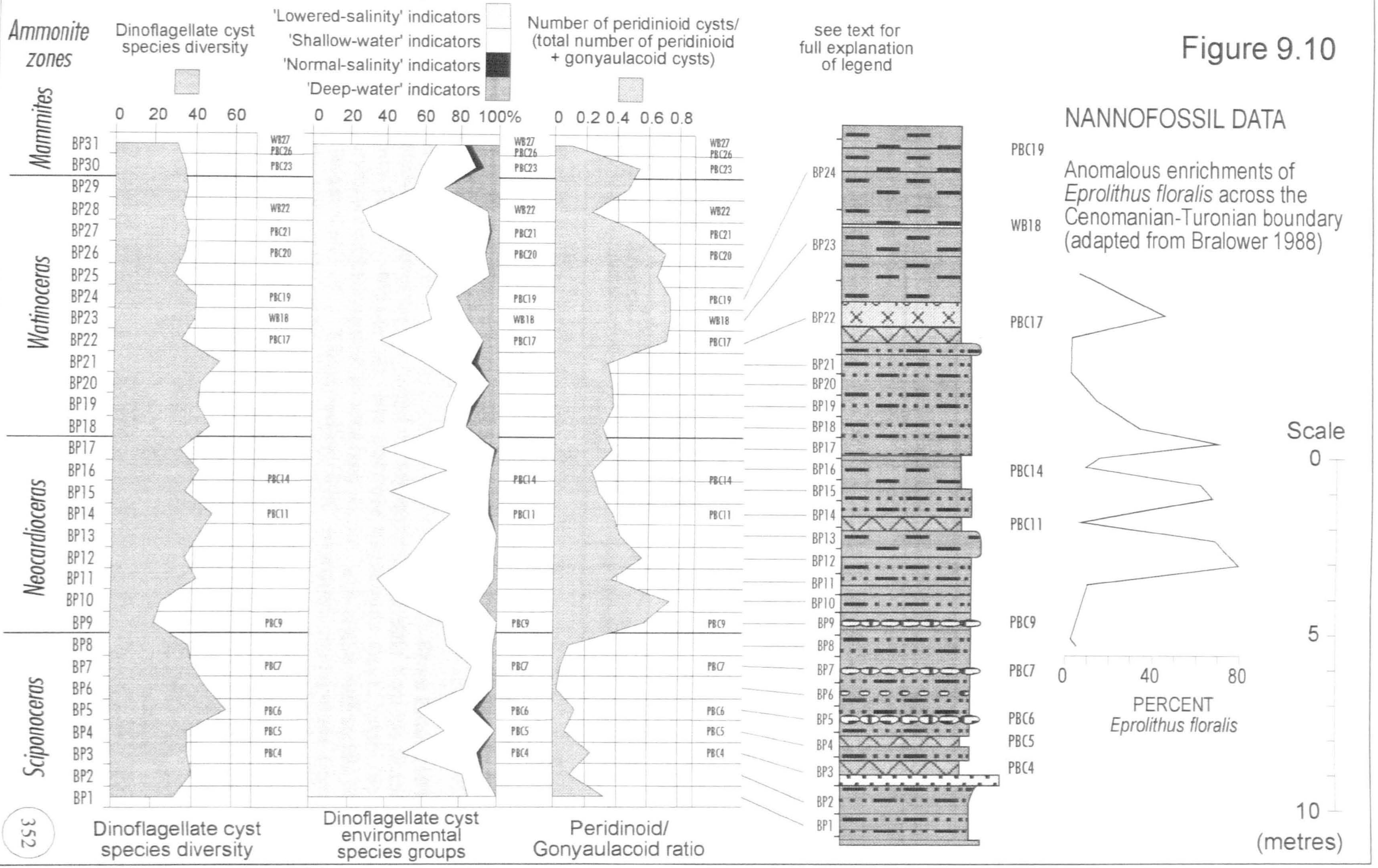
Sample depths are the same as for this study. Sample numbers listed are equivalent to those from this study.

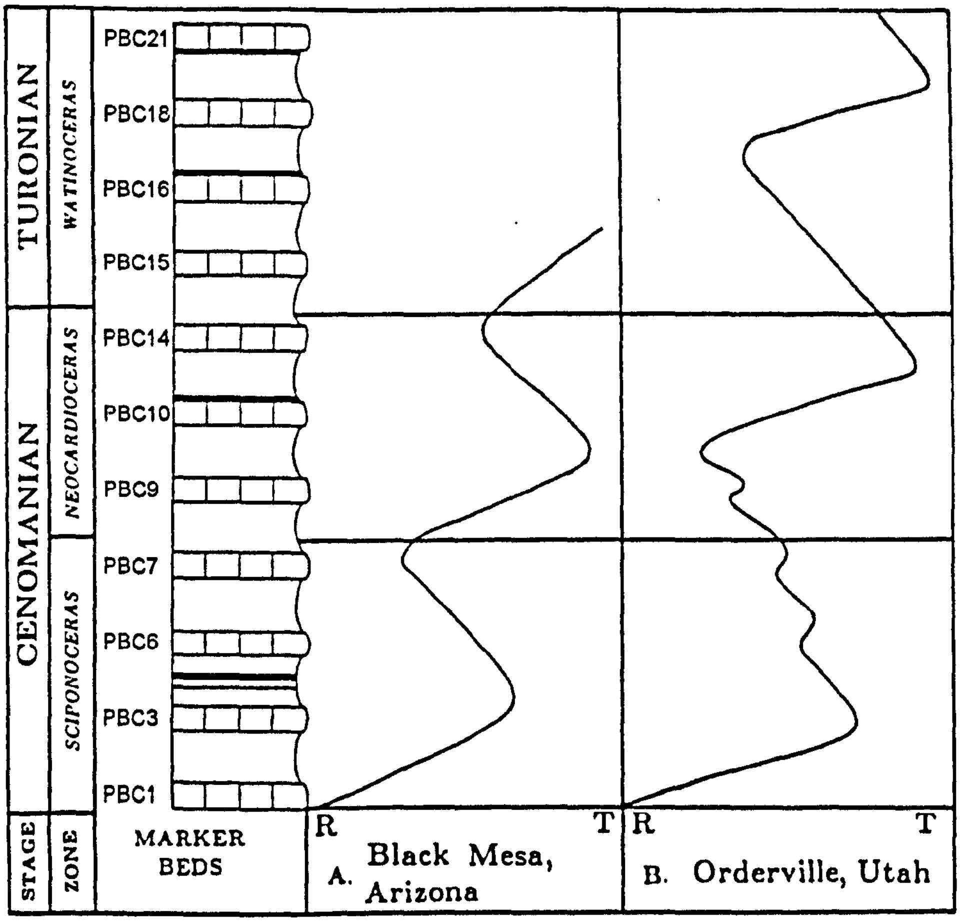
Ammonite stratigraphy is from Elder (1987). *Neo.* = *Neocardioceras*.

Lithostratigraphy is generalised except for positions of major bentonite and limestone horizons. Carbon isotope stratigraphy after Pratt & Threlkeld (1984).

Dinoflagellate cyst and nannofossil data: *Blue Point Section*

Figure 9.10





From Elder 1991

Relative sea-level curves based on sedimentological data from the Black Mesa Basin, Arizona (A), and from the Kaiparowits Basin, Utah (B). Curves are plotted against an idealised section, with stages and zones. R = Regression, T = Transgression. PBC equivalent marker-beds from Elder & Kirkland 1985.

Figure 9.11

a very strong positive correlation with the sea-level curve suggested by Elder (1991) for the Black Mesa Basin (Figure 9.11). This suggests that the species was either most abundant at times of fourth-order highstand and/or that other species of nannofossils were increasingly altered by diagenesis at times of fourth-order sea-level highstand (possibly from increased circulation and benthic oxygenation).

Eprolithus floralis has been noted by other authors (e.g. Roth & Krumback, 1986) as a potential indicator for cold or hyposaline waters. If the former is the case, then the species suggests that on the west side of the basin, periods of highstand were characterised by colder or lowered salinity surface waters (perhaps boreal influenced) rather than by warmer, higher salinity waters as suggested by the macrofauna and foraminifera. The only exception to the similarities in graphical curves between the abundance of this species and sea-level is in the upper half of the *Neocardioceras* Zone, where the sea-level is thought to fall. However, after a small, brief decrease, the species continues to display high abundances again. This may be the result of a subsaline cap suggested from a negative shift in $\delta^{18}O$ values (Pratt & Threlkeld, 1984, Elder, 1987) through the upper half of the *Neocardioceras* Zone.

In the Blue Point samples the abundance curve of *Eprolithus floralis* from Bralower, 1988, is very similar to that of some of the dinoflagellate cyst species, in particular *Spiniferites twistringiensis*, *Spiniferites lenzii*, *Coronifera oceanica*, *Cometodinium? whitei*, and *Dinopterygium cladoides*. This consequently produces a strong similarity with the 'shallow-water' indicator species (Figure 9.10). The abundance curve of *Eprolithus floralis* also shows some similarities with the curves of *Spiniferites ramosus ramosus*, *Spiniferites ramosus gracilis*, *Subtilisphaera? inaffecta*, *Subtilisphaera cheit* and *Palaeohystrichophora infusorioides* suggesting that there may be a link between this species and primary productivity. However there is little relationship between the curves of *Eprolithus floralis* abundance and the P/G ratio. The samples showing increased abundances of this nannofossil species also tend to be those showing decreased dinocyst species diversity compared with neighbouring samples.

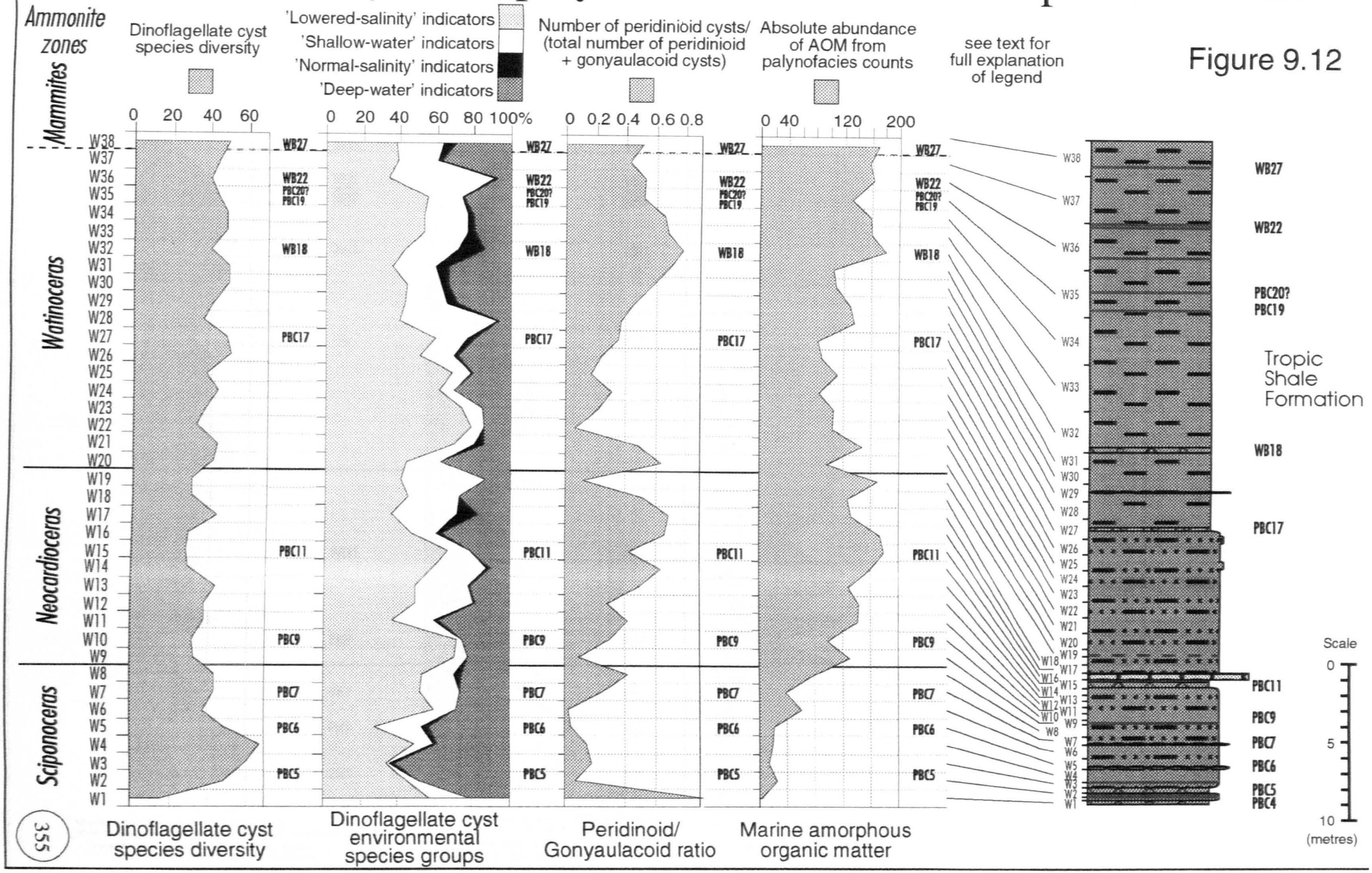
9.3 WAHWEAP WASH SECTION

The stratigraphic occurrences and abundances of individual species in the Wahweap Wash section (in order of first and last appearance datum) are illustrated in Charts 3A and 3B in Appendix E. The dinoflagellate cyst species diversities, proportions of dinoflagellate cyst indicator species (plotted out against each other), peridinioid/gonyaulacoid proportions and levels of marine amorphous organic matter (AOM) from the palynofacies counts referred to in this chapter, are plotted out alongside the lithostratigraphy of the section in Figure 9.12. The stratigraphic occurrences and abundances of individual palynofacies types referred to in this section are illustrated in Chart 3C (including marine amorphous organic matter (AOM) counts) and Chart 3D (excluding AOM counts) in Appendix E. Selected curves for the proportions of palynofacies types and groups referred to in this chapter, are plotted out alongside the lithostratigraphy of the section in Figure 9.13. The detailed lithostratigraphy is illustrated in Figure 3.13.

The pattern of geochemical and macrofaunal variation across the Cenomanian - Turonian boundary at Wahweap Wash (from Elder, 1989, 1991) is illustrated in Figure 9.14. The macrofaunal

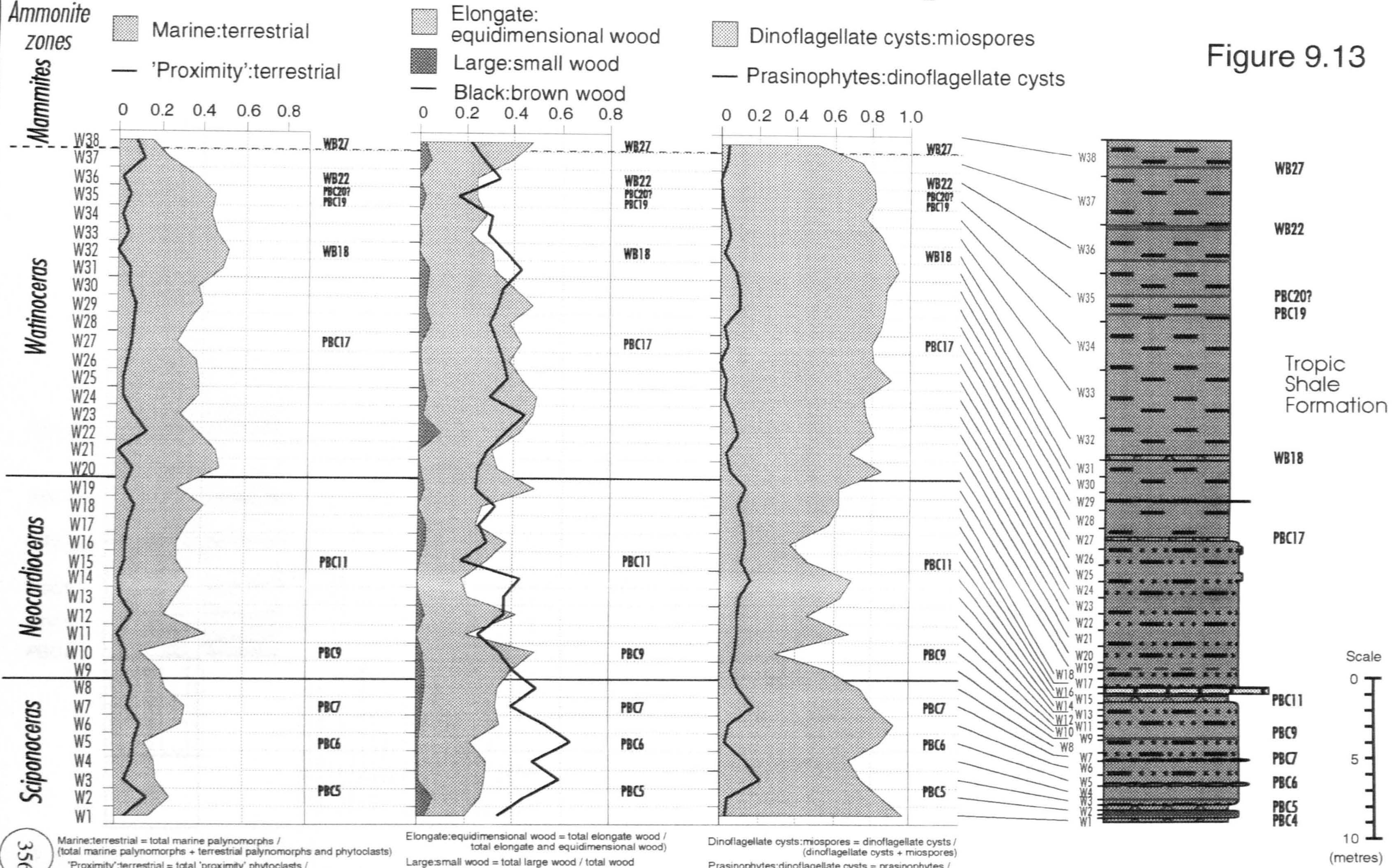
Dinoflagellate cyst and palynofacies data: Wahweap Wash Section

Figure 9.12



Selected palynofacies ratios: Wahweap Wash Section

Figure 9.13



Marine:terrestrial = total marine palynomorphs / (total marine palynomorphs + terrestrial palynomorphs and phytoclasts)

'Proximity':terrestrial = total 'proximity' phytoclasts / (total terrestrial phytoclasts + palynomorphs)

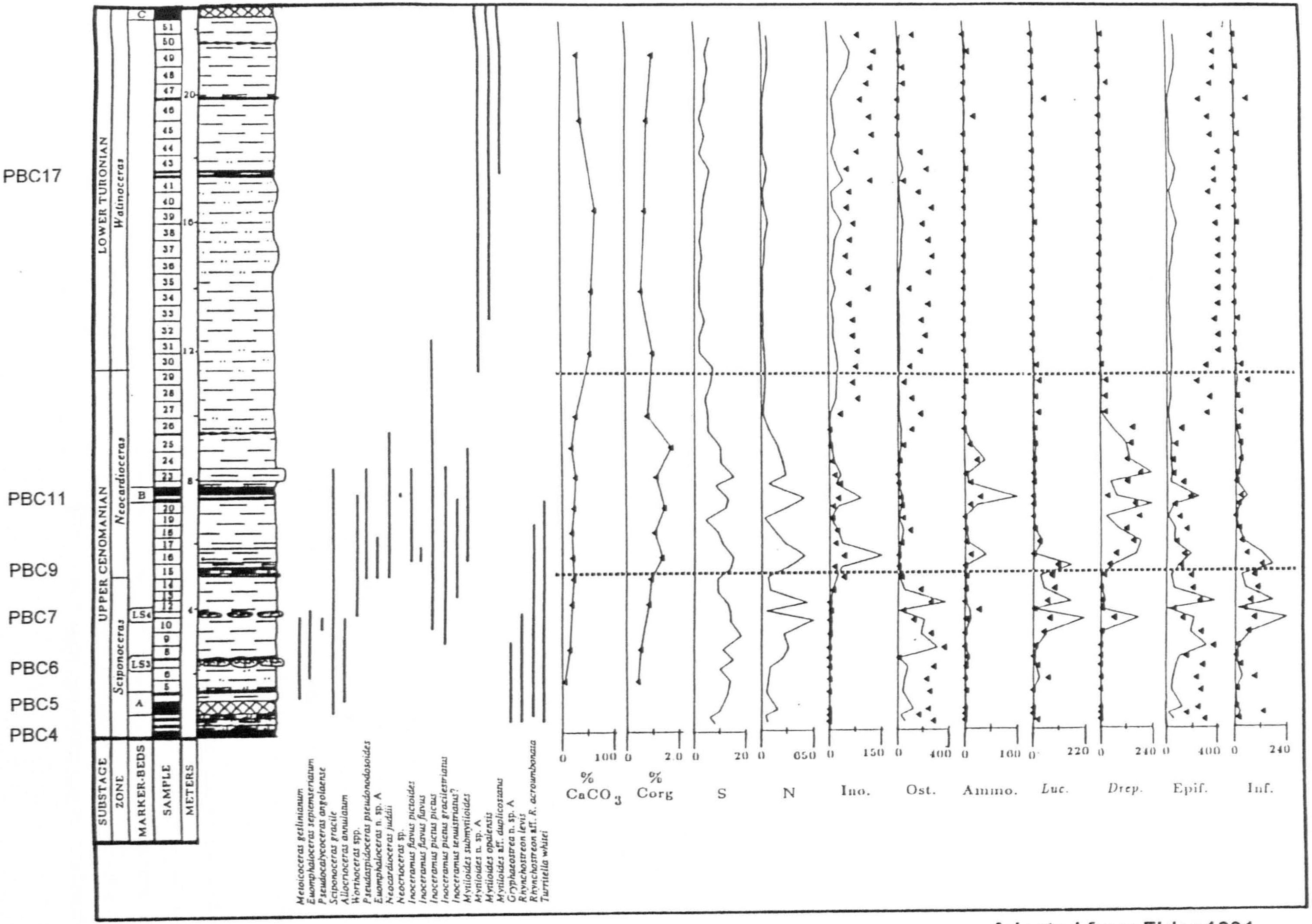
Elongate:equidimensional wood = total elongate wood / total elongate and equidimensional wood)

Large:small wood = total large wood / total wood

Black:brown wood = total black wood / total wood

Dinoflagellate cysts:miospores = dinoflagellate cysts / (dinoflagellate cysts + miospores)

Prasinophytes:dinoflagellate cysts = prasinophytes / (prasinophytes + dinoflagellate cysts)



Adapted from Elder 1991

with PBC marker bed equivalent designations from Elder & Kirkland 1985

Figure 9.14

Wahweap Wash, Utah: Geochemical and macrofaunal variation with ranges of biostratigraphically useful taxa plotted against stratigraphy across the Cenomanian - Turonian boundary interval.

species used in this diagram are listed with their authors in Figure 9.4. The key to the lithological and taxonomic plot symbols in Figure 9.14 is illustrated in Figure 9.5.

9.3.1 Tropic Shale Formation

The Tropic Shale Formation was deposited in an open marine environment following another transgressive pulse, which flooded the near-shore environments represented by the upper member of the Dakota Formation. Continued transgression decreased the shoreline proximity and hence decreased the silt content of the shales.

Important species in the samples from the section include species of *Achomosphaera* and *Spiniferites*, *Exochosphaeridium phragmites*, *Florentinia mantellii*, *Odontochitina costata*, *Tenua hystrix*, and the 'small peridinioid cysts'.

9.3.1.1 ***Sciponoceras* Zone:** The base of the zone is marked throughout the Western Interior Basin by a transgressive pulse causing a shoreward migration of the strandline and sediment trapping at the basin margins with a decrease in sedimentation rates through the seaway (Elder, 1991). The basal sample studied from the Tropic Shale Formation has a limited species diversity (16 species) and is strongly dominated by the 'small peridinioid group'. However, the sample was taken from silty shale which along with the presence of *Achomosphaera ramulifera* and *Achomosphaera* sp. A suggests that the site of deposition was not too near-shore. Whatever conditions created the high productivity at that time must also have restricted the dinoflagellate cyst assemblages.

The interval between the bentonite equivalents of PBC4 and PBC5 is characterised by conflicting palynofacies trends. A deepening trend is suggested by a pronounced decrease in the proportions of brown wood, by an increase in the proportions of marine palynomorphs (particularly dinoflagellate cysts), and by large increases in species diversity and the proportion of 'deep-water' indicator species. However the trend is also characterised by increases in proximal terrestrial indicators (very large woody fragments and membranous material), which may indicate an increase in terrigenous input.

Cyclic sedimentation (probably driven by Milankovitch cyclicity) was enhanced in this zone, due to decreased sedimentation rates and increased calcareous plankton productivity from the influx of warmer, normal marine waters. The macrofaunal diversity was greatest during the *Sciponoceras* Zone, particularly in the limestone/concretionary horizons (Figure 9.14), and included stenotopic macrofauna (e.g. echinoids), arising from small transgressive pulses involving the influx of southern waters with associated fauna, decreased sedimentation rates, increased substrate firmness and increased benthic oxygenation (Elder, 1991).

Across the basin, the most diverse fauna are developed in the horizon equivalent to PBC6, indicating that the most widespread 'normal' marine conditions were developed in the basin at that time (Elder, 1991). The dinoflagellate cyst species diversity increases through the zone, reaching a peak just below the horizon equivalent to PBC6. The proportions of 'deep-water' indicators reaches a maximum in the sample just above the bentonite equivalent to PBC5 and then peaks again in the sample including the equivalent of PBC6. The rise in diversity and 'deep-water' indicators is also matched by a small peak in the proportion of peridinioid cysts.

The lithostratigraphic interval including the samples from PBC6, PBC7 and in between show a number of variations. The samples including the concretionary horizons show a smaller abundance of AOM than the sample in between suggesting improved bottom oxygenation during the deposition of the concretionary horizons. The sample in between also shows an increase in proximal terrestrial indicators suggesting increased terrestrial input between the concretionary horizons. The proportions of marine palynomorphs are greater in the samples below and including PBC7.

Above the equivalent of PBC6 the samples show a general decline in dinoflagellate cyst species diversity and an increase in 'lowered-salinity' and 'shallow-water' indicator species perhaps suggesting a stillstand event with progradation of the shoreline or an extension of low-salinity surface waters, which continues into the basal two samples of the *Neocardioceras* Zone. The sample below PBC7 is marked by the correlatable *Cyclonephelium compactum* acme. Macro-fossil extinction episodes occurred in the shales above the equivalents of PBC6 and PBC7 (Figure 9.14), both associated with increased sedimentation rates, decreased substrate firmness and decreasing benthic oxygen levels. A period of faunal demise and community restructuring occurred preceding the extinction event at the top of the zone (Elder, 1991). The top of the *Sciponoceras* Zone is marked by a peak in the P/G ratio and a slight increase in the proportion of 'normal-salinity' dinoflagellate cyst indicator species.

9.3.1.2 ***Neocardioceras* Zone:** The base of the zone is marked by an influx of cosmopolitan and subtropical ammonites and inoceramids (Elder, 1991). It is also marked by a sharp increase in the abundance of AOM, by a short sharp abundance peak of *Oligosphaeridium complex*, by an increase in brown wood fragments, a further increase in the proportions of 'lowered-salinity' dinoflagellate indicator species, and by a decrease in numbers of black wood fragments, marine palynomorphs and 'proximity phytoclasts'. This suggests a progradational event or an increase in terrigenous input although it is thought that the proximity proportions of phytoclasts should have increased under either circumstance.

The marked increase in AOM at the base of the zone is followed by a comparative fall in the shale equivalent to PBC9 suggesting temporarily increased benthic oxygen levels. The abundance of AOM through the zone is generally much higher than in the *Sciponoceras* Zone with the abundances fluctuating between around 50% and 90% of the total palynofacies counts. The abundance curve of foraminiferal test linings approximately parallels the AOM abundance curve, suggesting that either foraminiferal test lining production was greatest at times of reduced benthic oxygen levels or that the abundance of linings is related to palaeoproductivity which in turn affected AOM production. A relationship between AOM and foraminiferal test linings is also noted in Courtinat, 1993. The samples through the *Neocardioceras* Zone contain slightly higher numbers of leiospheres but few other prasinophytes.

The palynofacies signals through the *Neocardioceras* Zone fluctuate much more than those in the *Sciponoceras* Zone. The implications of the signals also seem more in tune with each other perhaps due to deeper water conditions with less distortion by near-shore proximity. In addition the sample spacing is slightly finer and more in tune with lithostratigraphic alternations. A number of fluctuations can be seen through the zone related to certain samples (with the reverse conditions in between). These samples include the one from the shale equivalent of PBC9 (W10), the samples including the bentonite horizon PBC11 and the marlstone above, and sample W19. These are characterised by high amounts of AOM (except for the sample from PBC9), higher abundances of foraminiferal test linings and brown wood, and lower abundances and diversities of dinoflagellate cysts. Consequently they have low marine palynomorph:terrestrial palynomorph and phytoclast ratios. However the abundances of black wood and proportions of 'proximity phytoclasts' are variable, higher in the lower two samples and lower in the upper two samples, leaving a variable black wood:brown wood ratio and a less clear shoreline proximity signal.

The macrofaunal diversification at the base of the zone was 'short-lived', and followed by further faunal deterioration with a small extinction event immediately overlying the equivalent of PBC9 with a subsequent increase in detritus-feeding gastropods indicating an increase in organic carbon levels within the sediment (Elder, 1991). This sample is marked by a small peak in 'deep-water' indicator species and by rising species diversity suggesting a transgressive event. It is also marked by a peak in the proportions of peridinioid cysts and a large peak in foraminiferal test linings suggesting an increase in productivity. The samples above this contain increasing proportions of 'lowered-salinity' and 'shallow-water' indicators reaching a maximum in the sample below the equivalent of PBC11, suggesting an extension of low salinity surface waters.

A slight macrofaunal recovery with an increase in ammonites occurred from just below the bentonite equivalent to PBC11 through to above the marlstone horizon above this bentonite, suggesting an increase in the circulation of southern waters from a transgressive pulse (Elder, 1991). However, no increase occurs in 'deep-water' or 'normal-salinity' species in the samples below or including PBC11, although the sample below does show a peak in the P/G ratio. The abundance of AOM also increases reaching a peak through the sample including the bentonite equivalent to PBC11. The sample from the marlstone above the equivalent of PBC11 does show an increase in 'deep-water' and 'normal-salinity' indicator species and a further peak in P/G ratios which continues almost to the top of the zone. The two samples below and including the equivalent of PBC11 also contain large numbers of foraminiferal test linings, though these return to only trace amounts in higher samples.

The macrofaunal recovery around the equivalent of PBC11 ended in another extinction event, particularly of ammonites, probably due to further deterioration in benthic oxygen levels and substrate firmness. The strata through to the top of the zone have a low diversity of eurytopic macrofauna leading to a final extinction event (Elder, 1991). The top of the zone is marked by a decrease in the P/G ratio, and by an increase in the proportion of 'shallow-water' dinoflagellate cyst indicator species and the abundance of AOM.

9.3.1.3 ***Watinoceras* and *Mammites* Zones:** The base of the zone at Wahweap Wash is marked by a thin, virtually unfossiliferous interval and characterised by a slight increase in carbonate content. The influx of new, Early Turonian bivalves, suggests a possible increase in salinity and oxygenation (Elder, 1991). The base is also marked by an increase in dinoflagellate cyst diversity, an increase in the proportions of 'deep-water' indicator species, peridinioid cysts, and marine palynomorphs (particularly dinocysts and foraminiferal test linings) and a decrease in abundance of woody phytoclasts and the proportions of 'proximity phytoclasts'. This suggests a transgression causing sediment baffling at the basin margins and increased surface productivity.

Macrofaunal diversity increases slowly through the lower part of the zone, followed by a more rapid increase further up, though low abundances of the infauna indicate continued low oxygen levels within the sediments. Increasing abundance of the epifauna suggests increasing substrate firmness up-section. Ammonite immigration in the western part of the basin (in comparison with further east) was poorly developed, perhaps due to continued lower than normal marine salinities (Elder, 1991). The brief transgressive pulse at the base of the zone is followed in the sample above (W21) by a large increase in the proportion of 'lowered-salinity' dinoflagellate cyst indicator species, a decrease in species diversity and a decrease in the P/G ratio, which continue (with small fluctuations) through to the sample W25 and suggest renewed lower salinity surface waters and decreased productivity over this period. The proportions of 'proximity phytoclasts' also show a large increase in the sample W22 suggesting an increase in terrigenous input at this level.

At Wahweap Wash, the benthic realm was reoxygenated much more quickly than sections from the centre and east of the basin allowing earlier establishment and greater diversity among the benthic macrofauna (Harries & Kauffman, 1990). The abundance of AOM through the *Watinoceras* and *Mammites* Zones continues to be generally high (40% to 90%), dominating the samples, though with levels lower than in the *Neocardioceras* Zone. The number of foraminiferal test linings also continues to parallel the abundance of AOM, as they do through the *Sciponoceras* and *Neocardioceras* Zones.

The fluctuations in palynofacies assemblages through the *Watinoceras* Zone are comparatively minor. Part of this reason is probably the much wider sample spacing which has probably led to the averaging out of various signals. In addition, the comparative shortage of lithostratigraphic marker horizons has not helped correlation of the palynofacies trends.

The abundance of woody phytoclasts and the proportions of 'proximity' indicating phytoclasts, 'lowered-salinity' and 'shallow-water' dinoflagellate cyst indicator species all reach a peak in the samples including the equivalent of bentonite PBC17 and the sample above suggesting an increase in terrigenous input or a progradational event.

A significant increase in 'normal-salinity' and 'deep-water' dinoflagellate cyst indicator species along with an increase in the proportion of marine palynomorphs and a decrease in the abundance of woody phytoclasts occurs in the sample containing the calcarenite bed (W29), suggesting a transgressive pulse at this level. This is followed by a more gradual but significant increase in the P/G ratio which reaches a peak in the sample including the bentonite WB18 suggesting increasing productivity. This sample also shows a decrease in the abundances of woody phytoclasts and 'proximity phytoclasts' and an increase in the proportion of marine palynomorphs (suggesting transgression). However the same sample also shows a decrease in the proportion of 'deep-water' dinoflagellate cyst indicator species (suggesting progradation of the shoreline).

Although no level is given for the *Watinoceras/Mammites* zonal boundary for the Wahweap Wash section, the sample above the double bentonite (WB22) again shows a significant increase in 'deep-water' and 'normal-salinity' indicator species (as it does in the samples from the Blue Point section) suggesting a further transgressive pulse as is also noted in the other sections. However, the palynofacies assemblages suggest very different environmental changes, with an increase in the abundance of woody phytoclasts and 'proximity phytoclasts', and a large decrease in the abundance of marine palynomorphs through this interval, suggesting a progradational phase or increase in terrigenous input.

9.4 PUEBLO SECTION

The stratigraphic occurrences and abundances of individual species in the Pueblo section (in order of first and last appearance datum) are illustrated in Charts 4A and 4B in Appendix E. The dinoflagellate cyst species diversities, proportions of dinoflagellate cyst indicator species (plotted out against each other), peridinioid/gonyaulacoid proportions and levels of marine amorphous organic matter (AOM) from the palynofacies counts referred to in this chapter, are plotted out alongside the lithostratigraphy of the section in Figure 9.15. The stratigraphic occurrences and abundances of individual palynofacies types referred to in this section are illustrated in Chart 4C (including marine amorphous organic matter (AOM) counts) and Chart 4D (excluding AOM counts) in Appendix E. Selected curves for the proportions of palynofacies types and groups referred to in this chapter, are plotted out alongside the lithostratigraphy of the section in Figure 9.16. The detailed lithostratigraphy is illustrated in Figure 3.9.

The macrofaunal biozones for the Pueblo section are illustrated in Figure 9.17. The stratigraphic ranges of the macrofauna, pattern of macrofaunal variation, and pattern of geochemical variation across the Cenomanian - Turonian boundary at Pueblo are illustrated in Figures 9.18, 9.19, and 9.20 respectively. The macrofaunal species used in Figure 9.18 are listed with their authors in Figure 9.4. The key to the lithological and taxonomic plot symbols in Figures 9.18, 9.19 and 9.20, is illustrated in Figure 9.5. The geochemical data from the section has also been plotted against the abundance of AOM and the lithological log in Figure 9.21. The stratigraphic ranges of selected foraminiferal species are illustrated in Figure 9.22. Trends in the foraminiferal assemblages are illustrated in Figure 9.23.

9.4.1 Hartland Member

The Hartland Member is thought to have been deposited at a time of sustained oxygen depletion in the Western Interior Seaway, with its low diversity macrofauna, organic rich, finely laminated sediments and absence of benthic foraminifera (Sageman, 1985). Relatively negative values for oxygen isotope ratios of whole rock carbonate in the Hartland Member have been interpreted (Pratt, 1981, 1984, 1985) as indicating salinity lower than normal marine levels (see Figure 9.29).

The most striking feature of the palynological assemblages from the Hartland Member samples is the overwhelming numbers of prasinophytes (particularly leiospheres, tasmanitids and species of *Pterospermella*) in all but the top sample. The acritarch *Wuroia* sp. A is also common in these samples. The numbers of prasinophytes in the samples from the Hartland Member of the Rebecca K. Bounds

Dinoflagellate cyst and palynofacies data: *Pueblo Section*

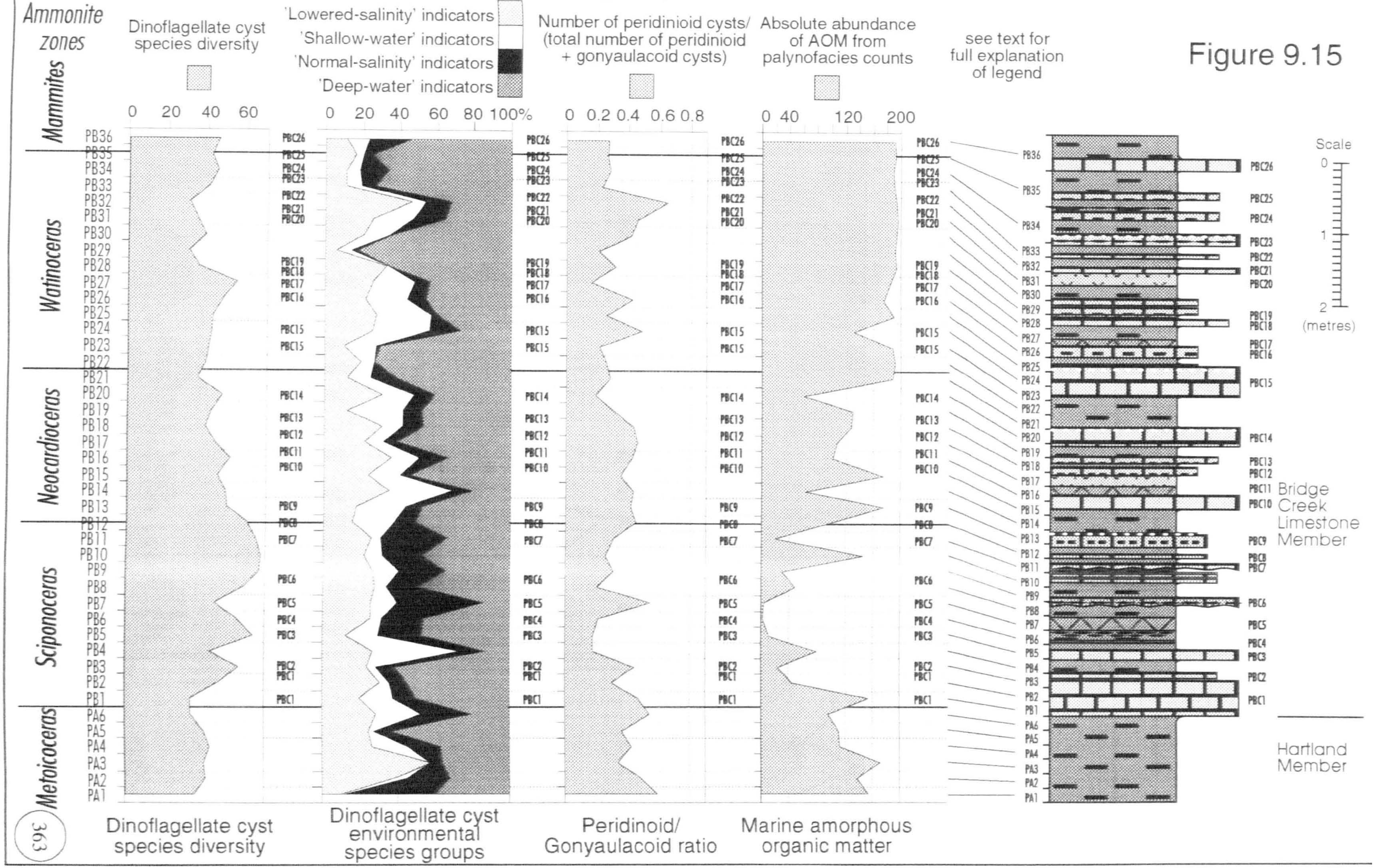
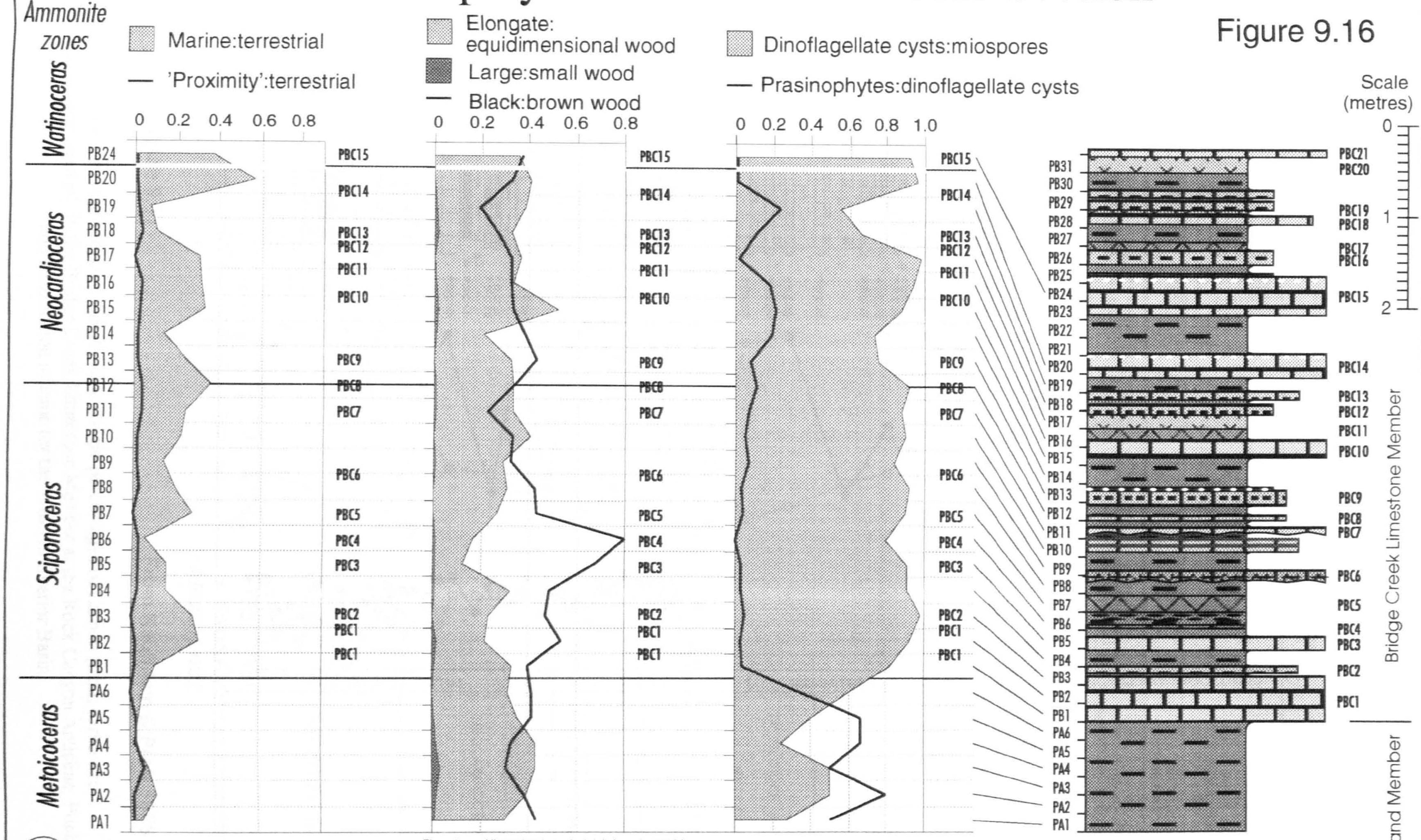


Figure 9.15

Selected palynofacies ratios: *Pueblo Section*

Figure 9.16



Marine:terrestrial = total marine palynomorphs / (total marine palynomorphs + terrestrial palynomorphs and phytoclasts)

'Proximity':terrestrial = total 'proximity' phytoclasts / (total terrestrial phytoclasts + palynomorphs)

Elongate:equidimensional wood = total elongate wood / total elongate and equidimensional wood)

Large:small wood = total large wood / total wood

Black:brown wood = total black wood / total wood

Dinoflagellate cysts:miospores = dinoflagellate cysts / (dinoflagellate cysts + miospores)

Prasinophytes:dinoflagellate cysts = prasinophytes / (prasinophytes + dinoflagellate cysts)

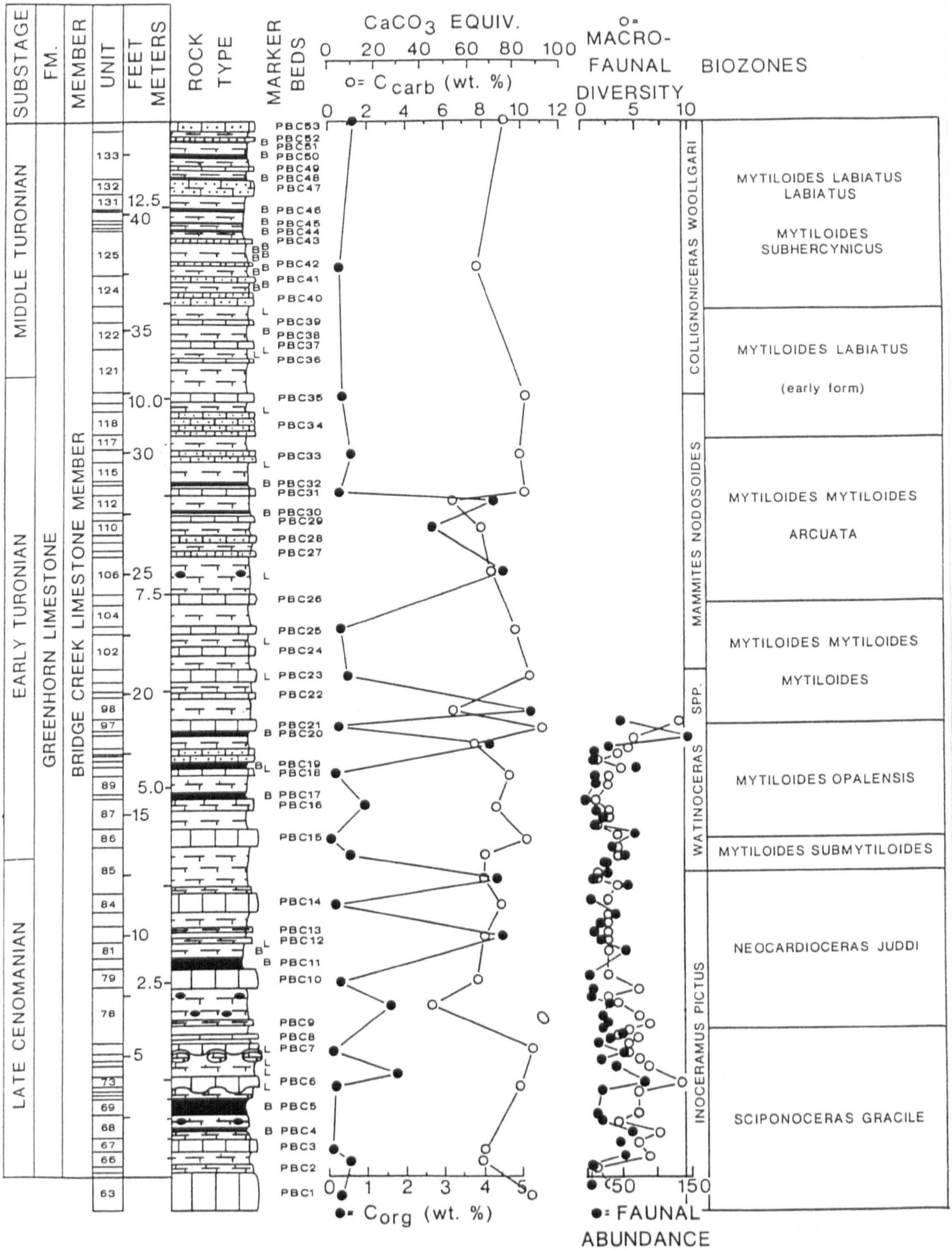
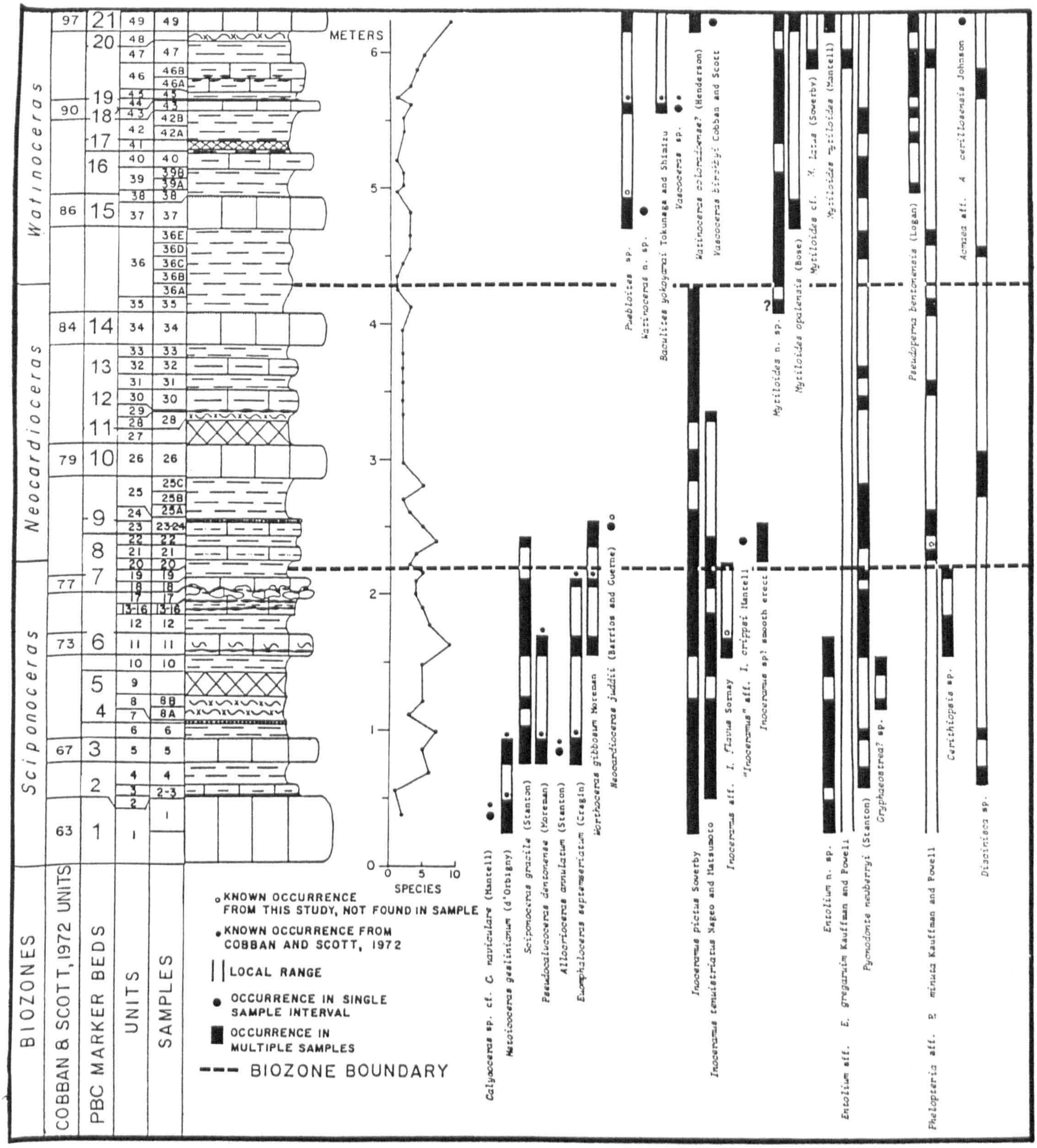


Figure 9.17 **From Kauffman & Pratt 1985**

Lithostratigraphy and variations in weight percentages of Carbon (from carbonate and organic matter) in the Bridge Creek Limestone Member at the Rock Canyon Anticline, Pueblo, and biozonation scheme for the Western Interior Basin.

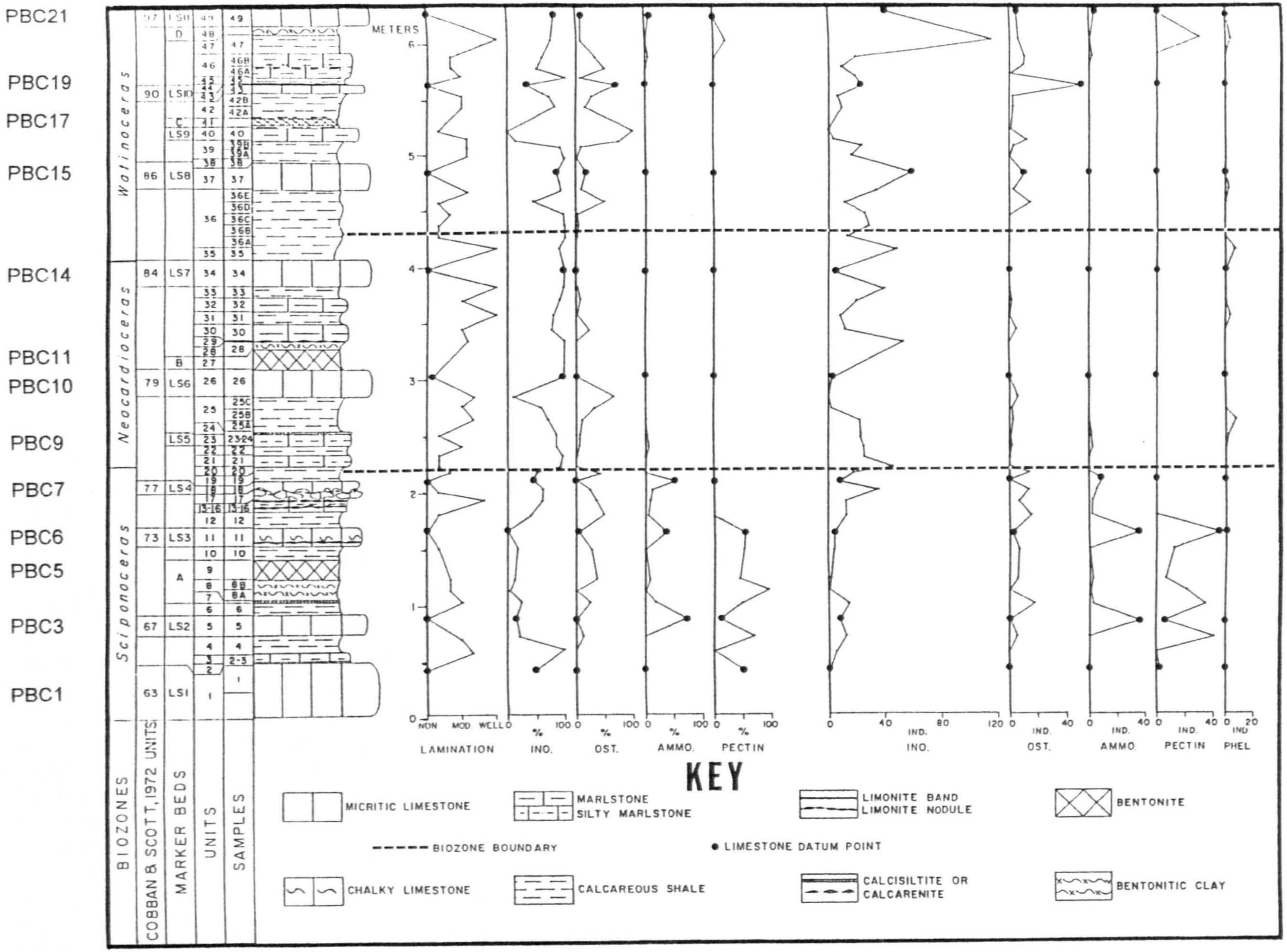


Stratigraphic range chart of common macrofaunal components across the C-T boundary near Pueblo, Colorado. Ranges at Rock Canyon anticline are plotted against the stratigraphic column and the species richness (Species) noted in each standardized macrofaunal sample.

with PBC marker bed
equivalent designations
from Elder & Kirkland 1985

Figure 9.18

Adapted from Elder 1985



with PBC marker bed equivalent designations from Elder & Kirkland 1985

Figure 9.19

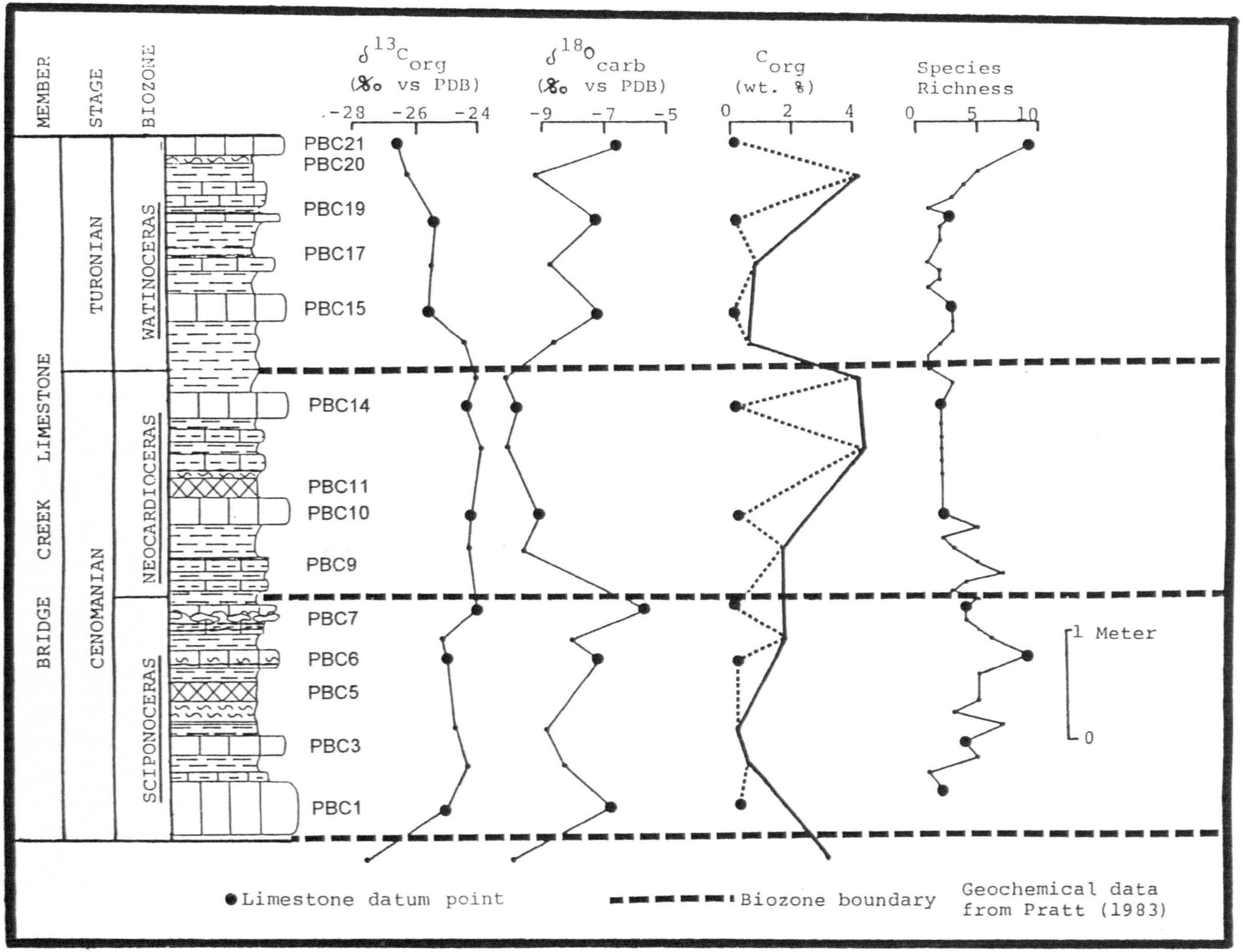
Adapted from Elder 1985

Pueblo, Colorado: Relative (percentages) and actual (individuals) abundances of the macrofauna across the Cenomanian - Turonian boundary interval plotted against stratigraphy.

Figure 9.20

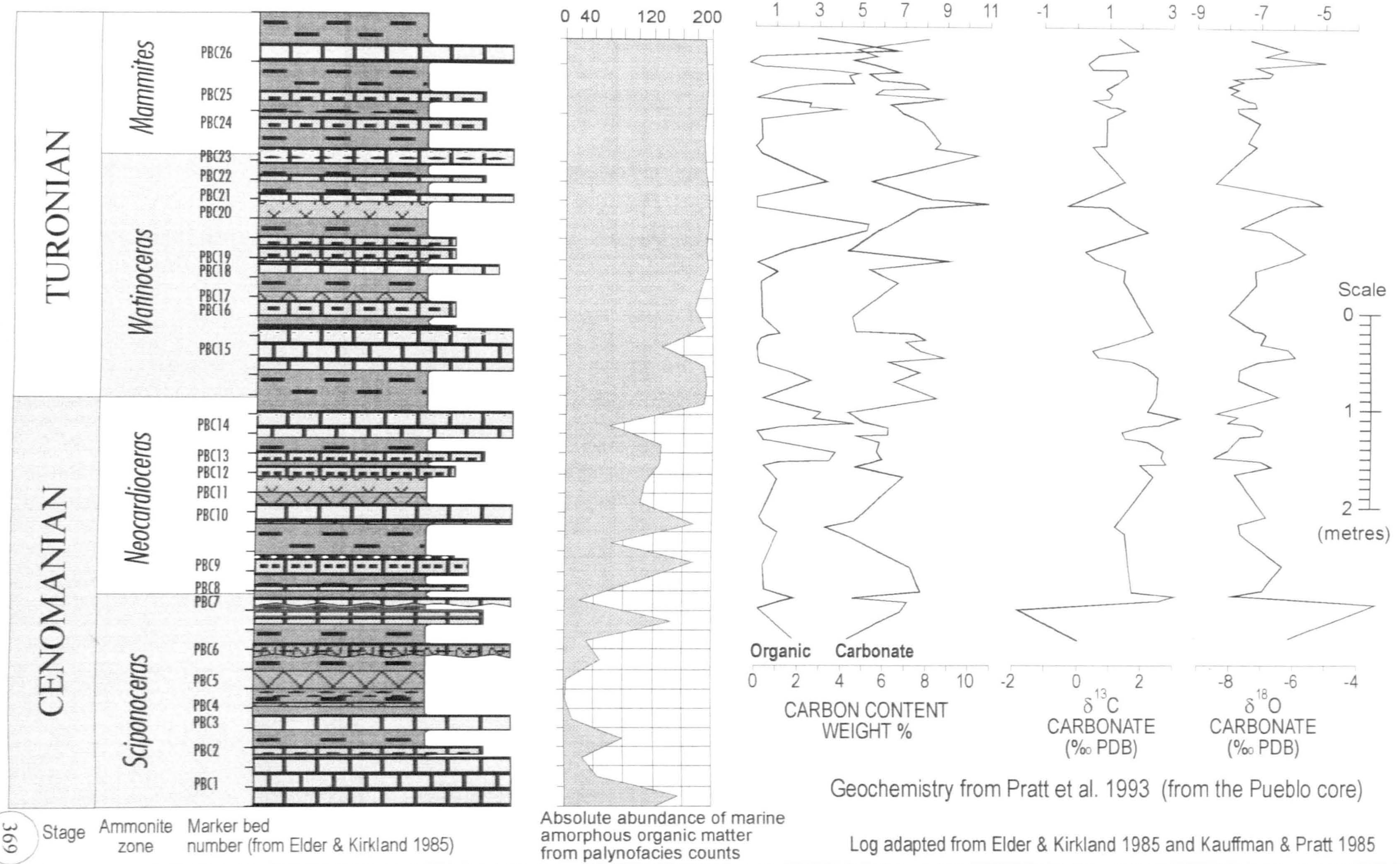
Stratigraphic column, carbon isotope ratios in organic matter, oxygen isotope ratios in carbonate, organic carbon content, and macrofaunal species richness across the Cenomanian - Turonian stage boundary in the lower Bridge Creek Limestone Member of the Greenhorn Limestone Formation near Pueblo, Colorado. The solid line on the organic carbon curve is drawn between shale and marlstone data points eliminating low values present in all limestone beds. PBC marker bed numbers from Elder & Kirkland (1985).

Adapted from Elder 1985



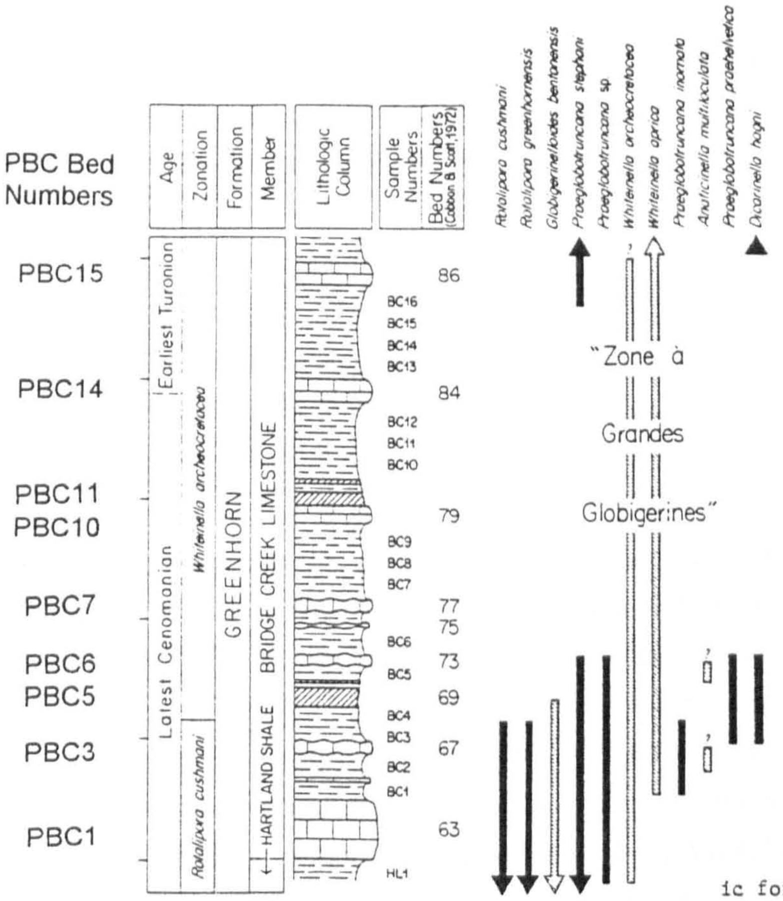
Comparison of levels of amorphous organic matter with selected geochemical and isotopic profiles from Pueblo, Colorado

Figure 9.21



Geochemistry from Pratt et al. 1993 (from the Pueblo core)

Log adapted from Elder & Kirkland 1985 and Kauffman & Pratt 1985



Rotalispora cushmani (Morrow)
Rotalispora greenhornensis (Morrow)
Globigerinelloides bentonensis (Morrow)
Praeglobotruncana stephani (Gandolfi)
Whiteinella archeocretacea (Pessagno)
Whiteinella aprica (Loeblich and Tappan)
Praeglobotruncana inornata (Bolli)
Anaticinella multiloculata (Morrow)
Praeglobotruncana praehelvetica (Trujillo)
Dicarinella hagni (Scheibnerova)

Figure 9.22

Stratigraphic distribution of key planktonic foraminifera in the Cenomanian-Turonian boundary interval of the Rock Canyon anticline section. Solid bars represent keeled morphotypes, hatch represents non-keeled forms. Ranges above and below study interval are based on data from Eicher and Worstell (1970). Shaded beds in lithologic column represent prominent bentonites. Divisions along left margin represent thickness in meters from base of the Bridge Creek Limestone.

Adapted from Leckie 1985

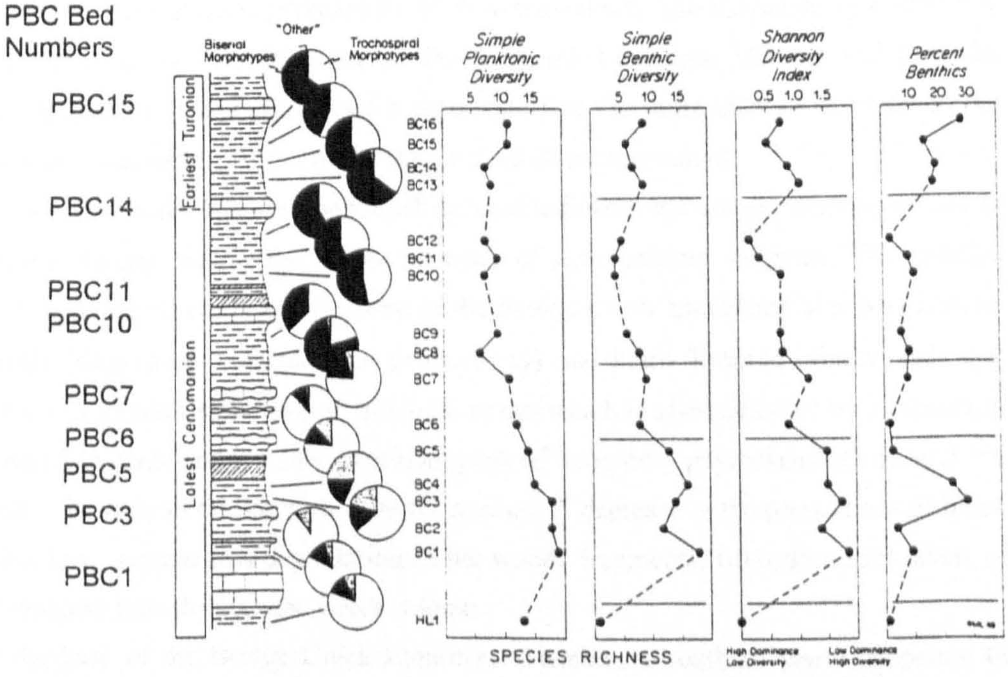


Figure 9.23

Trends in planktonic and benthic foraminifera from uppermost Hartland Shale and lower Bridge Creek Limestone at Rock Canyon anticline. Divisions in the plots for benthic foraminifera follow brief discussions in text. Samples BC1 to BC5 correspond to the benthonic zone of Eicher and Worstell (1970).

Adapted from Leckie 1985

core are also as high. This suggests that the Western Interior Basin may have been permanently stratified at the time of deposition of the member, perhaps by a lowered-salinity lid, which is probably the reason for the continuously depleted oxygen levels throughout most of the member. However, the scant numbers of prasinophytes in the C-T boundary sections suggests that the C-T boundary 'anoxic event' was not caused by permanent stratification. The assemblages from the Hartland Member samples also contain fairly high proportions of peridinioid cysts suggesting fairly high levels of productivity.

Cycles have been recognised in the relative severity of oxygen depletion. An alternating transgressive pulse/stillstand model is suggested to account for the patterns of cyclic sedimentation and oxygen-deficient biofacies distribution through the member at Pueblo (Sageman, 1985). The Hartland Member at Pueblo has been subdivided into three units. The basal unit has a low diversity and abundance of macroinvertebrates in highly laminated, organic-carbon rich shales. The middle unit has the highest levels of macrofaunal diversity in the member, particularly in the limestone and calcarenite beds, while the shales in between still show high organic-carbon content and low macrofaunal diversity.

The upper unit of the Hartland Member was deposited in a still stand period and progradational phase, with a higher clastic sediment input to the centre of the basin, and a decrease in bottom current energy. It is characterised by laminated to micro-bioturbated shales, with a return to low diversity, low abundance, inoceramid-dominated epifaunal macrofossil assemblages and preservation of high levels of organic-carbon. The inoceramids are particularly important as they had a high tolerance of oxygen-deficient environments and soft substrates (Sageman, 1985).

Through the Hartland Member samples, the dinoflagellate cysts are comparatively scarce and may only be those carried in from the basin margins (Tyson, 1987). This idea is supported by an increase in the proportions of marine palynomorphs to terrestrial palynomorphs and phytoclasts, and of dinoflagellate cysts to miospores during periods either of increased low-salinity surface waters or of progradation, as suggested by increased proportions of 'lowered-salinity' dinoflagellate cyst indicator species. The normal pattern in the samples from the Bridge Creek Limestone Member and from the other sections, is the reverse, with higher values for these ratios at the same time as increases in the proportions of 'deep-water' indicator species (suggesting periods of transgression).

The proportions of 'normal-salinity' dinoflagellate cyst indicator species are extremely high in the bottom two samples studied, mainly due to the presence of *Isabelidinium magnum*. The samples immediately above (1 metre to 60 cm below the base of the Bridge Creek Limestone Member) contain fewer peridinioid cysts (suggesting a decrease in productivity) and more 'lowered-salinity' indicator species. This suggests a progradational event or stillstand event, which is also indicated by increases in the abundance of wood fragments and the only important peak of 'proximity phytoclasts' (to around 7% of the total phytoclasts) through all the samples from the section. A decrease in the proportions of black to brown wood at this level suggest less degradation of the woody fragments, from decreased levels of oxygen and/or less transport time through the water column.

Just below the base of the Bridge Creek Limestone Member, a southern warm-temperate to subtropical water mass moved into the seaway, increasing the salinities to near-normal marine concentrations and allowing the immigration of diverse warm-water taxa from the south. This included the appearance and diversification of benthic foraminifera and a marked increase in planktonic foraminifera (Figures 8.6, 9.22 and 9.23; Eicher & Worstell, 1970, Eicher & Diner, 1985, Leckie, 1985). The event may have been related to a change in circulation patterns, climate, and/or rising sea-level reaching a critical water depth (perhaps at the southern entrance to the seaway) allowing well oxygenated waters to spread northwards. The calcareous benthic foraminifera appear 60 cm below the base of the Bridge Creek Limestone Member at Pueblo (Eicher & Diner, 1985).

The levels of AOM through the Hartland Member are generally high (between 70 and 80%) but decrease in the top 60 cm (to around 50 to 60%), suggesting increased benthic oxygenation. A substantial increase occurs in the number of marine palynomorphs in the sample between 60 and 40 cm below the base of the Bridge Creek Limestone Member. The highest numbers of foraminiferal test linings occur in the sample below the base of the Bridge Creek which also has the lowest abundances of AOM. Transgressive pulses are suggested by the dinoflagellate cyst assemblages in the sample between 40 and 20 cm below and at the base of the Bridge Creek Limestone Member by increases in 'deep-water' dinoflagellate cyst indicator species. The sample just below the base of the Bridge Creek also contains more peridinioid cysts suggesting increased productivity in association with the transgressive pulses. The transgression is also confirmed by decreasing abundances of woody phytoclasts and an increase in the ratio of black to brown wood suggesting better oxygenation and/or longer settling times in the water column.

9.4.2 Bridge Creek Limestone Member

The Bridge Creek Limestone Member records the peak transgression of the Greenhorn cycle (Hattin, 1975, Kauffman, 1977a) and the maximum extent of the Western Interior Seaway during the Cretaceous. The change from deposition of the Hartland Member to deposition of the Bridge Creek Limestone Member followed a rapid decrease in detrital input into the central seaway from eustatic rise and shoreward migration of the strand-line and involved a switch from dominantly calcareous shale to climatically controlled limestone-shale bedding couplets resulting perhaps from productivity fluctuations (Eicher & Diner, 1985, 1989) or from surface salinity fluctuations (e.g. Pratt, 1984, 1985, Arthur *et al.*, 1985, 1987). The bioturbated limestone beds were deposited at times of good circulation and relatively high oxygen levels in the water column while the shales were deposited at times of comparative stratification with depleted benthic oxygen levels.

The sedimentation rates seem to have been relatively consistent throughout the Bridge Creek Limestone Member at any one place, but varied between basinal and shelf environments. At Pueblo the rock accumulation rates, estimated from radiometric dates, are very slow (0.5 - 1.0 cm per 1000 years) due to transgressive disconformities and hiatuses, sediment bypass and winnowing, sediment trapping along the western coasts and in the foreland basins, and a lack of sediments from the stable craton to the east.

The macrofossil biostratigraphy has been studied in detail at Pueblo by a number of authors including Cobban & Scott (1972), Cobban (1985), Elder (1985) and Elder & Kirkland (1985).

9.4.2.1 *Sciponoceras* Zone: The faunas of the *Sciponoceras* Zone at the base of the 'lower' Bridge Creek Limestone Member contain mixed warm-temperate and subtropical components reflecting the incursion of warm southern water masses and increase in salinity to 'normal-marine' levels (Kauffman, 1984, Elder & Kirkland, 1985) at a time of rapid transgression, and is supported by a positive shift in $\delta^{18}O$ values (Figures 9.20 and 9.21; Pratt, 1985). The macrofaunas at this time were the most taxonomically diverse of the Greenhorn cyclothem as were the planktonic foraminifera (Figures 9.19 and 9.23).

Samples from the thick limestone bed at the base of the Bridge Creek Limestone Member show an increase in the number of 'deep-water' dinoflagellate cyst indicator species as well as an increase in species diversity, also suggesting that this limestone was deposited at the time of a major transgressive pulse.

The levels of AOM through the zone are highly variable. The base of the Bridge Creek Limestone Member is marked by a drastic fall in the levels of AOM, from around 75% at the base of PBC1 to around 10% around PBC2, suggesting that increased oxygenation of the water column exceeded the effects of increased production of marine organic carbon.

The shale sample between PBC2 and PBC3 contains a large increase in 'shallow-water' dinoflagellate cyst indicators at the expense of the 'deep-water' species and also shows a decrease in species diversity and a significant drop in the proportion of peridinioid cysts. This may suggest that the limestones PBC1 and PBC2 were deposited under higher productivity conditions and that the shale was deposited at a time of lower surface salinity. Species diversities peak again in the sample including PBC3 and above this level, the proportions of all the dinoflagellate cyst indicator species remain fairly stable through to the top of the zone.

The levels of woody phytoclast decrease through the lower half of the *Sciponoceras* Zone suggesting decreased terrigenous input or decreasing shoreline proximity. In contrast to the other phytoclasts and palynomorphs, the abundance of black wood reaches an unusually large peak in the sample including the bentonite PBC4 perhaps suggesting unusual water chemistries at the time of deposition, resulting in heavier degradation of the organic matter.

The planktonic foraminifera decrease in diversity from the shale above PBC3 through to above PBC7. The last occurrences of *Rotalipora* are in the sample immediately overlying PBC3 (Figure 9.22). This disappearance was not basinally synchronous, as it disappeared from waters further south in Texas before the equivalent of the base of the Bridge Creek Limestone Member (Frush & Eicher, 1975). This may suggest a gradual northward expansion of the mid-water oxygen minimum zone in the latest Cenomanian, resulting in the extinction of the genus (Leckie, 1985). Keeled planktonic foraminifera disappear in the shale above PBC6 and are not found again until just beneath PBC15. This interval is referred to as the zone of 'Grandes Globigerines' (Figure 9.22), and may be attributed to an expansion of the oxygen minimum zone (Eicher & Diner, 1985). The levels of foraminiferal linings are generally very low through the zone but are slightly higher through PBC1 to PBC2 and from PBC6 upwards suggesting that the species producing the organic linings did not necessarily respond to environmental change in the same way as the calcareous assemblages.

The proportions of marine palynomorphs to terrestrial palynomorphs and phytoclasts, and the proportions of peridinioid cysts follow very similar curves through the *Sciponoceras* Zone with peaks in the basal limestone and in the sample including the bentonite PBC5. The latter is partly due to increases in the numbers of *Subtilisphaera pontis-marie* which also in turn increases the proportions of 'normal-salinity' dinoflagellate cyst indicator species. Species diversities peak again in the samples including and between PBC6 and PBC7 perhaps suggesting a further transgressive pulse. However, this is contended by increasing levels of brown wood and a decrease in the proportions of marine palynomorphs around PBC6 and PBC7 suggest increasing terrigenous input at this time. A decrease in the black:brown wood ratio also suggests this or decreasing deterioration of woody phytoclasts, perhaps due to lowering oxygen levels in the water column.

In general, the shales of the *Sciponoceras* Zone contain greater amounts of AOM than the limestones, particularly below PBC6 and PBC7 and at the top of the zone. Intervals of decreased macrofaunal diversity and last occurrences of taxa in the middle and upper parts of the zone indicate periods of environmental deterioration immediately above PBC6 and PBC7 (Figure 9.18; Elder, 1985).

9.4.2.2 *Neocardioceras* **Zone**: The *Neocardioceras* Zone is generally an interval of decreased macrofaunal diversity. Ammonites are rare in this zone, perhaps due to lower oxygen levels in the water column or reduced salinities in the upper waters, though they are still indicative of warm southern waters within the seaway, at least lower in the water column. The base is marked by a macrofaunal immigration event and a sharp decrease in benthonic foraminifera, suggesting a decrease in benthic oxygen levels (Elder, 1985, Leckie, 1985).

The base of the zone is also marked by a large negative shift in the $\delta^{18}O$ values suggested to have occurred with the development of a more permanent subsaline cap across the surface of the seaway (Pratt, 1985). The proportions of prasinophytes to dinoflagellate cysts is fairly stable through the *Sciponoceras* Zone. However some fluctuations occur in the *Neocardioceras* Zone although their magnitude is only around a third to a quarter of the differences recorded through the Hartland Member. The samples from below PBC10 through to the basal part of PBC11 and the sample from the shale below PBC14 have levels of prasinophytes a quarter of the levels of dinoflagellate cysts although the majority of these are leiospheres. This suggests that water column stratification through these levels may have been more significant at this time.

Around the base of the *Neocardioceras* Zone, a switch in planktonic foraminifera from dominantly trochospiral (mainly *Hedbergella* spp.) to biserial (*Heterohelix* spp.) and trochospiral (*Whiteinella* and *Hedbergella* spp.) forms occurs. This trend continues through to the base of the *Watinoceras* Zone (just below PBC15), probably reflecting an ecological change in the upper water column at this time. It has been suggested that *Heterohelix* was a eurytopic surface dweller and that its occurrence may support the theory of sub-saline surface waters across the seaway through the *Neocardioceras* Zone (Leckie, 1985). The number of foraminiferal test linings is fairly low through the zone though they reach almost 5% in the samples from PBC10 and below and from PBC14 and PBC15.

The limestone horizon PBC9, at the base of the zone has a higher macrofaunal diversity from immigration with an increase in bottom water circulation (Elder, 1985). This interval is marked by an increase in the proportions of marine palynomorphs and by a slight increase in the proportions of 'deep-water' dinoflagellate cyst indicator species suggesting a possible transgressive pulse (although species diversity shows a slight decrease), and by an increase in the P/G ratio which then remains fairly high through the samples as far up as PBC13. The proportions of black to brown wood show a temporary increase in the limestone PBC9 suggesting greater degradation of phytoclasts in the water column.

The shale overlying PBC9 horizon represents a major macrofaunal deterioration interval, including most of the macrofaunal extinctions. A further decline occurs in the shale overlying PBC10 (Elder, 1985). The sample above PBC9 shows an increase in the proportions of 'lowered-salinity' and 'shallow-water' indicator species, a decrease in the proportion of marine palynomorphs and an increase in the abundance of woody phytoclasts, suggesting an increase in terrigenous input.

Smaller increases in the proportions of 'deep-water' dinoflagellate cyst indicators at the base of the limestone horizons PBC10 and PBC12 might suggest small transgressive pulses associated with the deposition of these limestones. This interval is also marked by increases in the proportions of marine palynomorphs.

Increases in terrigenous input are suggested by a large increase in woody material around PBC12 and PBC13 and in the shale below PBC14, while the proportions of black to brown wood also show a temporary decrease below PBC14 suggesting possible lowering of oxygen levels.

The limestone PBC14 shows a slight increase in 'lowered-salinity' dinoflagellate cyst indicator species and a slight decrease in P/G ratios suggesting that not all limestones were formed by transgressive pulses with increases in productivity, although the bed also shows an increase in the proportion of marine palynomorphs.

The final macrofaunal turnover occurs in and at the top of the *Neocardioceras* Zone, in the shale overlying PBC14 (Elder, 1985). The sample above PBC14 shows a significant increase in the proportions of 'deep-water' indicator species suggesting a transgressive pulse at the top of the zone, along with a small increase in the P/G ratio and a huge increase in the levels of AOM.

9.4.2.3 ***Watinoceras* and *Mammites* Zones:** The base of the *Watinoceras* Zone is marked by the first common *Mytiloides* species along with an increase in $\delta^{18}O$ values and a slight recovery in benthic foraminifera (Elder, 1985, Leckie, 1985, Pratt, 1985). As mentioned earlier, the proportions of 'deep-water' dinoflagellate cyst indicator species increase in the uppermost sample of the *Neocardioceras* Zone and remain high through to the base of PBC15.

The first prominent macrofaunal recovery occurs just below PBC15 along with a positive shift in $\delta^{18}O$ and a decrease in Corg content (Elder, 1985, Pratt, 1985). This is also synchronous with the first appearance of keeled planktonic foraminifera, that had been absent since the *Sciponoceras* Zone (Leckie, 1985). The sample from the middle of PBC15 contains an increase in the proportion of 'lowered-salinity' and 'shallow-water' indicator species which lasts through the samples to PBC17. The sample also contains high levels of woody phytoclast and low ratios of dinoflagellate cyst to miospore and marine palynomorphs to terrestrial palynomorphs and phytoclasts. This suggests that this limestone was deposited at a time of increased terrigenous input and lower surface salinities.

At Pueblo, where the basin was deepest and less oxygenated, the redevelopment of complex benthic communities was more prolonged and an infauna rarely became established, suggesting continued inhospitable conditions below the sediment-water interface. The appearance of ammonites was also slightly later than further west, suggesting a progressive, basinward oxygenation of the water column (Harries & Kauffman, 1990). The levels of AOM generally remain around 95% through the sediments of the *Watinoceras* and *Mammites* Zone.

In the *Watinoceras* and *Mammites* Zones (unlike the earlier zones) the P/G ratios are highest in those samples with greater proportions of 'lowered-salinity' and 'shallow-water' species, perhaps suggesting increased productivity at these times. A major increase in the proportions of 'deep-water' dinoflagellate cyst indicator species (e.g. *Hystrichodinium pulchrum*) occur in the sample including PBC18 and PBC19 although no transgression is mentioned in the literature for this level. The samples around PBC20 and PBC21 contain much larger proportions of 'shallow-water' and 'lowered-salinity' indicator species suggesting another period with lower salinity surface waters.

The 'middle' Bridge Creek Limestone Member reflects the peak eustatic rise of the Greenhorn marine cycle with the most laterally continuous limestones occurring in the seaway (Hattin, 1975). The ammonite and bivalve faunas in the lower half of the middle Bridge Creek Limestone Member have very high diversities with the largest influx of subtropical to tropical and cosmopolitan taxa (Kauffman, 1984). This again reflects open communication with the Tethyan ocean with an associated widespread increase in salinity and oxygen to 'normal-marine' levels. Increases in the proportions of 'deep-water' dinoflagellate cyst indicator species (e.g. *Hystrichodinium pulchrum*) occur again in the samples above PBC22, along with the earliest occurrences in the section of taxa such as *Florentinia buspina* and *Isabelidinium? globosum*.

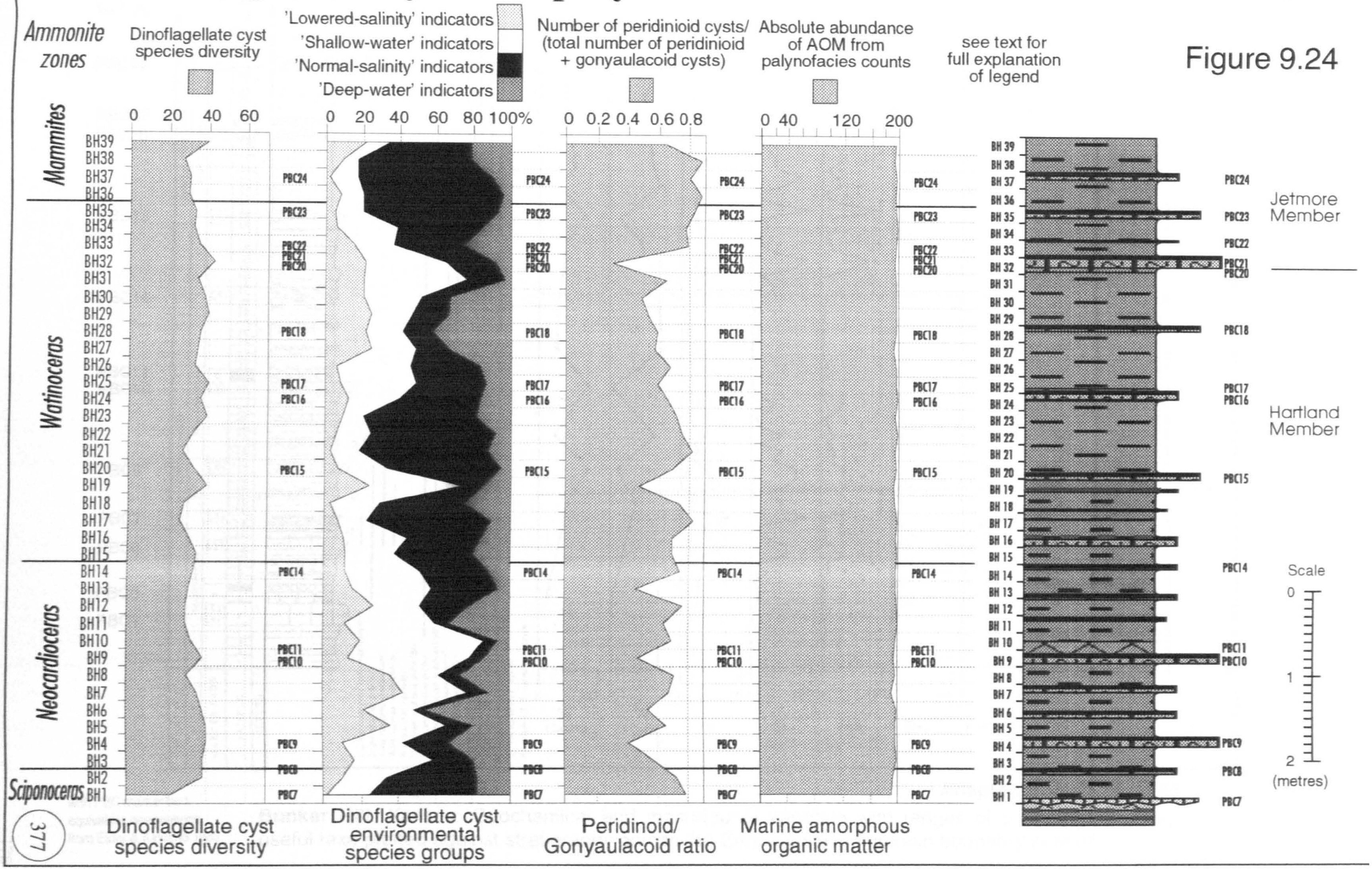
9.5 BUNKER HILL SECTION

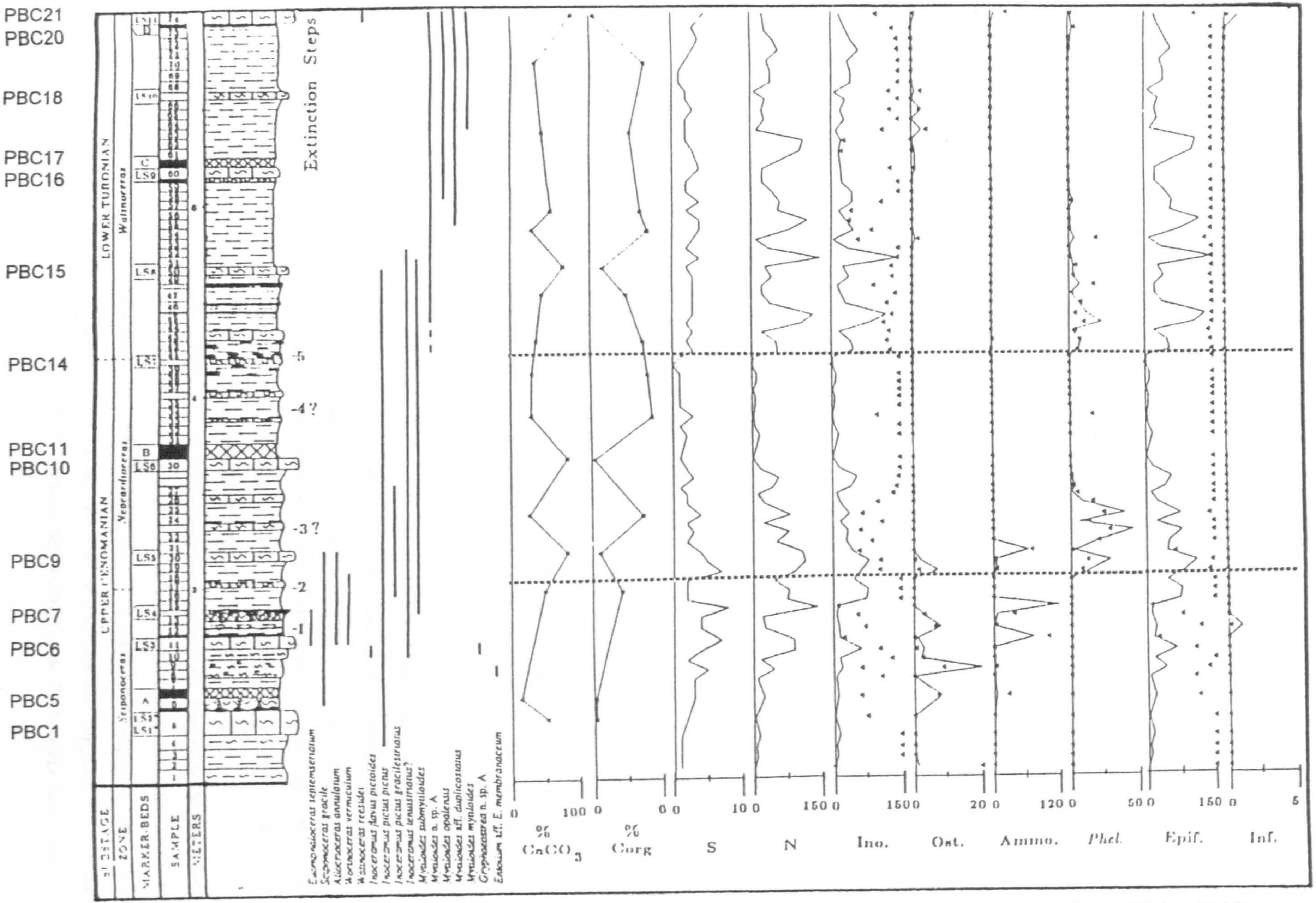
The stratigraphic occurrences and abundances of individual species in the Bunker Hill section (in order of first and last appearance datum) are illustrated in Charts 5A and 5B in Appendix E. The dinoflagellate cyst species diversities, proportions of dinoflagellate cyst indicator species (plotted out against each other), peridinioid/gonyaulacoid proportions and levels of marine amorphous organic matter (AOM) from the palynofacies counts referred to in this chapter, are plotted out alongside the lithostratigraphy of the section in Figure 9.24. The stratigraphic occurrences and abundances of individual palynofacies types (including marine amorphous organic matter (AOM) counts) referred to in this section are illustrated in Chart 5C in Appendix E. The detailed lithostratigraphy is illustrated in Figure 3.11.

The pattern of geochemical and macrofaunal variation across the Cenomanian - Turonian boundary at Bunker Hill (from Elder, 1989) is illustrated in Figure 9.25. The macrofaunal species used

Dinoflagellate cyst and palynofacies data: *Bunker Hill Section*

Figure 9.24





with PBC marker bed equivalent designations from Elder & Kirkland 1985

Figure 9.25 **Adapted from Elder 1989**

Bunker Hill, Kansas: Geochemical and macrofaunal variation with ranges of biostratigraphically useful taxa plotted against stratigraphy across the Cenomanian - Turonian boundary interval.

in this diagram are listed with their authors in Figure 9.4. The key to the lithological and taxonomic plot symbols in Figure 9.25 is illustrated in Figure 9.5.

9.5.1 Greenhorn Limestone Formation

The widespread development of the beds of the Greenhorn Limestone Formation suggests that the sea floor was broad, flat and nearly featureless with an extremely shallow gradient. The area to the east of the seaway lay on a stable craton, and was low and flat and for most of the Late Cretaceous was not an important terrigenous sediment source. The main source for detrital sediment in Kansas was (as with the rest of the basin) from the orogenic chain to the west. This is supported by the westward increase in terrigenous detritus within the sediments (Hattin, 1975).

A pattern of balance between pelagic and terrigenous deposition occurred in the Greenhorn Limestone Formation, producing alternating beds of shaly chalk and chalky limestone. During the deposition of the shaly chalk, low oxygen levels at the sea floor produced a periodically hostile environment when the sediments remained undisturbed by benthic fauna. The alternations occurred periodically as the influx of terrigenous material either waned in absolute or comparative terms, at times of greater oxygenation of the water column, resulting in layers of purer carbonate which were extensively bioturbated and subsequently lithified. The shaly chalks contain a low diversity of macrofauna, consisting mainly of inoceramid bivalves with some fish scales, while the chalky limestones contain a more diverse assemblage of inoceramids and ammonites. The detailed lithostratigraphy, macrofossil biostratigraphy and various macrofossil biozonation schemes are described by Hattin (1975).

The macrofossil assemblages, environmental energy levels and sedimentation/subsidence information (Kauffman, 1969, Hattin, 1975) suggest the maximum water depth to have been relatively shallow, ranging from 30 metres (for the lowermost Lincoln member) to 90 metres throughout the formation. The minimum depth of 30 metres was suggested, based on the lack of algal borings in bivalves. Harries & Kauffman (1990) suggested depths of less than 100 metres for peak transgression at Bunker Hill.

The sea floor, consisting of impure carbonate mud, would have been an unfavourable habitat for many forms of benthonic life, with the epifauna largely restricted to inoceramid bivalves and the infauna/deposit feeders almost non-existent. The general lack of current formed structures suggests that bottom currents were negligible. The poor circulation of the bottom waters with resulting low levels of oxygen (consumed by the oxidation of the organic matter) near the sea floor were a major factor in limiting the benthic fauna in most of the shaly chalk units (Hattin, 1975).

The abundance and variety of coccoliths suggests that salinity was close to that of the open ocean for all of the Greenhorn Limestone Formation, since coccolithophores are intolerant to salinities of greater than 38‰ or less than 25‰ (Black, 1965, Cepek & Hay, 1969, Watkins, 1985, 1989). The large diversity of planktonic foraminifera, ammonites and inoceramids also suggests water of normal or near-normal salinity (Eicher & Worstell, 1970) with only small, if any, fluctuations in salinity.

A large proportion of the shaly chalk is made up of foraminifera and contains relatively diverse planktonic assemblages. However, benthonic foraminifera were generally rare in the Greenhorn Limestone Formation except in the lowermost Hartland Member (Eicher & Worstell, 1970).

The bulk of the shaly chalk of the Greenhorn Limestone Formation consists of coccoliths, often as faecal pellets thought to be from coccolithophore-eating organisms (Hattin, 1975). The rock was also noted to contain a relatively high percentages of organic carbon, in sufficient quantities to be noticed in thin section as lenticular to wispy bodies of opaque material aligned parallel to the general laminations (Hattin, 1975). The palynological preparations are dominated by AOM (95 to 100% of the palynofacies counts) which frequently occurs in the form of ellipsoidally-shaped faecal pellets.

Only the first palynofacies count was attempted for this section, as other forms of particulate organic matter were too scarce. The minority material counted included dinoflagellate cysts/acritarchs, foraminiferal test linings, prasinophytes, pollen, black wood (elongate and equidimensional) and brown wood (elongate, equidimensional and very large). No membranous material or spores were noted, probably due to low proportions as the site of this section was furthest from the source of terrestrial input at the time of deposition.

All of the assemblages from the samples studied from the Bunker Hill section are strongly dominated by *Palaeohystrichophora infusorioides* and *Subtilisphaera? inaffecta*. Other taxa with significant numbers include *Subtilisphaera pontis-marie*, *Subtilisphaera cheit* and species of *Spiniferites*. This dominance has meant very little change occurs in the species diversity curve through the samples. The dinoflagellate cyst indicator curves fluctuate considerably (probably due to lower counts of indicator species) and hence have less value. However many of the increases in 'deep-water' indicator species occur at the same stratigraphic level as those in the other sections which suggests that these curves do have some validity. Furthermore, many of the fluctuating increases in proportions of peridinioid species parallel the increases in 'deep-water' indicators again suggesting that transgressional pulses in the seaway resulted in increases in productivity.

Palynofacies assemblages from organic-rich carbonate sediments from a probable upwelling system from the Late Cretaceous of Israel (Eshet *et al.*, 1994) are dominated by amorphous organic matter with little terrestrial palynomorphs or phytoclasts. The dinoflagellate cyst assemblages are dominated by peridinioid species along with species of *Spiniferites*. It is possible that upwelling may have been responsible for the high productivity suggested for this site by Harries & Kauffman (1990).

9.5.2 Hartland Member

9.5.2.1 ***Sciponoceras* Zone:** The beds at the base of the *Sciponoceras* Zone show an increase in diversity of macrofauna and of calcareous benthic foraminifera across much of the Western Interior Basin, suggesting a widespread improvement of water circulation at that time (Eicher & Worstell, 1970, Hattin, 1975). The benthonic foraminifera gradually disappear higher in the zone (probably due to lowered oxygen levels at the sea floor) and persist only sparingly through the Jetmore and Pfeifer Members and into the Fairport Chalky Shale Member. However, the upper Jetmore and Pfeifer Members contain abundant calcarenite horizons which indicate better circulation but are lacking in, or only contain sparse, benthonic foraminifera. Hence, the presence of benthonic foraminifera is not a clear-cut indication of improved circulation and benthic oxygen levels (Eicher & Worstell, 1970).

The chalky limestone equivalent to PBC6 also records the appearance of a number of species of ammonites, recording the highest diversity of macrofauna in the section studied and suggesting a Tethyan pulse (Figure 9.25; Elder, 1989).

The macrofaunal extinction steps at Bunker Hill are suggested to have occurred above the equivalent of PBC6 and PBC7. The top of the zone is marked by a significant decrease in macrofaunal diversity and abundance (Elder, 1989). The samples above the equivalent of PBC7, at the top of *Sciponoceras* Zone and base of the *Neocardioceras* Zone contain increasing proportions of 'lowered-salinity' and 'shallow-water' dinoflagellate cyst indicators which are possibly linked to these macrofossil extinctions.

9.5.2.2 *Neocardioceras* Zone: Macrofaunal diversities rapidly increase at the base of the zone suggesting a potential influx of southern waters (Figure 9.25; Elder, 1989). The samples around the equivalent of PBC9 show an increase in proportions of 'normal-salinity' and 'deep-water' dinoflagellate cyst species in reaction to this tethyan pulse along with an increase in the P/G ratio above the equivalent of PBC9.

A gradual decline in macrofaunal species diversity occurs in the overlying beds through to the limestone equivalent to PBC10, with macrofaunal extinction steps suggested in the horizons just above the bentonite equivalent to PBC11 and just above the limestone equivalent to PBC14, at the top of the zone (Elder, 1989). The proportions of 'normal-salinity' and 'deep-water' dinoflagellate cyst indicator species fluctuate but generally decline in the samples from above the equivalent of PBC9, to a minimum around the equivalents of PBC10 and PBC11. The samples between the equivalents of PBC11 and PBC15 show continued fluctuations in proportions of indicator species but increases in the ratios of 'lowered-salinity' and 'shallow-water' indicators below and above the equivalent of PBC14 which may indicate further environmental perturbations responsible for the macrofaunal extinctions.

The zone is marked by a fluctuating but sharp rise in the levels of organic carbon within the sediment (Elder, 1989).

9.5.2.3 *Watinoceras* Zone: The base of the Turonian at Bunker Hill, is not marked by a thin, unfossiliferous interval, seen in sections further west (e.g. Wahweap Wash), probably due to condensation/sediment starvation.

The levels of organic carbon remain high through the zone, while macrofossil species diversity sporadically but steadily increases. The benthic oxygen levels at Bunker Hill are thought to have been slightly higher than at sites from the central part of the basin but not as high as at sites on the western side of the basin. Notable increases in macrofaunal diversity occurred around PBC15 (with the appearance of the first new species of *Mytiloides*), in the shale just below the limestone equivalent to PBC16, and in the shale between the equivalents of PBC18 and PBC20 (Elder, 1989, Harries & Kauffman, 1990). Transgressive pulses from increased proportions of 'normal-salinity' and 'deep-water' dinoflagellate cyst indicator species are suggested for the horizons just above the equivalent of PBC15, and around PBC18. The former also shows increases in the proportions of peridinioid cysts at the same level.

9.5.3 Jetmore Member

9.5.3.1 ***Mammites* Zone:** Maximum transgression of the Greenhorn cycle is represented by the pelagic carbonates of the Jetmore Member, which has the lowest values of terrigenous residues, from within the cyclothem (Hattin, 1971). Circulation conditions were suggested to have improved with increased bioturbation and abundances of macrofossils. Macrofaunal diversities reached a maximum for the study interval at around the equivalents of PBC23 to PBC26 (Hattin, 1975, Harries & Kauffman, 1990).

Transgressive pulses from increased proportions of 'normal-salinity' and 'deep-water' dinoflagellate cyst indicator species are suggested for the horizons just above PBC22 and above PBC24. These horizons again also show increases in the proportions of peridinioid cysts.

The chalky limestones of the Jetmore Member have a fairly diverse macrofaunal assemblage including inoceramids and ammonites. The shaly chalks contain mostly only inoceramids, with fish scales and planktonic foraminifera (Hattin, 1975).

9.6 CONCLUSIONS

9.6.1 Milankovitch cyclicity

Much work has been published on the origin of the bedding couplets found in the Bridge Creek Limestone Member as well as in other members and formations from the Western Interior Basin and elsewhere. The sampling method for this study was not particularly conducive to studying the origin of these alternating lithologies. However the cycles that produced the bedding greatly affected benthic oxygen levels and hence must have affected the Cenomanian - Turonian oxygen depletion event in the Western Interior Basin to some extent. Some authors (e.g. Arthur *et al.*, 1987) have even suggested this Milankovitch-driven cyclic oxygen depletion as the cause of the OAE in the basin. Consequently it seems important to try to pick out some of the palynological trends from the alternations where possible, to try to deduce their origin and suggest their importance in this study. Again, a short review of previous work is given below to highlight some suggestions for the origin of the bedding couplets.

9.6.1.1 Previous work

The bedding rhythms that occur in most of the offshore sediments across much of the Western Interior Basin are suggested to reflect changing deposition from Milankovitch climatic fluctuations, as wet and/or cool and dry and/or warm cycles. The laminated shales were produced at times of persistent water column stratification with resulting oxygen depletion in the bottom waters. These shales generally contain few macrofossils (except for some thin inoceramid bivalves), and low diversity benthonic foraminiferal assemblages. The bioturbated limestones were produced at times of good circulation and relatively higher oxygen levels in the bottom waters. Two main conflicting arguments have been proposed for the cause of the lithological alternations and are discussed in depth in numerous papers (e.g. Pratt, 1984, 1985, Arthur *et al.*, 1985, 1987, Eicher & Diner, 1985, 1989, Glancy *et al.*, 1993, Pratt *et al.*, 1993).

The most widely published explanation suggests climatic precipitation fluctuations (e.g. Pratt, 1984, 1985, Arthur *et al.*, 1985, 1987, Glancy *et al.*, 1993, Pratt *et al.*, 1993). The supply of biogenic carbonate is though to have been relatively constant but at times of increased precipitation, a brackish lid is thought to have formed on the seaway, due to increased terrestrial run-off, causing stratification with subsequent oxygen depletion, and transporting greater quantities of siliciclastic material with resultant deposition as shale. The limestones are thought to have been deposited during drier intervals with less surface run-off and siliciclastic input and with increased surface salinities, vertical circulation and benthic oxygenation leading to heavy bioturbation. An influx of terrestrial material at times of higher run-off, is suggested for the dark-coloured clay-rich beds, by higher concentrations of Al, Fe, Mg, K, Ti, Na, Cr, Ni and V; higher Sr/Ca ratios; lower Si/Al ratios; and lighter $\delta^{18}O$ carbonate values (Figure 9.26). Higher concentrations of Corg (4-5 weight %), H, and S; and the preservation of lamination in the clay beds suggest stratification with the depletion of benthic oxygen levels (Pratt, 1984, Arthur *et al.*, 1985). The wet/dry cycles have more recently been supported by climatic modelling of the Western Interior Seaway (Glancy *et al.*, 1993).

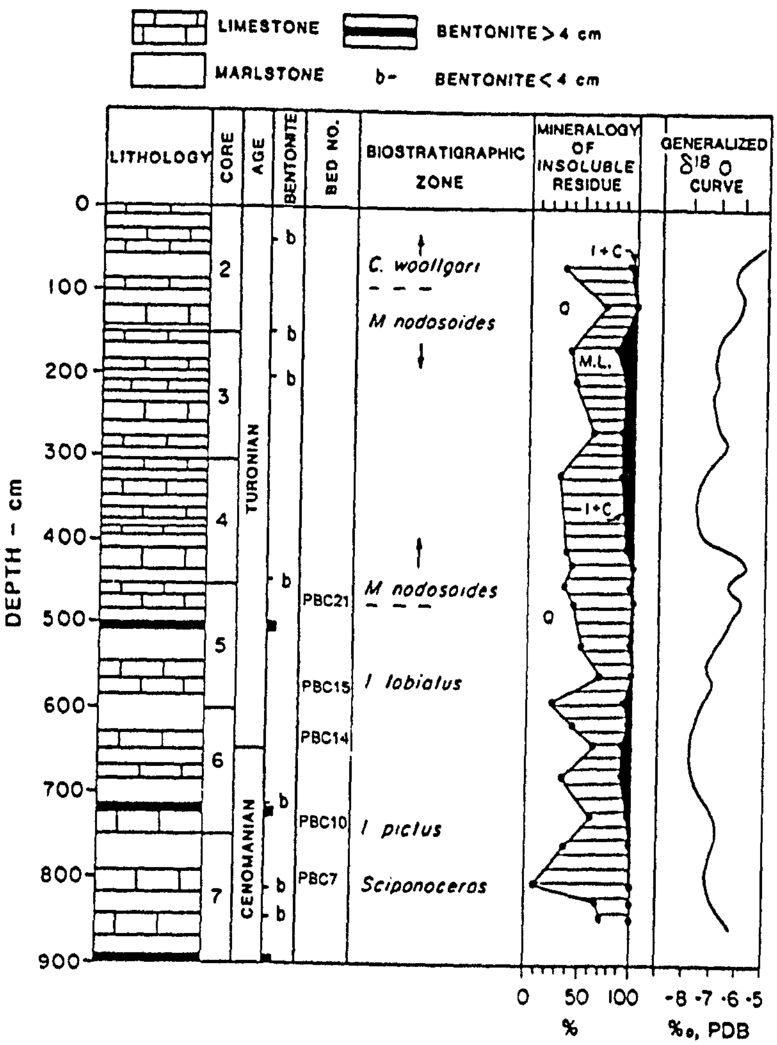
An alternative explanation is of temperature variations with consequent productivity fluctuations (Eicher & Diner, 1985, 1989). The supply of terrigenous material is considered to have been relatively constant but at times of higher temperature, subsequent increased plankton productivity would have produced much higher levels of biogenic carbonate and temporarily overwhelmed the volume of siliciclastic material, causing deposition of the limestones. Some of the evidence used to suggest this includes the abundant and diverse planktonic foraminiferal assemblages in the shale beds (which would not be supported by low salinities) and the presence of calcispheres and some silica (perhaps from radiolaria) in the limestones. The heavier $\delta^{18}O$ in the limestones are suggested to have resulted from a deeper water source brought to the surface by the increased vertical circulation.

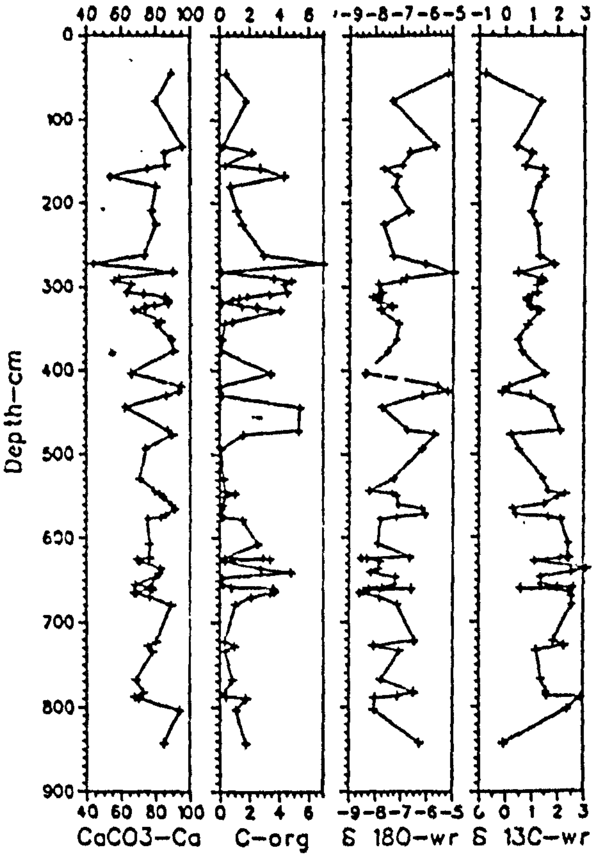
Nannofossil data have also been used to look into Milankovitch cyclicity changes. The marly shale and chalk couplets of the eastern margin of the seaway show significant alternations in assemblages (Watkins, 1989). However, this data supports neither the dilution cycle nor the productivity cycle models, since the nannofossil assemblages in the shales suggest higher productivity than in the limestones (contradicting Eicher & Diner, 1985, 1989) but also show diversities too high for reduced surface salinities (contradicting Pratt, 1984, 1985 etc.). Further nannofossil work (Watkins, 1986, Watkins *et al.*, 1993) shows clear evidence for three surface (upper 50 metres) water masses in the seaway (Figure 9.27) using time-slice techniques for the shale overlying the equivalent of bentonite PBC11. The nannofossil assemblages suggest a Boreal water mass, flowing south over the top of a relatively passive Tethyan water mass. The northern water mass is further divided with a western half which is thought to have been freshened by run-off from the Frontier delta system of Wyoming. Samples from the chalk/limestone are noted to have more uniform and diverse nannofossil assemblages, suggesting that during the deposition of the limestone the pattern of surface water masses broke down (Watkins *et al.*, 1993).

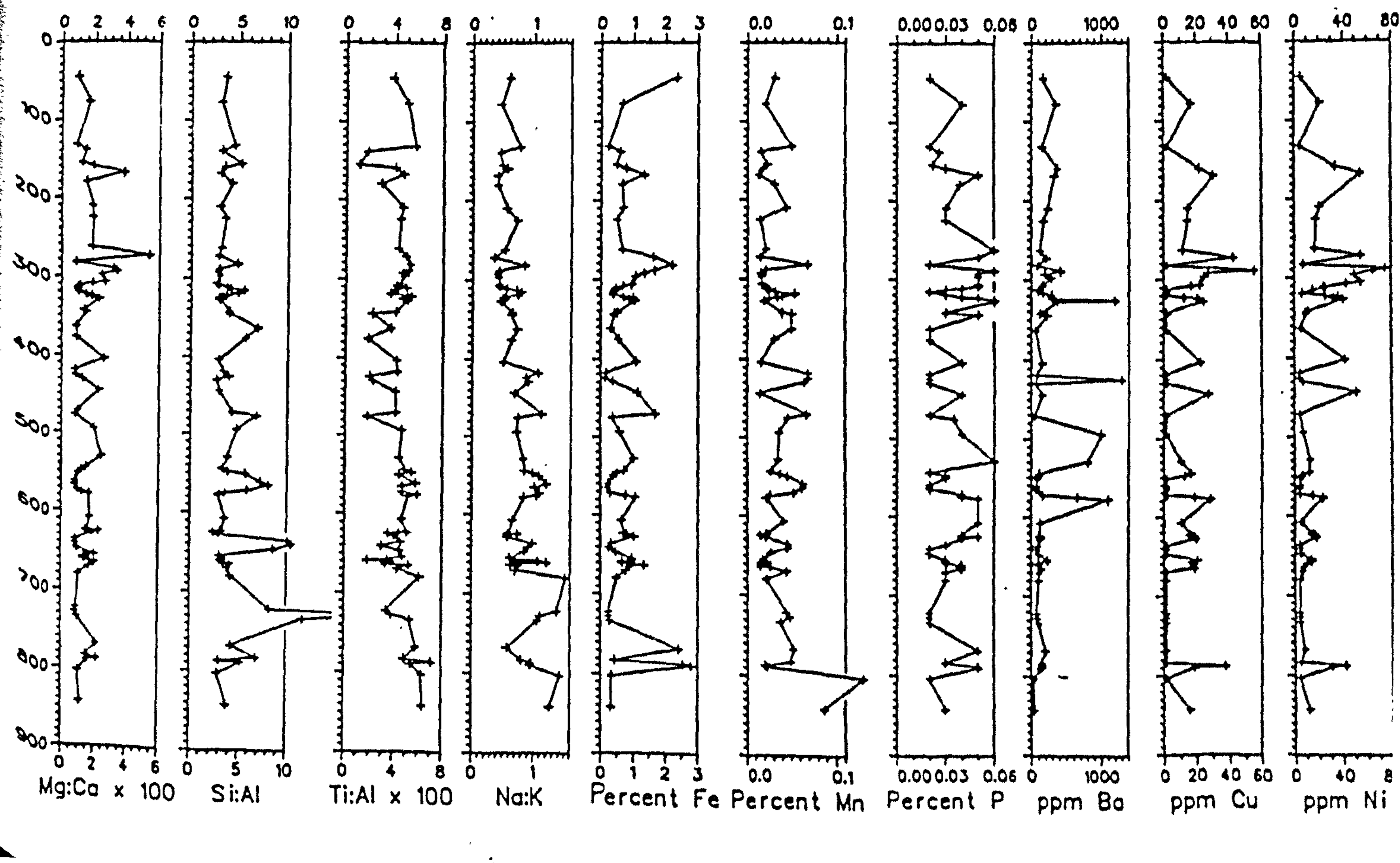
Figure 9.26

From Arthur *et al.* 1985

Lithology; biostratigraphy; insoluble-residue mineralogy; oxygen stable-isotope composition; variations in percent CaCO3 from percent total Ca, percent organic carbon, d^{18}O whole rock (wr: in %o, PDB), d^{18}C whole rock (wr; in %o, PDB), Mg/Ca ratio, Si/Al ratio, Ti/Al ratio, Na/K ratio, weight percent Fe, weight percent Mn, weight percent P, ppm Ba, ppm Cu, and ppm Ni versus depth in the cores of the Bridge Creek Limestone Member, from Rock Canyon Anticline, Pueblo.







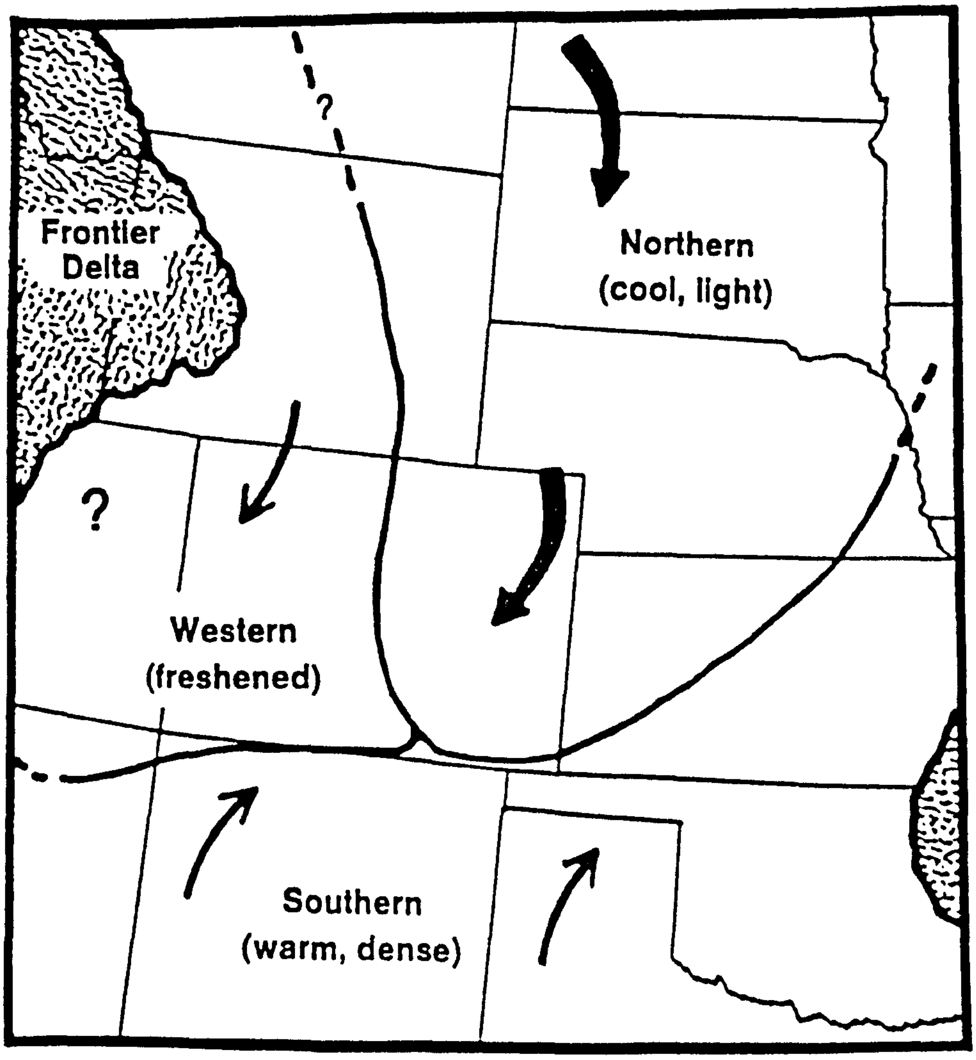


Figure 9.27

From Watkins 1986

Hypothetical surface-water map for the palaeocirculation of the Greenhorn Sea in the latest Cenomanian at the time of deposition of the horizon immediately overlying the bentonite equivalent to PBC11. Surface-water patterns determined by multivariant analysis of calcareous nannofossil distributions. The denser, southern water mass dives beneath the lighter northern and western water masses near the zone of convergence.

Stratification by a Boreal surface water mass freshened by additional run-off and overlying the Tethyan water mass would support the suggestion of stratification during shale deposition and would explain the geochemical and faunal evidence proposed for wetter climatic periods. The break up of the stratification with increased vertical circulation would also explain the evidence for suggested periods of higher productivity during limestone deposition. A negative shift in $\delta^{18}O$ (Figures 9.6 and 9.21) could be explained by a decrease in both salinity and temperature, suggesting greater dominance by the Boreal water mass. Consequently it might be suggested from previous work that the Milankovitch forced climatic cyclicity affected the relative dominance and circulation patterns for the Tethyan and Boreal water masses.

A directly comparable palynofacies and dinoflagellate cyst study is available for the Pueblo section (Courtinat, 1993) and although the samples were point samples, they were taken specifically for an examination of the rhythmic bedding (Figure 9.28). Palynofacies results suggest a relationship between the proportions of black and brown woody phytoclasts with the rhythmic bedding which support the dilution model of increased surface run-off during deposition of the shale. The dinoflagellate cysts were grouped into species associations, the validity of which is poorly explained. The *Achomosphaera* association is suggested to represent a normal marine environment and the *Cyclonephelium* association is suggested to represent a 'stressed' environment. An indeterminate association is also suggested, characterised by a low species diversity and a high AOM content. This casts doubt on the methodology of the counting procedures in Courtinat's study as many samples from Pueblo and other sections containing high abundances of AOM can also contain high dinoflagellate cyst species diversities. It seems likely that those samples containing high abundances of AOM were not properly studied for their dinoflagellate cyst content, owing to the difficulties in counting procedure. The conclusions from the dinoflagellate cyst assemblages, mimic Watkins (1989) in suggesting that alternations in the cyst associations are responding to mesotrophic-oligotrophic fluctuations in the water column which are not in-phase with the limestone-shale couplets, but without suggesting why.

9.6.1.2 Palynological Results

The sample spacing from Blue Point was probably not fine enough to study potential bedding cyclicity and none of the material from the limestone concretions was available to be processed. Similarly from Wahweap Wash, the sample spacing is too coarse where the rhythmic bedding is best developed and no samples entirely from concretionary horizons, except for one in the *Neocardioceras* Zone, were available for study. The material from Bunker Hill was evenly sampled and the chalky limestone horizons were too thin to be collected in a single sample without shale. The material from Pueblo offers the best potential to look at the cyclicity.

The alternating lithologies suggested to be produced by Milankovitch cyclicity are reflected much more strongly in the Pueblo section than in the western sections which were more strongly influenced by shoreline proximity. Hence the Pueblo section is probably the best section to study to try to examine palynofacies variations in response to Milankovitch cyclicity. It seems likely that many of the environmental fluctuations demonstrated by changes in palynofacies content from this study may be related to the suggested Milankovitch cyclicity lithologically expressed in the limestone-shale couplets.

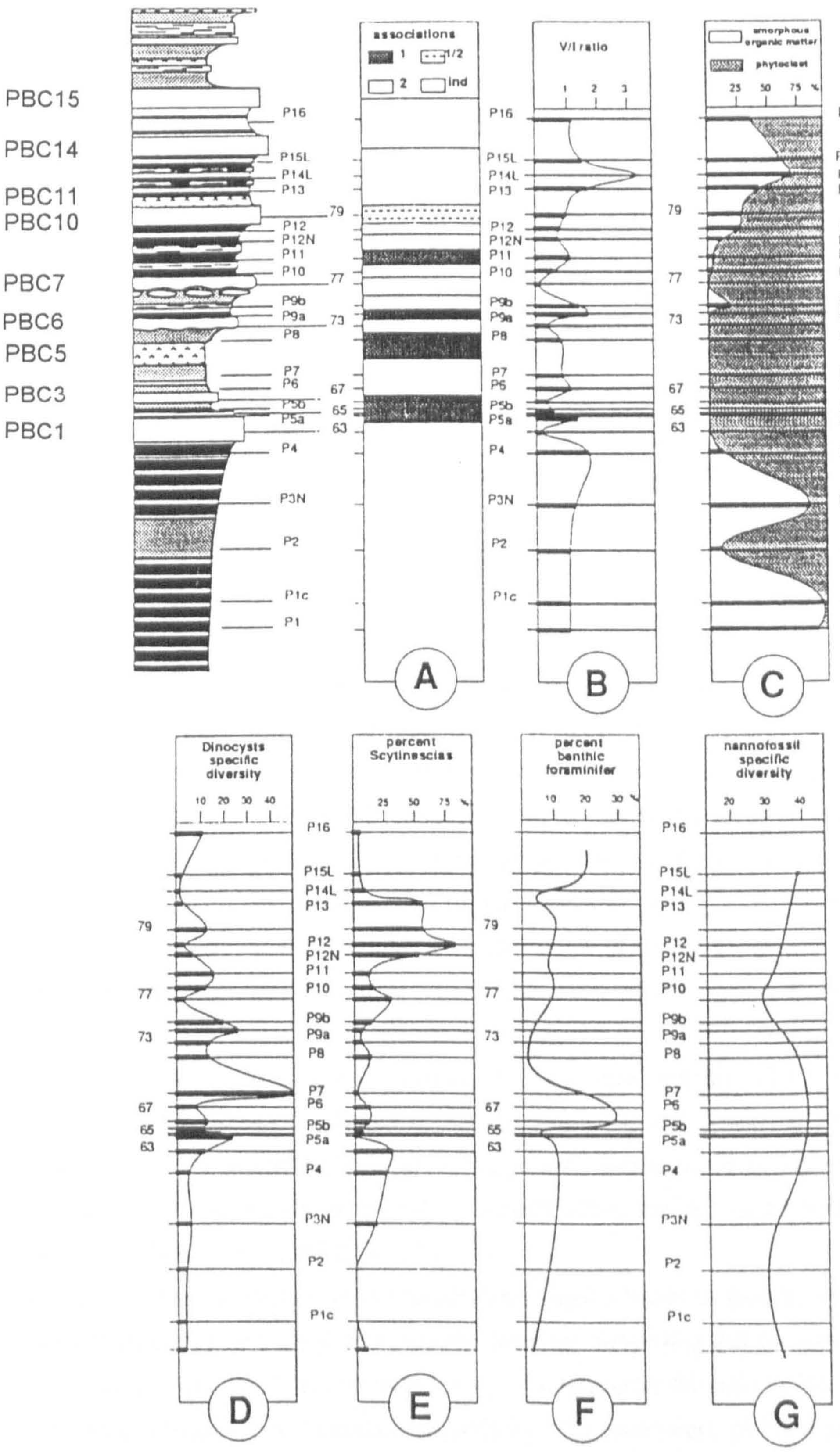


Figure 9.28

Adapted from Courtinat 1993

(A) dinocyst associations (1= *Achomosphaera* association, 2= *Cyclonephelium* association, 1/2 = mixed association, ind = indetermined association); (B) variations in the V/I (vitrinite/inertinite) ratio; (C) percentages of amorphous organic matter and phytoclasts; (D) dinocyst specific diversity; (E) percentage Scytinascias (foraminiferal test linings); (F) percent benthic foraminifers (from Hattin, 1985); (G) nannofossil specific diversity (from Bralower, 1988). PBC marker beds from Elder & Kirkland (1985).

The sampling was not intended to take into account lithological variations and as a consequence many of the samples contain material from both limestone and shale horizons. However some of the samples were taken entirely, or almost entirely, from either shale or limestone horizons and it is these that tend to display some of the largest magnitude fluctuations.

Those samples taken entirely or almost entirely from shales are PB4, PB14, PB19 and those from the Hartland Member (Figure 3.9). PB6 and PB7 contain no limestone but these samples do contain much bentonite material (particularly PB7) which in itself has no organic content, but does reduce the volume of particulate organic matter within the samples. Those samples taken entirely, or almost entirely, from the limestone horizons are PB1, PB2 and PB3 from PBC1 and PBC2; PB20 from PBC14 and PB24 from PBC15.

Palynofacies: Within the material studied the levels of AOM do not seem to be particularly related to the lithologies. The amounts of AOM in samples from the limestones can be very variable. The sample from the base of PBC1 contains around 75% AOM while the sample above from the same limestone bed contains only around 20% AOM. The sample from PBC14 contains 30% AOM while the sample from the next limestone up (PBC15) contains 65% AOM. Maximum Corg (weight %) in the Bridge Creek Limestone Member is also recorded from the limestone PBC14 (Arthur *et al.*, 1985) and not from a shale. Through the shale samples the levels of AOM preserved also varies. Within the Hartland Member the levels of AOM varies between 50% and 85% AOM. The sample from the shale above PBC9 contains just over 30% AOM while the sample from the shale above PBC13 contains 65% AOM. Despite the opinion that circulation (and hence benthic oxygenation) was much greater during the time of deposition of the limestones and much poorer during the deposition of the shales, the circulation did not necessarily affect the amounts of AOM preserved in the water column and at/or beneath the sediment-water interface.

The levels of brown wood are generally much higher in the shale samples. This is fairly well demonstrated by higher levels through the Hartland Member (50-65%) and in sample PB4 (40%), compared to samples PB1, PB2 and PB3 (30-50%). It is also well demonstrated by higher levels in PB14 (50%) compared to the samples above and below (around 40%), and by much higher levels in PB19 (70%) compared to PB20 (30%) and PB24 (35%).

In comparison the levels of black wood are usually only slightly higher in the shales than in the limestones. Greater differences occur through other samples however, suggesting that the levels of black wood may have been more strongly affected by other factors. Consequently the ratio of black wood to brown wood shows some relationship to Milankovitch cyclicity. The proportions of black wood do in many cases seem to be inversely proportional to the levels of AOM preserved suggesting a link as higher oxygen levels in the water column may have increased the production of black wood from brown. The ratio of elongate to equidimensional wood does not seem to follow any pattern in relation to limestone-shale couplets.

The relative abundance of marine palynomorphs seems to be particularly strongly affected by the limestone-shale couplets. The majority of limestone samples contain much higher proportions of marine palynomorphs. The levels in the samples from the base of the Bridge Creek Limestone Member are from 10-30% in the limestone samples PB1, PB2 and PB3. In comparison the levels in the Hartland

Member range from less than 5% to 10%. The levels in the shale sample PB4 are around 15%. The shale sample PB14 also contains around 15% marine palynomorphs. The levels in the shale sample PB19 are less than 10%, while in the limestone samples PB20 and PB24 they are 55% and 40% respectively.

In several cases the proportions of prasinophytes to dinoflagellate cysts are greater in the shale samples compared to the limestone samples. However the levels may be too low to be statistically significant. Apart from through the Hartland Member, higher proportions are noted in the shale samples PB14 and PB19, but not in sample PB4. The proportions of prasinophytes are low in all of the limestone samples. This may suggest that water column stratification was more important at the time of deposition of some of the shales but not as important as during deposition of the Hartland Member.

The ratios of dinoflagellate cysts to miospores and particularly of marine palynomorphs to terrestrial palynomorphs and phytoclasts is very good in relation to Milankovitch cyclicity, as a result of the changes in proportion of marine palynomorphs and brown wood.

Dinoflagellate cysts: The range of samples for comparison with dinoflagellate cyst data is larger than that for the palynofacies data. Further samples taken only from shale include PB21, PB22, PB27 and PB30. In addition, PB29 is almost entirely sampled from marlstone.

As far as can be determined from the limited samples available, the dinoflagellate cysts seem to show no clear relationships with the rhythmic bedding. Some shale samples (e.g. PB4, PB14, PB30) contain comparatively high proportions of 'lowered-salinity' or 'shallow-water' indicator species but many instead contain comparatively high proportions of 'normal-salinity' or 'deep-water' indicator species (e.g. PB6, PB7, PB19, PB21, PB22). Similarly some samples from limestone horizons contain comparatively high proportions of 'normal-salinity' or 'deep-water' indicator species (e.g. PB1, PB2 and PB3 from PBC1 and PB29 from the marlstones above PBC19), but some contain comparatively high proportions of 'lowered-salinity' or 'shallow-water' indicator species (e.g. PB20 from PBC14 and PB24 from PBC15).

The P/G ratios do not seem to show any relationship with the bedding cycles. Some limestones seem to show comparatively high productivity (e.g. PBC1, PBC2 and PBC15) but others do not (e.g. PBC14). Similarly some shale samples do (e.g. PB7, PB14) while others do not (e.g. PB4, PB27). As also noted by Courtinat (1993), the dinoflagellate cyst species diversity seems not to be related to the limestone - shale bedding couplets with peaks in diversity in both limestone and shale samples.

9.6.1.3 Conclusions

Palynofacies variations do seem to have been affected by Milankovitch cyclicity most strongly expressed in the proportions of brown wood and of marine palynomorphs. This would seem to support the suggestions of greater terrigenous input during deposition of the shales. It is not possible to suggest from the palynofacies, however, whether the increased production of marine palynomorphs during deposition of the limestones was absolute or only relative. None of the palynofacies variations are entirely driven by Milankovitch cyclicity, but are probably also strongly affected by other factors, such as changes in sea level and oxygen levels.

Changes in the populations of meroplanktonic dinoflagellates as far as can be determined (from proportions of dinoflagellate cyst indicator species, P/G ratios and the species diversity curve) do not follow the climatically forced fluctuations on a bed-by-bed scale, but as discussed in detail for each section, seem instead to have responded to other stronger environmental fluctuations, such as transgressive pulses and stillstand events, in line with the macrofaunal immigration and extinction events. Consequently they neither support the dilution or productivity models and do not seem to have reacted in response to the changes in water mass on a bed-by-bed scale.

9.6.2 Anomalies in sea levels curves in the western sections

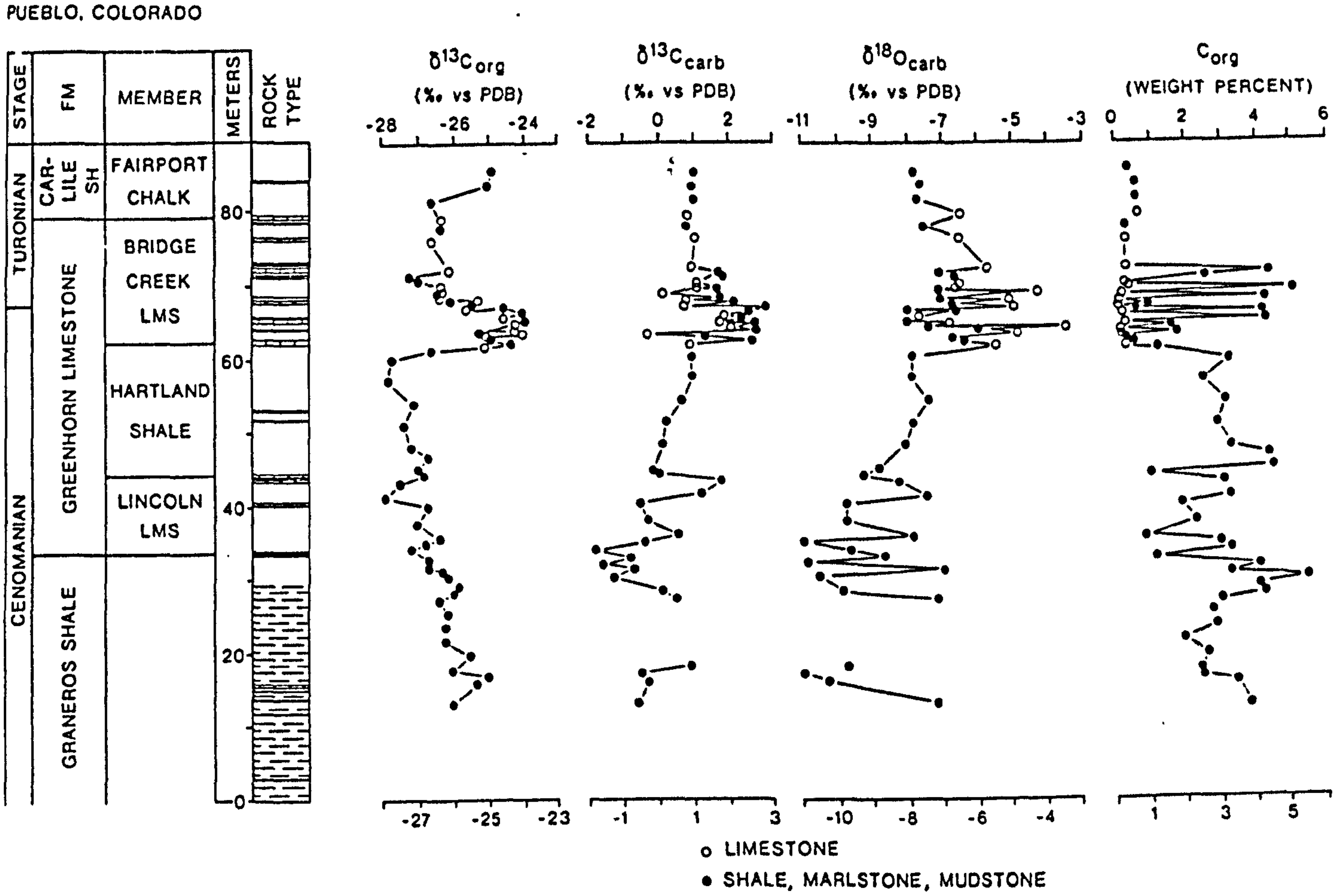
A discrepancy occurs in the timing of transgressive events displayed between the relative near-shore sections in the Black Mesa and Kaiparowits Basins (Figure 9.11). This is thought to be due to variations in tectonically controlled subsidence rates (Elder, 1991). In the Black Mesa Basin (Blue Point section), transgressive pulses caused westward shifts in the strandline, corresponding to winnowing events at the ammonite zone boundaries (*Sciponoceras*, *Neocardioceras* and *Watinoceras*). In the Kaiparowits Basin (Wahweap Wash section and other sections from that basin mentioned in Elder, 1991), the pattern of strandline migrations, lithostratigraphy and micropalaeontology suggests that the transgressive-regressive pulses were not synchronous with elsewhere. Transgression is indicated at the base of the *Sciponoceras* Zone, but not at the base of the *Neocardioceras* or *Watinoceras* Zones, where instead, regressive trends are implied by increasing sand and silt content across the zone boundaries. In contrast, a decrease in coarse clastic content just below the bentonite equivalent to PBC11 suggests a transgressive pulse at that time. A third transgressive pulse is suggested a short distance above the bentonite equivalent to PBC17, marked by a decrease in silt content elsewhere in Utah, and by calcarenite horizons at Wahweap Wash and in the San Juan Basin (further to the east).

The palynological evidence however suggests correlatable transgressive pulses in both sub-basins at the same time, both at the base of the *Neocardioceras* and *Watinoceras* Zones and around the equivalents of PBC11 and PBC17. However, the pulses at the bases of these ammonite zones at Wahweap Wash are immediately followed in the overlying samples by large increases in 'lowered-salinity' dinoflagellate cyst indicator species suggesting increased surface run-off at this time, perhaps as a result of increased dominance by the freshened western surface water mass (as suggested by Watkins, 1986 and Watkins *et al.*, 1993).

9.6.3 THE CENOMANIAN - TURONIAN BOUNDARY EVENT

9.6.3.1 Summary of previous work

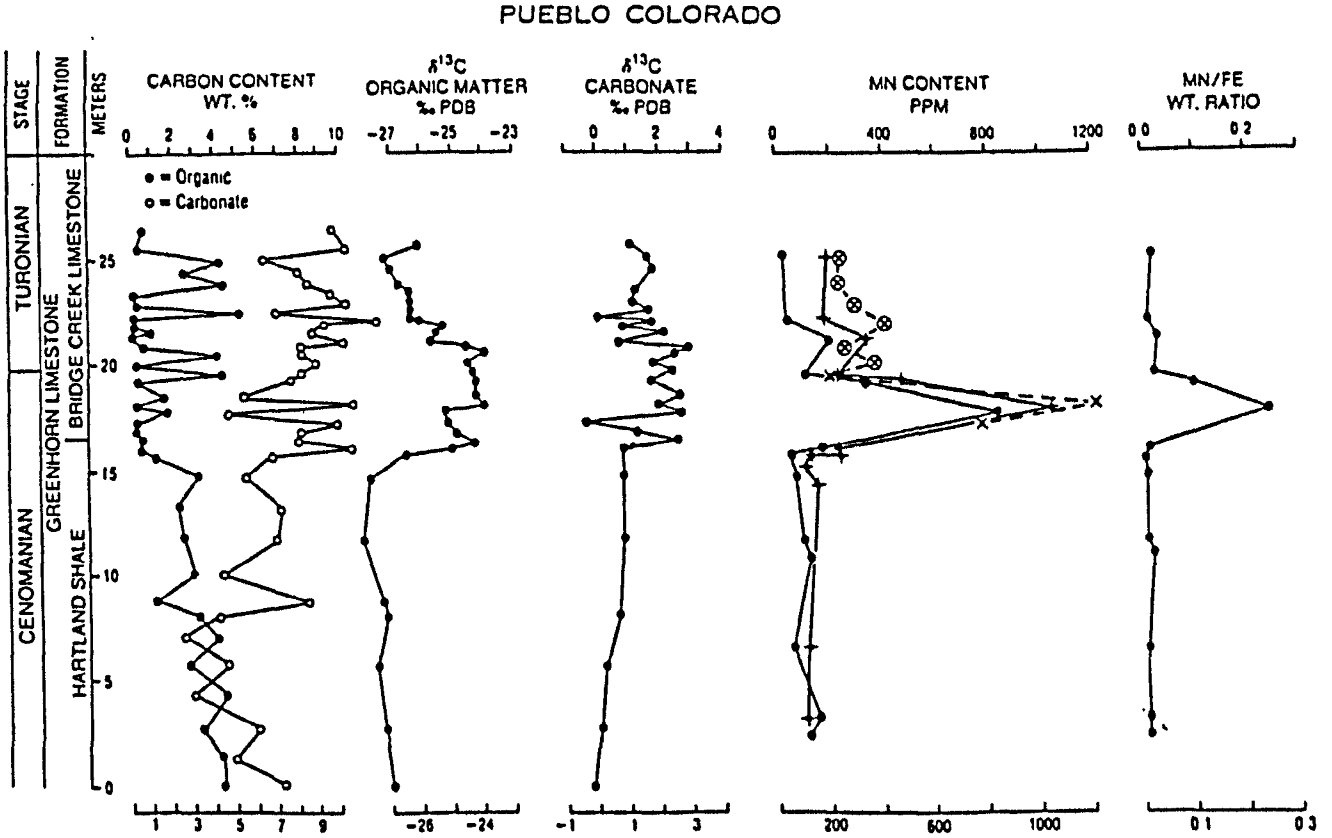
Geochemical Analyses: Variations in whole-rock proportions of organic carbon (Corg) and carbonate; in proportions of stable isotopes (^{13}C and ^{18}O) both in carbonates and in organic matter (Figures 9.29 and 9.30); and in amounts of major and trace metals (Al, Ca, Cr, Fe, K, Ir, Mg, Mn, Na, Ni, Sr, Th, Ti,



Stratigraphic column, carbon isotopic ratios in organic matter, carbon and oxygen isotopic ratio in whole-rock carbonate, and organic carbon content of the upper Graneros Shale, Greenhorn Limestone, and lowest Carlile Shale at Pueblo Reservoir State Recreation Area, Colorado.

Figure 9.29

From Pratt 1985



—Carbon isotopic and manganese values through the Cenomanian-Turonian boundary interval at Pueblo, Colorado. Organic-matter $\delta^{13}C$ from Pratt and Threlkeld (1984). Manganese values from Arthur et al. (1985) are shown by "x", the circled values representing 10-point averages. Large dots represent our XRF values; crosses are our total AA values. See Table 1 for partitioning of Mn between carbonate and insoluble fractions.

From Pratt *et al.* 1991

Figure 9.30

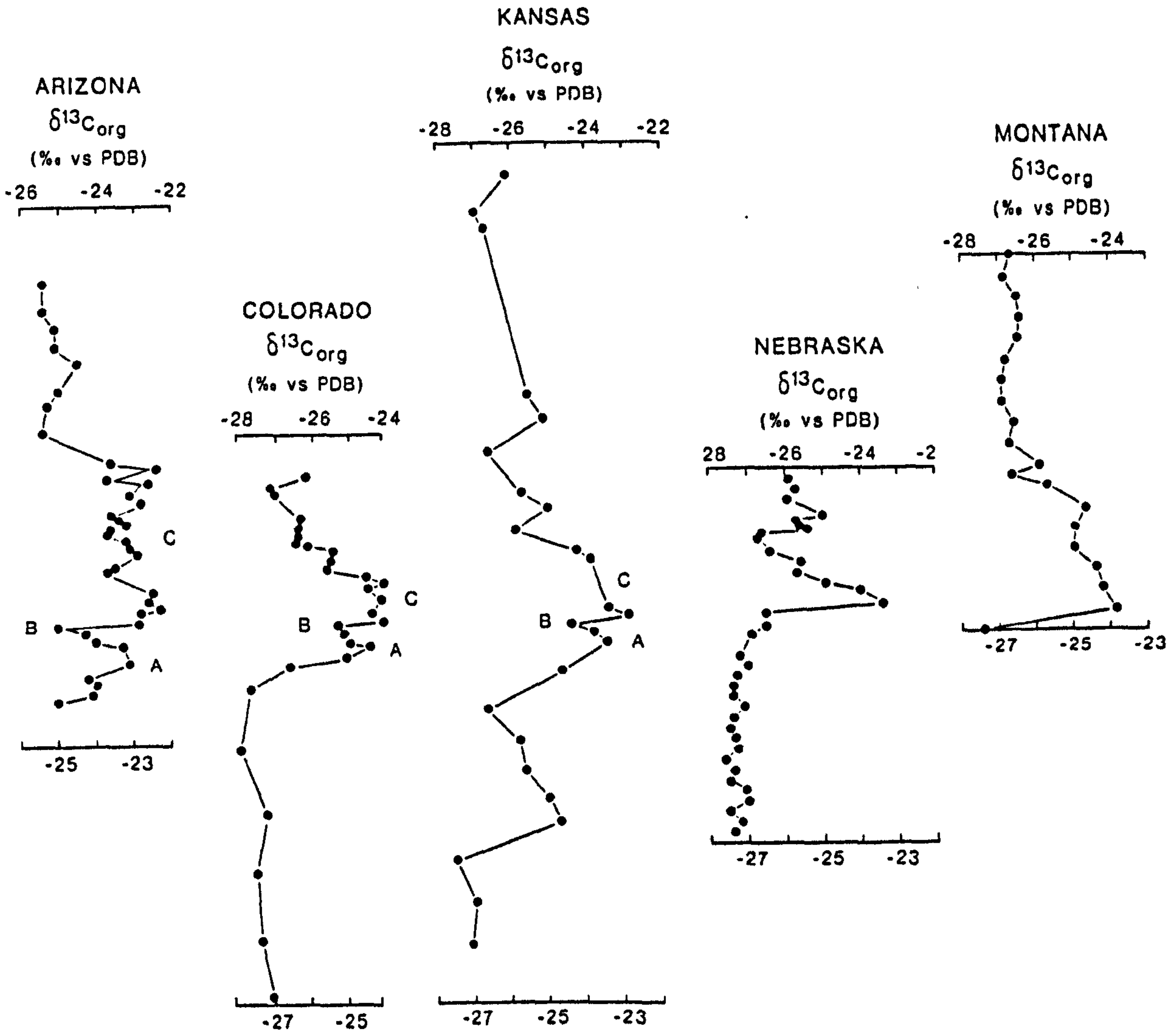
U, V) and other elements (H, S, Si) have all been recorded (Figures 9.26 and 9.30), mostly from the Pueblo section, to look at the evidence for, and effects of, the Cenomanian - Turonian boundary event.

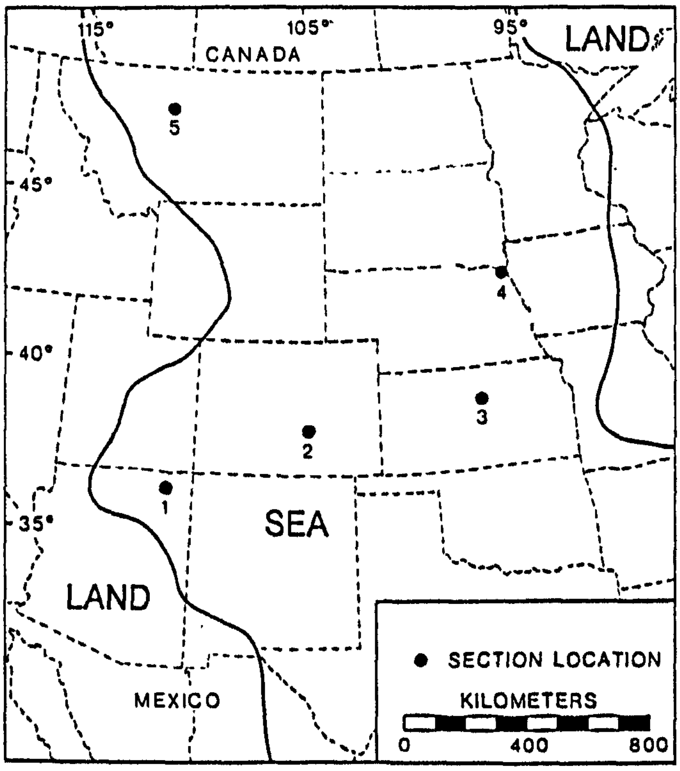
The Bridge Creek Limestone Member averages 78% $CaCO_3$ and 1.75% C_{org} with ranges 42-96% and 0.06-6.97% respectively (Arthur *et al.*, 1985). Maximum C_{org} (weight %) occurs in a limestone bed (PBC14) containing no macrofossils, just below the Cenomanian-Turonian boundary. A comparison of AOM and C_{org} for the Pueblo section is illustrated in Figure 9.21. This figure highlights a major discrepancy which occurs between the abundance of AOM in the palynological preparations and the percentage weight of organic carbon illustrated in Pratt (1985) and Pratt *et al.* (1993). Samples recorded with high percentage weights of C_{org} do not necessarily contain large relative abundances of AOM, and vice versa. This suggests that the data sets are incompatible and cannot easily be used for comparison. One reason for this may be that the samples taken for the geochemistry were point samples rather than channel samples. In addition the geochemistry does not take into account the type of organic matter. The picture presented by the levels of AOM within a sample are an average of that 20 cm band rather than a point from an individual horizon. From the point of view of this study however, the most effective way of recording the general levels of oxygen depletion in the water column and at the sea floor is with the abundance of AOM. The majority of the organic carbon preserved in pelagic sediments at the Cenomanian - Turonian boundary sites consists of marine AOM (e.g. Schlanger *et al.*, 1987).

Stable isotope excursions reach a minimum for heavy oxygen ($\delta^{18}O$) and reach a maximum for heavy carbon ($\delta^{13}C$) across the boundary (Figure 9.29 and 9.31; Arthur *et al.*, 1985). The $\delta^{18}O$ stable isotope curve corresponds on a bed-by-bed basis to a brief but marked decrease in mixed-layer illite/smectite clays (of volcanic origin) which is thought to be due to an abrupt increase in fresh water discharge at the boundary (Pratt, 1985). The effect of this would have been to increase stratification at this time and so cause further expansion and intensification of the oxygen minimum zone. The detailed features of the positive excursion (2.5‰-3.5‰) of the $\delta^{13}C$ curve are consistent and correlatable from sections across the basin (Figure 9.31), despite differences in C_{org} content, type of organic matter, distance from palaeo-shoreline and depth of burial between the sections. The $\delta^{13}C$ curve is likely to be more reliable for changes across the boundary since diagenetic alterations to the $\delta^{13}C$ curve from organic carbon, are likely to have been less than diagenetic alterations to isotope fractions from carbonate material (Figure 9.29) (Pratt & Threlkeld, 1984).

Manganese seems to show an excursion coincident with shifts in the carbon isotopes, at Pueblo as well as in Normandy, France (Pratt & Threlkeld, 1984). The Mn anomaly returns to background levels within the lower half of the $\delta^{13}C$ excursion. It may be caused by a rapid mobilization of the manganese reservoir held as deep sea oxides (as Mn^{4+}) and deposited within epicontinental carbonates (as Mn^{2+}). The mobilization would be caused by a change in redox potential during the expansion of the oxygen minimum zone (Figure 9.30; Pratt *et al.*, 1990).

Iridium reaches two peaks (0.11ppb compared with a background of 0.17ppb) just below the boundary at Pueblo. No other peaks have been found in 45 metres of strata above and below this level. The broader, lower of the two Ir peaks straddles the first of the major step-wise extinctions. It is thought unlikely that the Ir or other trace metal anomalies are caused by associated bolide impacts. Increased vulcanicity is also unlikely since bentonite deposition in the seaway had little or no effect on the biota. It





Adapted from Pratt 1985

Compilation of carbon isotopic ratios in organic matter for five locations from the Western Interior Basin.

Locations are: 1. Black Mesa, Arizona; 2. Pueblo, Colorado; 3. Bunker Hill, Kansas; 4. Ponca State Park, Nebraska; 5. Cone Hill, Montana.

The isotopic curves are aligned by correlation of the B notch (Arizona, Colorado, Kansas) or by centering the isotopic excursion (Nebraska, Montana).

Figure 9.31

seems more likely that the enrichment could be caused by upwelling of metal-rich waters from the Gulf of Mexico, brought along by a transgressive pulse (Orth *et al.*, 1988).

Palaeontological Analyses: The Bridge Creek Limestone Member represents a time of cosmopolitan faunal distributions, with a good mixing of Boreal and Tethyan fauna and a rapid evolutionary turnover, allowing the development of a highly refined global and regional biostratigraphy. The rapid evolution may be due to increased rates and sizes of environmental fluctuations from maximum eustatic rise. These fluctuations are represented by changes in the abundance and diversity of assemblages and in their biogeographical distributions.

Just before the start of the Bridge Creek Limestone Member deposition, the southern warm-temperate to sub-tropical water-mass of the Tethys moved into the sea-way, increasing salinities to 'near-normal' concentrations and allowing the immigration of the diverse warmer-water macro and microfauna characteristic of the *Sciponoceras* Zone. This allowed the enhancement of the climatically regulated couplets and changed the $\delta^{13}C$ and $\delta^{18}O$ isotopic values, suggesting major changes in the carbon cycle. The extinctions take place in a period of increasing water temperature (which would decrease the solubility of oxygen) from increasing Tethyan influences. The $\delta^{18}O$ stable isotope curve reaches its maximum for the Greenhorn cyclothem at around PBC6 and PBC7, which is when nearest-normal salinities were thought to have occurred, within the Western Interior Basin (Pratt, 1985).

Two scales of transgressive pulses are suggested by Elder (1991) for the Western Interior Basin for the boundary sections. Smaller-scale, shorter fluctuations are related to the cyclic sedimentary alternations resulting in the limestone-shale couplets. Larger scale pulses (with a frequency of three to four times longer than the short events) correlate to stepped increases in the overall carbonate content and to the macrofossil biozones. Transgressive pulses are characterised by periods of maximum macrofaunal diversity and immigration, with increased circulation and benthic oxygenation, increased substrate firmness and decreased sedimentation rates. Regressive episodes correlate to periods of macrofaunal deterioration, with a decrease in benthic oxygenation, a decrease in substrate firmness and an increase in sedimentation rates. The extinction events may also be related to fluvial run-off events (suggested by a major negative excursion in $\delta^{18}O$, particularly in the upper half of the *Neocardioceras* Zone) and/or an expansion of the oxygen minimum zone, and may be related to the transgressive-regressive pulses. Low faunal diversity and abundance near the top of the *Sciponoceras* and *Neocardioceras* Zones suggests a period of physical stress shortly before each zone boundary. The immediate base of the Turonian is marked by the replacement of eurytopic inoceramid bivalve species, by a decrease in organic carbon content and an increased calcareous content.

The extinctions occurred as a step-wise series of five events across the basin, either completely removing the taxa from the basin or geographically restricting the taxa from the localities (Elder, 1989). The faunal changes indicate repeated biological disruptions, from repeated and progressively stronger episodes of environmental disturbances, immediately preceding the abrupt biotic recoveries and immigration events with community reorganisation, that mark the zone boundaries.

The first two extinction events involved the removal of mostly stenotopic ammonites and bivalves, with the removal of more eurytopic fauna in the subsequent three events. The first event to occur was just above the limestone equivalent to PBC6, with the second just above the limestone equivalent to PBC7, marking the top of the *Sciponoceras* Zone. The remaining events occurred just above the equivalent of PBC9, PBC10 and PBC14, the last marking the top of the *Neocardioceras* Zone.

The boundary extinctions affected the ammonites more than any other taxonomic group and the cosmopolitan species were the most affected of the ammonites. The benthic or nekto-benthic taxa were more susceptible to the stresses responsible for the extinctions and showed earlier and greater extinction (and speciation) than the pelagic taxa, some of which crossed the boundary with little change. This may have been in response to an upwardly expanding zone of oxygen depletion, affecting the middle to outer shelf benthic environments, while the pelagic and near-shore environments were less affected.

The epifaunal bivalves were also strongly affected by the extinctions, but those families most affected were the Inoceramidae and Gryphaeidae. The inoceramids were a diverse group of eurytopic opportunists with a broad depth and facies range as well as an abundant occurrence in dysaerobic facies. They were intercontinentally distributed suggesting that their wide geographical ranges were due to planktotrophic larval dispersal. The widespread genus *Inoceramus* became extinct in the *Sciponoceras* and *Neocardioceras* Zones, and was replaced by the equally widespread genus *Mytiloides*. The extinction patterns suggest that the responsible mechanisms were highly selective against those taxa with intercontinental distributions. The global extinctions suggest that the global oxygen depletion may have affected the pelagic taxa and planktotrophic larval stages of benthic taxa.

The environmental perturbations also affected other taxa such as the relatively deep-water, keeled planktonic foraminifera, followed by later disruptions of the shallower-water forms (Jarvis *et al.*, 1988).

Most of the species turnover in the calcareous nannofossil assemblages through the Greenhorn cyclothem occurs near the Cenomanian - Turonian boundary, including extinctions of several long-ranging taxa, suggesting that this time was one of higher selective pressure for the surface dwelling calcareous phytoplankton (Watkins *et al.*, 1993). Some quite significant blooms, for example of *Eprolithus floralis*, were noted from boundary sections across the world (Bralower, 1988). It is thought that they may indicate lowered surface salinities but their significance is not fully understood.

It has been suggested that the timing of oxygen depletion and faunal extinctions across the globe and even across the Western Interior Basin were not synchronous (Bralower, 1988). This in turn implies that the high-resolution stratigraphic framework based on bentonite and limestone correlation across the Western Interior Basin is invalid as the nannofossil zones are diachronous with respect to the macrofaunal biostratigraphy and 'HIRES' lithological event horizons. Bralower suggests that calcareous nannofossils are less affected by other palaeoecological factors than the macrofauna and hence that changes in the nannofossil assemblage biostratigraphy should be synchronous. However, Elder (1989), suggests that the nannofossil zones must be diachronous since the macrofaunal biostratigraphy and lithological event framework are supported by geochemical anomalies as well as by the correlation of the individual chemistries of each bentonite across the basin. The dinoflagellate cyst event stratigraphy (appearances, disappearances and acme events) from the boundary sections also validates and reinforces the high-resolution event stratigraphic framework.

The macrofauna in the sections also show a step-wise origination and repopulation pattern through the Early and Middle Turonian rather than a slowly increasing origination rate, which probably reflected continuing fluctuations in marine temperature and water chemistry. These discrete origination peaks are precisely or closely correlatable across the basin, suggesting that the repopulation responded to at least basin-wide environmental forcing, responding to regional environmental control. The first appearance of abundant ammonites correlates almost exactly between the sections across the basin suggesting that chemical conditions in the water column simultaneously improved across the basin. However the improvements in the middle and lower part of the water column took longer than the waters at the surface or at the sediment-water interface, suggesting that the mid-water oxygen minimum zone persisted long after the initial oxygenation of the benthic zone and surface waters. The nektonic macrofauna (particularly those inhabiting the lower and middle parts of the water column) were more susceptible to fluctuations in the environment than the recolonising benthic taxa. The benthic realm was oxygenated earlier, but at different rates across the transect, first in the west, then with improvements in the shallow waters of the east, and finally in the centre of the basin. By the late Early Turonian (*Mammites* Zone), stable isotope data indicates stabilisation of the marine environment while the macrofaunal abundances and diversities suggest that the ecosystems were effectively equivalent to those prior to the extinction event (Harries & Kauffman, 1990).

9.6.3.2 Palynological interpretations

The use of the dinoflagellate cyst indicator proportions suggested by the 'time-slice' transect are corroborated by their close correlation with the foraminiferal data from the same samples in the Rebecca K. Bounds core and the macrofaunal and foraminiferal immigration events in the boundary sections. Generally the changes in proportions of indicator species also have very good correlation with the palynofacies signals.

The transgressive pulses at the base of each ammonite zone are indicated by increases in the proportions of 'deep-water' and 'normal-salinity' dinoflagellate cyst indicator species and supported by distal shifts in the palynofacies. The general pattern through each zone is then an increase in the proportions of 'lowered-salinity' and 'shallow-water' dinoflagellate cyst indicator species and a proximal shift in the palynofacies, particularly at the top of each zone, suggesting progradation or regressive events. Alternatively these changes may be due to the changing dominance of surface water mass.

The transgressive pulses are generally directly correlatable between the sections studied using the high-resolution stratigraphic framework. They not only occurred at the base of each ammonite zone but also in between, often associated with macrofaunal immigration events. The horizons include below the equivalents of PBC1 (the base of the *Sciponoceras* Zone), around PBC3 and PBC6, above PBC9 (just above the base of the *Neocardioceras* Zone), above PBC11, above PBC14 (the base of the *Watinoceras* Zone), around PBC16, around PBC18 and PBC19, above PBC22 (near the base of the *Mammites* Zone) and around PBC26 (Figure 9.32).

However, some anomalies seemed to occur in the timing of events, particularly at the base of the *Neocardioceras* Zone, perhaps suggesting that surface waters were not always in tune with deeper

TRANSGRESSIVE PULSE AND PRODUCTIVITY SURGE CORRELATION BETWEEN SECTIONS INFERRED FROM DINOFLAGELLATE CYST ASSEMBLAGES

PBCNumber	Blue Point		Wahweap Wash		Pueblo		Bunker Hill	
PBC27					-	-	-	-
				O			-	-
PBC26	X		X				-	-
					X		-	-
PBC25					X		-	-
							X	O
PBC24								
								O
PBC23		O			X			O
	X	O			X			
PBC22							X	O
								O
PBC21						O		
						O		
PBC20		O	X			O		
			X		X	O		O
PBC19	X	O	X		X			
	X	O	X	O	X	O	X	
PBC18	X	O		O	X	O	X	
		O	X	O			X	O
PBC17		O		O				
PBC16	X		X	O	X	O		
								O
PBC15						O		
	X		X	O	X		X	O
PBC14		O						O
PBC13								
PBC12								
	X		X	O	X	O	X	O
PBC11	X					O		
		O		O		O		
PBC10								
	X	O	X	O	X	O	X	O
PBC9		O						
PBC8						O		
				O				
PBC7								
							-	-
PBC6	X	O	X		X		-	-
			X	O		O	-	-
PBC5							-	-
							-	-
PBC4	X	O			X		-	-
	-	-	-	-	X		-	-
PBC3	-	-	-	-	X		-	-
	-	-	-	-			-	-
PBC2	-	-	-	-	X	O	-	-
	-	-	-	-	X	O	-	-
PBC1	-	-	-	-	X		-	-

X Suggested transgression from comparative increase in 'deep-water' indicator species
O Suggested productivity increase from comparative increase in proportion of peridinioid cysts
\- Data not available

Figure 9.32

waters. In the western sections (at Blue Point and Wahweap Wash), at the base of the *Neocardioceras* Zone the macrofaunal immigration event at the time of deposition of the equivalent level of PBC9 also seemed to occur at a time of continued low-salinity surface waters which had increased at the top of the *Sciponoceras* Zone. This is suggested by the dinoflagellate cysts assemblages and palynofacies and supported by a negative shift in $\delta^{18}O$ (Elder, 1987). The increase in the proportions of 'deep-water' indicator species did not occur until after the deposition of the equivalent of PBC9, suggesting that the gonyaulacoid species did not react at first to the Tethyan pulse. In both sections, however, a productivity increase still occurs around PBC9 suggesting that the peridinioid species did react to the transgressive pulse. It seems likely that the proportions of dinoflagellate cyst indicator species reacted to the changing dominance of surface water masses but that the surface water masses did not always react in the same way at times of transgression.

The step-wise macrofaunal extinction events tend to be associated with increases in the proportions of 'lowered-salinity' dinoflagellate cyst indicator species and palynofacies changes indicating increased terrigenous input, suggesting periodical times of stress for the macrofauna from progradation or lower salinity surface water masses.

The diversity and huge abundance of prasinophytes in the palynological preparations from the Hartland Member suggest that the anoxic conditions at this time may have resulted from continuous stratification of the water column. The levels of prasinophytes around the Cenomanian - Turonian boundary are comparatively very low and consist only of leiospheres. Some increases occur at times of suggested increased lowered surface salinities, for example at the top of the *Sciponoceras* Zone at Blue Point and through the *Neocardioceras* Zone at Pueblo, although these are comparatively small and still only involve increasing numbers of leiospheres. This suggests that the oxygen depletion event at the Cenomanian - Turonian boundary in the Western Interior Basin was not a result of permanent stratification of the water column although increased stratification may have helped to reduce benthic oxygen levels.

Almost all suggested transgressive pulses are associated with a corresponding increase in the ratio of peridinioid to gonyaulacoid cysts suggesting an increase in primary productivity with each sea level rise and influx of Tethyan waters (Figure 9.32). The transgressive and progradational events in the surface waters have been suggested based largely on relative proportions of different gonyaulacoid species, while changes in productivity have been suggested using the proportions of peridinioid cysts, hence the two suggestions are independent. Exceptions occur at Pueblo, where not all increases in the proportions of peridinioid cysts occurred at times of transgression. Around PBC15 and PBC21/PBC22 the increases are noted to have occurred at times of lowered surface salinity or stillstand/regression.

Each transgressive pulse is suggested to have caused a warming of the waters and an increase in salinity to 'normal-levels'. Each pulse is also noted to be reflected in an increase in overall carbonate production, suggesting increased primary productivity in the surface waters which in turn would be reflected by increasing proportions of heterotrophic meroplanktonic dinoflagellates. The heterotrophic dinoflagellates may at times dominate the heterotrophic plankton populations in marine waters, as effective grazers of nannoplankton (Schnepf & Elbrachter, 1992). The increase in primary productivity would have increased the production of organic carbon, removing oxygen from the water column, causing a lowering of oxygen levels and increasing organic carbon preservation at the sediment-water interface.

The levels of AOM within the sediment are governed by a number of factors including primary productivity although this is unlikely to be the most important (Tyson, 1987). However, one prominent feature of the palynological assemblages which supports the suggestion of productivity pulses is the close correlation of the AOM abundance and P/G ratio curves. i.e. Increases in the levels of marine AOM within the samples follow the increases in the P/G curve very closely. Often, however, the increase in AOM occurs in the sample overlying the one with the increase in peridinioid cysts. This suggests a time lag between the transgressive pulses and the depletion in oxygen levels at the sea floor. At Pueblo the calculated deposition rates suggest that this time lag may have been around 20000 to 40000 years. It may be that it took time for the levels of oxygen to become permanently depleted within the water column, or that the first reaction of the transgressive pulses was to increase primary productivity and only continued transgression a little later on brought up an expanding OMZ. In the palynofacies counts there is also a good correlation between the abundance of foraminiferal test linings and the abundance of AOM, which suggests either a preservational link or a productivity link.

High productivity in upwelling areas is generally associated with large numbers of microplankton with siliceous skeletons (e.g. diatoms, radiolaria) which thrive in the unstable water column and result in the deposition of siliceous sediments (e.g. Lewis *et al.*, 1990, Powell *et al.*, 1990). Many of the sediments from boundary interval sites contain significant numbers of radiolarian tests and/or calcispheres suggested to indicate increased surface water instability, fertility and productivity (Arthur *et al.*, 1987). However, radiolarians are generally rare in deposits of epicontinental seas (Eicher & Diner, 1989). The Sharon Springs Member of the Pierre Shale was deposited on the east side of the Western Interior Basin in the Campanian and is suggested to have formed at a time of high biological productivity resulting from upwelling (Parrish & Gautier, 1993) but contains no biogenic silica. In the Western Interior Basin, potential siliceous material and calcispheres are noted in the chalky limestones of Kansas (Hattin, 1975) and limestones at Pueblo (Pratt, 1981, Eicher & Diner, 1989). This suggests increased water column instability during the deposition of the limestone beds. However, in general the higher primary productivity during deposition of the Bridge Creek Limestone Member probably resulted in increased production of calcareous nannoplankton, which may have held an advantage over siliceous or other calcareous phytoplankton in more stably stratified waters, and which provided the food source for the heterotrophic meroplanktonic dinoflagellates.

In summary, the major increases in AOM follow increases in the proportion of peridinioid cysts which suggest productivity increases in tune with third- and fourth-order eustatic sea-level fluctuations. This suggests a possible origin for the oxygen depletion in the Western Interior Seaway from productivity increases associated with Tethyan transgressive pulses and increases in temperature, salinity and nutrient levels, rather than from permanent stratification of the water column. These productivity increases did not seem to be in tune with the Milankovitch cyclicity.

9.6.3.3 Discussion

As mentioned earlier, the 'anoxic event' in the Western Interior Basin has been suggested to have been caused by high surface run-off leading to salinity-stratified surface water masses (Arthur *et al.*, 1987). However the palynological results suggest that the Milankovitch cyclicity did not particularly affect AOM on an individual-bed scale, and consequently was not the reason for the main accumulation of AOM in the sediments across the Cenomanian - Turonian boundary, although it would surely have helped the oxygen depletion in the Western Interior Seaway.

The main model suggested by Arthur *et al.* (1987) to account for the oceanic anoxic event is linked to changes in sea level, with the OAE occurring during a period of transgression approaching a combined first- and second-order maximum flooding interval. The source of oceanic bottom water in the Cretaceous (with a comparatively warm and equable climate and no cold polar deep-water masses) is suggested to have been warm saline water produced at low latitudes in areas with a negative water balance (Brass *et al.*, 1982). The production of warm saline bottom waters is though to have been proportional to the area of epicontinental seas. The transgression at the end of the Cenomanian/beginning of the Turonian would have greatly increased shelf-sea area, increased warm saline bottom water production, displaced greater volumes of nutrient-rich deep-ocean waters to the surface and caused greater surface productivity, with increasing organic carbon production and a consequent expansion of the OMZ. During the Cenomanian - Turonian transgression the high productivity areas and the top of the oxygen-minimum zone were supposed to have impinged into epicontinental and shelf seas (Arthur *et al.*, 1987).

Hay *et al.* (1993) proposed a more recent model of oceanographic circulation in the Western Interior Seaway to account for the accumulation of the organic rich sediments. They suggested that the Boreal and Tethyan water masses (though having different temperatures and salinities) would have the same densities and on mixing within the seaway would combine and produce a new water mass of greater density. This would rapidly sink, saturate the lower water column with organic matter from the surface and thus cause the oxygen depletion. Draining out of the Western Interior Seaway, these dense waters have also been suggested as a potential source of oxygen depleted intermediate ocean waters causing expansion of oxygen minimum zones across the globe and hence causing the OAE. This model also suggests upward displacement of nutrient-rich deep-ocean waters with consequent surface productivity increases. Greatest displacement would have occurred at times of greatest transgression with the maximum mixing of Boreal and Tethyan waters in the seaway.

Either of the latter two models is supported by increases in productivity (suggested by the dinoflagellate cyst assemblages) and the relative abundance of AOM at times of transgression.

CHAPTER 10

CONCLUSIONS

10.1 CONCLUSIONS

The Cretaceous geological record of the Western Interior Seaway of North America is one of the most thoroughly studied in the world. The sedimentary record suggests a complex and dynamic history of interrelated tectonic, eustatic, oceanographic and climatic change. During the mid Cretaceous, the Western Interior Seaway linked the Cretaceous Arctic ocean with the subtropical Tethyan ocean. A series of major eustatic fluctuations caused the mixing of the two very different water masses and greatly affected the deposition of predominantly fine siliciclastic and pelagic sediments. Basin subsidence was affected by tectonic activity which in turn resulted in a series of basin-wide correlatable volcanic ash horizons. At the same time climatic fluctuations left series of laterally traceable strata across the seaway. Extensive work on the lithostratigraphy, biostratigraphy, and geochemistry has resulted in a high-resolution chronostratigraphic framework, allowing precise bed-by-bed correlation between sections hundreds of kilometres apart.

Middle Cenomanian to Middle Turonian strata from the Rebecca K. Bounds core (Kansas), and outcrop material from latest Cenomanian to earliest Turonian strata from four sites (Blue Point, Arizona; Wahweap Wash, Utah; Pueblo, Colorado; and Bunker Hill, Kansas) have been analysed for their marine palynomorph and palynofacies assemblages.

10.1.1 Taxonomy

Nineteen new species are described, two species are reattributed (*Alterbidinium rhombovale* and *Impagidinium delicatum*) and a further two pairs are placed in synonymy (*Downiesphaeridium aciculare* with *Downiesphaeridium multispinosum* and *Pervosphaeridium cenomaniense* with *Pervosphaeridium truncatum*). The sediments studied contain an extremely diverse assemblage of dinoflagellate cysts and other marine palynomorphs (220 species). The diverse assemblages are largely made up of species already described from mid Cretaceous strata from around the globe by numerous authors. The large number of species recorded seems excessively high. The reasons for this are likely to be a product of environmental and/or systematic factors and may suggest a need for further taxonomic revision, although careful comparison of holotypes would be needed for this. A number of forms seem to show a gradation or merging between two-or-more species and even two-or-more genera. However as these are fossil assemblages, it is not possible to say how much of this variability is morphological and how much is specific, and hence it is difficult to decide which to group and which to split.

In addition, a number of the species recorded here only have a few occurrences and hence (at least in some instances) their identification could be questionable, whilst the importance of including them within the study could also be argued. However many of these rarer species are shown to cluster in the multivariate statistical analyses and their appearance corresponds with other palaeontological and geochemical changes. Effectively these minority species seem to have responded to (and hence may be used to indicate) important environmental changes. Thoroughness is needed for detailed taxonomic work, particularly if the field of palynology is to be advanced, and I would suggest that correct identification and inclusion of minority species should occur, if a detailed and thorough picture is to be built up for subsequent palaeogeographic and stratigraphic use.

10.1.2 Biostratigraphy

The dinoflagellate cyst biostratigraphy supports a Cenomanian and Turonian age for the strata from the core and sections. In the centre of the basin the dinoflagellate cysts place the Cenomanian - Turonian boundary to within a few metres of the boundary as defined by ammonite biostratigraphy, based on the disappearance of *Adnatosphaeridium tutulosum, Chichaouadinium vestitum* and species of *Ovoidinium*; and on the appearance of *Florentinia buspina*.

Using the detailed high-resolution chronostratigraphic framework between sections, it is possible to show that many of the biostratigraphically useful dinoflagellate cyst taxa have synchronous range tops and bases across the basin, perhaps due to basin-wide fluctuations in water mass. The range top of *Adnatosphaeridium tutulosum* coincides with the appearance of species of *Neocardioceras* in the Western Interior Basin. Comparison with previous work (Marshall & Batten, 1988) suggests that this range-top may be synchronous with the Saxony Basin of Germany.

Many species are noted in this study with lower or higher stratigraphic ranges than previously described. The reason for this is not (on the most part) thought to be reworking, but may be due to the dynamic nature of the Western Interior Seaway, with the moving and mixing of very different Boreal and Tethyan water masses affected by eustatic fluctuations. Alternatively it may result from more detailed and thorough taxonomic work than is often used.

10.1.3 Palaeoenvironmental analysis

At the time of deposition, the sites sampled are thought to have been palaeoenvironmentally very different in terms of shoreline proximity, bathymetry, and salinity. Precise correlation of samples between the sites using the high-resolution chronostratigraphic framework has provided a valuable testing ground for palaeoenvironmental comparison using the dinoflagellate cyst and palynofacies assemblages.

A number of dinoflagellate cyst species are noted to have palaeoenvironmental preferences (with respect to salinity and bathymetry) and they are grouped for use as environmental indicators. Multivariate statistical analysis of the data generally confirms these environmental associations of species which show lowered-salinity, shallow-water, normal-salinity and deep-water preferences. The cluster analysis also identifies close links between the former and the latter two groups, suggesting salinity to be the more important environmental control. It must be stressed, however, that these species associations are only tentatively suggested and further, more detailed work is needed to confirm or redress their merit.

Previous petrological, stratigraphical and geochemical studies suggest that the Bunker Hill site had comparatively much higher levels of primary productivity. In comparison with the other sections, all of the palynological assemblages from the Bunker Hill samples are dominated by peridinioid species (particularly *Palaeohystrichophora infusorioides* and species of *Subtilisphaera*). This supports previous palynological work (e.g. Eshet *et al.*, 1994) in suggesting that the ratio of peridinioid to gonyaulacoid cysts can be used as a measure of palaeoproductivity in pre-Quaternary studies.

10.1.4 Greenhorn marine cycle

The strata from the core record the second-order transgressive-regressive eustatic Greenhorn marine cycle with superimposed third- and fourth-order fluctuations. Previous work suggests that the range of environments studied here include probable freshwater through near-shore to distal pelagic environments and back to near-shore again. The lowermost sample from the core contains a distinctive dinoflagellate cyst assemblage almost entirely dominated by *Nyktericysta* sp. A, and is thought to have been deposited under fresh-water conditions.

Foraminifera have long been used in the basin for palaeoenvironmental interpretation, particularly with respect to changes in water mass characteristics. Direct comparison with the foraminiferal data available suggests that the dinoflagellate cyst indicator species are equally as good at tracing the sea-level and water mass fluctuations (including third/fourth-order transgressive pulses) despite the limitations of the sampling resolution. This supports the use of the associations of indicator species.

10.1.5 Cenomanian-Turonian boundary event

A global marine oxygen depletion event is suggested to have occurred at the Cenomanian - Turonian boundary. Integration of the dinoflagellate cyst and palynofacies data with the well documented lithostratigraphy, macropalaeontology, micropalaeontology, and geochemistry again supports the use of the dinoflagellate cyst indicator species and suggests a reason for the oxygen depletion event in the Western Interior Seaway.

Hartland Member (Late Cenomanian) palynological assemblages from Pueblo are dominated by prasinophytes suggesting permanent stratification of the water column as a cause of oxygen depletion at the time of deposition. In contrast, both the strata of the Bridge Creek Limestone Member (latest Cenomanian to Middle Turonian) at Pueblo, and the equivalent strata from the other sections show comparatively little increase in prasinophytes. This suggests that a model for the anoxic event in the Western Interior Basin by permanent water column stratification is not correct.

The proportions of 'deep-water' and 'normal-salinity' dinoflagellate cyst indicator species, ratio of peridinioid to gonyaulacoid cysts and abundance of amorphous organic matter follow very similar curves. This suggests that increased burial of amorphous organic matter in the Western Interior Basin across the Cenomanian - Turonian boundary was related to increases in primary productivity which occurred with an increase in water temperature and salinity resulting from the expansion of the Tethyan water mass at times of third- and fourth-order transgression. The step-wise macrofaunal extinction events tend to be associated with increases in the proportions of 'lowered-salinity' indicator species suggesting stress induced by shoreline progradation or lower salinity surface waters.

This integrated, high-resolution study with tight chronostratigraphic control credits the use of dinoflagellate cysts, not only as a biostratigraphic tool but also with a very real and precise potential for palaeoenvironmental and palaeoecological interpretation.

10.2 FUTURE WORK

This project represented a unique opportunity to study the changes in palynological assemblages in response to changing palaeoenvironmental parameters. However, the main problem with this is that too many environmental parameters are involved, which are all interlinked and not easily separable. The numerous variables include stratigraphic changes; palaeogeographic changes (shoreline proximity, bathymetry, paleolatitude); oceanographic changes (eustasy, water mass, salinity, temperature, oxygen levels etc.); and climatic changes. Further work to stem from this study would need to try and address this problem and identify the palynological responses to individual environmental parameters with tighter control.

As mentioned earlier, the environmental interpretations based on the 'time-slice' transects should only be taken as preliminary results which need further work to achieve better control and confirm or redress the findings. This should involve an expansion of the data sets, the number of sections studied and the number of time slices used. Further and more detailed statistical analysis is also needed to lend further credibility to the results.

Perhaps the most important study would be to try and determine changes in dinoflagellate cyst assemblages with water mass. A study parallel to that of Watkins (1986) is needed to map the changes in dinoflagellate cyst assemblages with palaeogeography and water-mass. This would involve the use of the most widely correlatable bentonite horizons in a basin-wide study using sites with a wide variation in both longitude and latitude.

Great potential also exists for studying the palynological changes in response to the presumed Milankovitch cyclicity. This would involve an even higher-resolution study using finer channel-sampling, 'in tune' with the lithological alternations. Again the potential for this would be improved if sample sets were to be taken from a number of sites using the HIRES chronostratigraphic control available.

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APPENDIX A

SECTION LOCALITIES AND INFORMATION

Core Used

Rebecca K. Bounds core
Location: Rebecca K. Bounds #1 Core (AMOCO 15129), Greeley County, Kansas
Map Location: 1754'FNL, 30'FEL. SE, NE Sec.17, T18S, R42W
Greatful acknowledgements are due to AMOCO Production Company for the ready processed material and information that was kindly donated.

Sections Used

Pueblo Section
Location: Rock Canyon Anticline, Pueblo, Colorado
The section forms part of the Rock Canyon Anticline, located in the Pueblo Reservoir State Recreation area, 6 miles west of Pueblo. The outcrops used are in railway cuttings, on the Atchison, Topeka and Santa Fe line, three-quarters of a mile NE of the north end of the Pueblo dam, and in steep bluffs to the north of the Arkansas River, a mile to the east of the dam.
Map Location: Northwest Pueblo, Colorado, Quadrangle. Revised 1974 Edition, 1:24000
NW, SE, NE 1/4, Sec. 25, T20S, R66W

Bunker Hill Section
Location: Bunker Hill, Russell County, Kansas
The town of Bunker Hill is located just north of Interstate Highway 70, 8 miles east of Russell. The section is the steep exposure on the east side of the Bunker Hill - Luray road, three miles north of the town of Bunker Hill.
Map Location: Dorrance NW, Kansas, Quadrangle. 1967 Edition, 1:24000
SE, SE, NE 1/4, Sec. 13, T13S, R13W

Wahweap Wash Section
Location: Wahweap Wash section, Kane County, Utah.
The section lies in south-central Utah, three miles east of Big Water (formerly Glen Canyon City, located on Highway 89), to the north of the Wahweap Creek and on the north side of the Warm Creek access road. The exposure sampled is located in a short arroyo, two arroyos before the end, on the west side of the southern-most tip of Straight Cliffs Point (an extension of Mustard Point), which forms part of Nipple Bench. The Nipple Bench lies on the north side of Lake Powell in the Glen Canyon National Recreation Area, NNW of Wahweap and Page.
Map Location: Lone Rock, Utah-Arizona, Quadrangle. 1981 Edition, 1:24000
SW, SW, NW 1/4, Sec. 18, T43S, R7E

Blue Point Section
Location: Blue Point, in the Black Mesa Basin, Cocconino County, Arizona.
Map Location: Garces Mesa NE, Arizona, Quadrangle. 1967 Edition, 1:24000
NW, SW, NE 1/4, Sec. 22, T27N, R14E
The Black Mesa basin lies in Navajo and Hopi Indian reservations in northeastern Arizona. The mesa (table) itself is formed by the resistant Mesaverde Group (of which the Toreva Formation forms a part) overlying the weaker Mancos Shale Formation (which forms steep cliffs) overlying the Dakota Formation which forms lower sandstone cliffs at the base. The exposure sampled is located on the western side of Blue Point, which lies 17 miles southwest of Hotevilla, and 35 miles south east of Tuba City on Highway 160, and is located between the Dinnebito Wash and Oraibi Wash (rivers) on the southwestern side of the Black Mesa basin.

APPENDIX B

The slides examined for this study are held at the Palynological Research Centre, Institute of Earth Studies, University of Wales, Aberystwyth.

LIST OF SAMPLES USED

BLUE POINT SECTION

Slide No.	Preparation Sample No.	Study Sample No.	Stratabugs Plot Depth (metres)
PRCIES 3134	BMS4 3-5	BP1	33.42
PRCIES 3135	BMS4 7	BP2	32.7
PRCIES 3136	BMS4 8-11A	BP3	31.9
PRCIES 3137	BMS4 11B-14A	BP4	31.15
PRCIES 3138	BMS4 14B-16A	BP5	30.42
PRCIES 3139	BMS4 16B-18A	BP6	29.72
PRCIES 3140	BMS4 18B-20A	BP7	29.02
PRCIES 3141	BMS4 20B-20C	BP8	28.35
PRCIES 3142	BMS4 20D-24	BP9	27.72
PRCIES 3143	BMS4 25A-25B	BP10	27.15
PRCIES 3144	BMS4 26-27A	BP11	26.6
PRCIES 3145	BMS4 27B-28A	BP12	25.95
PRCIES 3146	BMS4 28B-30	BP13	25.3
PRCIES 3147	BMS4 32-33B	BP14	24.62
PRCIES 3148	BMS4 33C-34A	BP15	23.95
PRCIES 3149	BMS4 34B-36A	BP16	23.35
PRCIES 3150	BMS4 36B-38B	BP17	22.75
PRCIES 3151	BMS4 38C-38D	BP18	22.15
PRCIES 3152	BMS4 38E-38F	BP19	21.55
PRCIES 3153	BMS4 38G-38H	BP20	20.95
PRCIES 3154	BMS4 38I-39A	BP21	20.37
PRCIES 3155	BMS4 39B-42A	BP22	19.05
PRCIES 3156	BMS4 42B-44A	BP23	17
PRCIES 3157	BMS4 44B-44C	BP24	15
PRCIES 3158	BMS4 44D-45A	BP25	13
PRCIES 3159	BMS4 45B-48A	BP26	11
PRCIES 3160	BMS4 48B-51A	BP27	9
PRCIES 3161	BMS4 51B-54A	BP28	7
PRCIES 3162	BMS4 54B-54C	BP29	5
PRCIES 3163	BMS4 54D-58A	BP30	3
PRCIES 3164	BMS4 58B-60A	BP31	1

WAHWEAP WASH SECTION

Slide No.	Preparation Sample No.	Study Sample No.	Stratabugs Plot Depth (metres)
PRCIES 3131	NBU 23-24	W1	44.63
PRCIES 3320	NBU 26-28	W2	44.39
PRCIES 3321	NBU 30	W3	43.74
PRCIES 3322	NBU 32A-32B	W4	43.17
PRCIES 3323	NBU 33-35A	W5	42.43
PRCIES 3324	NBU 35B-35C	W6	41.66
PRCIES 3325	NBU 36-37A	W7	40.96
PRCIES 3326	NBU 37B-37C	W8	40.3
PRCIES 3327	NBU 38-39	W9	39.76
PRCIES 3328	NBU 40	W10	39.42
PRCIES 3329	NBU 41A	W11	39.02
PRCIES 3330	NBU 41B	W12	38.62
PRCIES 3331	NBU 41C	W13	38.22
PRCIES 3332	NBU 41D	W14	37.81
PRCIES 3333	NBU 43-46	W15	37.31
PRCIES 3334	NBU 47	W16	36.81
PRCIES 3335	NBU 48A	W17	36.35
PRCIES 3336	NBU 48B	W18	35.85
PRCIES 3132	NBU 48C	W19	35.35
PRCIES 3337	NBU 48D-48E	W20	34.6
PRCIES 3338	NBU 48F-48G	W21	33.6
PRCIES 3339	NBU 48H-48I	W22	32.6
PRCIES 3340	NBU 48J-48K	W23	31.6
PRCIES 3341	NBU 48L-48M	W24	30.6
PRCIES 3342	NBU 48N-48O	W25	29.6
PRCIES 3343	NBU 48P-48Q	W26	28.7
PRCIES 3344	NBU 48R-52A	W27	27.45
PRCIES 3345	NBU 52B-52C	W28	26.25
PRCIES 3346	NBU 52D-54A	W29	25.15
PRCIES 3347	NBU 54B-54C	W30	24.1
PRCIES 3348	NBU 54D-54E	W31	23.09
PRCIES 3351	WW 5-6	W32	21.5
PRCIES 3352	WW 7-8	W33	18.5
PRCIES 3353	WW 9-10	W34	15.5
PRCIES 3354	WW 11-12	W35	12.5
PRCIES 3355	WW 13-14	W36	9.5
PRCIES 3356	WW 15-16	W37	6.5
PRCIES 3133	WW 17	W38	3.87

PUEBLO SECTION

Slide No.	Preparation Sample No.	Study Sample No.	Stratabugs Plot Depth (metres)
PRCIES 3399	PH4	PA1	9.9
PRCIES 3398	PH3	PA2	9.7
PRCIES 3397	PH2	PA3	9.5
PRCIES 3396	PH1	PA4	9.3
PRCIES 2391	PUH2	PA5	9.1
PRCIES 2392	PUH3	PA6	8.9
PRCIES 2393	PUB1	PB1	8.7
PRCIES 2394	PUB2	PB2	8.5
PRCIES 2395	PUB3	PB3	8.3
PRCIES 2385	PUB4	PB4	8.1
PRCIES 2396	PUB5	PB5	7.9
PRCIES 2397	PUB6	PB6	7.7
PRCIES 2398	PUB7	PB7	7.5
PRCIES 2399	PUB8	PB8	7.3
PRCIES 2400	PUB9	PB9	7.1
PRCIES 2401	PUB10	PB10	6.9
PRCIES 2402	PUB11	PB11	6.7
PRCIES 2403	PUB12	PB12	6.5
PRCIES 2404	PUB13	PB13	6.3
PRCIES 2405	PUB14	PB14	6.1
PRCIES 2406	PUB15	PB15	5.9
PRCIES 2407	PUB16	PB16	5.7
PRCIES 2408	PUB17	PB17	5.5
PRCIES 2409	PUB18	PB18	5.3
PRCIES 2410	PUB19	PB19	5.1
PRCIES 2411	PUB20	PB20	4.9
PRCIES 2412	PUB21	PB21	4.7
PRCIES 2413	PUB22	PB22	4.5
PRCIES 2414	PUB23	PB23	4.3
PRCIES 2415	PUB24	PB24	4.1
PRCIES 2416	PUB25	PB25	3.9
PRCIES 2417	PUB26	PB26	3.7
PRCIES 2418	PUB27	PB27	3.5
PRCIES 2419	PUB28	PB28	3.3
PRCIES 2420	PUB29	PB29	3.1
PRCIES 2421	PUB30	PB30	2.9
PRCIES 2422	PUB31	PB31	2.7
PRCIES 2423	PUB32	PB32	2.5
PRCIES 2687	PUB33	PB33	2.3
PRCIES 3417	PUB35	PB34	1.95
PRCIES 3418	PUB36	PB35	1.45
PRCIES 3419	PUB37	PB36	0.95

REBECCA K. BOUNDS CORE

Slide No.	Preparation Sample No.	Study Sample No.	Stratabugs Plot Depth (feet)
AMOCO loc.15129 s.65	N/A	750'	750'
AMOCO loc.15129 s.66	N/A	760'	760'
AMOCO loc.15129 s.67	N/A	770'	770'
AMOCO loc.15129 s.68	N/A	780'	780'
AMOCO loc.15129 s.69	N/A	790'	790'
AMOCO loc.15129 s.70	N/A	800'	800'
AMOCO loc.15129 s.71	N/A	810'	810'
AMOCO loc.15129 s.72	N/A	820'	820'
AMOCO loc.15129 s.73	N/A	830'	830'
AMOCO loc.15129 s.74	N/A	840'	840'
AMOCO loc.15129 s.75	N/A	850'	850'
AMOCO loc.15129 s.76	N/A	860'	860'
AMOCO loc.15129 s.77	N/A	870'	870'
AMOCO loc.15129 s.78	N/A	880'	880'
AMOCO loc.15129 s.79	N/A	890'	890'
AMOCO loc.15129 s.80	N/A	900'	900'
AMOCO loc.15129 s.81	N/A	910'	910'
AMOCO loc.15129 s.82	N/A	920'	920'
AMOCO loc.15129 s.83	N/A	930'	930'
AMOCO loc.15129 s.84	N/A	940'	940'
AMOCO loc.15129 s.85	N/A	950'	950'
AMOCO loc.15129 s.86	N/A	960'	960'
AMOCO loc.15129 s.87	N/A	970'	970'
AMOCO loc.15129 s.88	N/A	980'	980'
AMOCO loc.15129 s.89	N/A	990'	990'
AMOCO loc.15129 s.90	N/A	1000'	1000'
AMOCO loc.15129 s.91	N/A	1010'	1010'
AMOCO loc.15129 s.92	N/A	1020'	1020'
AMOCO loc.15129 s.93	N/A	1030'	1030'
AMOCO loc.15129 s.94	N/A	1040'	1040'
AMOCO loc.15129 s.95	N/A	1050'	1050'
AMOCO loc.15129 s.96	N/A	1060'	1060'
AMOCO loc.15129 s.97	N/A	1070'	1070'
AMOCO loc.15129 s.98	N/A	1080'	1080'
AMOCO loc.15129 s.99	N/A	1090'	1090'
AMOCO loc.15129 s.100	N/A	1100'	1100'
AMOCO loc.15129 s.101	N/A	1110'	1110'
AMOCO loc.15129 s.102	N/A	1119.5'	1119.5'
AMOCO loc.15129 s.103	N/A	1128'	1128'

BUNKER HILL SECTION

Slide No.	Preparation Sample No.	Study Sample No.	Stratabugs Plot Depth (feet)
PRCIES 2689	BH1	BH1	9.9
PRCIES 2690	BH2	BH2	9.7
PRCIES 2691	BH3	BH3	9.5
PRCIES 2692	BH4	BH4	9.3
PRCIES 2693	BH5	BH5	9.1
PRCIES 2694	BH6	BH6	8.9
PRCIES 2695	BH7	BH7	8.7
PRCIES 2696	BH8	BH8	8.5
PRCIES 2697	BH9	BH9	8.3
PRCIES 2698	BH10	BH10	8.1
PRCIES 2699	BH11	BH11	7.9
PRCIES 2700	BH12	BH12	7.7
PRCIES 2701	BH13	BH13	7.5
PRCIES 2702	BH14	BH14	7.3
PRCIES 2703	BH15	BH15	7.1
PRCIES 2704	BH16	BH16	6.9
PRCIES 2705	BH17	BH17	6.7
PRCIES 2706	BH18	BH18	6.5
PRCIES 2707	BH19	BH19	6.3
PRCIES 2708	BH20	BH20	6.1
PRCIES 2709	BH21	BH21	5.9
PRCIES 2710	BH22	BH22	5.7
PRCIES 2711	BH23	BH23	5.5
PRCIES 2712	BH24	BH24	5.3
PRCIES 2713	BH25	BH25	5.1
PRCIES 2714	BH26	BH26	4.9
PRCIES 2715	BH27	BH27	4.7
PRCIES 2716	BH28	BH28	4.5
PRCIES 2717	BH29	BH29	4.3
PRCIES 2718	BH30	BH30	4.1
PRCIES 2719	BH31	BH31	3.9
PRCIES 2720	BH32	BH32	3.7
PRCIES 2721	BH33	BH33	3.5
PRCIES 2722	BH34	BH34	3.3
PRCIES 2723	BH35	BH35	3.1
PRCIES 2724	BH36	BH36	2.9
PRCIES 2725	BH37	BH37	2.7
PRCIES 2726	BH38	BH38	2.5
PRCIES 2727	BH39	BH39	2.3

APPENDIX C

REFERENCE LIST OF SPECIES

Previously described species found in material

	Page	Plate/Figure(s)
Acanthaulax wilsonii Yun 1981	59	26/8,9
Achomosphaera crassipellis (Deflandre & Cookson 1955) Stover & Evitt 1978	89	7/4
Achomosphaera neptunii (Eisenack 1958a) Davey & Williams 1966a	89	7/3
Achomosphaera ramulifera (Deflandre 1937b) Evitt 1963	90	7/1,2
Achomosphaera regiensis Corradini 1973	91	7/5,6
Adnatosphaeridium tutulosum (Cookson & Eisenack 1960a) Morgan 1980	118	24/6
Alterbidinium emulatum Mao Shaozhi & Norris 1988	178	35/7,8
Alterbidinium rhombovale (Cookson & Eisenack 1970a) n. comb.	179	36/5,6
Apteodinium deflandrei (Clarke & Verdier 1967) Lucas-Clarke 1987	71	28/5,6
Apteodinium maculatum grande (Cookson & Hughes 1964) Below 1981a	72	28/7
Apteodinium reticulatum Singh 1971	73	28/3,4
Atopodinium haromense Thomas & Cox 1988	142	25/1
Baltisphaeridium crameri Singh 1971	198	41/4
Batiacasphaera euteiches (Davey 1969a) Davey 1979d	143	14/8
Batiacasphaera granulosa (Cookson & Eisenack 1974) Jansonius 1989	143	14/7
Callaiosphaeridium asymmetricum (Deflandre & Courteville 1939) Davey & Williams 1966b	105	2/7
Canningia reticulata Cookson & Eisenack 1960b	119	21/1,2
Canningia scabrosa Cookson & Eisenack 1970a	120	20/4,5,6
Canningia senonica Clarke & Verdier 1967	121	20/1,2,3
Canninginopsis colliveri (Cookson & Eisenack 1960b) Backhouse 1988	123	19/6
Chatangiella granulifera granulifera (Manum 1963) Lentin & Williams 1976	181	36/1,2
Chatangiella granulifera tenuis (Davey 1970) Lentin & Williams 1976	182	36/3,4
Chatangiella spectabilis (Alberti 1959b) Lentin & Williams 1976	183	35/4,5
Chatangiella victoriensis (Cookson & Manum 1964) Lentin & Williams 1976	184	35/6
Chichaouadinium boydii (Morgan 1975) Bujak & Davies 1983	170	38/2,3
Chichaouadinium vestitum (Brideaux 1971) Bujak & Davies 1983	170	38/1
Chlamydophorella discreta Clarke & Verdier 1967	144	13/5
Chlamydophorella nyei Cookson & Eisenack 1958	144	13/7,10
Circulodinium distinctum (Deflandre & Cookson 1955) Jansonius 1986	124	18/2
Cometodinium? whitei (Deflandre & Courteville 1939) Stover & Evitt 1978	106	16/8
Coronifera oceanica Cookson & Eisenack 1958	107	3/1
Coronifera striolata (Deflandre 1937b) Stover & Evitt 1978	108	3/2,3
Crassosphaera papillata Singh 1971	211	44/4
Cribroperidinium cooksoniae Norvick in Norvick & Burger 1976	73	29/3,4,5
Cribroperidinium orthoceras (Eisenack 1958a) Davey 1969a	74	29/1

	Page	Plate/Figure(s)
Cyclonephelium brevispinatum (Millioud 1969) Below 1981a	125	19/3,4
Cyclonephelium chabaca Below 1981a	126	19/1,2
Cyclonephelium compactum Deflandre & Cookson 1955	127	17/2
Cyclonephelium membraniphorum Cookson & Eisenack 1962b	128	17/3,4
Cyclonephelium paucimarginatum Cookson & Eisenack 1962b	129	19/7
Cyclonephelium uncinatum Norvick in Norvick & Burger 1976	129	17/5,6
Cyclonephelium vannophorum Davey 1969a	129	19/5
Cymatiosphaera costata Davey 1970	212	44/7
Dapsilidinium ambiguum (Deflandre 1937b) Wheeler & Sarjeant 1990	146	13/8,9
Dapsilidinium laminaspinosum (Davey & Williams 1966b) Lentin & Williams 1981	147	15/4,5
Dapsilidinium marinum Singh 1983	148	15/1,2,3
Dapsilidinium multispinosum (Davey 1974) Bujak, Downie, Eaton & Williams 1980	149	16/9
Dapsilidinium? pumilum (Davey & Williams 1966b) Lentin & Williams 1981	149	15/6,7
Dinogymnium vozzhennikovae Lentin & Williams 1973	54	39/3
Dinopterygium cladoides Deflandre 1935	140	23/1,2
Dinopterygium reticulatum Singh 1983	140	22/2
Diplofusa gearlensis Cookson & Eisenack 1960a	198	42/1
Disphaeria macropyla Cookson & Eisenack 1960a	150	25/2,3
Dorocysta litotes Davey 1970	150	39/10
Downiesphaeridium armatum (Deflandre 1937b) Islam 1993	151	16/3
Downiesphaeridium multispinosum (Singh 1964) Islam 1993	152	16/7
Ellipsodinium rugulosum Clarke & Verdier 1967	155	25/6
Endoscrinium campanula (Gocht 1959) Vozzhenikova 1967	60	26/1
Epelidosphaeridia spinosa (Cookson & Hughes 1964) Davey 1969a	192	38/6
Eurydinium eyrensis Cookson & Eisenack 1971	184	34/5,6,7
Eurydinium glomeratum (Davey 1970) Stover & Evitt 1978	185	34/3
Eurydinium ingramii (Cookson & Eisenack 1970a) Stover & Evitt 1978	185	34/2
Eurydinium saxoniensis Marshall & Batten 1988	186	34/4
Exochosphaeridium arnace Davey & Verdier 1973	155	11/4
Exochosphaeridium bifidum (Clarke & Verdier 1967) Clarke, Davey, Sarjeant & Verdier 1968	156	12/3,4
Exochosphaeridium phragmites Davey, Downie, Sarjeant & Williams 1966	156	11/5,6
Eyrea nebulosa Cookson & Eisenack 1970b / 1971	199	43/5,6
Florentinia buspina (Davey & Verdier 1976) Duxbury 1980	76	4/3
Florentinia clavigera (Deflandre 1937b) Davey & Verdier 1973	76	4/1,2
Florentinia cooksoniae (Singh 1971) Duxbury 1980	77	5/6
Florentinia deanei (Davey & Williams 1966b) Davey & Verdier 1973	77	5/5
Florentinia ferox (Deflandre 1937b) Duxbury 1980	78	4/4,6
Florentinia laciniata Davey & Verdier 1973	79	5/3
Florentinia mantellii (Davey & Williams 1966b) Davey & Verdier 1973	80	5/4

	Page	Plate/Figure(s)
Nelsoniella aceras Cookson & Eisenack 1960a	189	38/4
Occisucysta hinzii Below 1984	64	26/4
Odontochitina costata Alberti 1961	133	31/3
Odontochitina operculata (Wetzel 1933a) Deflandre & Cookson 1955	135	31/1
Odontochitina rhakodes Bint 1986	136	31/2
Oligosphaeridium albertense (Pocock 1962) Davey & Williams 1969	64	6/3
Oligosphaeridium complex (White 1842) Davey & Williams 1966b	65	6/1
Oligosphaeridium dividuum Williams 1978	67	6/6
Oligosphaeridium pulcherrimum (Deflandre & Cookson 1955) Davey & Williams 1966b	67	6/4
Oligosphaeridium reticulatum Davey & Williams 1966b	68	6/2
Oligosphaeridium totum Brideaux 1971	68	6/5
Ovoidinium scabrosum (Cookson & Hughes 1964) Davey 1970	193	38/8
Ovoidinium verrucosum (Cookson & Hughes 1964) Davey 1970	193	38/7
Palaeohystrichophora infusorioides Deflandre 1935	172	33/1,2
Palaeoperidinium cretaceum Pocock 1962	173	38/5
Palaeotetradinium silicorum Deflandre 1936b	196	39/2
Palambages morulosa Wetzel 1961	208	43/3
Paralecaniella indentata (Deflandre & Cookson 1955) Cookson & Eisenack 1970b	201	44/6
Pareodinia ceratophora Deflandre 1947c	58	39/1
Pervosphaeridium brevispinum (Norvick in Norvick & Burger 1976) Below 1982c	112	12/1
Pervosphaeridium pseudhystrichodinium (Deflandre 1937b) Yun 1981	112	12/2,5
Pervosphaeridium truncatum (Davey 1969a) Below 1982c	113	12/6,7
Petalosporites quadrangulus Agasie 1969	209	41/10
Platycystidia diptera Cookson & Eisenack 1960a	202	41/6
Prolixosphaeridium conulum Davey 1969a	162	15/8
Prolixosphaeridium parvispinum (Deflandre 1937b) Davey, Downie, Sarjeant & Williams 1969	163	15/11
Psaligonyaulax deflandrei Sarjeant 1966b	96	26/2,3
Pseudoceratium eisenackii (Davey 1969a) Bint 1986	137	30/4,5,6
Pterodinium cingulatum (Wetzel 1933b) Below 1981a	97	27/8
Pterodinium? cornutum Cookson & Eisenack 1962b	98	27/7
Pterospermella aureolata (Cookson & Eisenack 1958) Eisenack 1972	212	45/1
Pterospermella australiensis (Deflandre & Cookson 1955) Eisenack, Cramer & Diez 1973	213	45/3
Pterospermella centrata (Cookson & Eisenack 1971) Eisenack, Cramer & Diez 1973	213	45/2
Pterosphaeridia pachytheca (Eisenack 1957) Madler 1963	214	44/3
Raetiaedinium truncigerum (Deflandre 1937b) Kirsch 1991	164	2/1,2
Rhiptocorys veligera (Deflandre 1937b) Lejeune-Carpentier & Sarjeant 1983	57	13/6
Schizocysta laevigata Cookson & Eisenack 1962a	209	41/8
Scuticabolus lapidaris (Wetzel 1933) Loeblich III 1967	203	43/4
Senoniasphaera microreticulata Brideaux & McIntyre 1975	130	22/1

	Page	Plate/Figure(s)
Spiniferites lenzii Below 1982c	99	10/3,4,5,6,7
Spiniferites porosus (Manum & Cookson 1964) Harland 1973	100	9/6
Spiniferites ramosus gracilis (Davey & Williams 1966a) Lentin & Williams 1973	100	9/2
Spiniferites ramosus granomembranaceous (Davey & Williams 1966a) Lentin & Williams 1973	101	9/7
Spiniferites ramosus ramosus (Ehrenburg 1838) Mantell 1854	101	9/1
Spiniferites ramosus reticulatus (Davey & Williams 1966a) Lentin & Williams 1973	103	9/3,4
Spiniferites tripus Singh 1983	103	10/2
Spiniferites twistringiensis (Maier 1959) Fensome, Williams, Barss, Freeman & Hill 1990	103	9/5
Spiniferites wetzelii (Deflandre 1937b) Sarjeant 1970	104	10/1
Stephodinium coronatum Deflandre 1936a	117	25/4,5
Subtilisphaera cheit Below 1981a	174	33/3,4
Subtilisphaera foliacea (Eisenack & Cookson 1960) Stover & Evitt 1978	175	33/13
Subtilisphaera hyalina Singh 1983	175	33/11,12
Subtilisphaera? inaffecta (Drugg 1978) Bujak & Davies 1983	176	33/5,6
Subtilisphaera pirnaensis (Alberti 1959b) Jain & Millepied 1973	176	33/10
Subtilisphaera pontis-marie (Deflandre 1936b) Lentin & Williams 1976	177	33/7,8
Subtilisphaera zawia Below 1981a	177	33/9
Surculosphaeridium? longifurcatum (Firtion 1952) Davey, Downie, Sarjeant & Williams 1966	117	1/5
Tanyosphaeridium salpinx Norvick in Norvick & Burger 1976	164	15/12,13
Tanyosphaeridium variecalamus Davey & Williams 1966b	165	15/9,10
Tehamadinium coummia (Below 1981a) Jan du Chen *et al.* 1986a	70	26/7
Tenua hystrix Eisenack 1958a	131	18/1
Trichodinium castanea (Deflandre 1935) Clarke & Verdier 1967	70	26/6
Trigonopyxidia ginella (Cookson & Eisenack 1960a) Downie & Sarjeant 1965	166	39/5
Trithyrodinium dubium Singh 1983	189	37/1,2,3
Trithyrodinium suspectum (Manum & Cookson 1964)	191	37/4,5
Valensiella magna (Davey 1974) Courtinat 1989	167	22/3
Valensiella reticulata (Davey 1969a) Coutinat 1989	167	22/6,7,8,9
Valensiella tazadensis (Below 1981a) Lentin & Williams 1993	168	22/4,5
Veryhachium collectum Wall 1965	203	40/4
Veryhachium europeum Stockmans & Williere 1960	203	40/1,2
Veryhachium formosum Stockmans & Williere 1960	204	40/5
Veryhachium irregulare de Jekhowsky 1961	204	40/8
Veryhachium reductum (Deunff 1959) Downie & Sarjeant 1965	204	40/7
Veryhachium rhomboideum Downie 1959	205	40/6
Veryhachium valiente Deflandre 1946c	205	40/3
Wallodinium anglicum (Cookson & Hughes 1964) Lentin & Williams 1973	196	39/4
Wallodinium luna (Cookson & Eisenack 1960a) Lentin & Williams 1973	197	39/6,7
Xenascus australensis Cookson & Eisenack 1969	138	32/2,3,4

	Page	Plate/Figure(s)
Xenascus perforatus (Vozzhennikova 1967) Yun 1981	138	32/1
Xenascus plotei Below 1981a	139	32/5,6
Xiphophoridium alatum (Cookson & Eisenack 1962b) Sarjeant 1966b	169	23/3,4

Additional species described from material

Cribroperidinium sp. aff. *C.vexillum*	76	28/1,2
Cribroperidinium sp. cf. *C.aceras*	75	27/1
Spongodinium sp. cf. *S.delitiense*	88	29/2
Trithyrodinium sp. cf. *T. evittii*	190	37/6,7
Achomosphaera sp. A	92	8/1,2,3,4,5,6
acritarch sp. A	206	41/5
acritarch sp. B	207	45/5,6,7
acritarch sp. C	207	42/3,4
Batiacasphaera sp. A	143	14/1,2,3,4
Canningia sp. A	121	21/3,4
Canningia sp. B	122	21/5,6
Downiesphaeridium sp. A	154	16/10,11,12
Impagidinium sp. C	95	27/4
Kallosphaeridium sp. A	84	13/11,12
Leiosphaeridia spp.	212	43/1,2
Litosphaeridium sp. A	63	2/5
Nyktericysta sp. A	132	32/2,3
Odontochitina sp. A	136	30/1
Operculodinium sp. A	85	16/1,2
Pervosphaeridium sp. A	116	11/1,2,3
Pterospermella sp. A	214	45/4
Systematophora sp. A	69	3/5,6,8
Tasmanites spp.	215	44/1,2
Tetraedron sp. A	210	41/9
Tetraporina sp. A	211	41/7
Wuroia sp. A	206	42/5,6

Additional species referred to in text

Achomosphaera sagena Davey & Williams 1966a

Apteodinium granulatum Eisenack 1958a

Catastomocystis spinosa Singh 1983

Chatangiella tripartita (Cookson & Eisenack 1960a) Lentin & Williams 1976

Circulodinium attadalicum (Cookson & Eisenack 1962b) Helby 1987

Cribroperidinium aceras (Eisenack 1958a) Sarjeant 1985a

Cribroperidinium edwardsii (Cookson & Eisenack 1958) Davey 1969a

Cribroperidinium exilicristatum (Davey 1969a) Stover & Evitt 1978

Cribroperidinium intricatum Davey 1969a

Cribroperidinium vexillum Prossl 1990

Cyclonephelium hughesii Clarke & Verdier 1967

Dinogymnium albertii Clarke & Verdier 1967

Disphaeria hypoflata Yun 1981

Disphaeria munda (Davey & Verdier 1973) Norvick in Norvick & Burger 1976

Downiesphaeridium aciculare (Davey 1969a) Islam 1993

Elytrocysta circulata (Clarke & Verdier 1967) Stover & Helby 1987d

Florentinia tenera (Davey & Verdier 1976) Duxbury 1980

Florentinia tridactylites (Valensi 1955a) Duxbury 1980

Gonyaulacysta helicoidea (Eisenack & Cookson 1960) Sarjeant 1966b

Hystrichosphaeridium paracostatum Cookson & Eisenack 1974

Isabelidinium gallium (Davey & Verdier 1973) Stover & Evitt 1978

Kleithriasphaeridium corrugatum Davey 1974

Kleithriasphaeridium eoinodes (Eisenack 1958a) Davey 1974

Kleithriasphaeridium loffrense Davey & Verdier 1976

Leberidocysta chlamydata (Cookson & Eisenack 1962b) Stover & Evitt 1978

Litosphaeridium arundum (Eisenack & Cookson 1960) Davey 1979b

Litosphaeridium conispinum Davey & Verdier 1973

Microdinium? crinitum Davey 1969a

Microdinium distinctum Davey 1969a

Muderongia asymmetrica Brideaux 1977

Nematosphaeropsis densiradiata (Cookson & Eisenack 1962b) Stover & Evitt 1978

Nematosphaeropsis labyrinthus (Ostenfeld 1903) Reid 1974

Nyktericysta pentagonum (Singh 1983) Bint 1986

Oligosphaeridium prolixospinosum Davey & Williams 1966b

Operculodinium centrocarpum (Deflandre & Cookson 1955) Wall 1967

Operculodinium israelinum (Rossignol 1962) Wall 1967

Palaeoperidinium pyrophorum (Ehrenberg 1838) Sarjeant 1967b

Pervosphaeridium cenomaniense (Norvick & Burger 1976) Below 1982c

Pervosphaeridium morgenrothii (Corradini 1973) Kirsch 1991

Protoellipsodinium spinosum Davey & Verdier 1971

Pterodinium cingulatum granulatum (Clarke & Verdier 1967) Lentin & Williams 1981

Pterodinium cingulatum reticulatum (Davey & Williams 1966a) Lentin & Williams 1981

Schizocysta rugosa Cookson & Eisenack 1962a

Senoniasphaera rotundata Clarke & Verdier 1967

Spinidinium echinoideum (Cookson & Eisenack 1960a) Lentin & Williams 1976

Spiniferites seghiris (Below 1982c) Lentin & Williams 1993

Spongodinium delitiense (Ehrenberg 1838) Deflandre 1936b

Subtilisphaera deformans (Davey & Verdier 1973) Stover & Evitt 1978

Subtilisphaera? habibi Masure 1988b

Tanyosphaeridium boletus Davey 1974

Tanyosphaeridium isocalamus (Deflandre & Cookson 1955) Davey & Williams 1969

Trithyrodinium evittii Drugg 1967

Trithyrodinium rhomboideum Singh 1983

Valensiella pygmaea (Stevens 1987) Lentin & Williams 1993

Williamsidinium banksianium Lentin 1983

Wuroia tubiformis Stover & Helby 1987a

Xenascus ceratioides (Deflandre 1937b) Lentin & Williams 1973

Xenascus gochtii (Corradini 1973) Stover & Evitt 1978

APPENDIX D

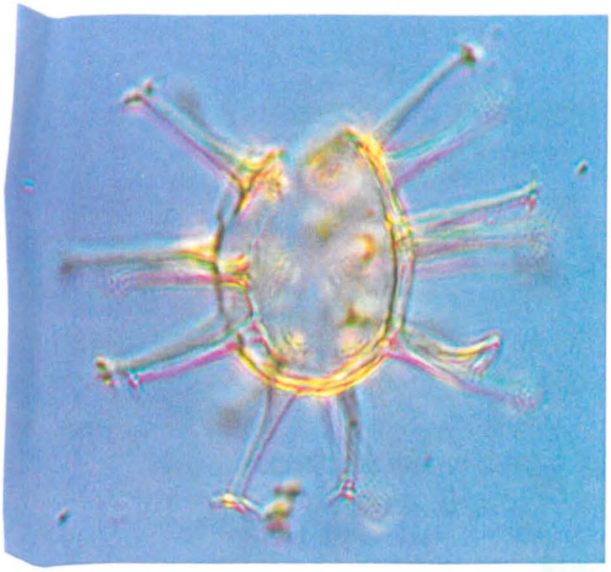
PLATES

Plates 1-45

All plates at a magnification
of ×900 unless specified

Plate 1

1. ***Hystrichosphaeridium bowerbankii***
   Blue Point Section, Sample BMS4/11B-14A, Slide PRCIES 3137.3, England Finder Reference: U363
2. ***Hystrichosphaeridium bowerbankii***
   Blue Point Section, Sample BMS4/11B-14A, Slide PRCIES 3137.3, England Finder Reference: U363
3. ***Hystrichosphaeridium recurvatum***
   Wahweap Wash Section, Sample NBU/37B-37C, Slide PRCIES 3326.2, England Finder Reference: F583
4. ***Hystrichosphaeridium recurvatum***
   Rebecca K. Bounds Core, Sample 970', AMOCO Loc. 15129, Slide 87, England Finder Reference: F384
5. ***Surculosphaeridium? longifurcatum***
   Rebecca K. Bounds Core, Sample 920', AMOCO Loc. 15129, Slide 82, England Finder Reference: E432/4



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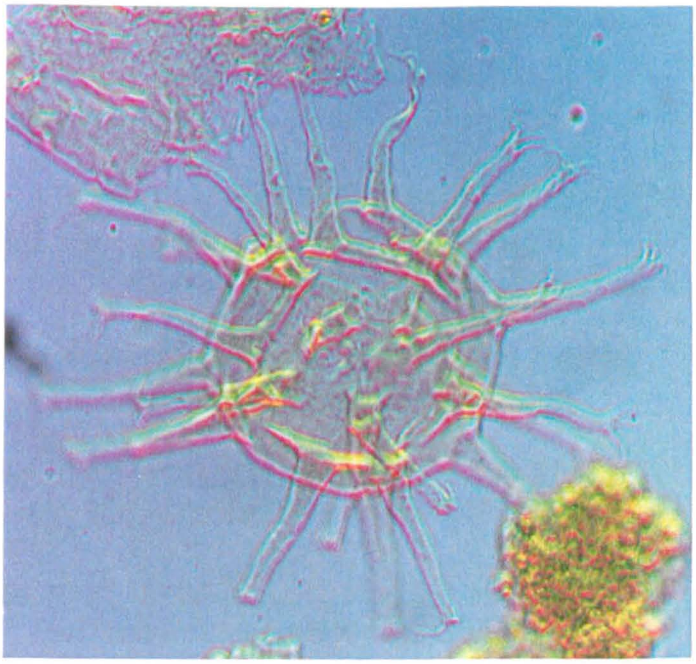

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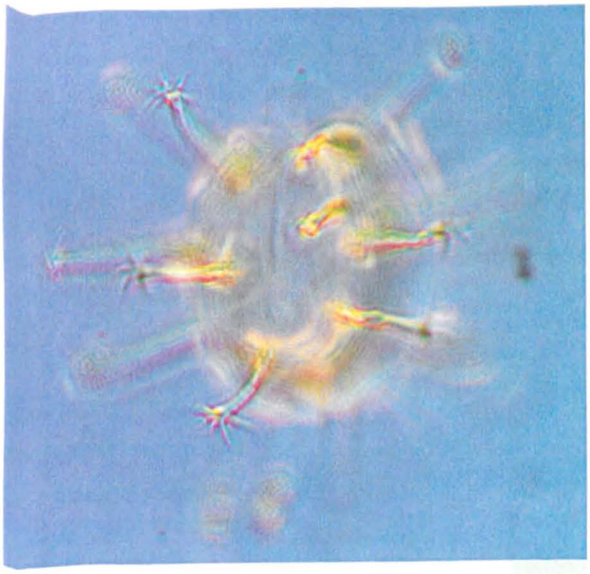

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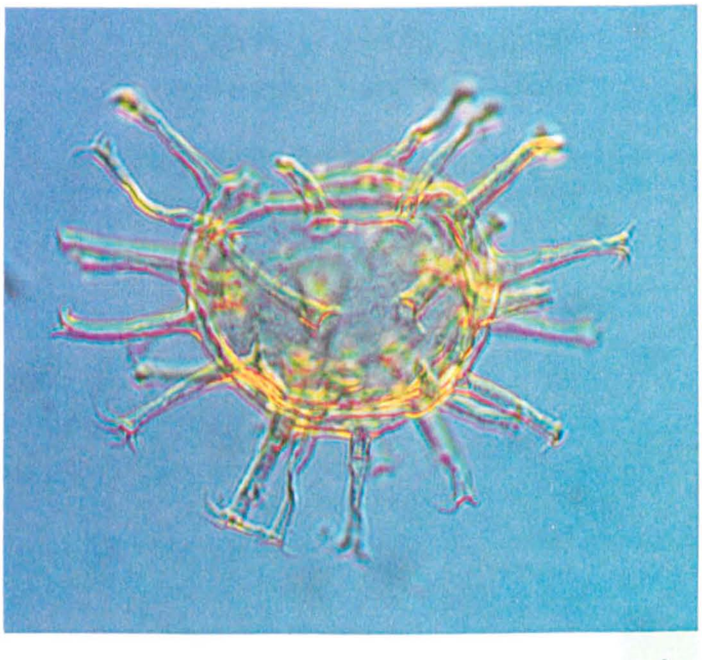

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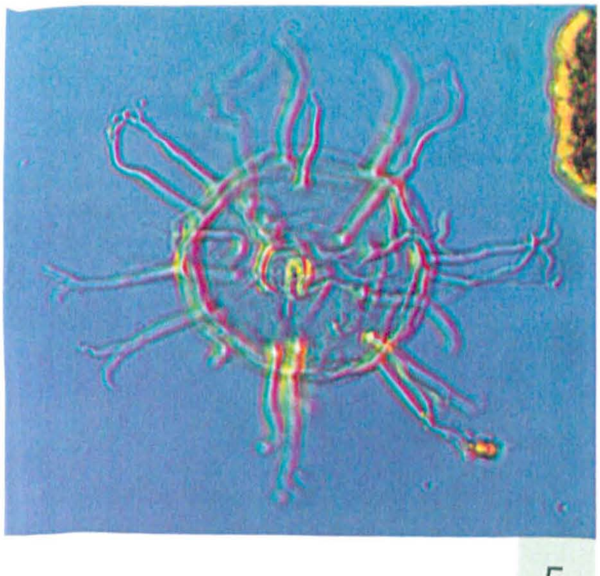

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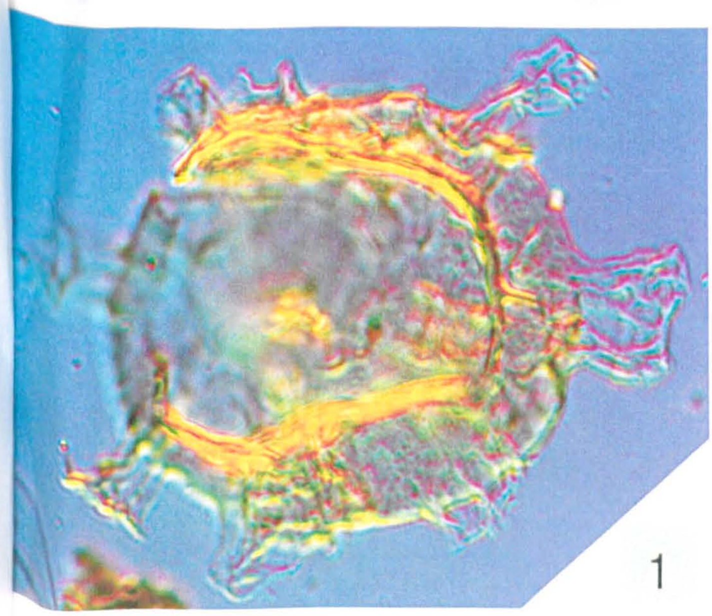
Plate 1

Plate 2

1. ***Raetiaedinium truncigerum***
   Rebecca K. Bounds Core, Sample 890', AMOCO Loc. 15129, Slide 79, England Finder Reference: P394
2. ***Raetiaedinium truncigerum***
   Rebecca K. Bounds Core, Sample 890', AMOCO Loc. 15129, Slide 79, England Finder Reference: P394
3. ***Litosphaeridium siphoniphorum***
   Rebecca K. Bounds Core, Sample 1010', AMOCO Loc. 15129, Slide 91, England Finder Reference: G472/481
4. ***Litosphaeridium siphoniphorum***
   Rebecca K. Bounds Core, Sample 1050', AMOCO Loc. 15129, Slide 95, England Finder Reference: G324/333
5. ***Litosphaeridium* sp. A**
   Blue Point Section, Sample BMS4/14B-16A, Slide PRCIES 3138.4, England Finder Reference: W233
6. ***Kleithriasphaeridium readiae***
   Rebecca K. Bounds Core, Sample 800', AMOCO Loc. 15129, Slide 70, England Finder Reference: D351
7. ***Callaiosphaeridium asymmetricum***
   Blue Point Section, Sample BMS4/34B-36A, Slide PRCIES 3149.2, England Finder Reference: B314/C312



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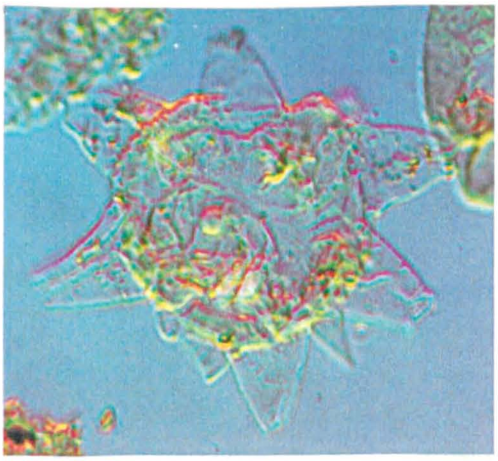

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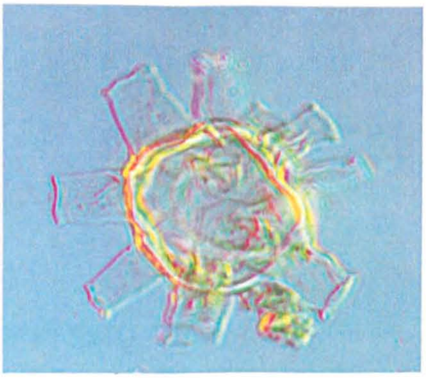

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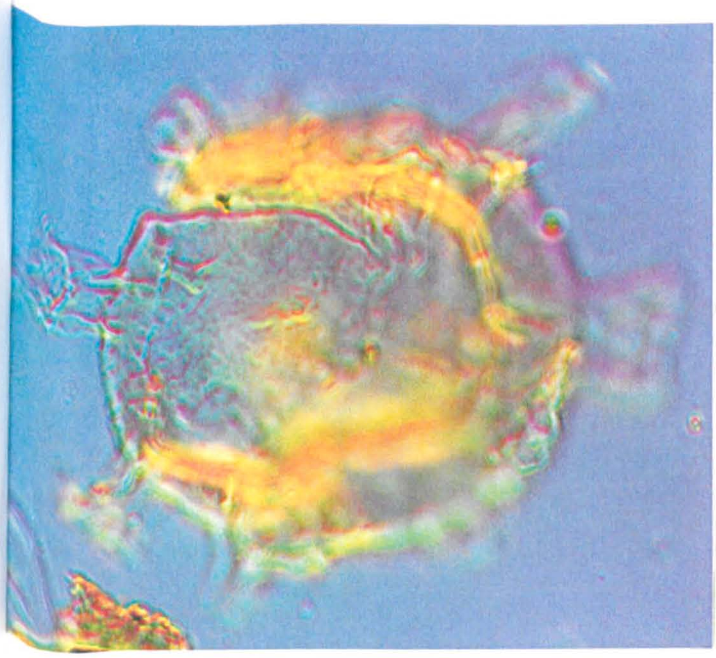

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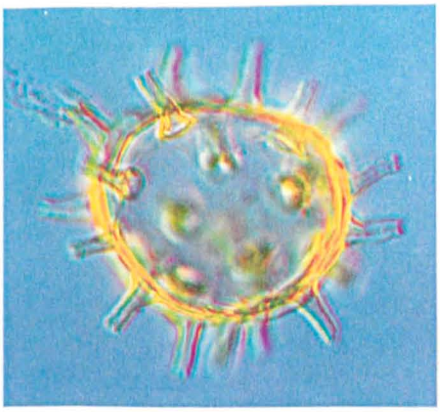

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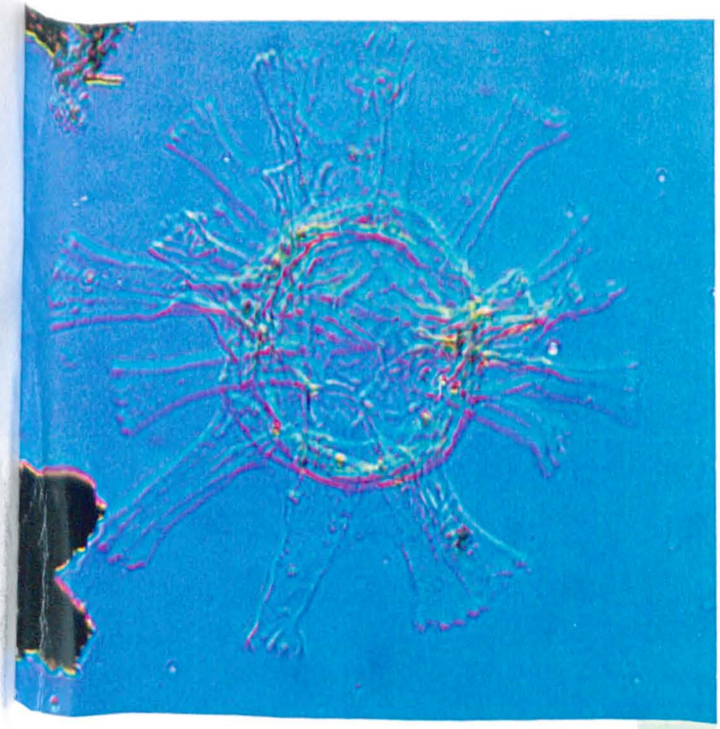

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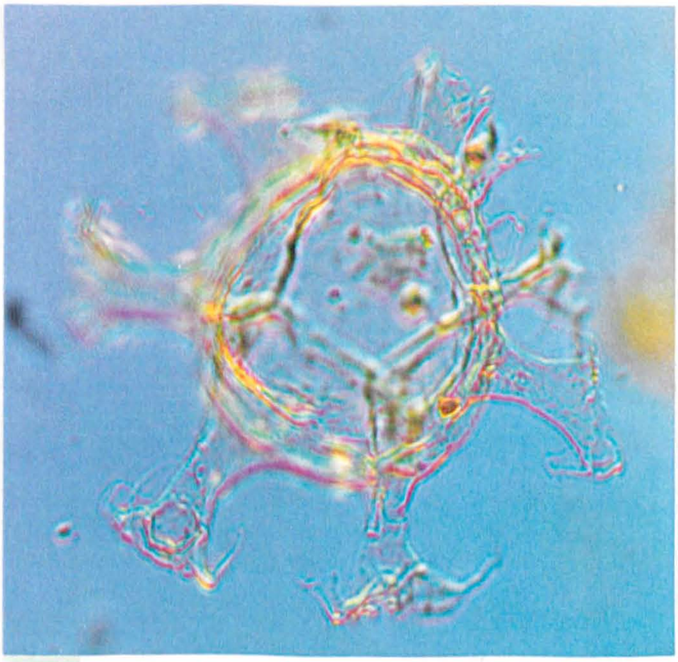

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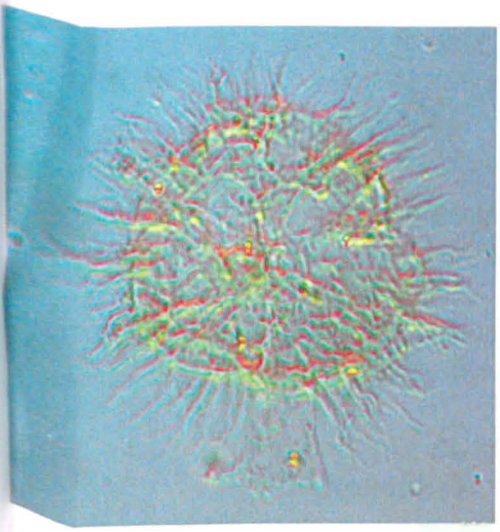
Plate 2

Plate 3

1. ***Coronifera oceanica***
Rebecca K. Bounds Core, Sample 770', AMOCO Loc. 15129, Slide 67, England Finder Reference: F451
2. ***Coronifera striolatum***
Blue Point Section, Sample BMS4/26-27A, Slide PRCIES 3144.3, England Finder Reference: C243/D241
3. ***Coronifera striolatum***
Blue Point Section, Sample BMS4/16B-18A, Slide PRCIES 3139.2, England Finder Reference: L402/4
4. ***Kiokansium unituberculatum***
Blue Point Section, Sample BMS4/8-11A, Slide PRCIES 3136.2, England Finder Reference: F323
5. ***Systematophora* sp. A**
Blue Point Section, Sample BMS4/11B-14A, Slide PRCIES 3137.3, England Finder Reference: F501
6. ***Systematophora* sp. A**
Blue Point Section, Sample BMS4/11B-14A, Slide PRCIES 3137.3, England Finder Reference: F501
7. ***Kiokansium williamsii***
Wahweap Wash Section, Sample NBU/52D-54A, Slide PRCIES 3346.1, England Finder Reference: L541
8. ***Systematophora* sp. A**
Wahweap Wash Section, Sample NBU/33-35A, Slide PRCIES 3323.2, England Finder Reference: G442



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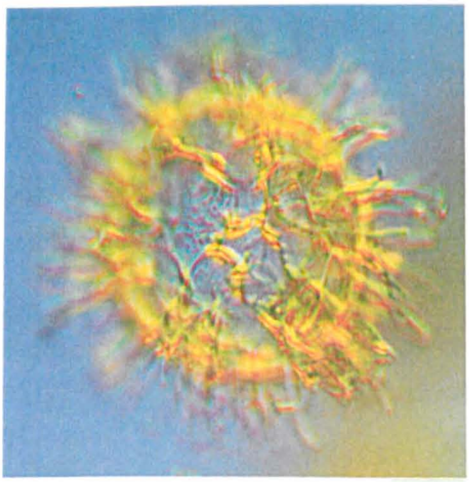

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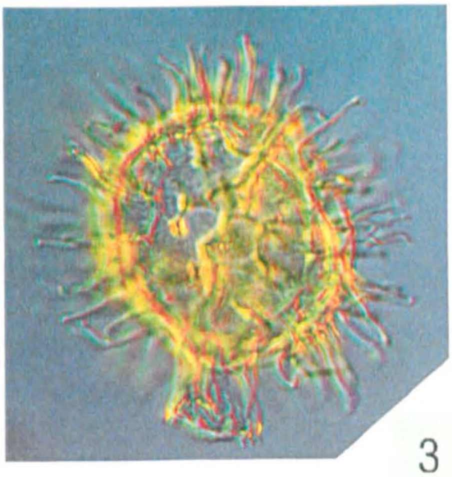

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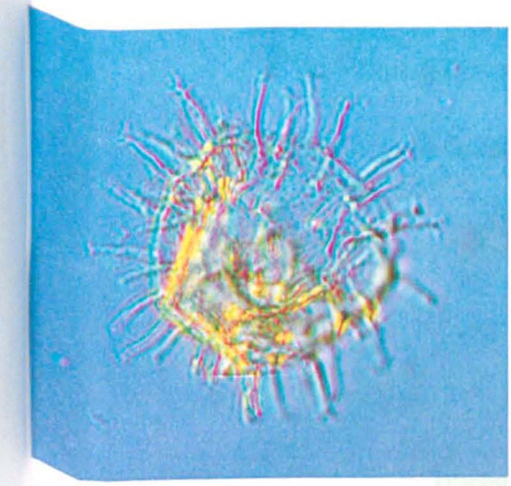

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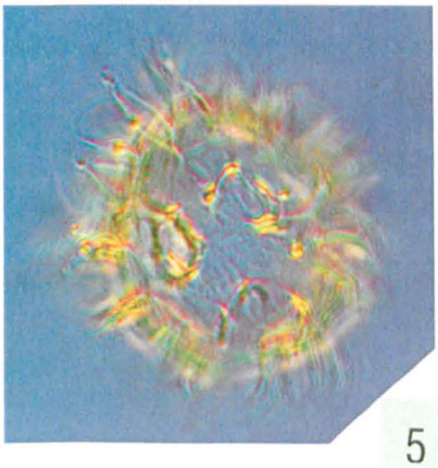

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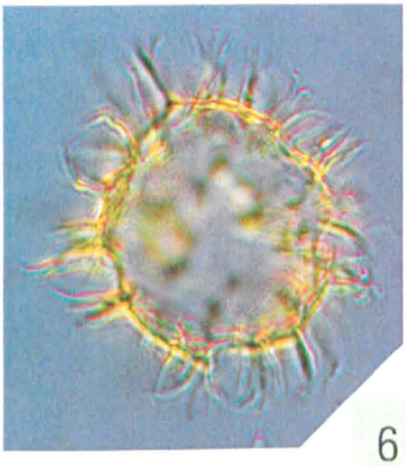

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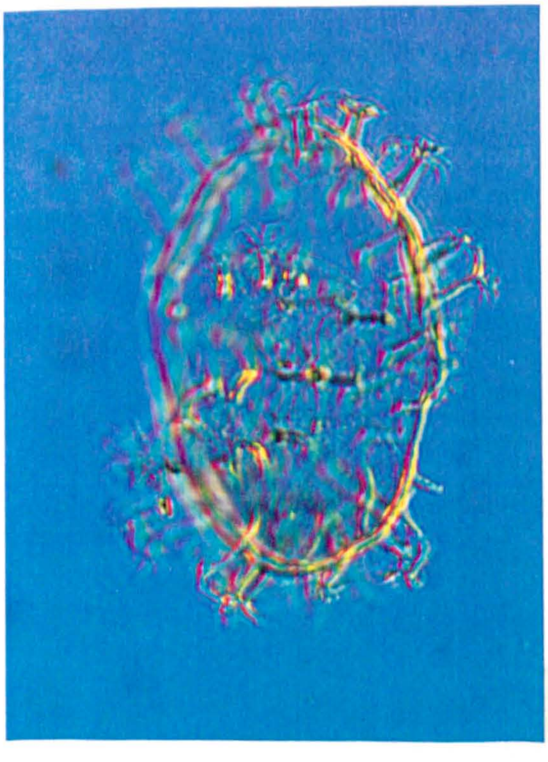

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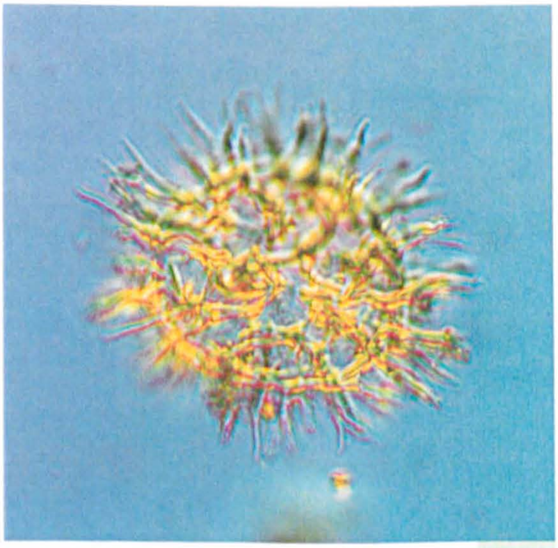

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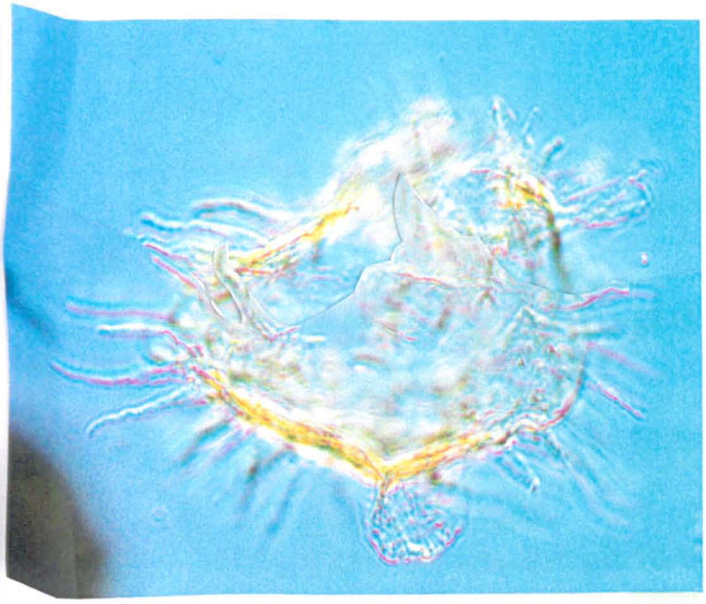
Plate 3

Plate 4

1. ***Florentinia clavigera***
   Blue Point Section, Sample BMS4/11B-14A, Slide PRCIES 3137.3, England Finder Reference: G572/581
2. ***Florentinia clavigera***
   Blue Point Section, Sample BMS4/11B-14A, Slide PRCIES 3137.3, England Finder Reference: G572/581
3. ***Florentinia buspina***
   Rebecca K. Bounds Core, Sample 900', AMOCO Loc. 15129, Slide 80, England Finder Reference: H491
4. ***Florentinia ferox***
   Pueblo Section, Sample PUB5, Slide PRCIES 2396.2, England Finder Reference: K251
5. ***Florentinia resex***
   Blue Point Section, Sample BMS4/16B-18A, Slide PRCIES 3139.2, England Finder Reference: Q432
6. ***Florentinia ferox***
   Rebecca K. Bounds Core, Sample 1070', AMOCO Loc. 15129, Slide 97, England Finder Reference: B311/2



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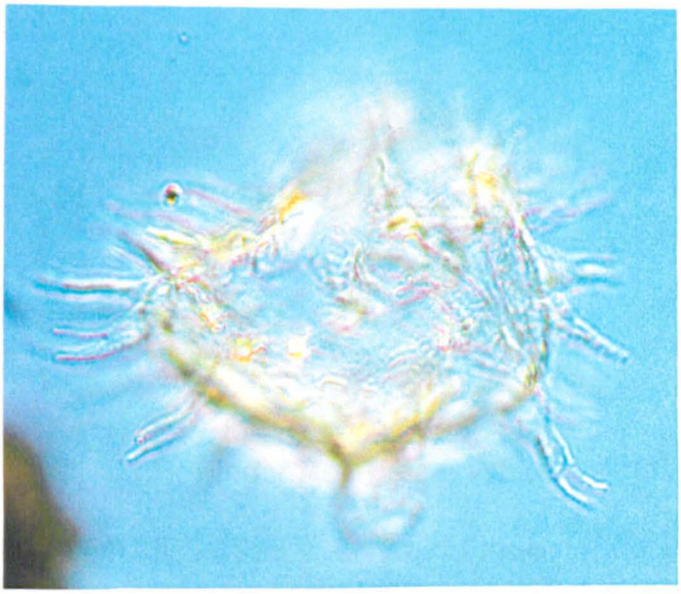

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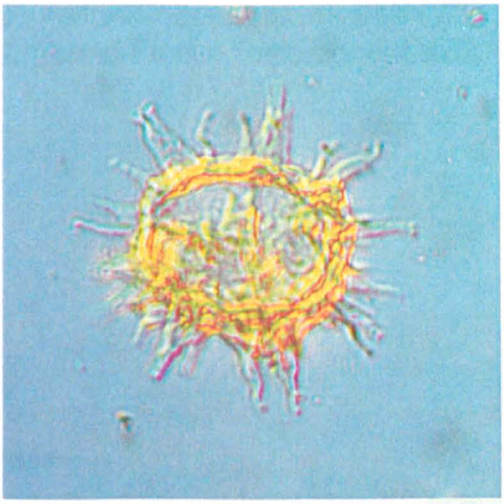

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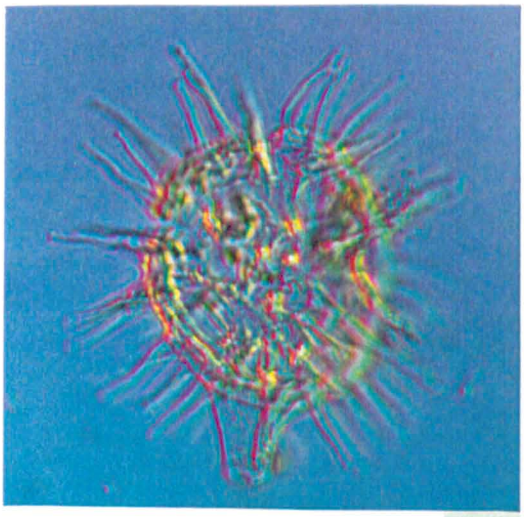

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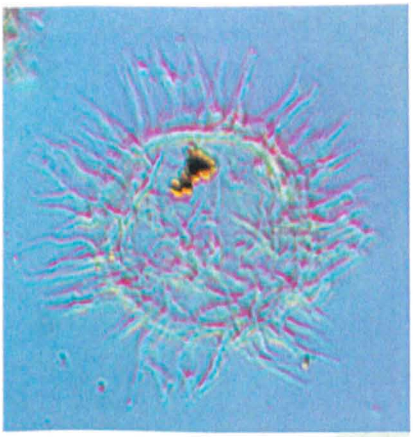

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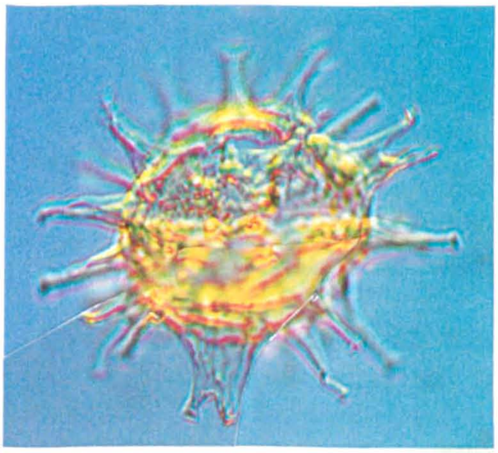
Plate 4

Plate 5

1. ***Florentinia radiculata***
Wahweap Wash Section, Sample NBU/26-28, Slide PRCIES 3320.2, England Finder Reference: C273
2. ***Florentinia radiculata***
Blue Point Section, Sample BMS4/16B-18A, Slide PRCIES 3139.2, England Finder Reference: Q300
3. ***Florentinia laciniata***
Blue Point Section, Sample BMS4/16B-18A, Slide PRCIES 3139.2, England Finder Reference: W564
4. ***Florentinia mantellii***
Blue Point Section, Sample BMS4/7, Slide PRCIES 3135.4, England Finder Reference: M482
5. ***Florentinia deaniae***
Rebecca K. Bounds Core, Sample 1100', AMOCO Loc. 15129, Slide 100, England Finder Reference: E352
6. ***Florentinia cooksoniae***
Rebecca K. Bounds Core, Sample 880', AMOCO Loc. 15129, Slide 78, England Finder Reference: D402



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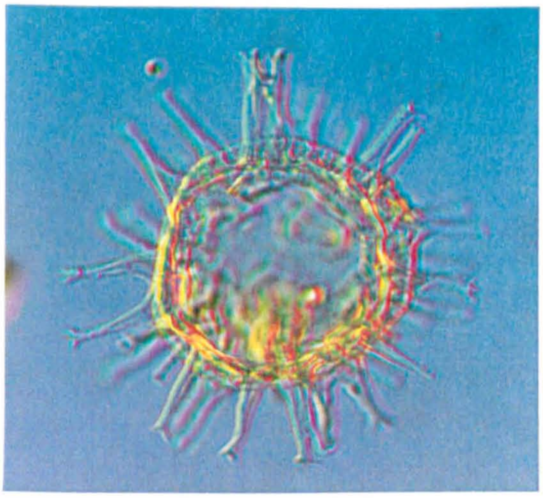

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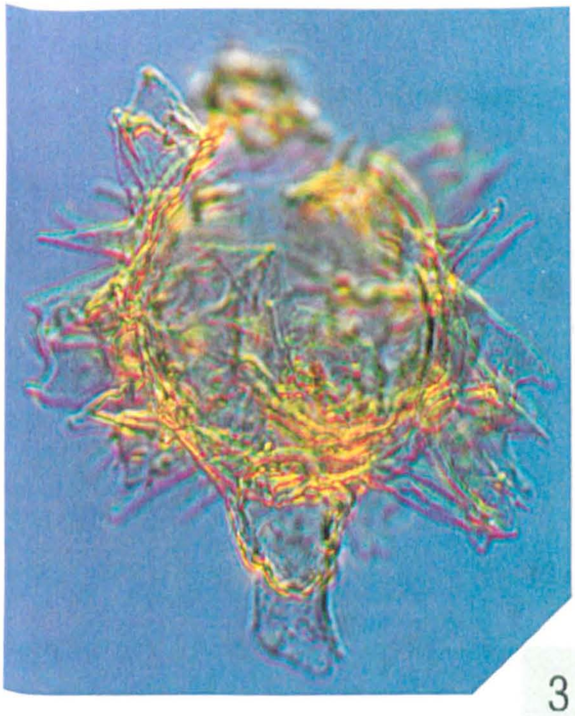

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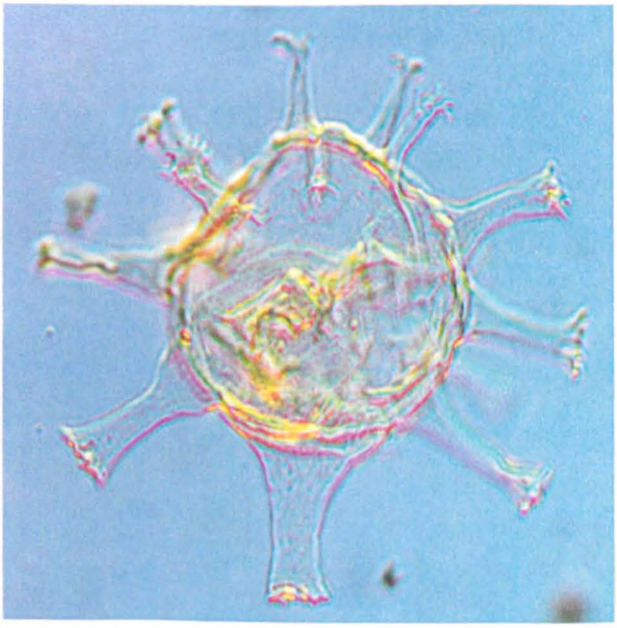

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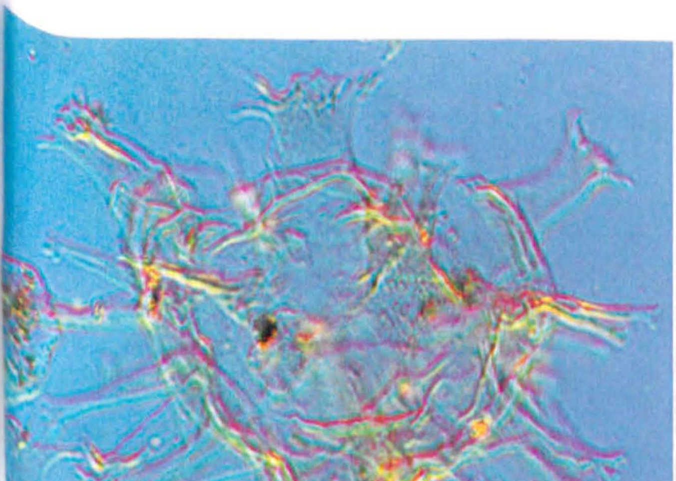

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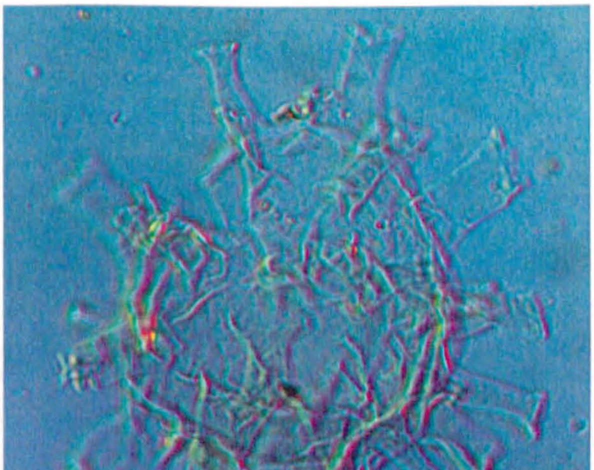

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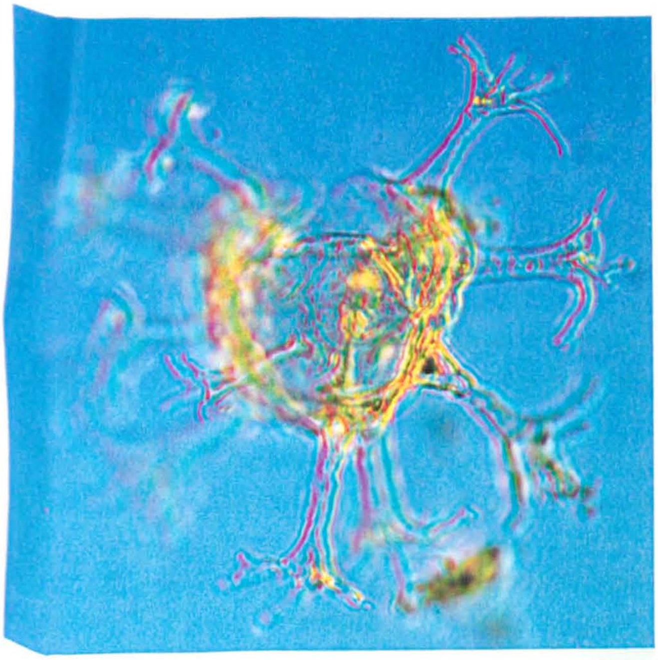
Plate 5

Plate 6

1. ***Oligosphaeridium complex***
Blue Point Section, Sample BMS4/51B-54A, Slide PRCIES 3161.2, England Finder Reference: N263/O261
2. ***Oligosphaeridium reticulatum***
Pueblo Section, Sample PUB27, Slide PRCIES 2418.10, England Finder Reference: K373
3. ***Oligosphaeridium albertense***
Rebecca K. Bounds Core, Sample 790', AMOCO Loc. 15129, Slide 69, England Finder Reference: J373
4. ***Oligosphaeridium pulcherrimum***
Blue Point Section, Sample BMS4/34B-36A, Slide PRCIES 3149.2, England Finder Reference: J483/4
5. ***Oligosphaeridium totum***
Rebecca K. Bounds Core, Sample 800', AMOCO Loc. 15129, Slide 70, England Finder Reference: H372
6. ***Oligosphaeridium dividuum***
Rebecca K. Bounds Core, Sample 1050', AMOCO Loc. 15129, Slide 95, England Finder Reference: G313



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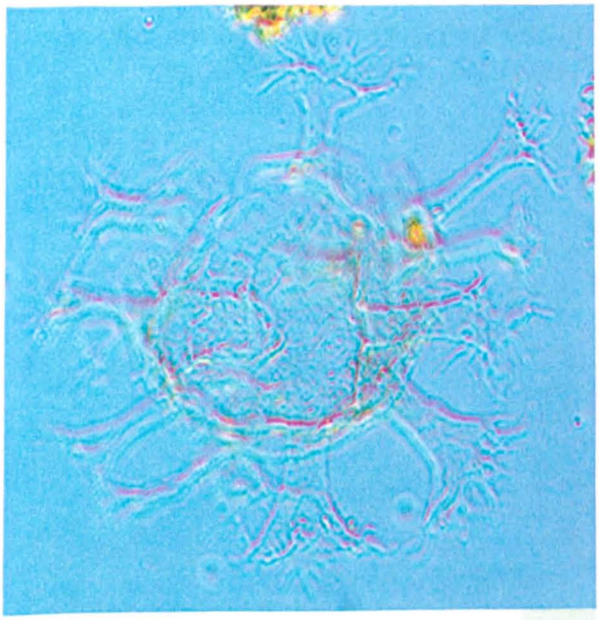

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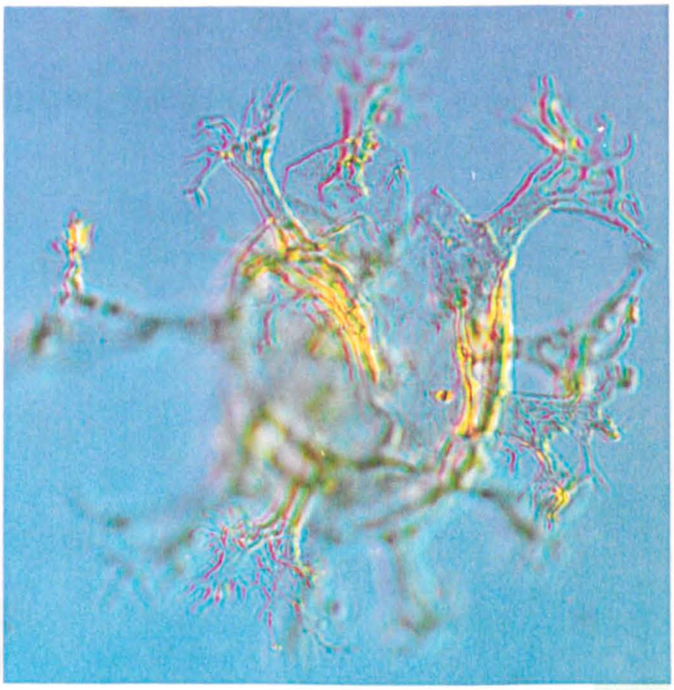

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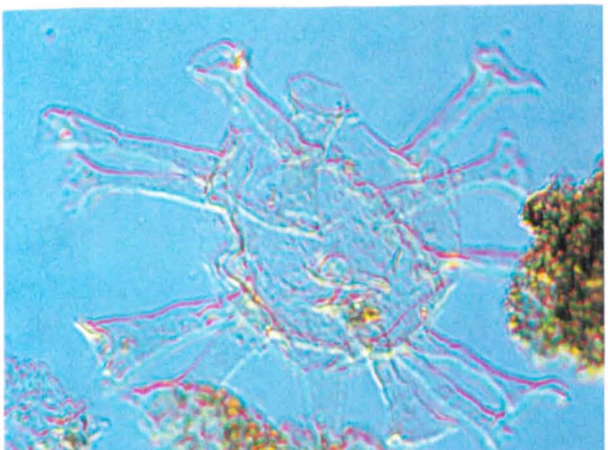

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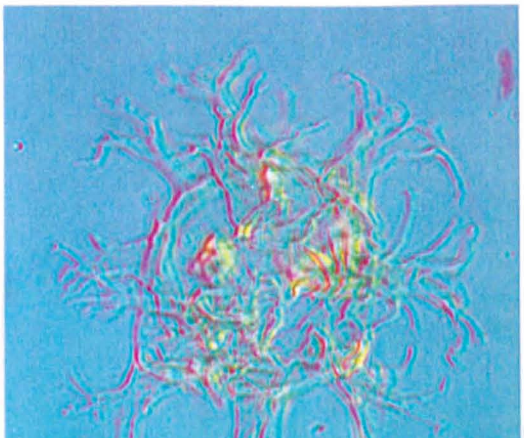

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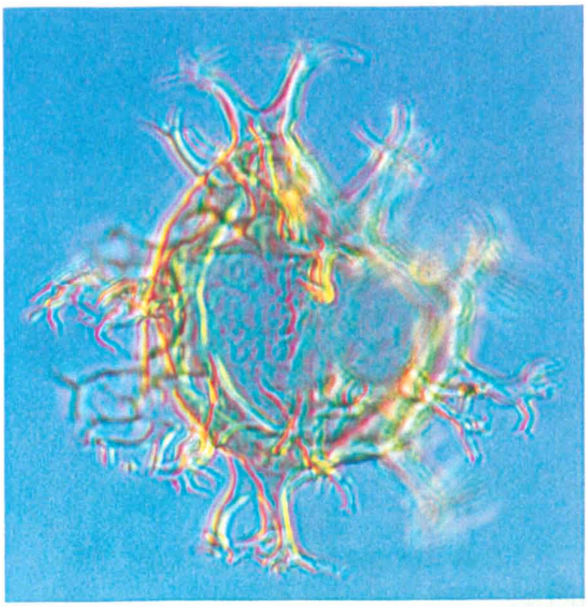
Plate 6

Plate 7

1. ***Achomosphaera ramulifera***
   Pueblo Section, Sample PUB1, Slide PRCIES 2393.4, England Finder Reference: U422/4
2. ***Achomosphaera ramulifera***
   Blue Point Section, Sample BMS4/16B-18A, Slide PRCIES 3139.2, England Finder Reference: E314
3. ***Achomosphaera neptunii***
   Wahweap Wash Section, Sample NBU/48C, Slide PRCIES 3132.6, England Finder Reference: F480
4. ***Achomosphaera crassipellis***
   Pueblo Section, Sample PUB3, Slide PRCIES 2395.1, England Finder Reference: V191
5. ***Achomosphaera regiensis***
   Wahweap Wash Section, Sample NBU/54B-54C, Slide PRCIES 3347.5, England Finder Reference: L484
6. ***Achomosphaera regiensis***
   Blue Point Section, Sample BMS4/44B-44C, Slide PRCIES 3157.5, England Finder Reference: G403/4



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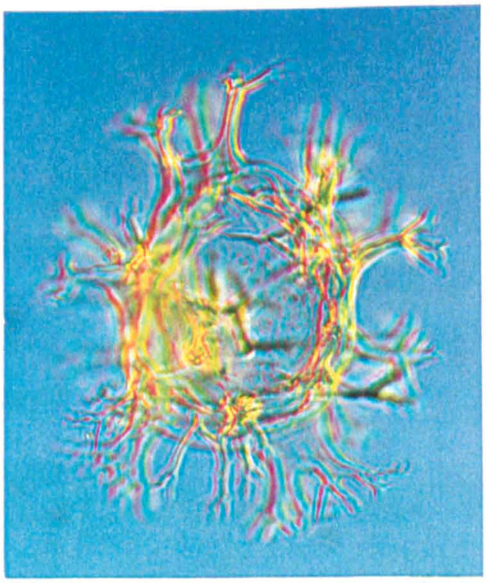

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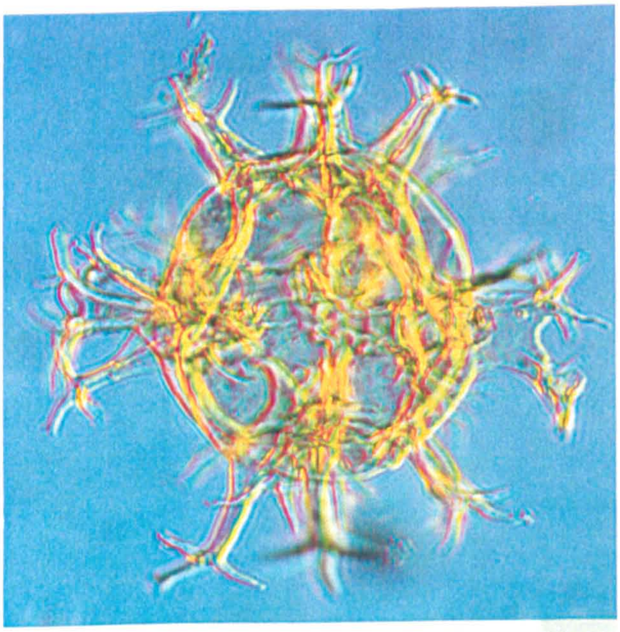

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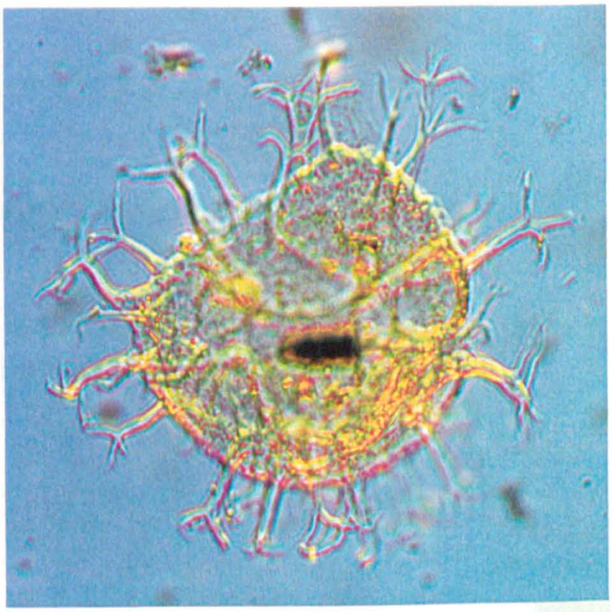

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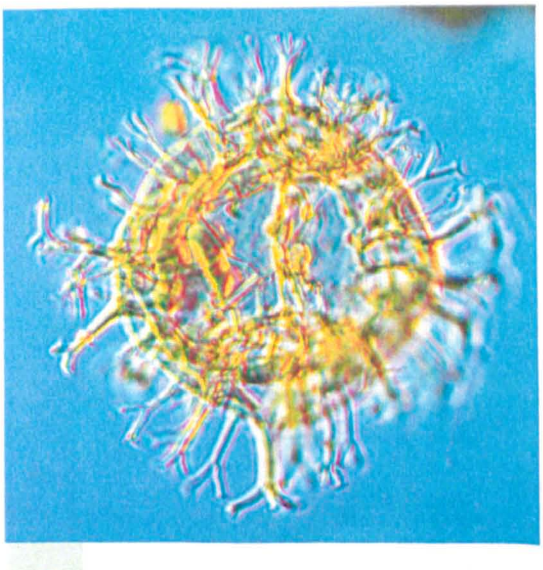

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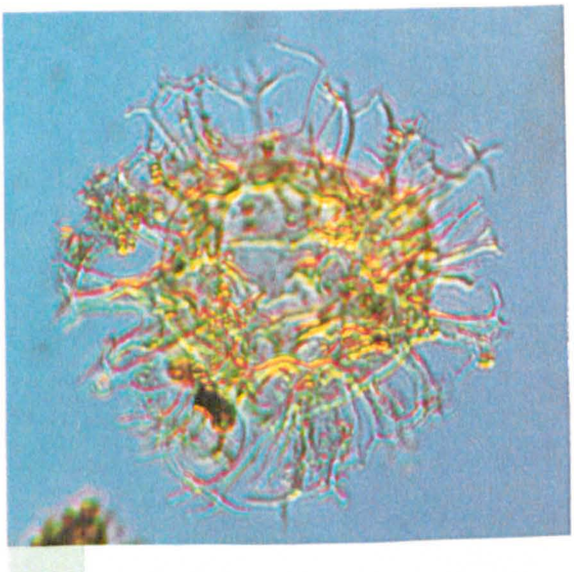

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Plate 7

Plate 8

1. ***Achomosphaera* sp. A**
   Pueblo Section, Sample PUB27, Slide PRCIES 2418.7, England Finder Reference: F421/2
2. ***Achomosphaera* sp. A**
   Rebecca K. Bounds Core, Sample 980', AMOCO Loc. 15129, Slide 88, England Finder Reference: N314
3. ***Achomosphaera* sp. A**
   Rebecca K. Bounds Core, Sample 980', AMOCO Loc. 15129, Slide 88, England Finder Reference: N314
4. ***Achomosphaera* sp. A**
   Pueblo Section, Sample PUB19, Slide PRCIES 2410.4, England Finder Reference: U534/543
5. ***Achomosphaera* sp. A**
   Pueblo Section, Sample PUB23, Slide PRCIES 2414.10, England Finder Reference: B243/C242
6. ***Achomosphaera* sp. A**
   Bunker Hill Section, Sample BH39, Slide PRCIES 2727.17, England Finder Reference: L263/M261
7. ***Hystrichostrogylon membraniphorum***
   Pueblo Section, Sample PUB5, Slide PRCIES 2396.2, England Finder Reference: M393
8. ***Hystrichostrogylon membraniphorum***
   Rebecca K. Bounds Core, Sample 940', AMOCO Loc. 15129, Slide 84, England Finder Reference: L401/3

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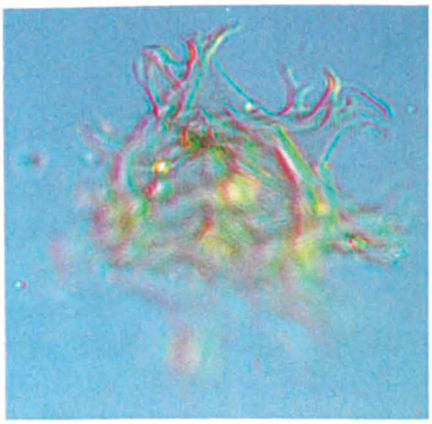

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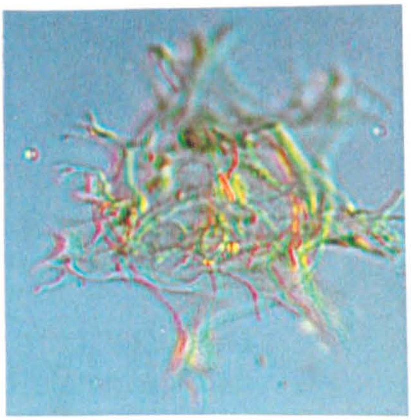

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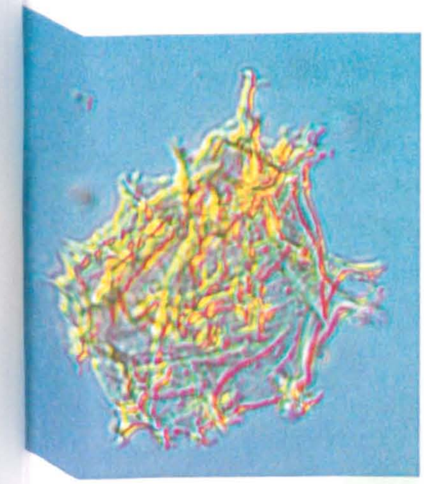

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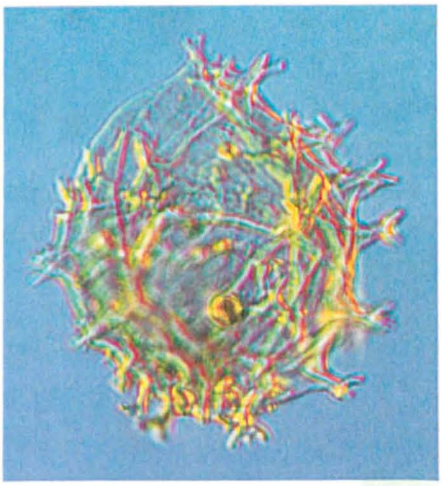

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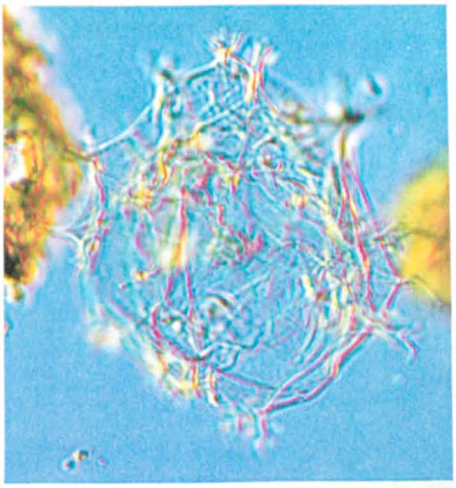

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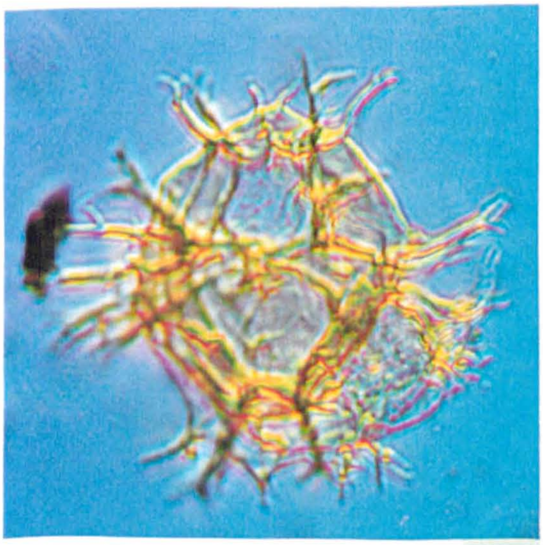

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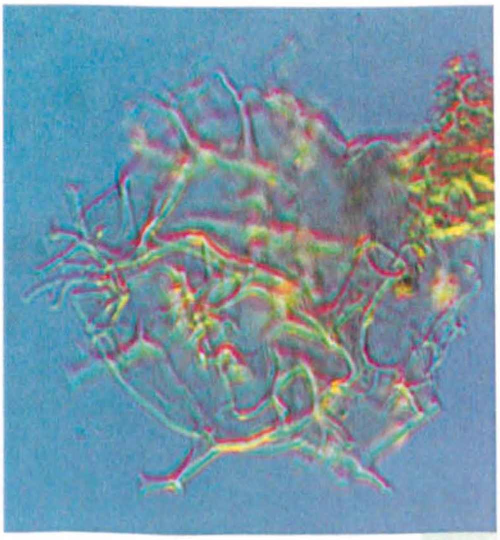

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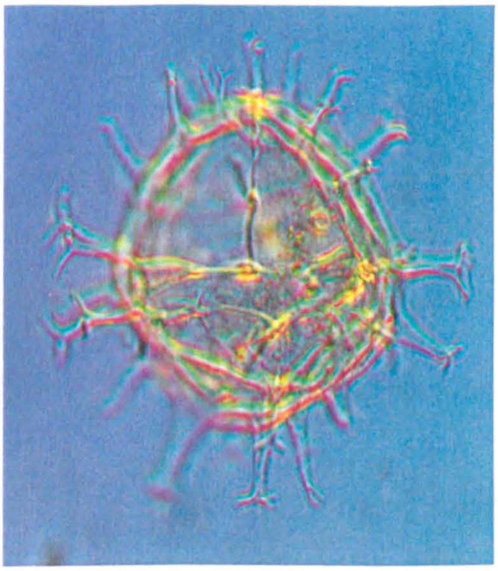
Plate 8

Plate 9

1. ***Spiniferites ramosus ramosus***
Blue Point Section, Sample BMS4/16B-18A, Slide PRCIES 3139.2, England Finder Reference: N231
2. ***Spiniferites ramosus gracilis***
Blue Point Section, Sample BMS4/14B-16A, Slide PRCIES 3138.2, England Finder Reference: P550
3. ***Spiniferites ramosus reticulatus***
Pueblo Section, Sample PUB4, Slide PRCIES 2385.3, England Finder Reference: K384
4. ***Spiniferites ramosus reticulatus***
Pueblo Section, Sample PUB4, Slide PRCIES 2385.3, England Finder Reference: K384
5. ***Spiniferites twistringiensis***
Rebecca K. Bounds Core, Sample 840', AMOCO Loc. 15129, Slide 74, England Finder Reference: H471
6. ***Spiniferites porosus***
Rebecca K. Bounds Core, Sample 770', AMOCO Loc. 15129, Slide 67, England Finder Reference: K352
7. ***Spiniferites ramosus granomembranaceous***
Rebecca K. Bounds Core, Sample 890', AMOCO Loc. 15129, Slide 79, England Finder Reference: N431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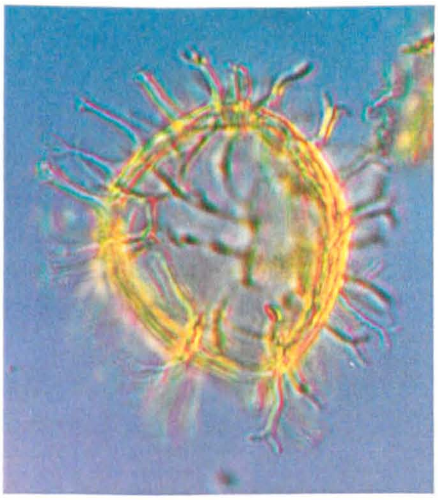
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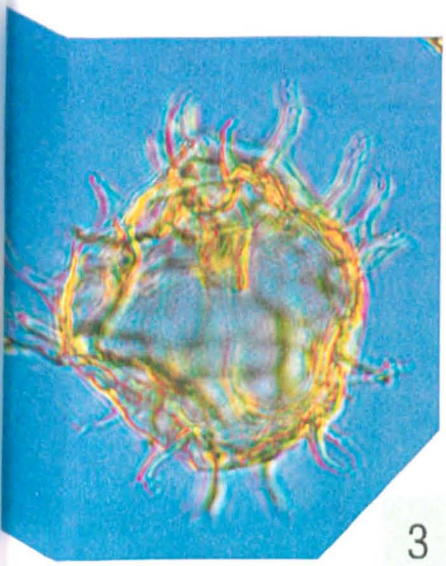
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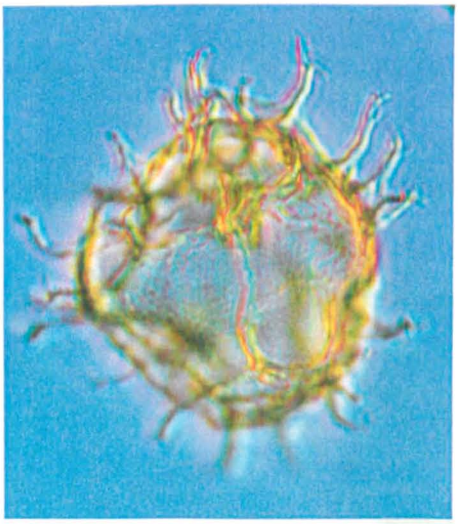
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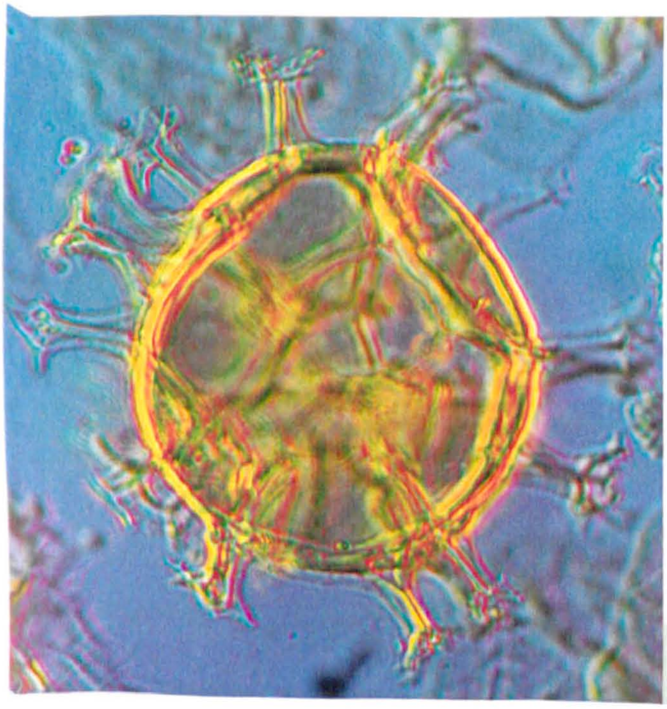
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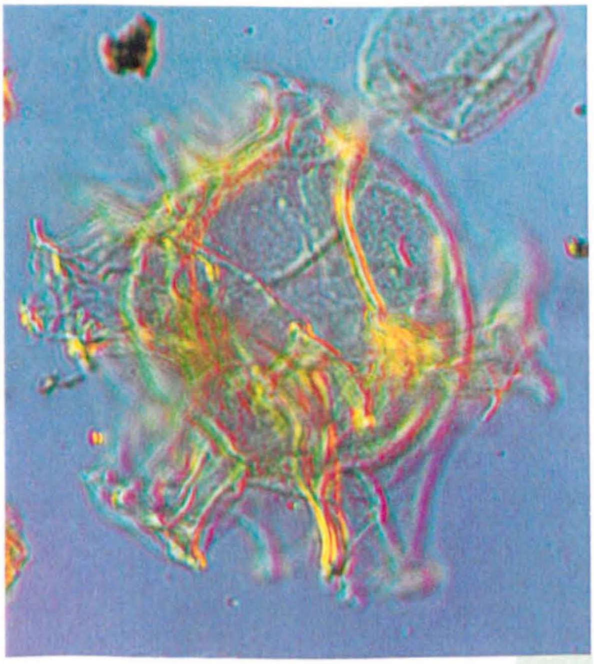
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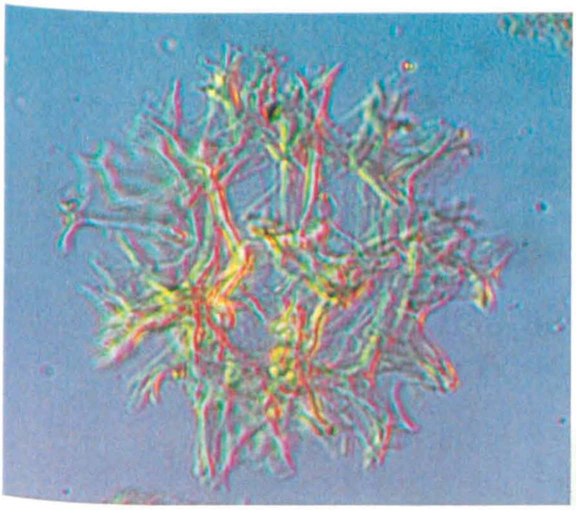
Plate 9

Plate 10

1. ***Spiniferites wetzellii***
   Rebecca K. Bounds Core, Sample 1000', AMOCO Loc. 15129, Slide90, England Finder Reference: K312
2. ***Spiniferites tripus***
   Rebecca K. Bounds Core, Sample 860' (1), AMOCO Loc. 15129, Slide 76, England Finder Reference: J362
3. ***Spiniferites lenzii***
   Blue Point Section, Sample BMS4/28B-30, Slide PRCIES 3146.3, England Finder Reference: E333/4
4. ***Spiniferites lenzii***
   Blue Point Section, Sample BMS4/28B-30, Slide PRCIES 3146.3, England Finder Reference: E333/4
5. ***Spiniferites lenzii***
   Blue Point Section, Sample BMS4/26-27A, Slide PRCIES 3144.3, England Finder Reference: X502
6. ***Spiniferites lenzii***
   Wahweap Wash Section, Sample NBU/48C, Slide PRCIES 3132.6, England Finder Reference: O543
7. ***Spiniferites lenzii***
   Bunker Hill Section, Sample BH32, Slide PRCIES 2720.8, England Finder Reference: G384



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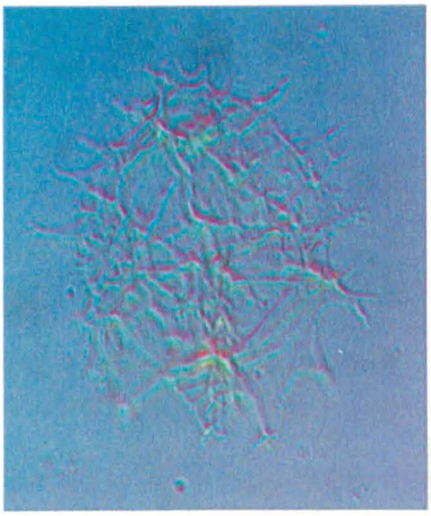

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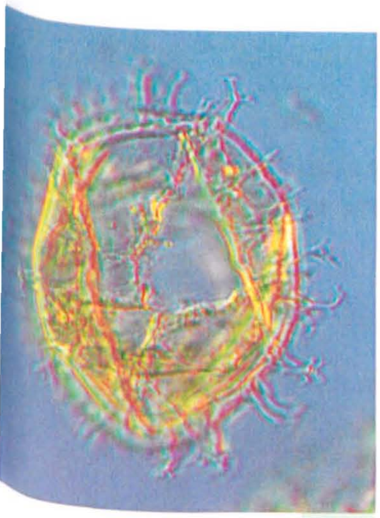

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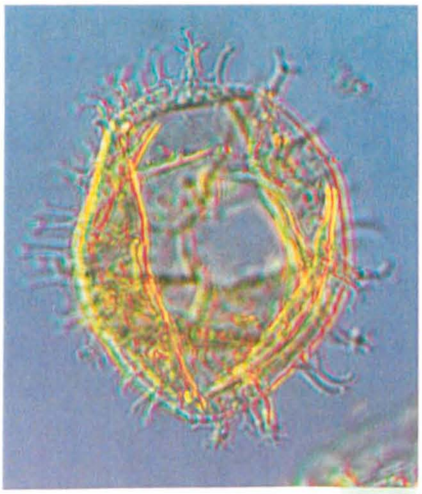

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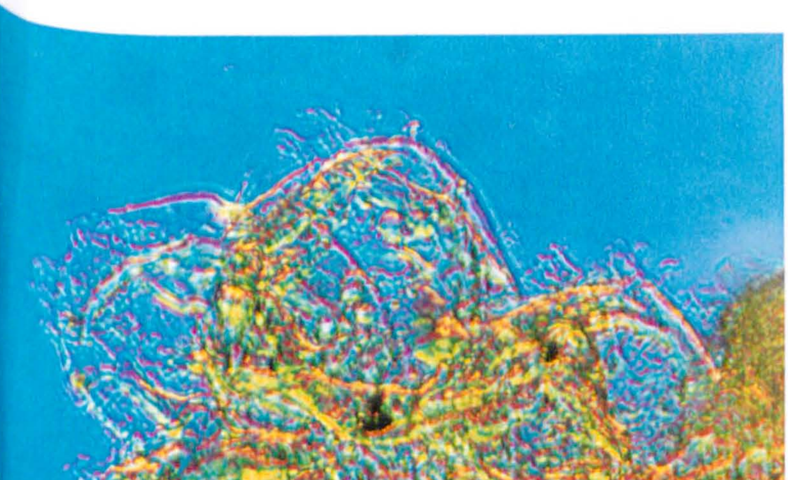

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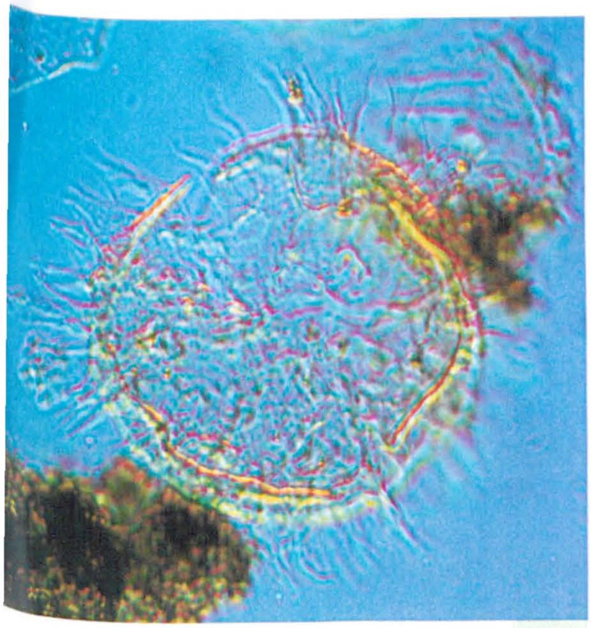
Plate 10

Plate 11

1. ***Pervosphaeridium* sp. A**
   Rebecca K. Bounds Core, Sample 800', AMOCO Loc. 15129, Slide 70, England Finder Reference: H384/J382
2. ***Pervosphaeridium* sp. A**
   Rebecca K. Bounds Core, Sample 800', AMOCO Loc. 15129, Slide 70, England Finder Reference: H384/J382
3. ***Pervosphaeridium* sp. A**
   Rebecca K. Bounds Core, Sample 780', AMOCO Loc. 15129, Slide 68, England Finder Reference: E362
4. ***Exochosphaeridium arnace***
   Wahweap Wash Section, Sample NBU/48P-48Q, Slide PRCIES 3343.1, England Finder Reference: B404
5. ***Exochosphaeridium phragmites***
   Blue Point Section, Sample BMS4/34B-36A, Slide PRCIES 3149.2, England Finder Reference: Q464
6. ***Exochosphaeridium phragmites***
   Blue Point Section, Sample BMS4/34B-36A, Slide PRCIES 3149.2, England Finder Reference: Q464



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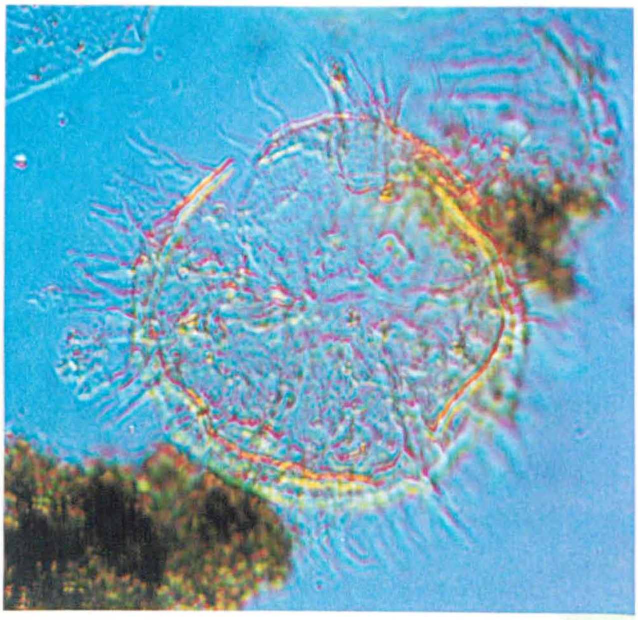

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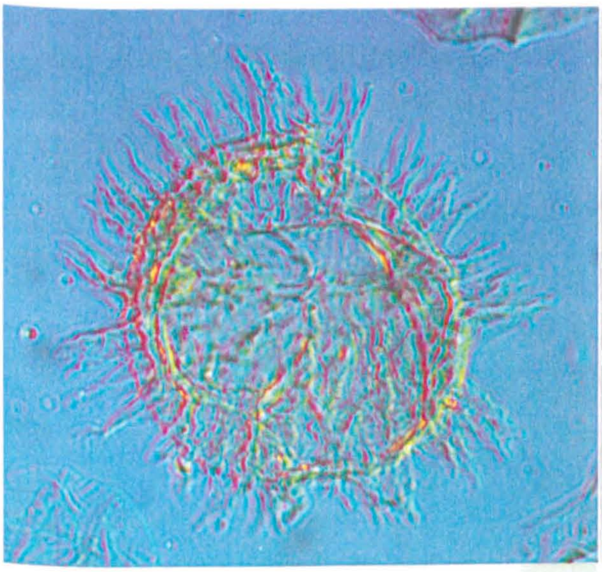

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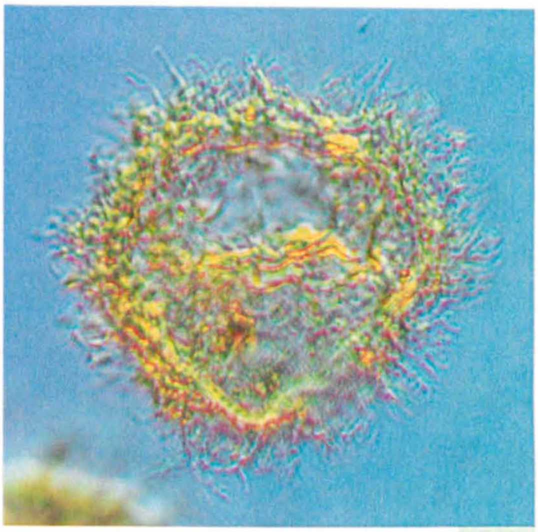

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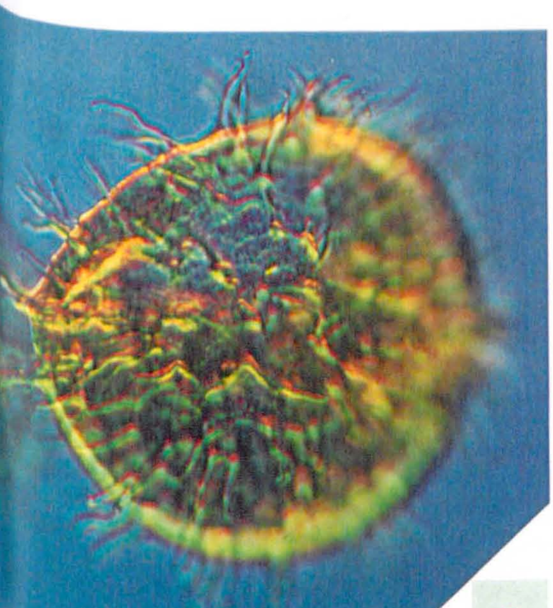

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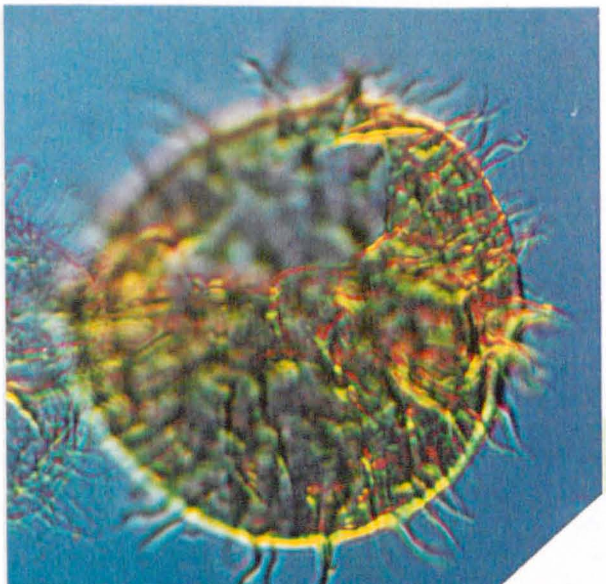

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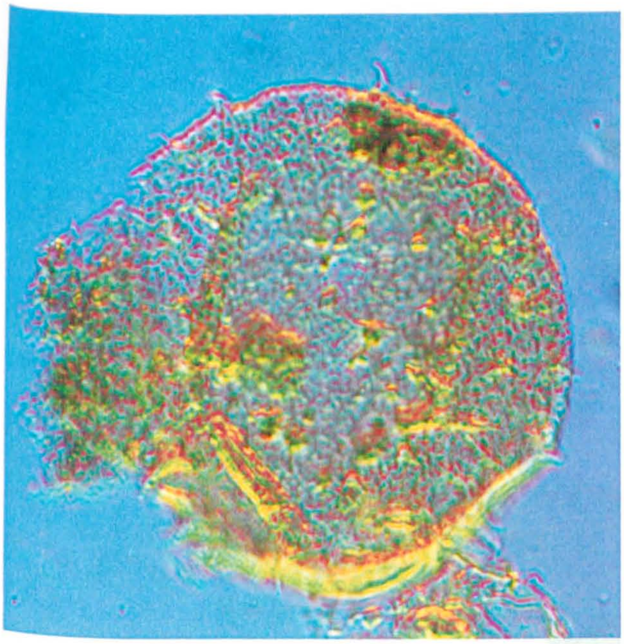
Plate 12

1. ***Pervosphaeridium brevispinum***
Rebecca K. Bounds Core, Sample 1090', AMOCO Loc. 15129, Slide 99, England Finder Reference: T533
2. ***Pervosphaeridium pseudhystrichodinium***
Wahweap Wash Section, Sample NBU/33-35A, Slide PRCIES 3323.2, England Finder Reference: N473
3. ***Exochosphaeridium bifidum***
Blue Point Section, Sample BMS4/27B-28A, Slide PRCIES 3145.2, England Finder Reference: D303
4. ***Exochosphaeridium bifidum***
Blue Point Section, Sample BMS4/27B-28A, Slide PRCIES 3145.2, England Finder Reference: D303
5. ***Pervosphaeridium pseudhystrichodinium***
Pueblo Section, Sample PUB5, Slide PRCIES 2396.2, England Finder Reference: G253
6. ***Pervosphaeridium truncatum***
Blue Point Section, Sample BMS4/38E-38F, Slide PRCIES 3152.2, England Finder Reference: Q433
7. ***Pervosphaeridium truncatum***
Blue Point Section, Sample BMS4/7, Slide PRCIES 3135.4, England Finder Reference: U342



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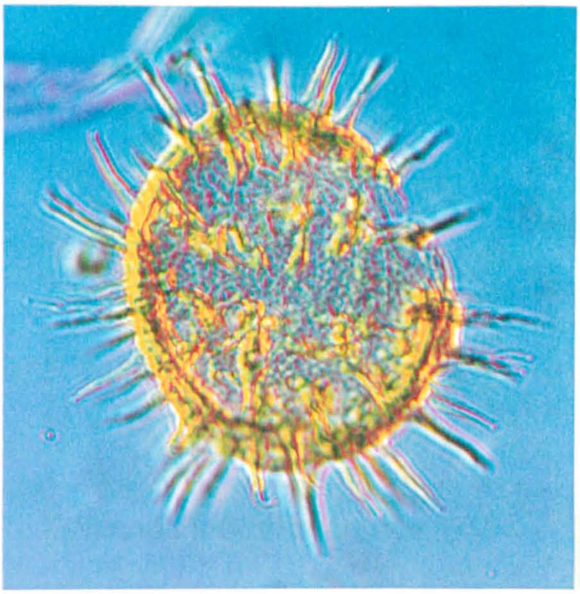

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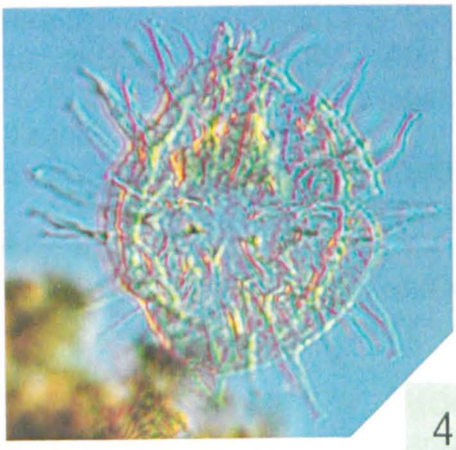

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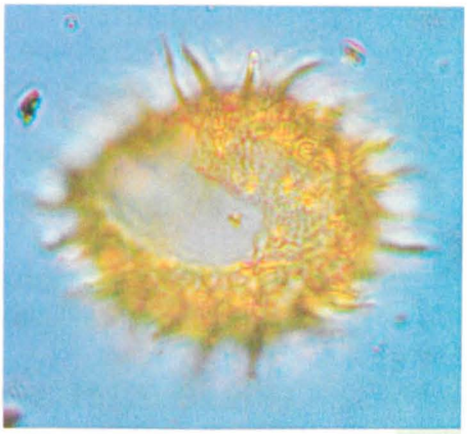

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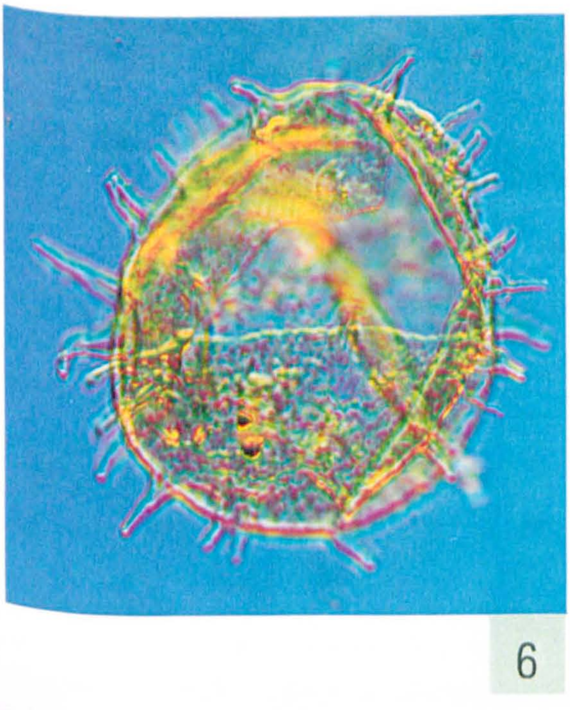

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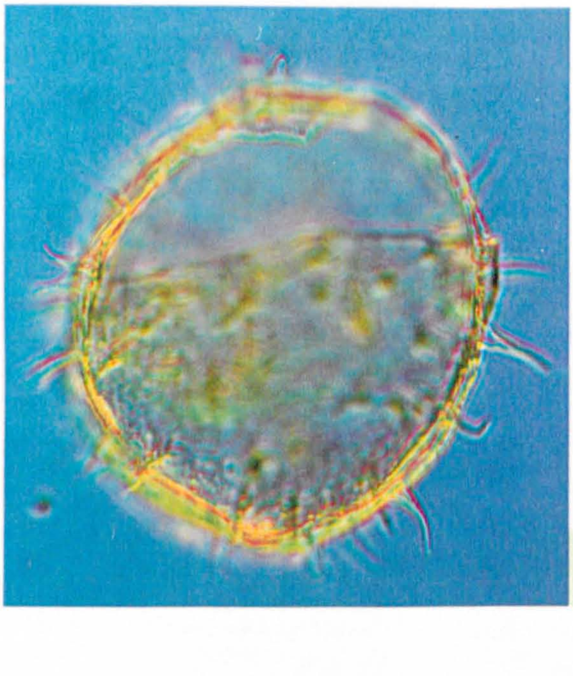

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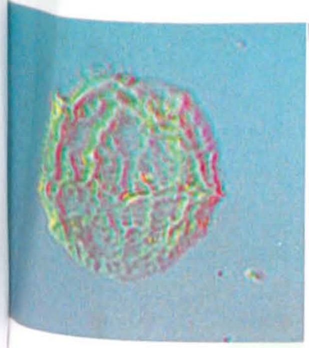
Plate 12

Plate 13

1. ***Microdinium setosum***
   Rebecca K. Bounds Core, Sample 1070', AMOCO Loc. 15129, Slide 97, England Finder Reference: Y444
2. ***Microdinium ornatum***
   Rebecca K. Bounds Core, Sample 920', AMOCO Loc. 15129, Slide 82, England Finder Reference: P413
3. ***Microdinium reticulatum***
   Rebecca K. Bounds Core, Sample 940', AMOCO Loc. 15129, Slide 84, England Finder Reference: B504
4. ***Histiocysta palla***
   Rebecca K. Bounds Core, Sample 980', AMOCO Loc. 15129, Slide 88, England Finder Reference: R414
5. ***Chlamydophorella discreta***
   Rebecca K. Bounds Core, Sample 940', AMOCO Loc. 15129, Slide 84, England Finder Reference: C462
6. ***Rhiptocorys veligera***
   Rebecca K. Bounds Core, Sample 980', AMOCO Loc. 15129, Slide 88, England Finder Reference: L443
7. ***Chlamydophorella nyei***
   Rebecca K. Bounds Core, Sample 990', AMOCO Loc. 15129, Slide 89, England Finder Reference: H314
8. ***Dapsilidinium ambiguum***
   Rebecca K. Bounds Core, Sample 920', AMOCO Loc. 15129, Slide 82, England Finder Reference: D482
9. ***Dapsilidinium ambiguum***
   Rebecca K. Bounds Core, Sample 920', AMOCO Loc. 15129, Slide 82, England Finder Reference: D482
10. ***Chlamydophorella nyei***
    Rebecca K. Bounds Core, Sample 1090', AMOCO Loc. 15129, Slide 99, England Finder Reference: F423
11. ***Kallosphaeridium* sp. A**
    Rebecca K. Bounds Core, Sample 1010', AMOCO Loc. 15129, Slide 91, England Finder Reference: L512
12. ***Kallosphaeridium* sp. A**
    Rebecca K. Bounds Core, Sample 1060', AMOCO Loc. 15129, Slide 96, England Finder Reference: J401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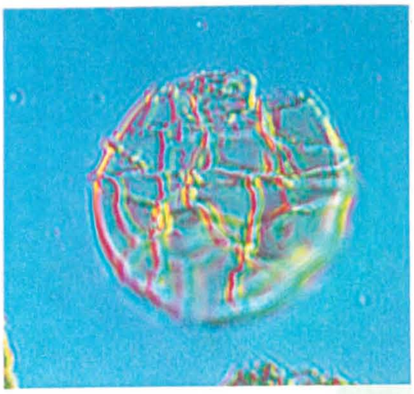
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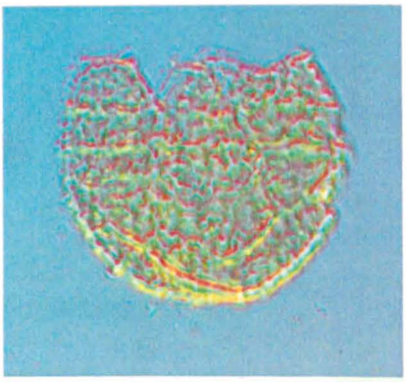
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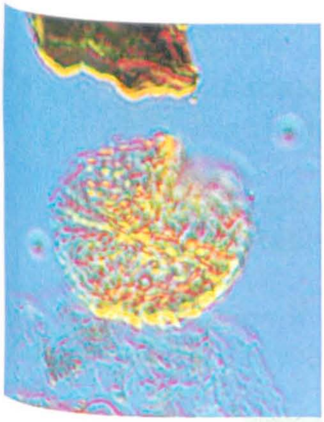
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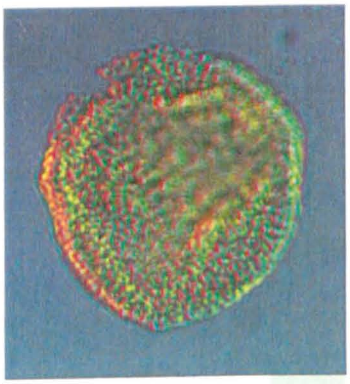
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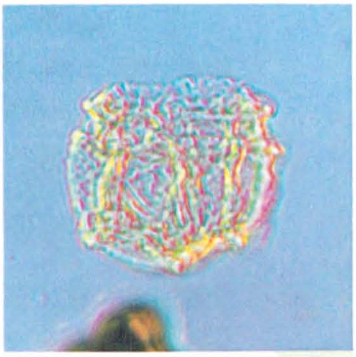
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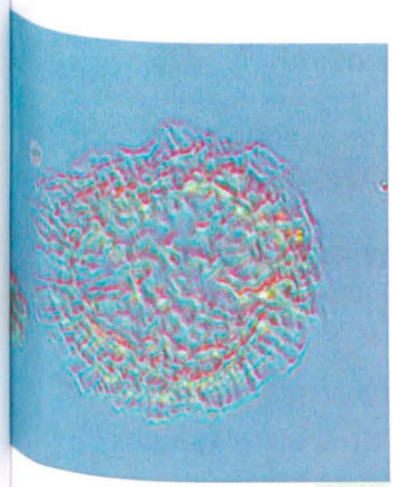
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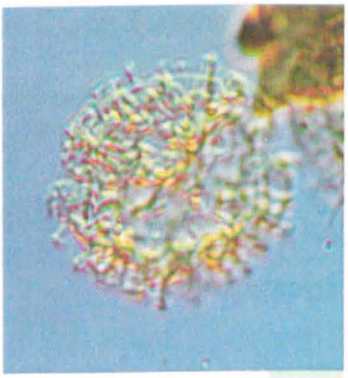
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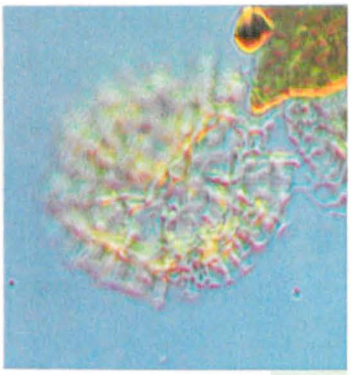
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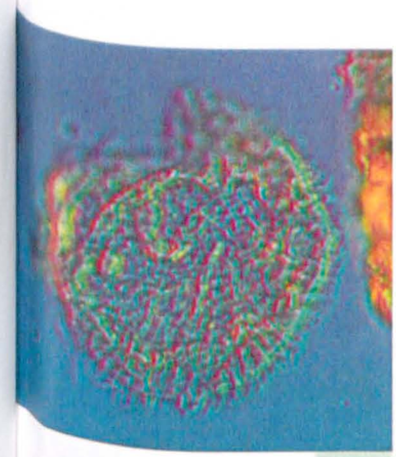
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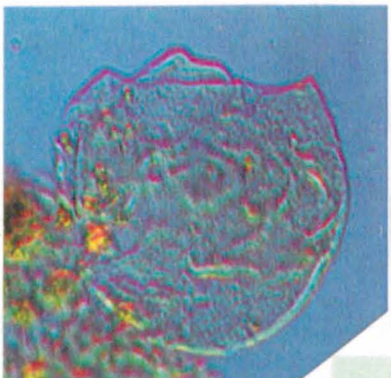
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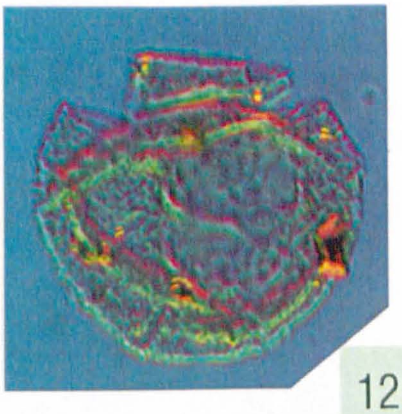
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Plate 13

Plate 14

1. ***Batiacasphaera* sp. A**
   Wahweap Wash Section, Sample NBU/30, Slide PRCIES 3321.1, England Finder Reference: E304
2. ***Batiacasphaera* sp. A**
   Wahweap Wash Section, Sample NBU/30, Slide PRCIES 3321.1, England Finder Reference: E304
3. ***Batiacasphaera* sp. A**
   Rebecca K. Bounds Core, Sample 1050', AMOCO Loc. 15129, Slide 95, England Finder Reference: N492
4. ***Batiacasphaera* sp. A**
   Blue Point Section, Sample BMS4/26-27A, Slide PRCIES 3144.3, England Finder Reference: E363
5. ***Kallosphaeridium? granulatum***
   Rebecca K. Bounds Core, Sample 970', AMOCO Loc. 15129, Slide 87, England Finder Reference: N451
6. ***Kallosphaeridium? granulatum***
   Rebecca K. Bounds Core, Sample 750', AMOCO Loc. 15129, Slide 65, England Finder Reference: B372/383
7. ***Batiacasphaera granulosa***
   Wahweap Wash Section, Sample NBU/48R-52A, Slide PRCIES 3344.1, England Finder Reference: R303
8. ***Batiacasphaera euteiches***
   Rebecca K. Bounds Core, Sample 920', AMOCO Loc. 15129, Slide 82, England Finder Reference: L482
9. ***Kallosphaeridium? ringnesiorum***
   Rebecca K. Bounds Core, Sample 820', AMOCO Loc. 15129, Slide 72, England Finder Reference: G324/H322
10. ***Kallosphaeridium? helbyi***
    Rebecca K. Bounds Core, Sample 770', AMOCO Loc. 15129, Slide 67, England Finder Reference: F354/363


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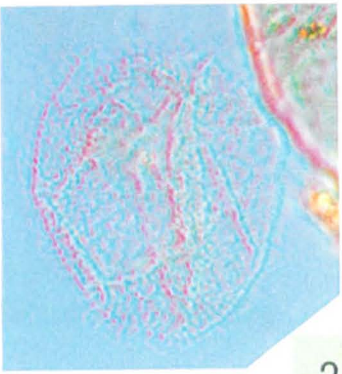
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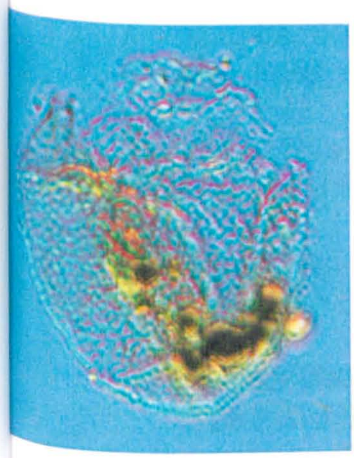
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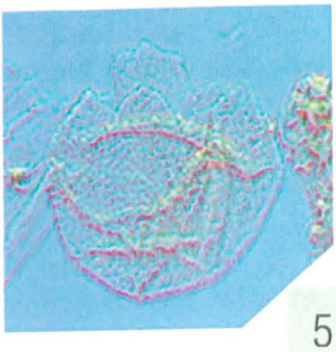
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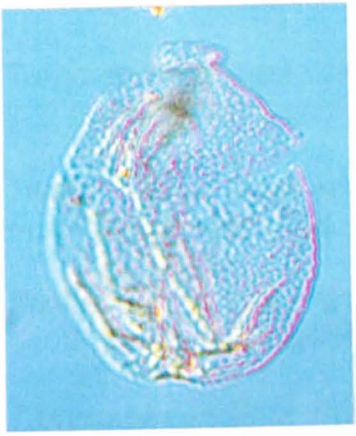
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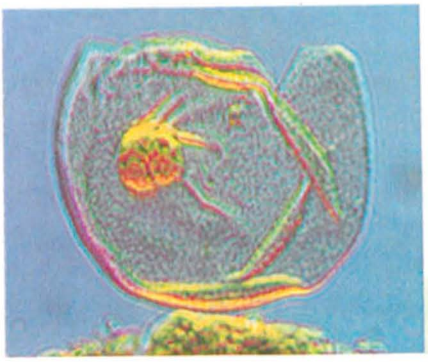
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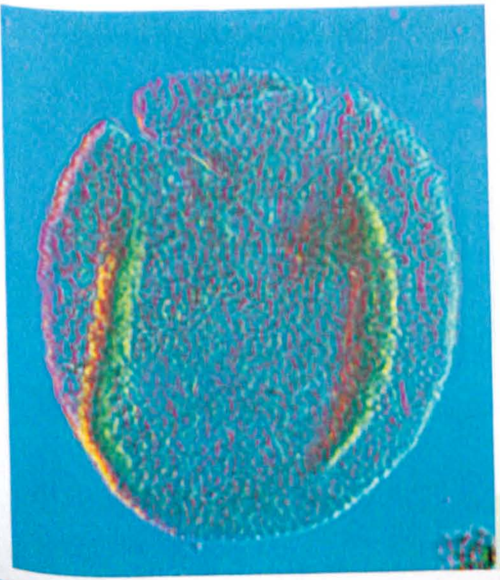
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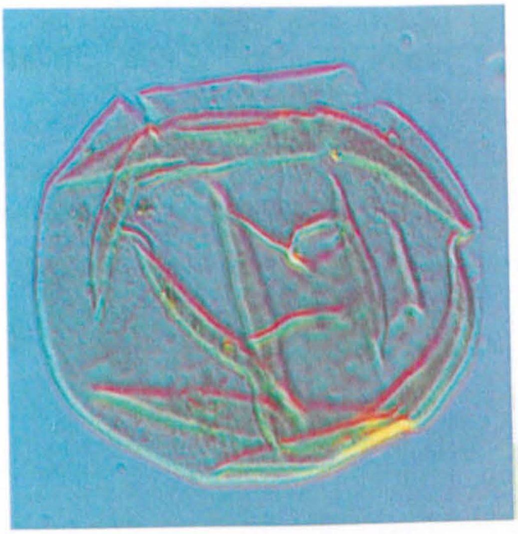
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Plate 14

Plate 15

1. ***Dapsilidinium marinum***
   Rebecca K. Bounds Core, Sample 1110', AMOCO Loc. 15129, Slide 101, England Finder Reference: N391/2
2. ***Dapsilidinium marinum***
   Wahweap Wash Section, Sample NBU/41C, Slide PRCIES 3331.1, England Finder Reference: D562
3. ***Dapsilidinium marinum***
   Wahweap Wash Section, Sample NBU/41C, Slide PRCIES 3331.1, England Finder Reference: D562
4. ***Dapsilidinium laminaspinosum***
   Blue Point Section, Sample BMS4/14B-16A, Slide PRCIES 3138.2, England Finder Reference: N554
5. ***Dapsilidinium laminaspinosum***
   Blue Point Section, Sample BMS4/14B-16A, Slide PRCIES 3138.2, England Finder Reference: N554
6. ***Dapsilidinium? pumilum***
   Blue Point Section, Sample BMS4/27B-28A, Slide PRCIES 3145.2, England Finder Reference: K423/L422
7. ***Dapsilidinium? pumilum***
   Blue Point Section, Sample BMS4/27B-28A, Slide PRCIES 3145.2, England Finder Reference: K423/L422
8. ***Prolixosphaeridium conulum***
   Rebecca K. Bounds Core, Sample 830', AMOCO Loc. 15129, Slide 73, England Finder Reference: D504
9. ***Tanyosphaeridium variecalamus***
   Rebecca K. Bounds Core, Sample 940', AMOCO Loc. 15129, Slide 84, England Finder Reference: G382
10. ***Tanyosphaeridium variecalamus***
    Blue Point Section, Sample BMS4/14B-16A, Slide PRCIES 3138.2, England Finder Reference: D494
11. ***Prolixosphaeridium parvispinum***
    Rebecca K. Bounds Core, Sample 890', AMOCO Loc. 15129, Slide 79, England Finder Reference: L394
12. ***Tanyosphaeridium salpinx***
    Pueblo Section, Sample PUB8, Slide PRCIES 2399.3, England Finder Reference: M414
13. ***Tanyosphaeridium salpinx***
    Rebecca K. Bounds Core, Sample 790', AMOCO Loc. 15129, Slide 69, England Finder Reference: F314

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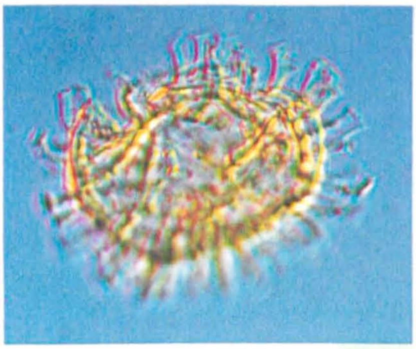

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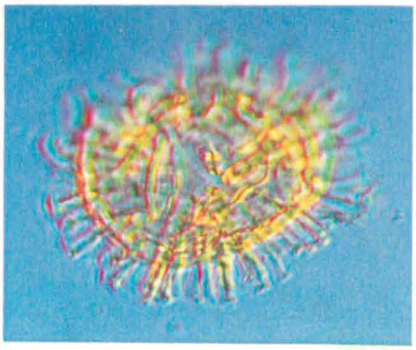

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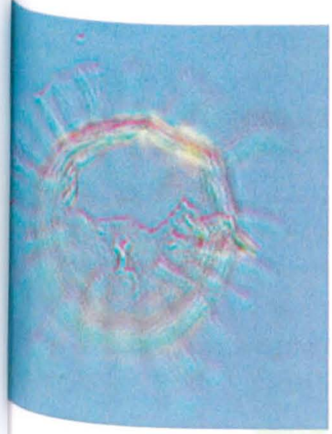

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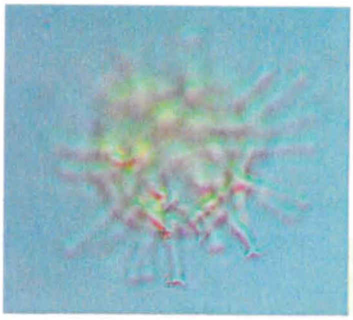

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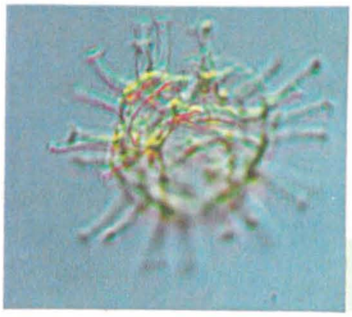

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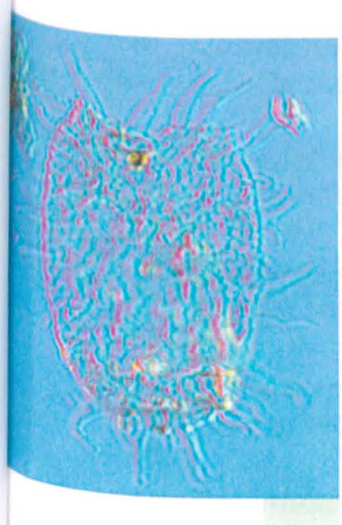

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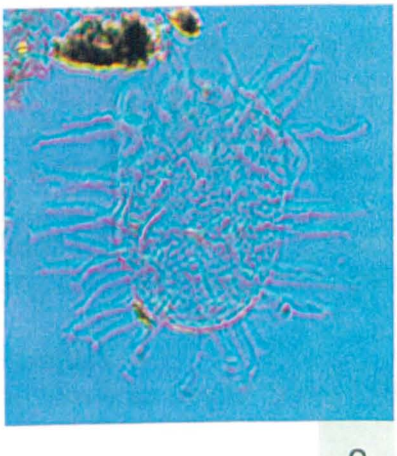

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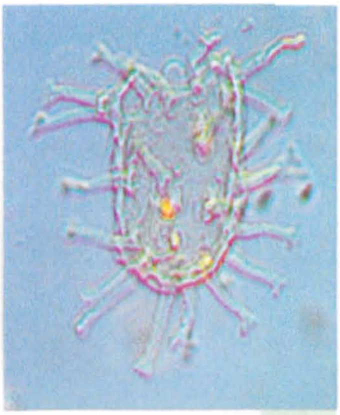

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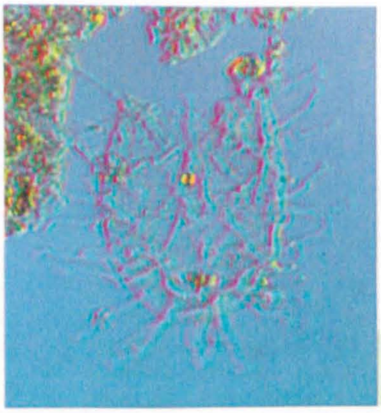

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Plate 15

Plate 16

1. ***Operculodinium* sp. A**
   Blue Point Section, Sample BMS4/14B-16A, Slide PRCIES 3138.2, England Finder Reference: F231/2
2. ***Operculodinium* sp. A**
   Blue Point Section, Sample BMS4/14B-16A, Slide PRCIES 3138.2, England Finder Reference: F231/2
3. ***Downiesphaeridium armatum***
   Rebecca K. Bounds Core, Sample 980', AMOCO Loc. 15129, Slide 88, England Finder Reference: F473
4. ***Heterosphaeridium multifurcatum***
   Blue Point Section, Sample BMS4/16B-18A, Slide PRCIES 3139.2, England Finder Reference: V474/483
5. ***Heterosphaeridium multifurcatum***
   Blue Point Section, Sample BMS4/16B-18A, Slide PRCIES 3139.2, England Finder Reference: V474/483
6. ***Impletosphaeridium clavulum***
   Rebecca K. Bounds Core, Sample 950', AMOCO Loc. 15129, Slide 85, England Finder Reference: N443
7. ***Downiesphaeridium multispinosum***
   Rebecca K. Bounds Core, Sample 830', AMOCO Loc. 15129, Slide 73, England Finder Reference: J413
8. ***Cometodinium? whitei***
   Rebecca K. Bounds Core, Sample 910', AMOCO Loc. 15129, Slide 81, England Finder Reference: F403
9. ***Dapsilidinium multispinosum***
   Blue Point Section, Sample BMS4/27B-28A, Slide PRCIES 3145.2, England Finder Reference: H201
10. ***Downiesphaeridium* sp. A**
    Bunker Hill Section, Sample BH30, Slide PRCIES 2718.17, England Finder Reference: D344
11. ***Downiesphaeridium* sp. A**
    Bunker Hill Section, Sample BH30, Slide PRCIES 2718.17, England Finder Reference: D344
12. ***Downiesphaeridium* sp. A**
    Rebecca K. Bounds Core, Sample 1020', AMOCO Loc. 15129, Slide 92, England Finder Reference: C444

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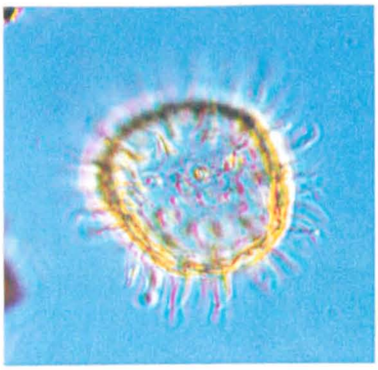

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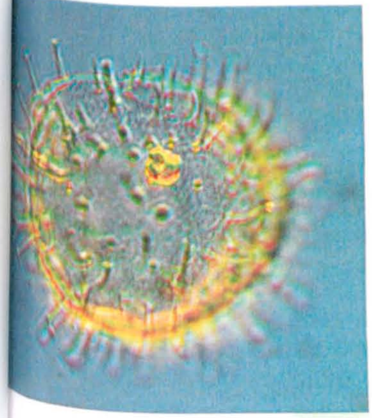

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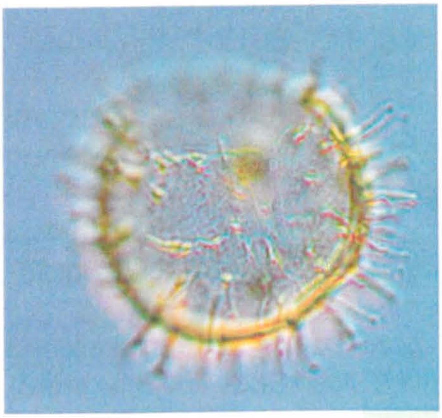

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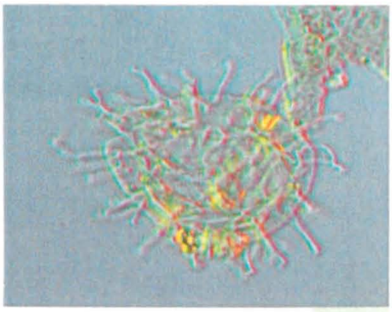

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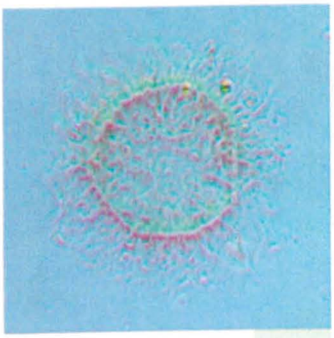

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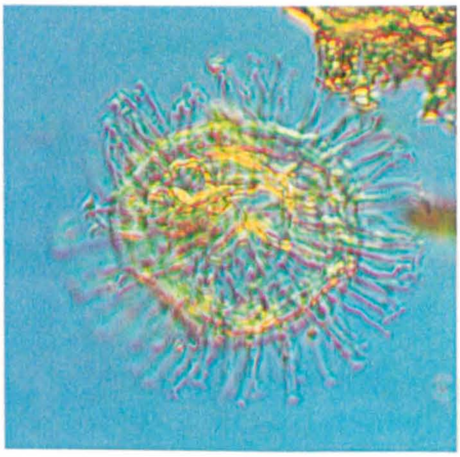

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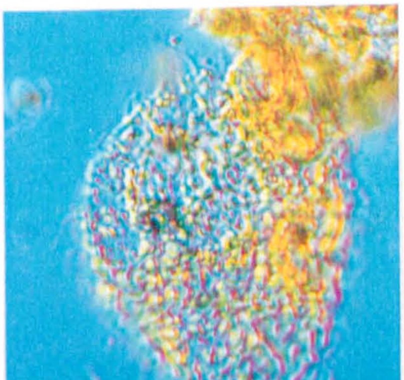

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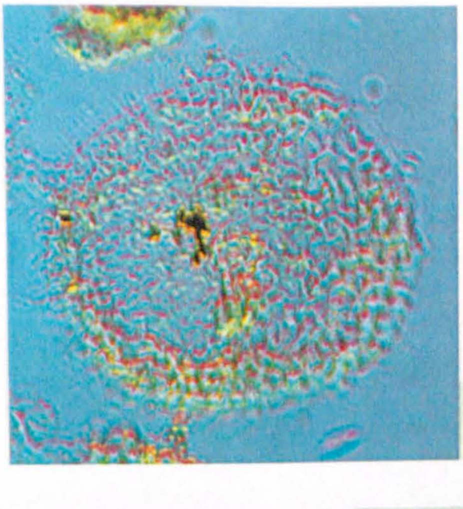

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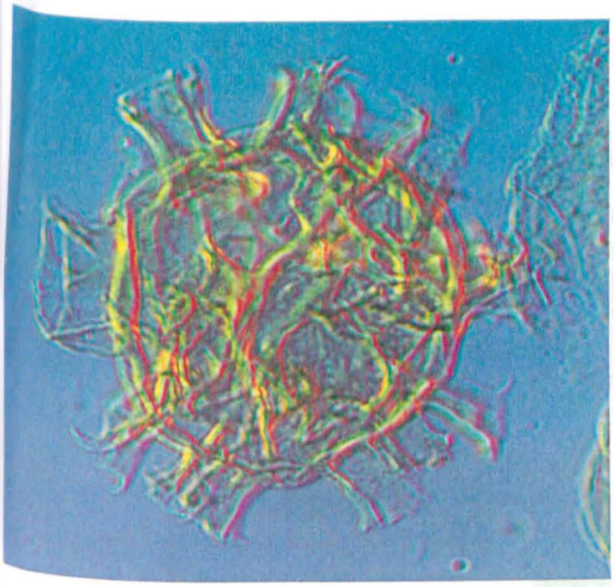
Plate 16

Plate 17

1. ***Heterosphaeridium difficile***
   Rebecca K. Bounds Core, Sample 760', AMOCO Loc. 15129, Slide 66, England Finder Reference: E444
2. ***Cyclonephelium compactum***
   Rebecca K. Bounds Core, Sample 780', AMOCO Loc. 15129, Slide 68, England Finder Reference: N422
3. ***Cyclonephelium membraniphorum***
   Blue Point Section, Sample BMS4/16B-18A, Slide PRCIES 3139.2, England Finder Reference: N274
4. ***Cyclonephelium membraniphorum***
   Rebecca K. Bounds Core, Sample 850', AMOCO Loc. 15129, Slide 75, England Finder Reference: B463
5. ***Cyclonephelium uncinatum***
   Blue Point Section, Sample BMS4/33C-34A, Slide PRCIES 3148.2, England Finder Reference: J411
6. ***Cyclonephelium uncinatum***
   Blue Point Section, Sample BMS4/33C-34A, Slide PRCIES 3148.2, England Finder Reference: J411



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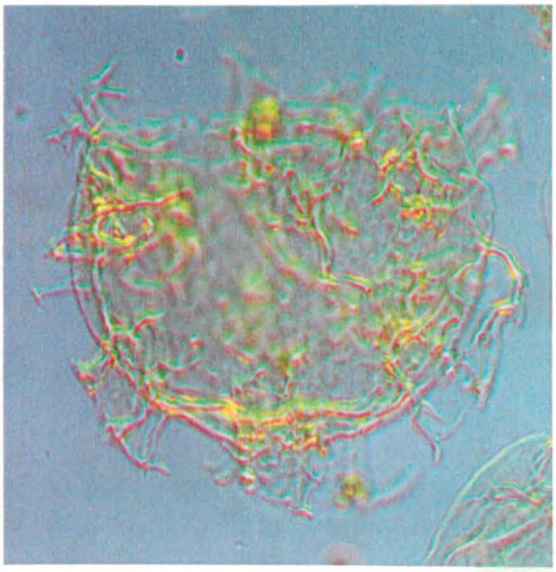

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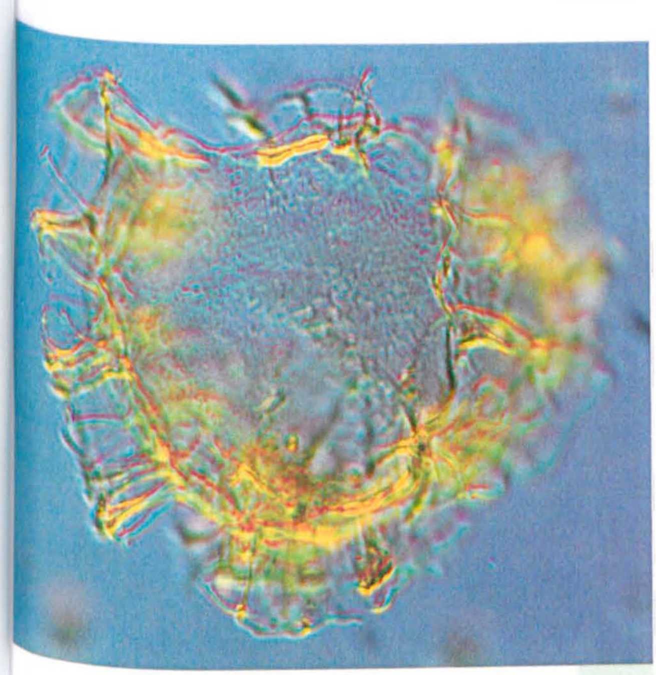

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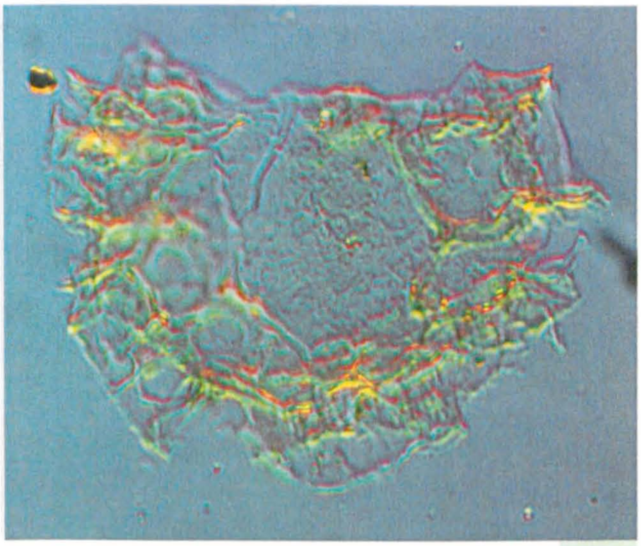

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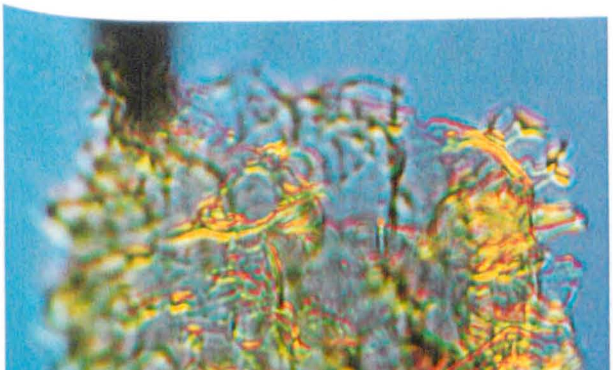

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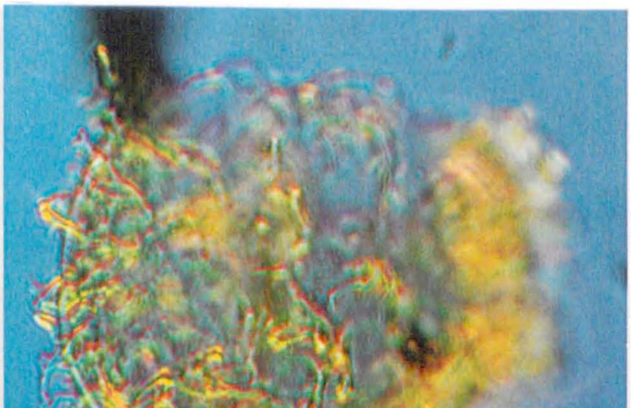

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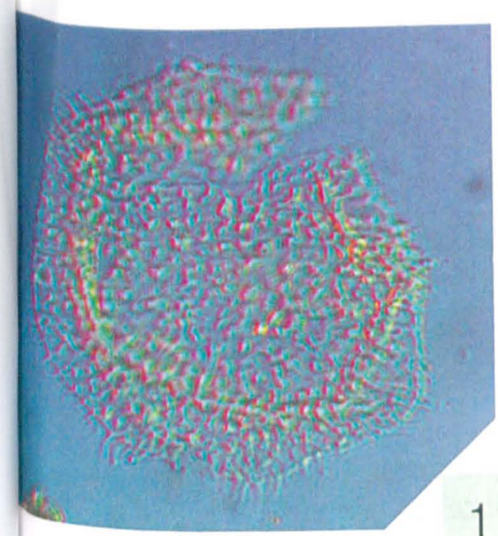
Plate 17

Plate 18

1. ***Tenua hystrix***
   Rebecca K. Bounds Core, Sample 850', AMOCO Loc. 15129, Slide 75, England Finder Reference: L502
2. ***Circulodinium distinctum***
   Blue Point Section, Sample BMS4/7, Slide PRCIES 3135.4, England Finder Reference: S563
3. ***Heterosphaeridium? heteracanthum***
   Pueblo Section, Sample PUB27, Slide PRCIES 2418.7, England Finder Reference: K382
4. ***Heterosphaeridium? heteracanthum***
   Pueblo Section, Sample PUB4, Slide PRCIES 2385.1, England Finder Reference: T471
5. ***Heterosphaeridium? heteracanthum***
   Pueblo Section, Sample PUB4, Slide PRCIES 2385.1, England Finder Reference: T471
6. ***Heterosphaeridium conjunctum***
   Rebecca K. Bounds Core, Sample 810', AMOCO Loc. 15129, Slide 71, England Finder Reference: C412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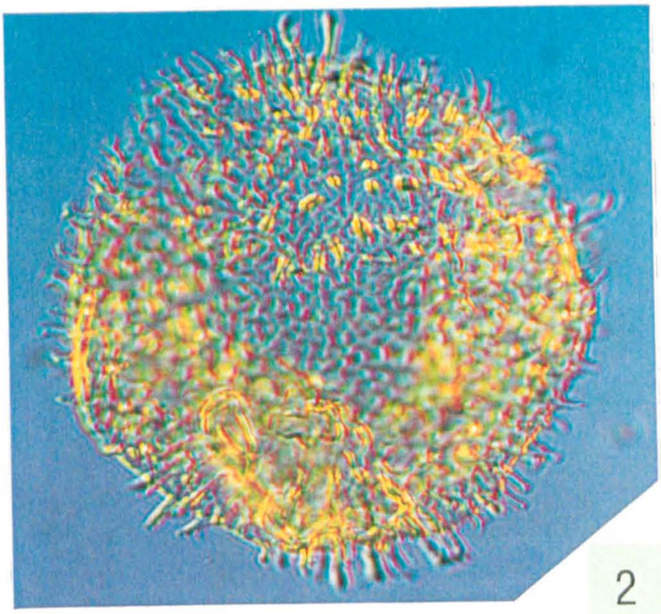
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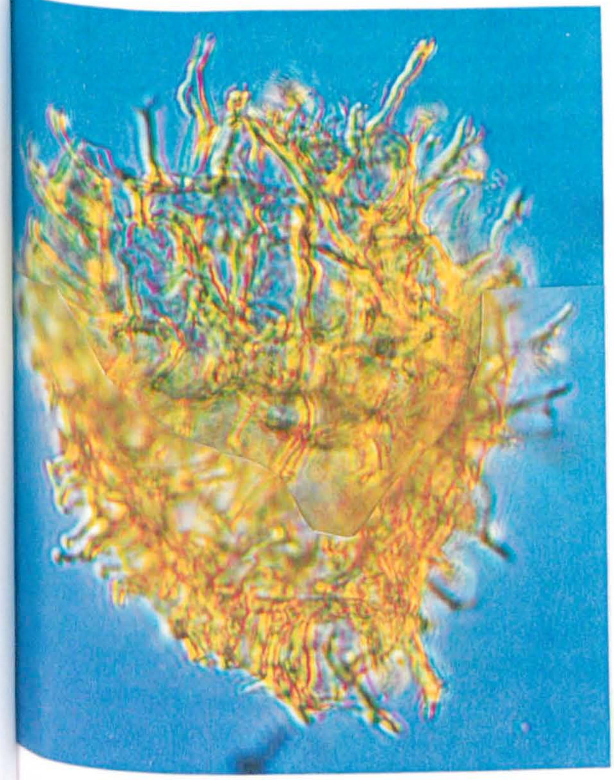
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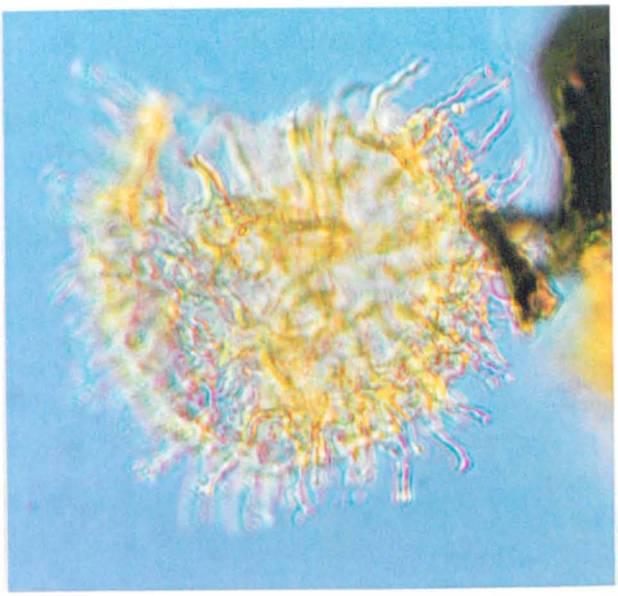
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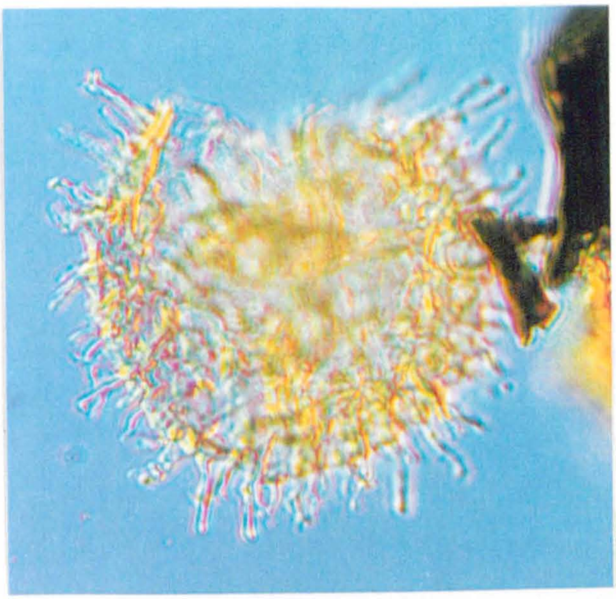
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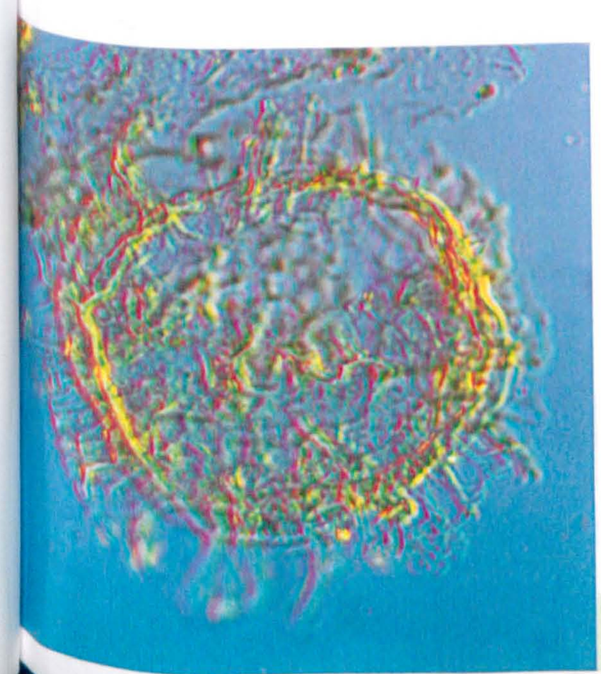
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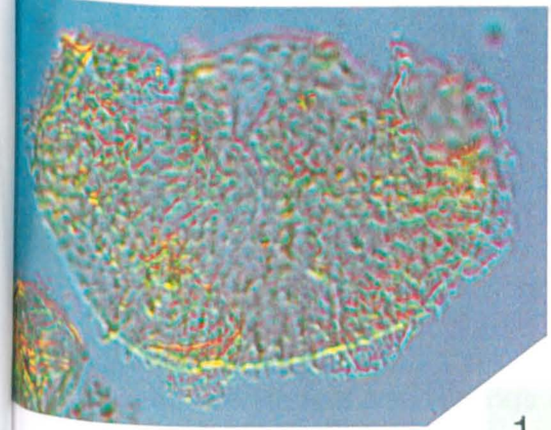
Plate 18

Plate 19

1. ***Cyclonephelium chabaca***
   Rebecca K. Bounds Core, Sample 1110', AMOCO Loc. 15129, Slide 101, England Finder Reference: B394
2. ***Cyclonephelium chabaca***
   Blue Point Section, Sample BMS4/16B-18A, Slide PRCIES 3139.2, England Finder Reference: L354/M352
3. ***Cyclonephelium brevispinatum***
   Rebecca K. Bounds Core, Sample 970', AMOCO Loc. 15129, Slide 87, England Finder Reference: E383
4. ***Cyclonephelium brevispinatum***
   Rebecca K. Bounds Core, Sample 890', AMOCO Loc. 15129, Slide 79, England Finder Reference: F441
5. ***Cyclonephelium vannophorum***
   Blue Point Section, Sample BMS4/3-5, Slide PRCIES 3134.1, England Finder Reference: X351/3
6. ***Canninginopsis colliveri***
   Rebecca K. Bounds Core, Sample 1040', AMOCO Loc. 15129, Slide 94, England Finder Reference: C512
7. ***Cyclonephelium paucimarginatum***
   Rebecca K. Bounds Core, Sample 950', AMOCO Loc. 15129, Slide 85, England Finder Reference: M481



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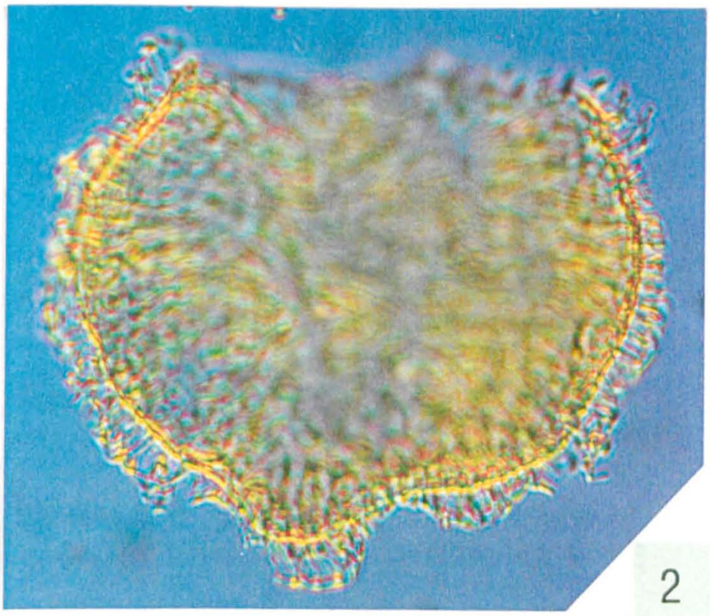

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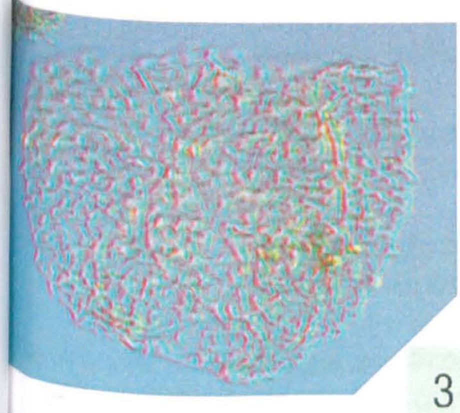

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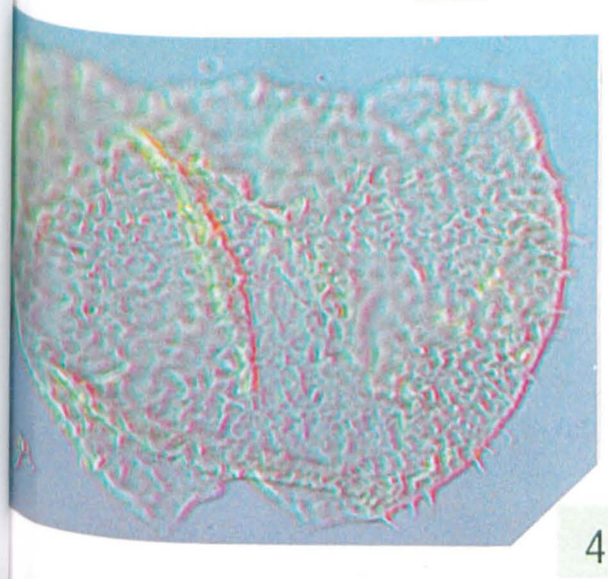

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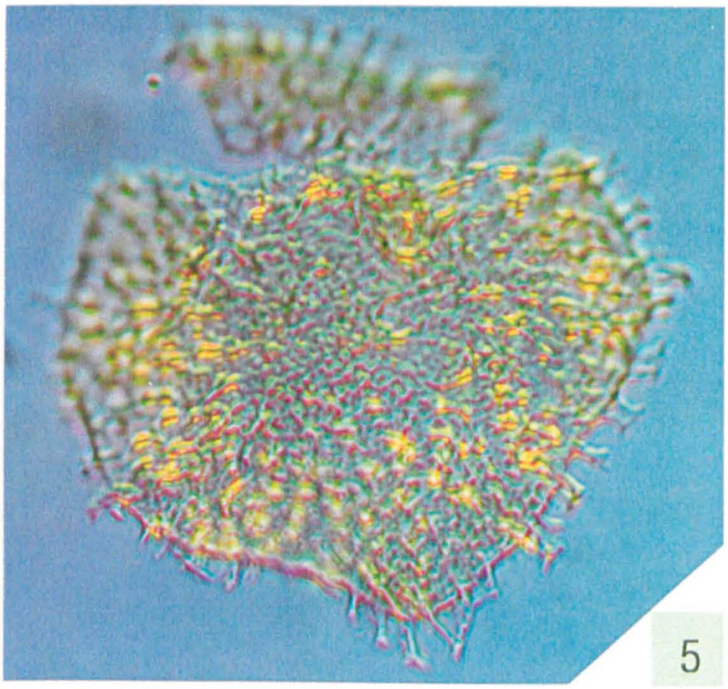

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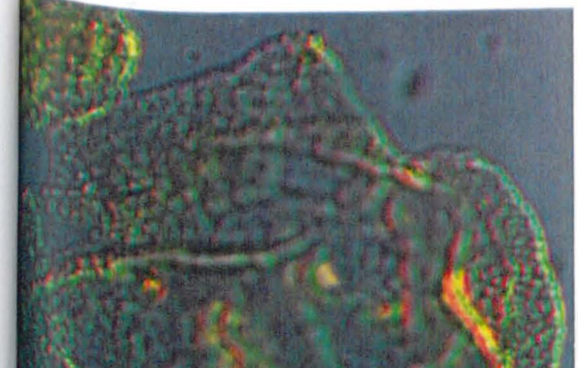

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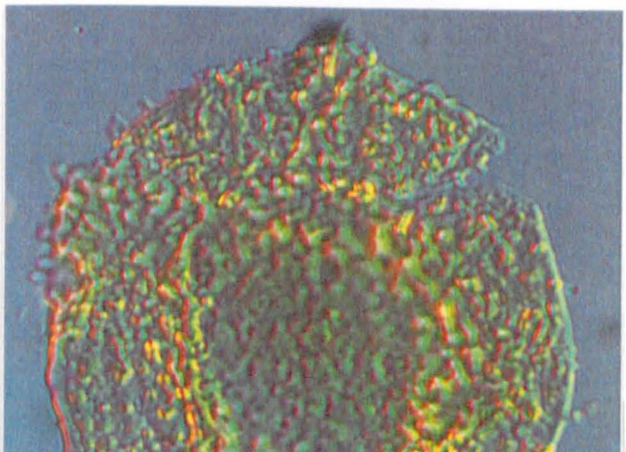

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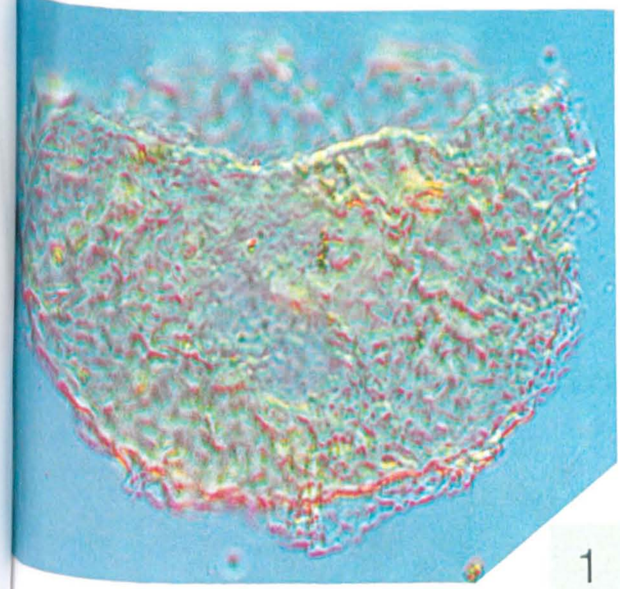
Plate 19

Plate 20

1. ***Canningia senonica***
   Rebecca K. Bounds Core, Sample 880', AMOCO Loc. 15129, Slide 78, England Finder Reference: D463
2. ***Canningia senonica***
   Rebecca K. Bounds Core, Sample 880', AMOCO Loc. 15129, Slide 78, England Finder Reference: M383
3. ***Canningia senonica***
   Rebecca K. Bounds Core, Sample 880', AMOCO Loc. 15129, Slide 78, England Finder Reference: M383
4. ***Canningia scabrosa***
   Rebecca K. Bounds Core, Sample 1000', AMOCO Loc. 15129, Slide90, England Finder Reference: W292
5. ***Canningia scabrosa***
   Rebecca K. Bounds Core, Sample 1110', AMOCO Loc. 15129, Slide 101, England Finder Reference: H382
6. ***Canningia scabrosa***
   Rebecca K. Bounds Core, Sample 1110', AMOCO Loc. 15129, Slide 101, England Finder Reference: H382



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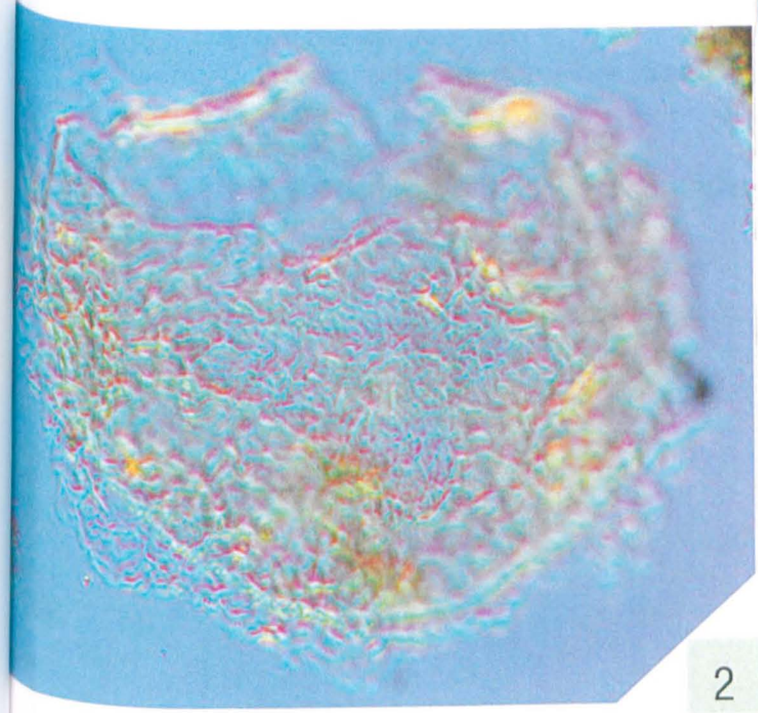

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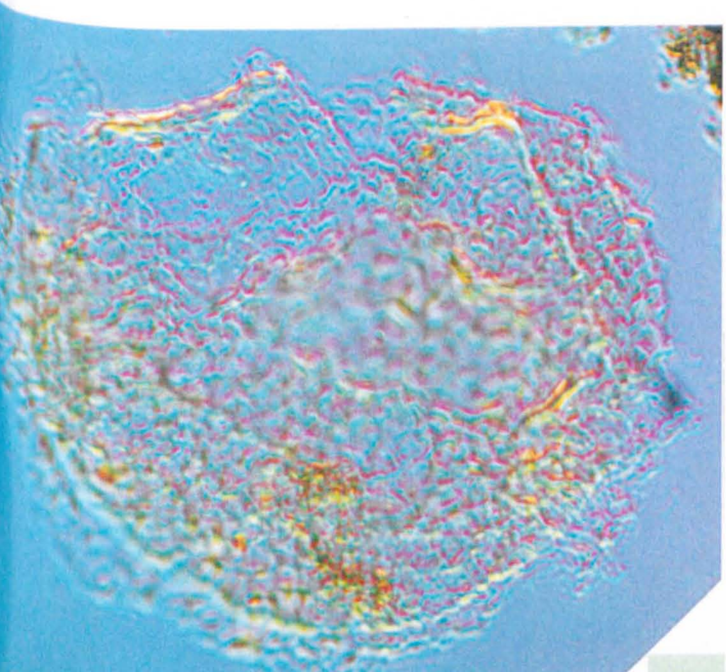

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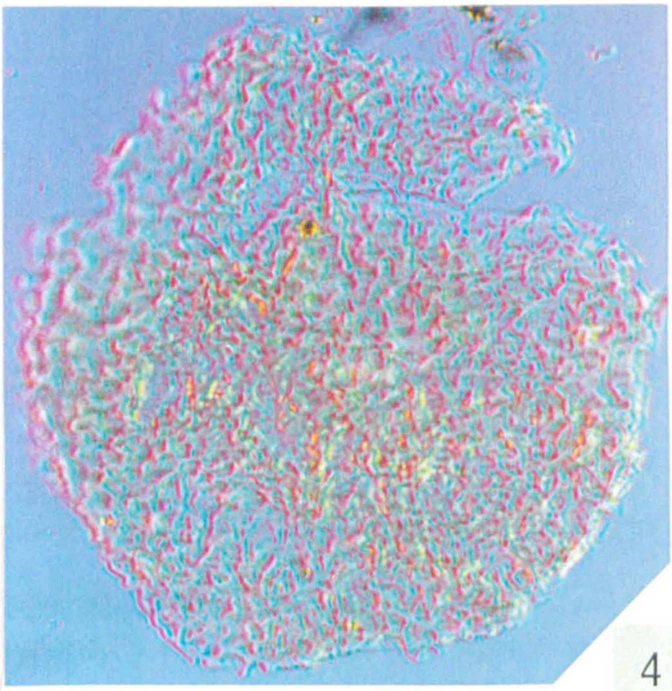

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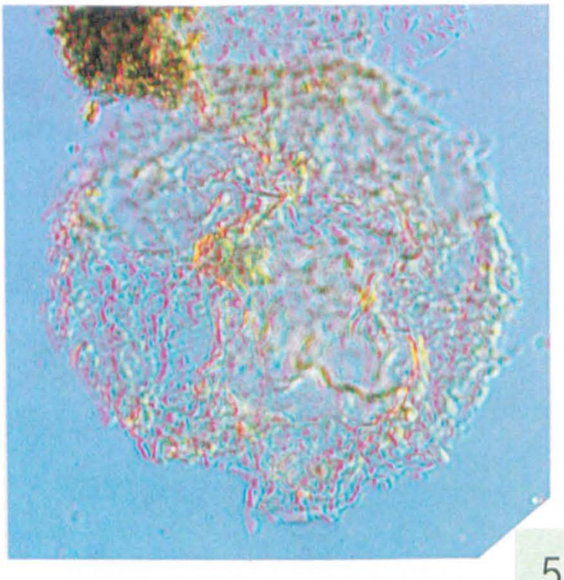

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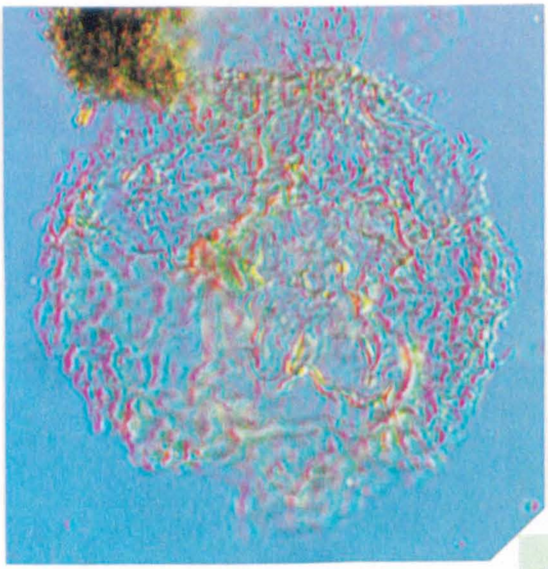

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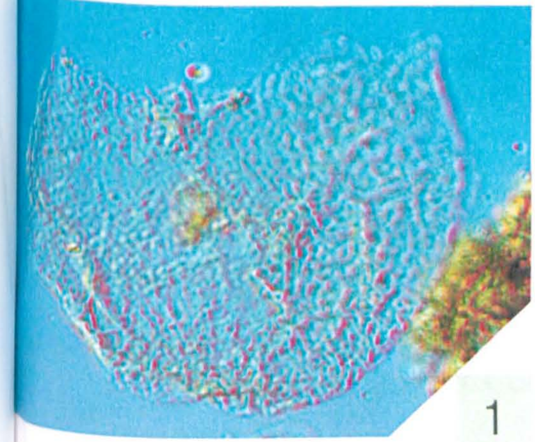
Plate 20

Plate 21

1. ***Canningia reticulata***
   Rebecca K. Bounds Core, Sample 790', AMOCO Loc. 15129, Slide 69, England Finder Reference: G451
2. ***Canningia reticulata***
   Rebecca K. Bounds Core, Sample 780', AMOCO Loc. 15129, Slide 68, England Finder Reference: B373
3. ***Canningia* sp. A**
   Rebecca K. Bounds Core, Sample 920', AMOCO Loc. 15129, Slide 82, England Finder Reference: P363/Q361
4. ***Canningia* sp. A**
   Rebecca K. Bounds Core, Sample 820', AMOCO Loc. 15129, Slide 72, England Finder Reference: E462/471
5. ***Canningia* sp. B**
   Rebecca K. Bounds Core, Sample 880', AMOCO Loc. 15129, Slide 78, England Finder Reference: D474/E472
6. ***Canningia* sp. B**
   Rebecca K. Bounds Core, Sample 770', AMOCO Loc. 15129, Slide 67, England Finder Reference: F503



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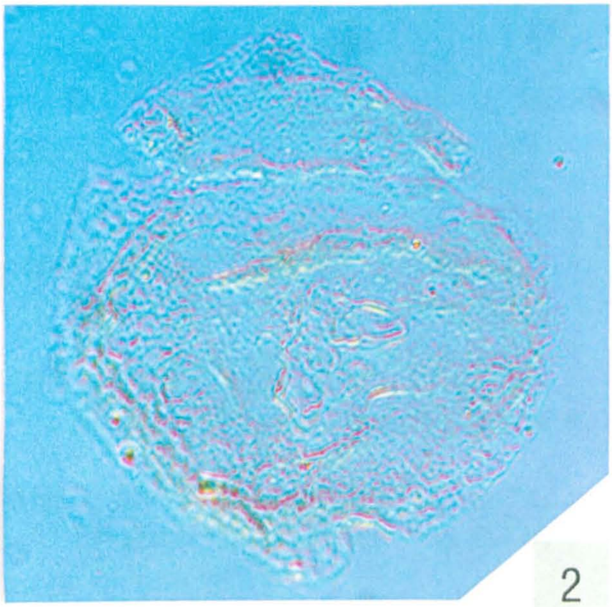

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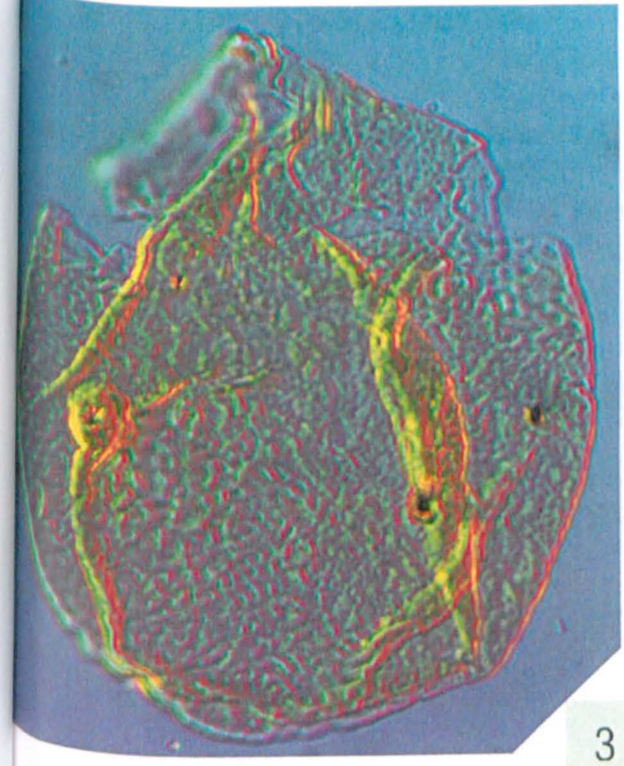

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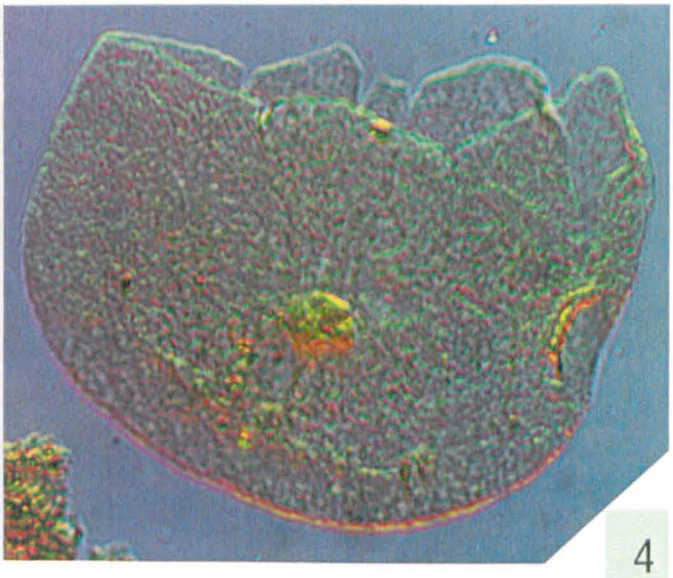

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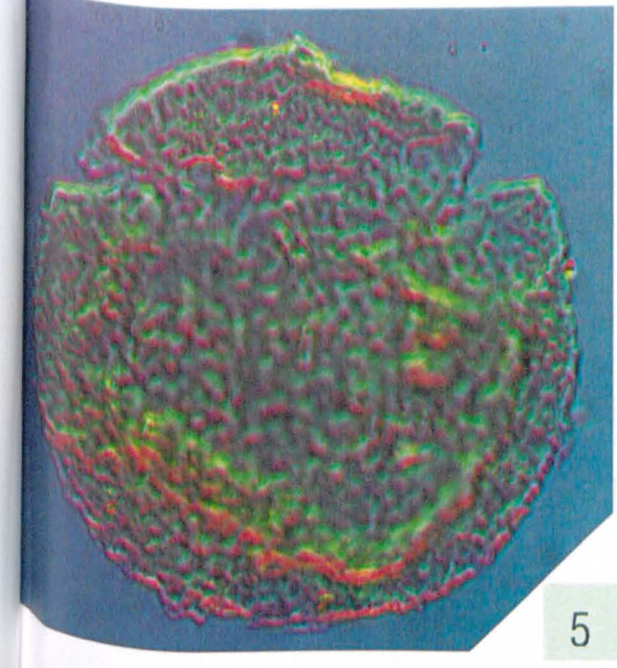

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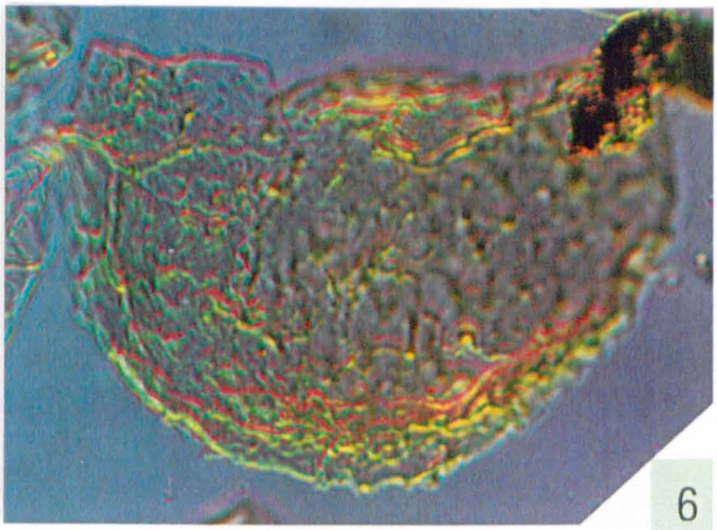

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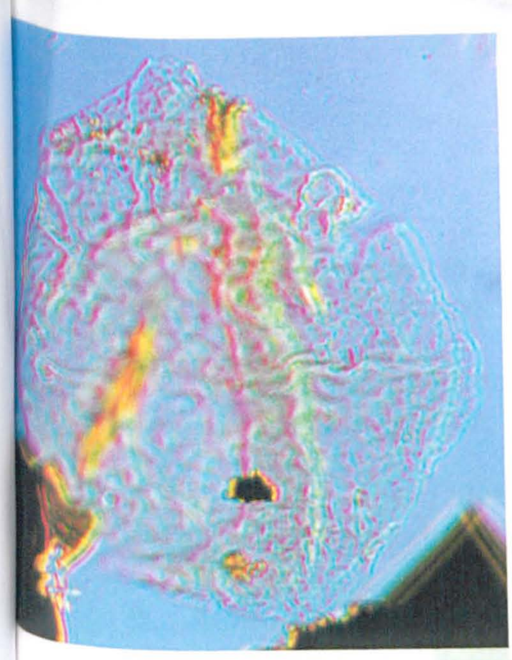
Plate 21

Plate 22

1. ***Senoniasphaera microreticulata***
   Rebecca K. Bounds Core, Sample 1060', AMOCO Loc. 15129, Slide 96, England Finder Reference: E461
2. ***Dinopterygium reticulatum***
   Rebecca K. Bounds Core, Sample 1119.5', AMOCO Loc. 15129, Slide 102, England Finder Reference: M324
3. ***Valensiella magna***
   Rebecca K. Bounds Core, Sample 810', AMOCO Loc. 15129, Slide 71, England Finder Reference: D444
4. ***Valensiella tazadensis***
   Rebecca K. Bounds Core, Sample 840', AMOCO Loc. 15129, Slide 74, England Finder Reference: D351
5. ***Valensiella tazadensis***
   Rebecca K. Bounds Core, Sample 1040', AMOCO Loc. 15129, Slide 94, England Finder Reference: F332/341
6. ***Valensiella reticulata***
   Blue Point Section, Sample BMS4/8-11A, Slide PRCIES 3136.2, England Finder Reference: F301
7. ***Valensiella reticulata***
   Blue Point Section, Sample BMS4/8-11A, Slide PRCIES 3136.2, England Finder Reference: F301
8. ***Valensiella reticulata***
   Blue Point Section, Sample BMS4/11B-14A, Slide PRCIES 3137.3, England Finder Reference: V481/2
9. ***Valensiella reticulata***
   Blue Point Section, Sample BMS4/11B-14A, Slide PRCIES 3137.3, England Finder Reference: V481/2



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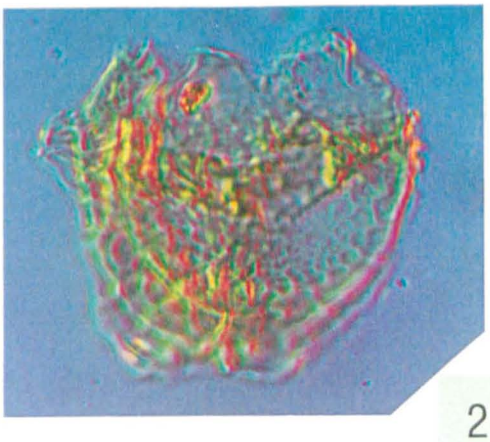

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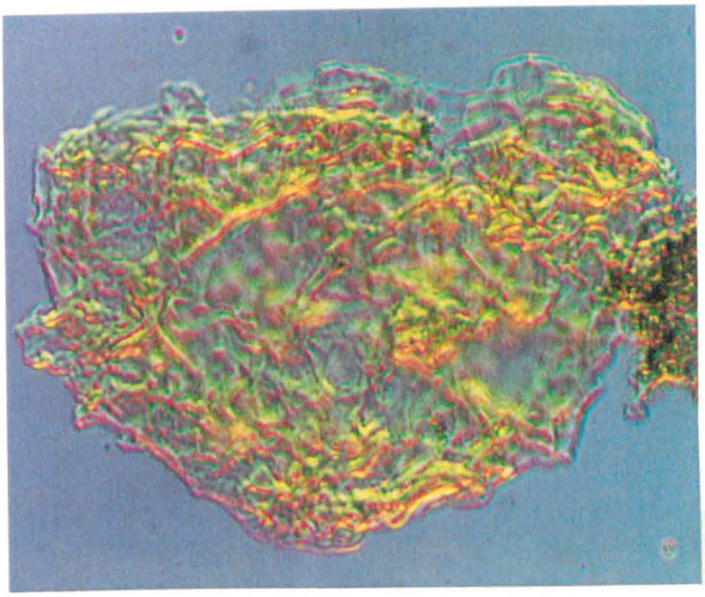

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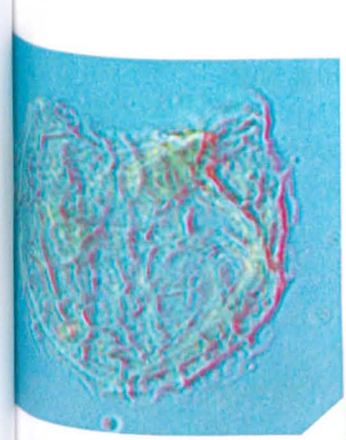

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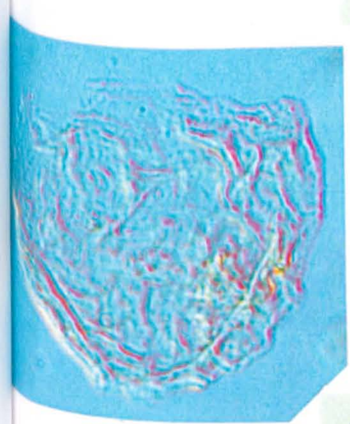

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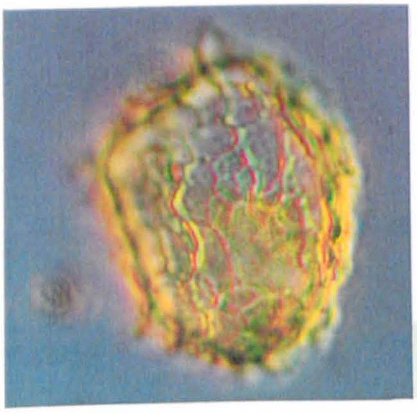

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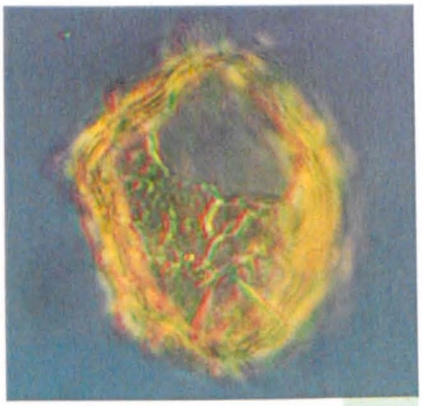

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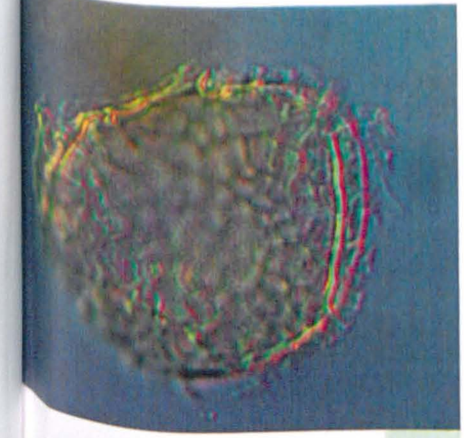

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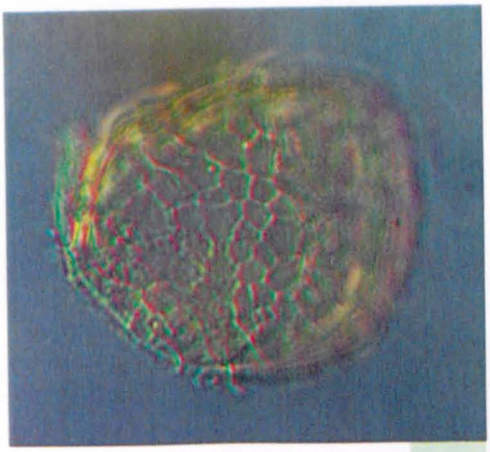

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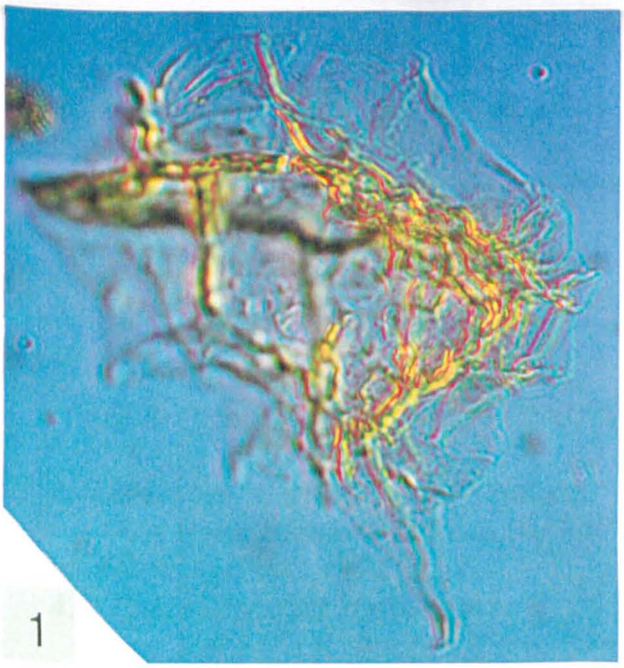
Plate 22

Plate 23

1. ***Dinopterygium cladoides***
Wahweap Wash Section, Sample NBU/33-35A, Slide PRCIES 3323.2, England
Finder Reference: N553
2. ***Dinopterygium cladoides***
Wahweap Wash Section, Sample NBU/33-35A, Slide PRCIES 3323.2, England
Finder Reference: N553
3. ***Xiphophoridium alatum***
Blue Point Section, Sample BMS4/16B-18A, Slide PRCIES 3139.2, England
Finder Reference: N522
4. ***Xiphophoridium alatum***
Blue Point Section, Sample BMS4/16B-18A, Slide PRCIES 3139.2, England
Finder Reference: N522
5. ***Hystrichodinium pulchrum***
Blue Point Section, Sample BMS4/8-11A, Slide PRCIES 3136.2, England
Finder Reference: W431/3
6. ***Hystrichodinium pulchrum***
Blue Point Section, Sample BMS4/8-11A, Slide PRCIES 3136.2, England
Finder Reference: W431/3



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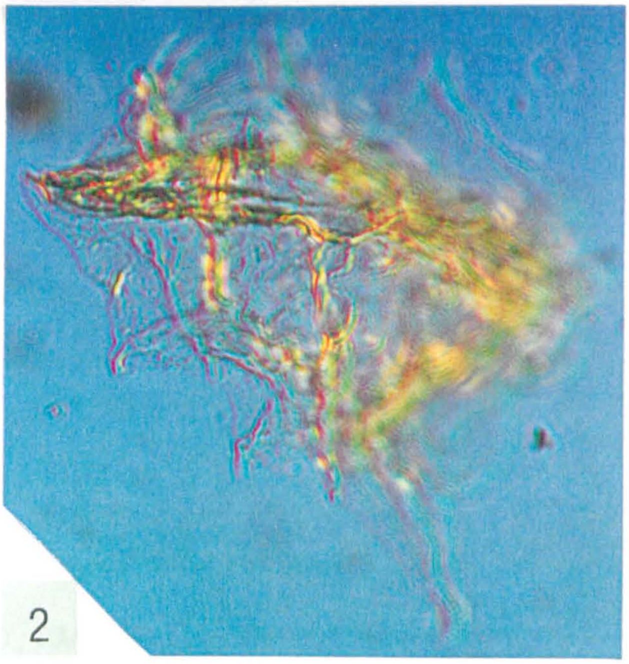

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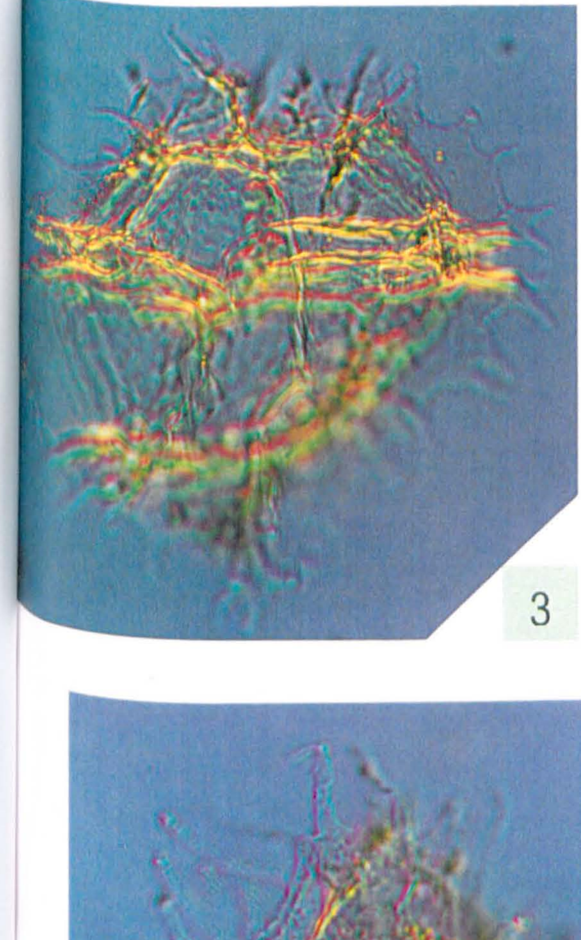

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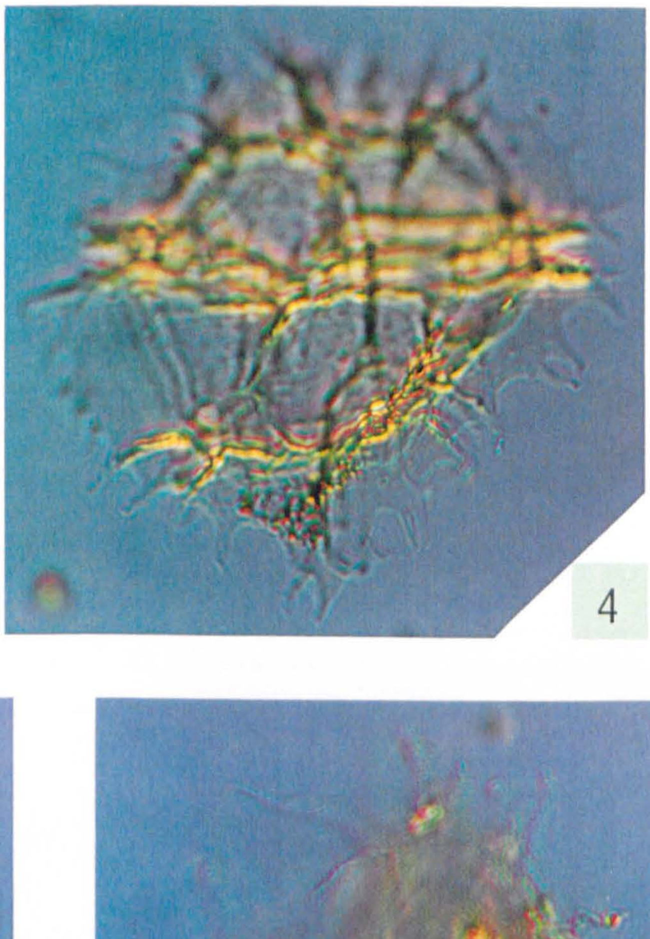

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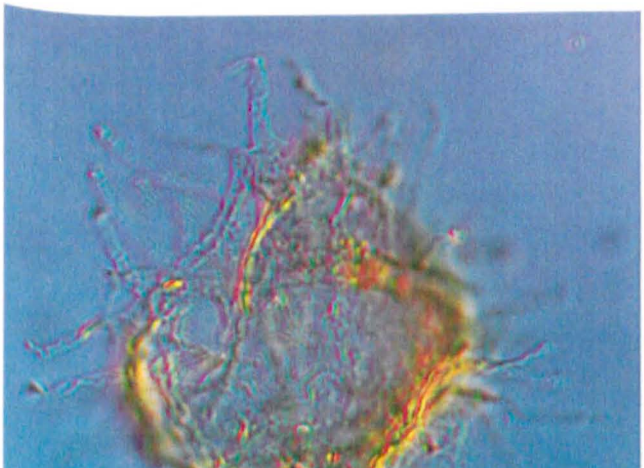

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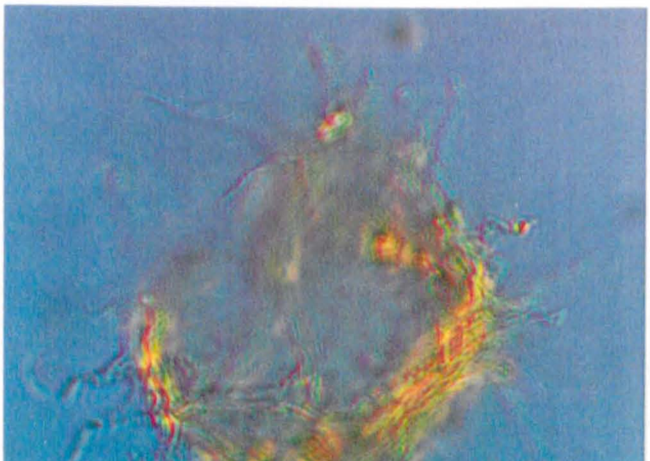

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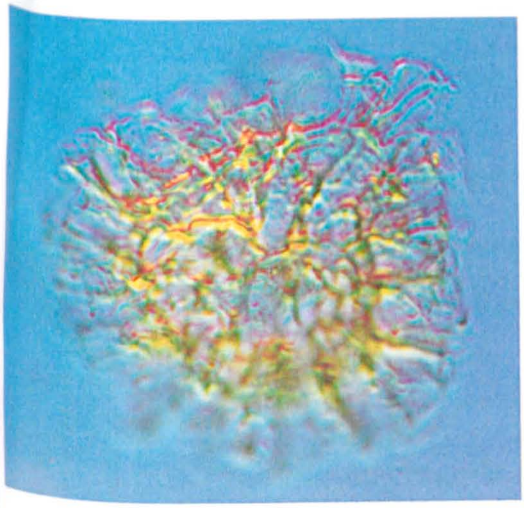
Plate 23

Plate 24

1. ***Membranilarnacia polycladiata***
   Blue Point Section, Sample BMS4/14B-16A, Slide PRCIES 3138.2, England Finder Reference: G573
2. ***Membranilarnacia polycladiata***
   Blue Point Section, Sample BMS4/14B-16A, Slide PRCIES 3138.2, England Finder Reference: G573
3. ***Membranilarnacia polycladiata***
   Blue Point Section, Sample BMS4/16B-18A, Slide PRCIES 3139.2, England Finder Reference: D503
4. ***Leberidocysta defloccata***
   Rebecca K. Bounds Core, Sample 900', AMOCO Loc. 15129, Slide 80, England Finder Reference: L441
5. ***Hapsocysta peridictya***
   Rebecca K. Bounds Core, Sample 750', AMOCO Loc. 15129, Slide 65, England Finder Reference: M331
6. ***Adnatosphaeridium tutulosum***
   Rebecca K. Bounds Core, Sample 980', AMOCO Loc. 15129, Slide 88, England Finder Reference: J463



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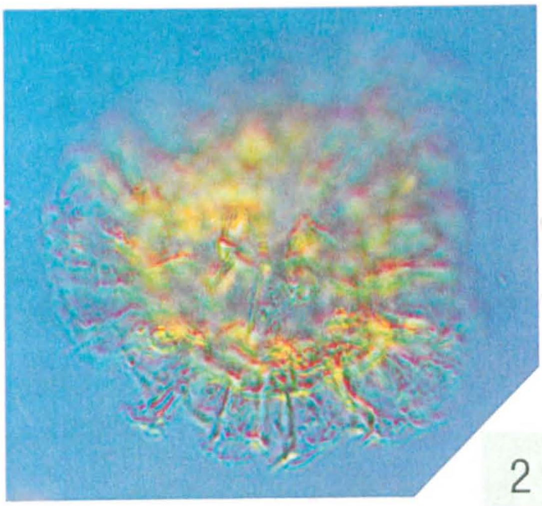

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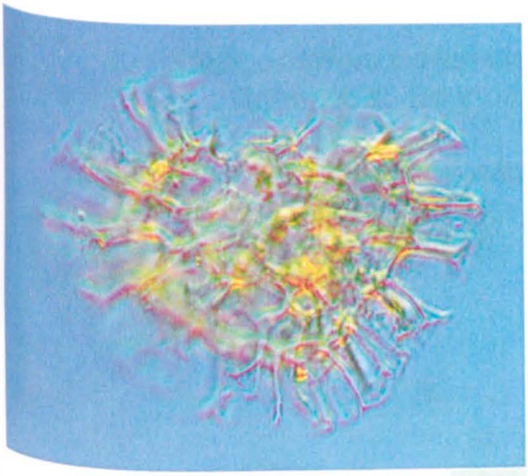

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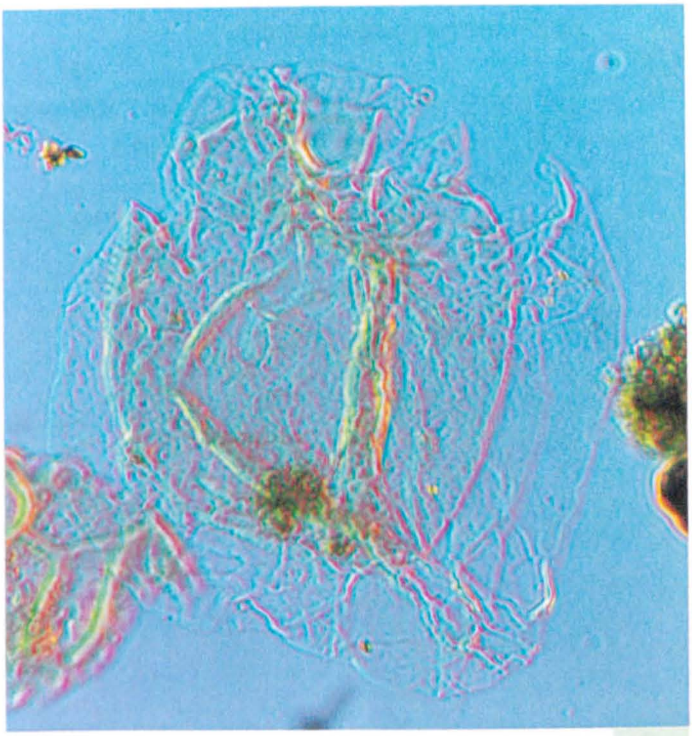

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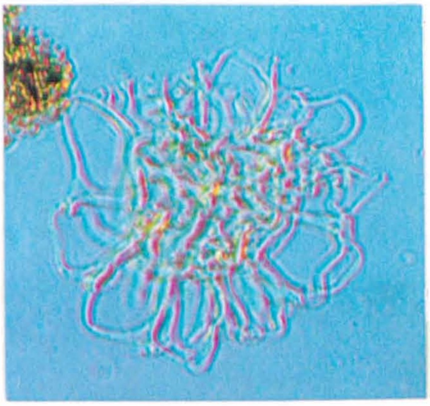

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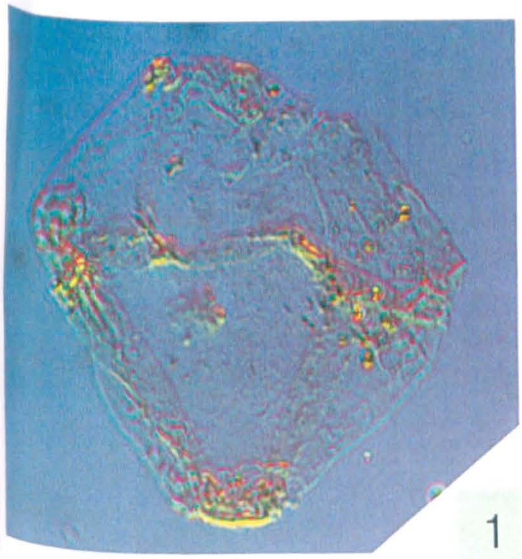
Plate 24

Plate 25

1. ***Atopodinium haromense***
   Rebecca K. Bounds Core, Sample 800', AMOCO Loc. 15129, Slide 70, England Finder Reference: G382/391
2. ***Disphaeria macropyla***
   Wahweap Wash Section, Sample NBU/52D-54A, Slide PRCIES 3346.1, England Finder Reference: C473
3. ***Disphaeria macropyla***
   Rebecca K. Bounds Core, Sample 800', AMOCO Loc. 15129, Slide 70, England Finder Reference: J442
4. ***Stephodinium coronatum***
   Blue Point Section, Sample BMS4/8-11A, Slide PRCIES 3136.3, England Finder Reference: F344
5. ***Stephodinium coronatum***
   Rebecca K. Bounds Core, Sample 900', AMOCO Loc. 15129, Slide 80, England Finder Reference: H501
6. ***Ellipsodinium rugulosum***
   Rebecca K. Bounds Core, Sample 950', AMOCO Loc. 15129, Slide 85, England Finder Reference: N472/4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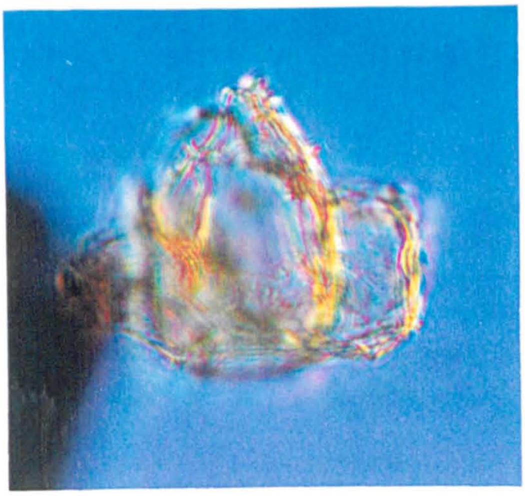
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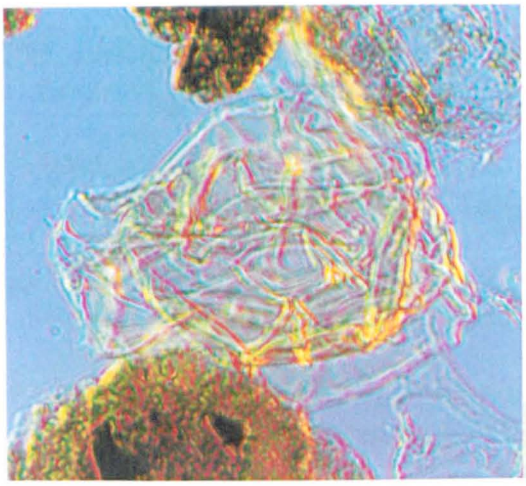
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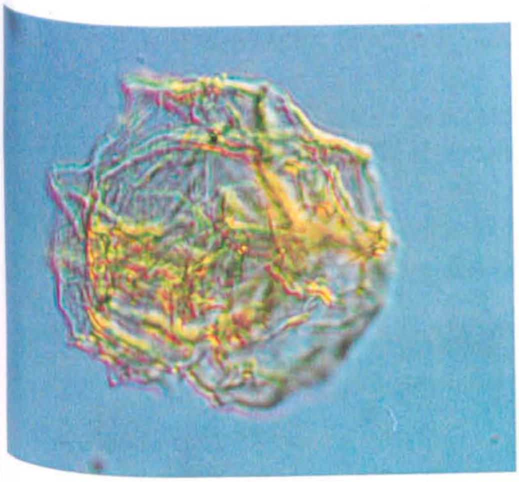
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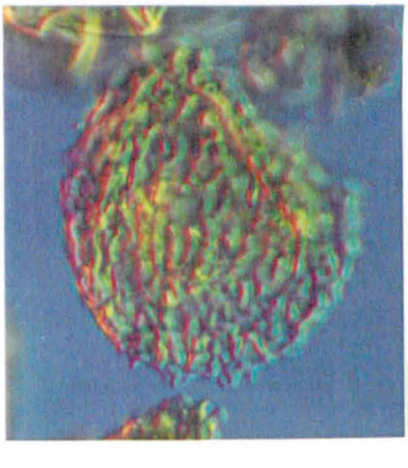
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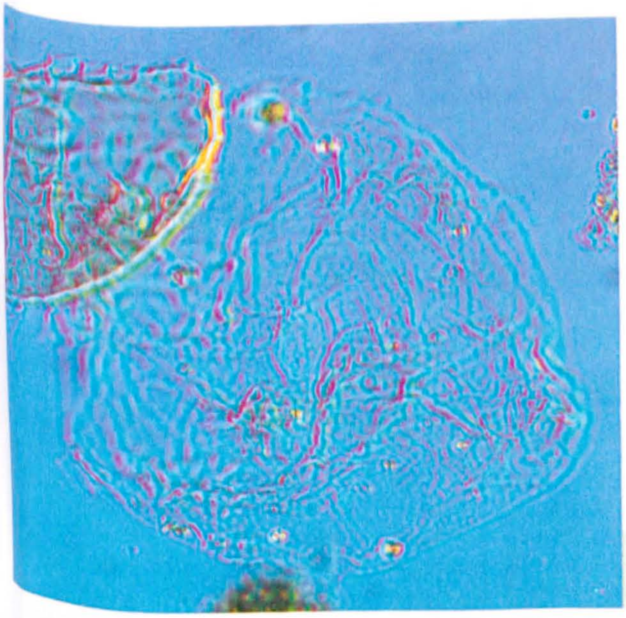
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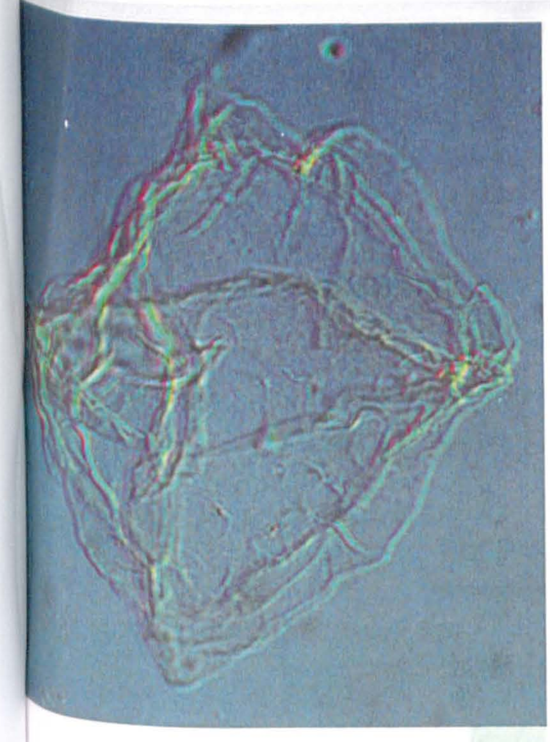
Plate 25

Plate 26

1. ***Endoscrinium campanula***
   Rebecca K. Bounds Core, Sample 870' (1), AMOCO Loc. 15129, Slide 77, England Finder Reference: M542/551
2. ***Psaligonyaulax deflandrei***
   Rebecca K. Bounds Core, Sample 930', AMOCO Loc. 15129, Slide 83, England Finder Reference: K473
3. ***Psaligonyaulax deflandrei***
   Rebecca K. Bounds Core, Sample 930', AMOCO Loc. 15129, Slide 83, England Finder Reference: K473
4. ***Occisucysta hinzii***
   Pueblo Section, Sample PUB10, Slide PRCIES 2401.7, England Finder Reference: C172
5. ***Gonyaulacysta cassidata***
   Rebecca K. Bounds Core, Sample 800', AMOCO Loc. 15129, Slide 70, England Finder Reference: E362
6. ***Trichodinium castanea***
   Blue Point Section, Sample BMS4/28B-30, Slide PRCIES 3146.3, England Finder Reference: N432/4
7. ***Tehamadinium coummia***
   Rebecca K. Bounds Core, Sample 980', AMOCO Loc. 15129, Slide 88, England Finder Reference: J383
8. ***Acanthaulax wilsonii***
   Blue Point Section, Sample BMS4/14B-16A, Slide PRCIES 3138.2, England Finder Reference: F251
9. ***Acanthaulax wilsonii***
   Blue Point Section, Sample BMS4/14B-16A, Slide PRCIES 3138.2, England Finder Reference: F251



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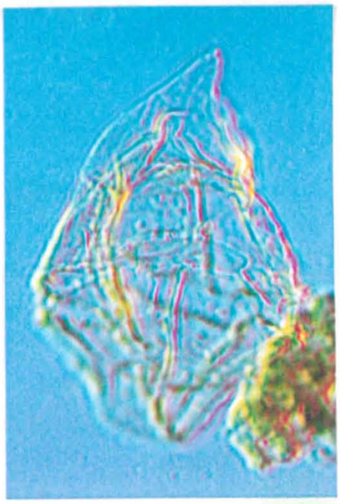

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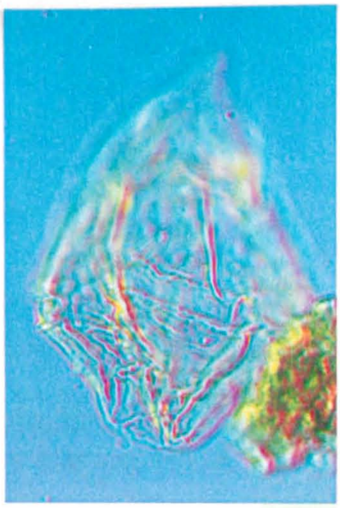

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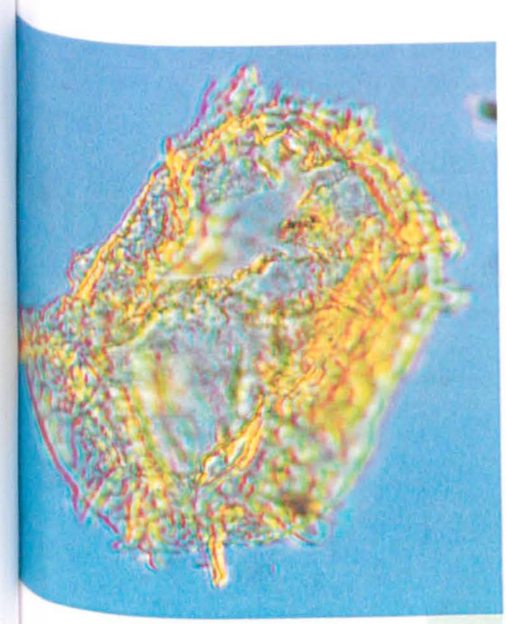

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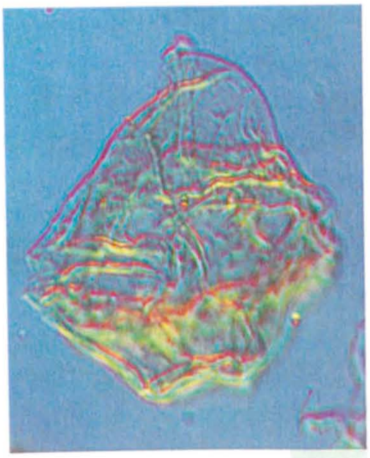

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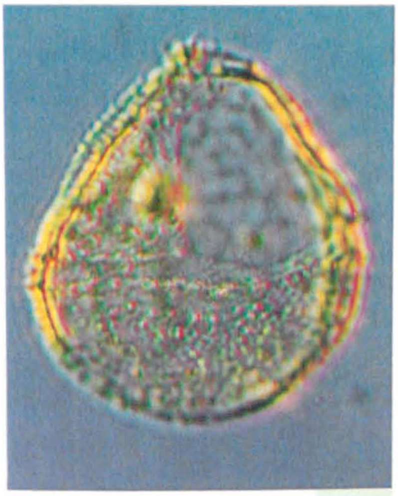

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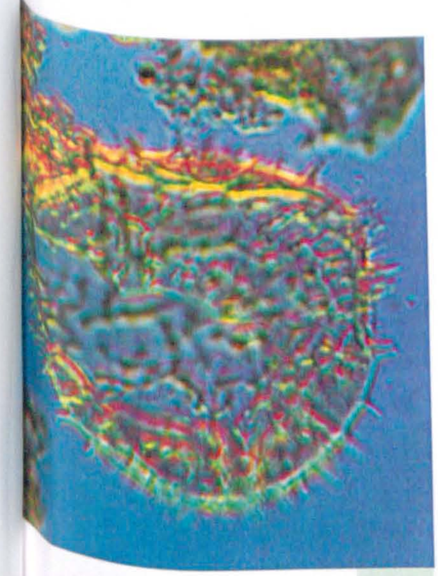

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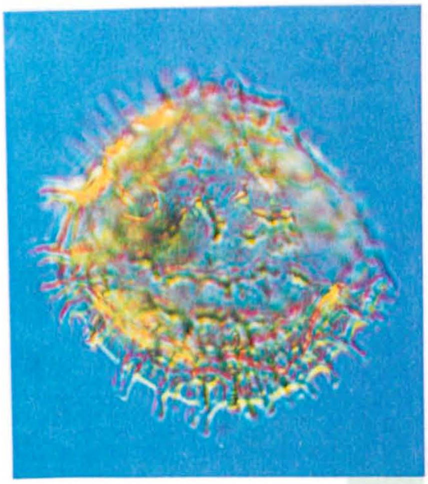

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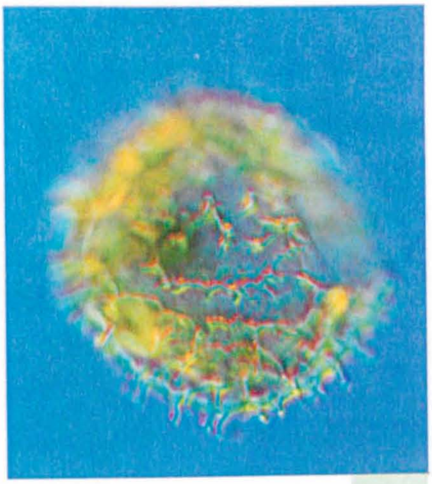

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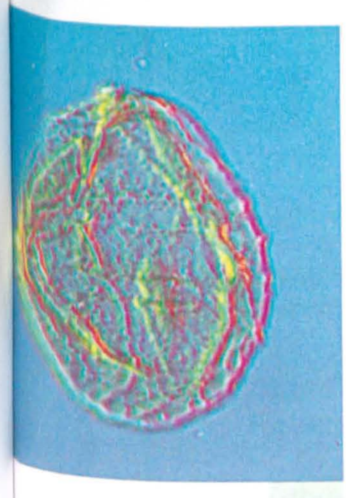
Plate 26

Plate 27

1. ***Cribroperidinium* sp. cf. *C. aceras***
   Rebecca K. Bounds Core, Sample 780', AMOCO Loc. 15129, Slide 68,
   England Finder Reference: F443
2. ***Impagidinium modicum***
   Rebecca K. Bounds Core, Sample 930', AMOCO Loc. 15129, Slide 83,
   England Finder Reference: H514
3. ***Impagidinium modicum***
   Rebecca K. Bounds Core, Sample 970', AMOCO Loc. 15129, Slide 87,
   England Finder Reference: L404
4. ***Impagidinium* sp. C**
   Rebecca K. Bounds Core, Sample 800', AMOCO Loc. 15129, Slide 70,
   England Finder Reference: K352
5. ***Impagidinium delicatum***
   Rebecca K. Bounds Core, Sample 870' (1), AMOCO Loc. 15129, Slide 77,
   England Finder Reference: E463
6. ***Impagidinium delicatum***
   Rebecca K. Bounds Core, Sample 890', AMOCO Loc. 15129, Slide 79,
   England Finder Reference: J523
7. ***Pterodinium? cornutum***
   Rebecca K. Bounds Core, Sample 890', AMOCO Loc. 15129, Slide 79,
   England Finder Reference: F361
8. ***Pterodinium cingulatum***
   Rebecca K. Bounds Core, Sample 1030', AMOCO Loc. 15129, Slide 93,
   England Finder Reference: E482/4



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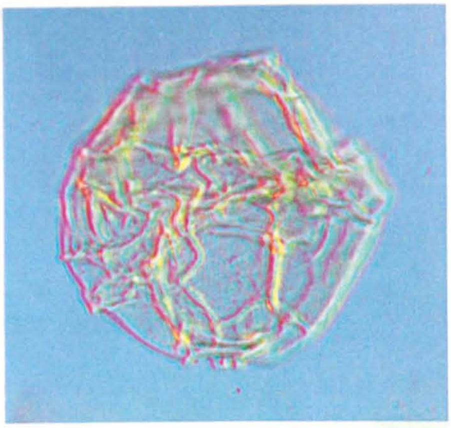

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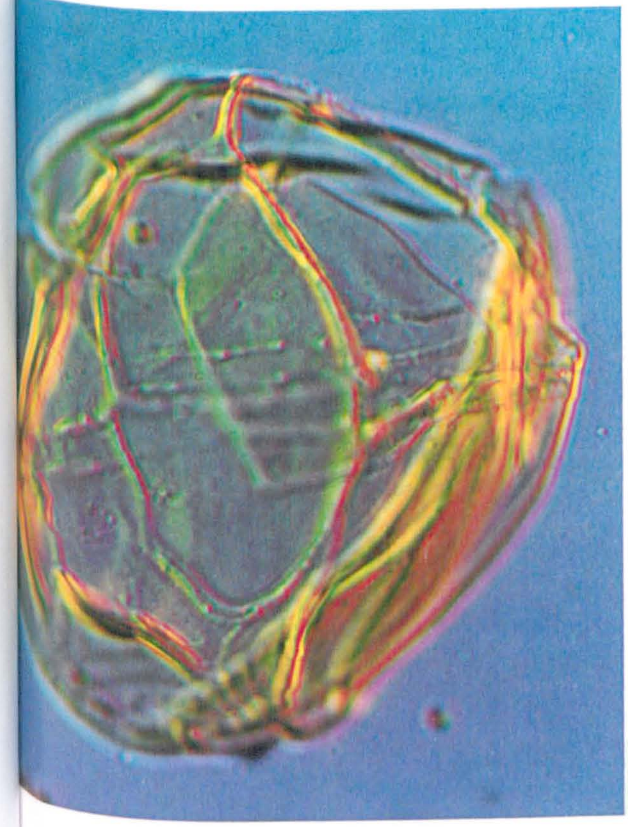

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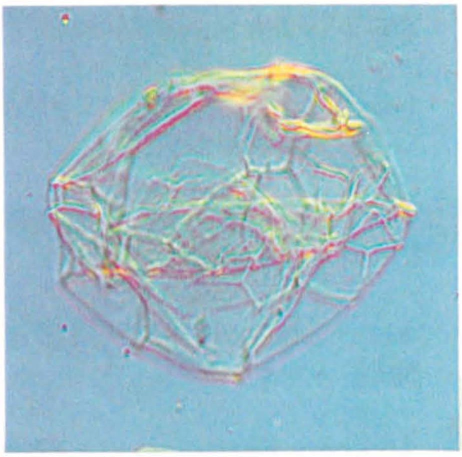

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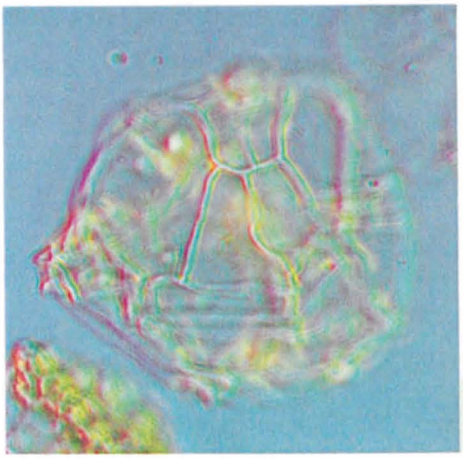

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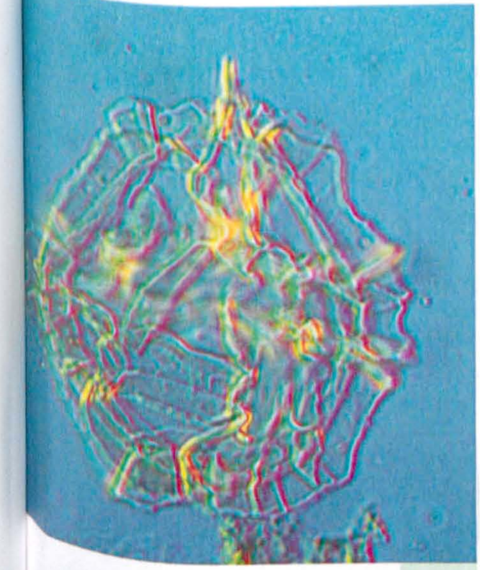

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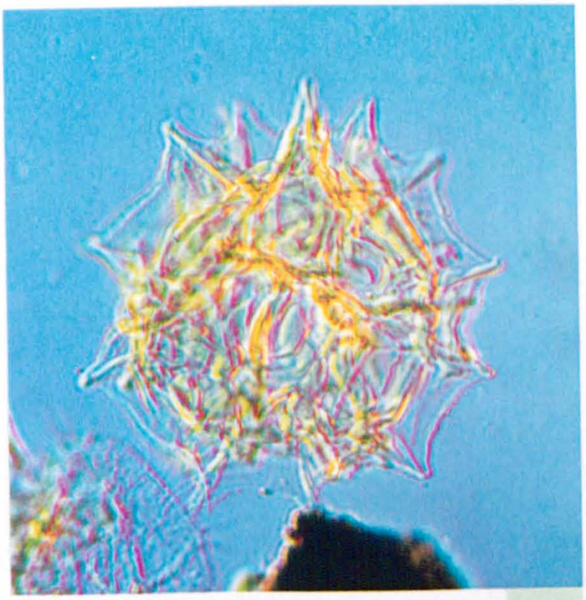

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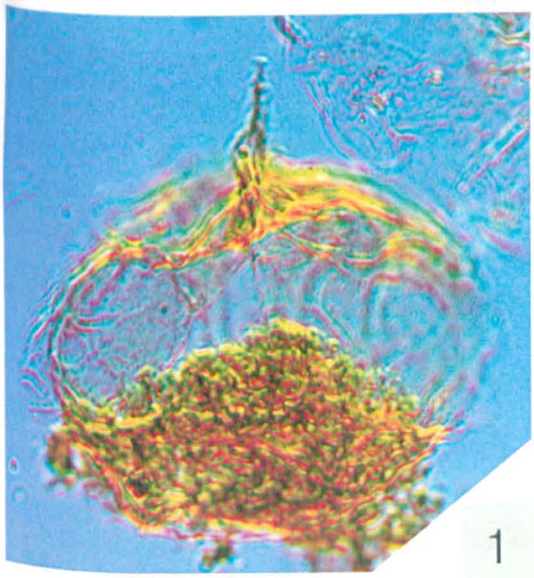
Plate 27

Plate 28

1. ***Cribroperidinium* sp. aff. *C. vexillum***
   Rebecca K. Bounds Core, Sample 750', AMOCO Loc. 15129, Slide 65, England Finder Reference: C421
2. ***Cribroperidinium* sp. aff. *C. vexillum***
   Rebecca K. Bounds Core, Sample 750', AMOCO Loc. 15129, Slide 65, England Finder Reference: K382
3. ***Apteodinium reticulatum***
   Rebecca K. Bounds Core, Sample 1030', AMOCO Loc. 15129, Slide 93, England Finder Reference: L474/483
4. ***Apteodinium reticulatum***
   Pueblo Section, Sample PUB6, Slide PRCIES 2397.3, England Finder Reference: C243
5. ***Apteodinium deflandrei***
   Bunker Hill Section, Sample BH29, Slide PRCIES 2717.16, England Finder Reference: X343
6. ***Apteodinium deflandrei***
   Bunker Hill Section, Sample BH29, Slide PRCIES 2717.16, England Finder Reference: X343
7. ***Apteodinium maculatum grande***
   Rebecca K. Bounds Core, Sample 940', AMOCO Loc. 15129, Slide 84, England Finder Reference: M383



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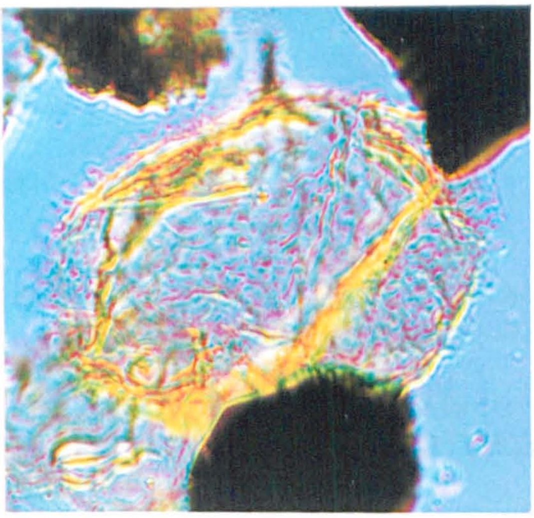

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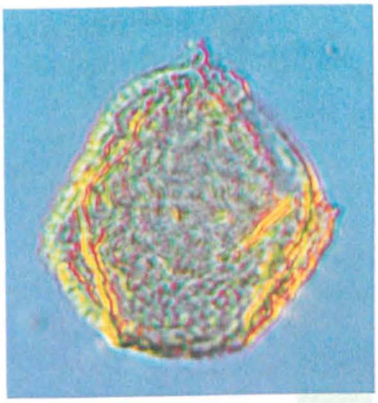

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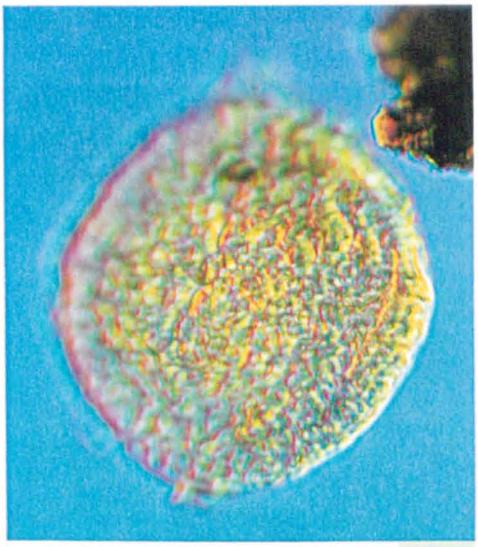

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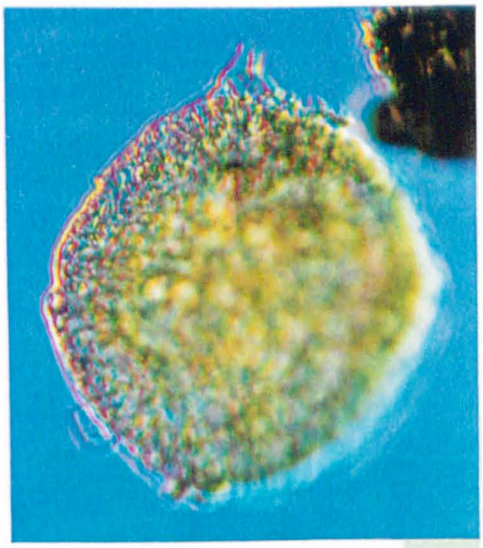

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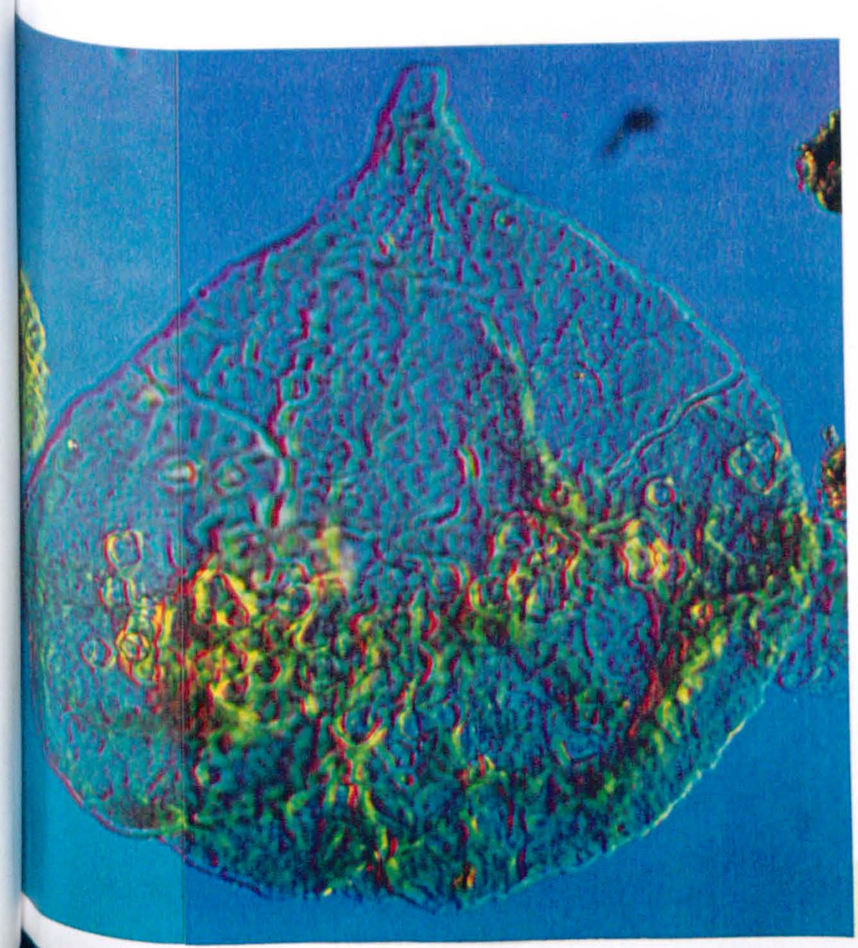

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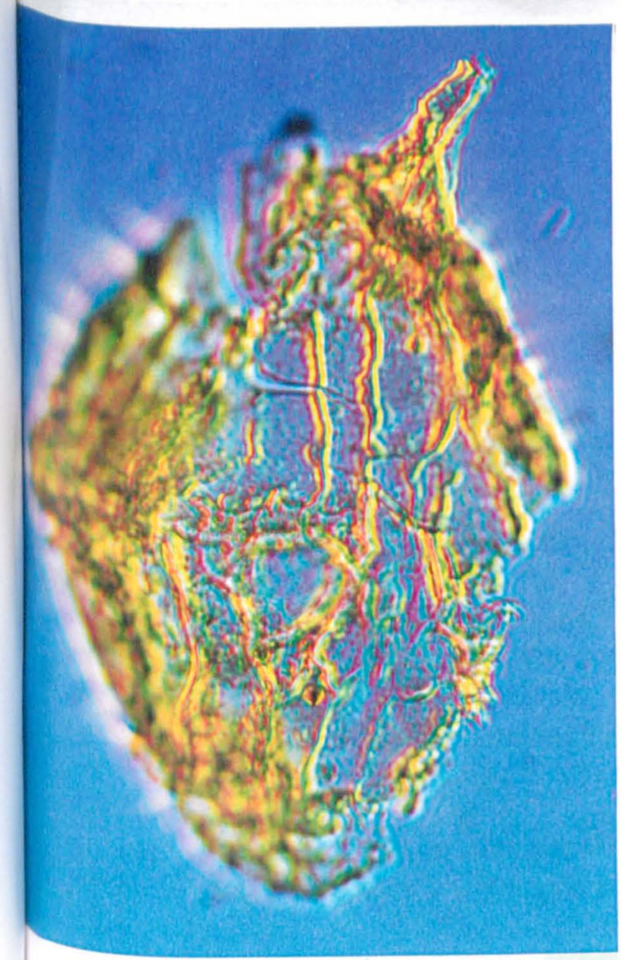
Plate 28

Plate 29

1. ***Cribroperidinium orthoceras***
   Blue Point Section, Sample BMS4/58B-60A, Slide PRCIES 3164.6, England Finder Reference: O392
2. ***Spongodinium* sp. cf. *S. delitiense***
   Rebecca K. Bounds Core, Sample 1110', AMOCO Loc. 15129, Slide 101, England Finder Reference: R352/363
3. ***Cribroperidinium cooksoniae***
   Blue Point Section, Sample BMS4/16B-18A, Slide PRCIES 3139.2, England Finder Reference: N553
4. ***Cribroperidinium cooksoniae***
   Blue Point Section, Sample BMS4/14B-16A, Slide PRCIES 3138.2, England Finder Reference: J241
5. ***Cribroperidinium cooksoniae***
   Blue Point Section, Sample BMS4/14B-16A, Slide PRCIES 3138.2, England Finder Reference: J241



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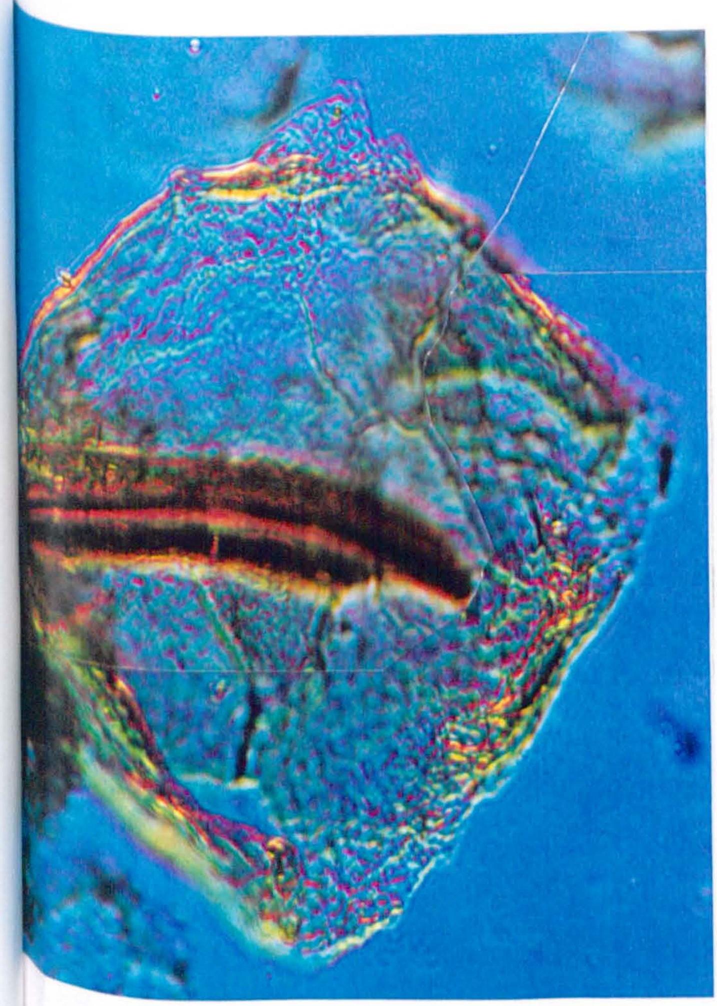

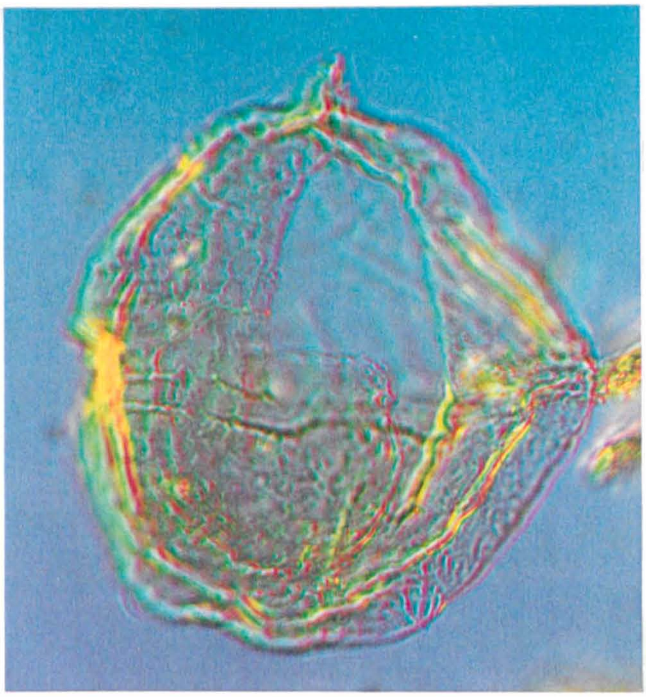

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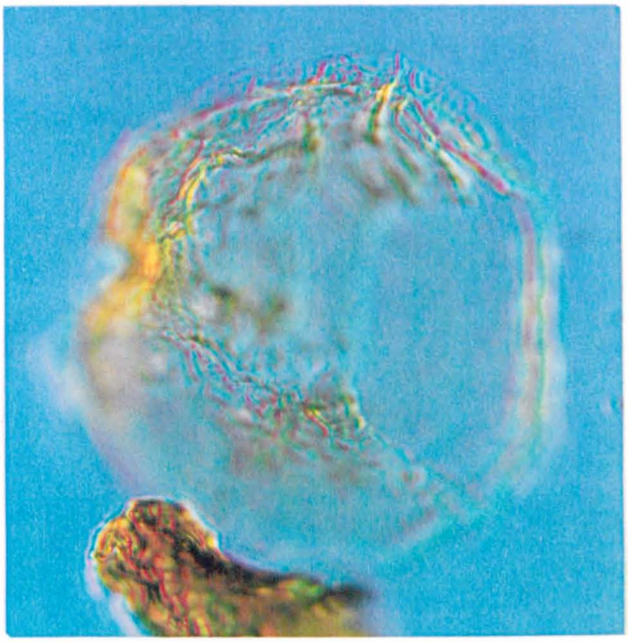

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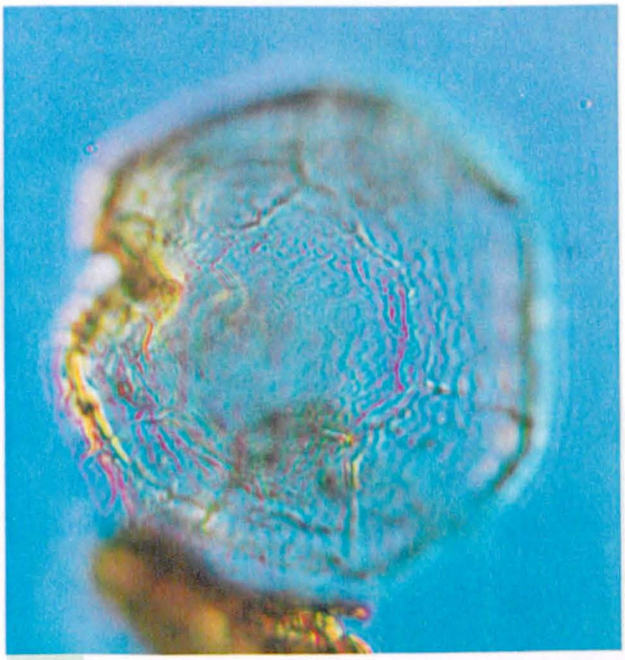

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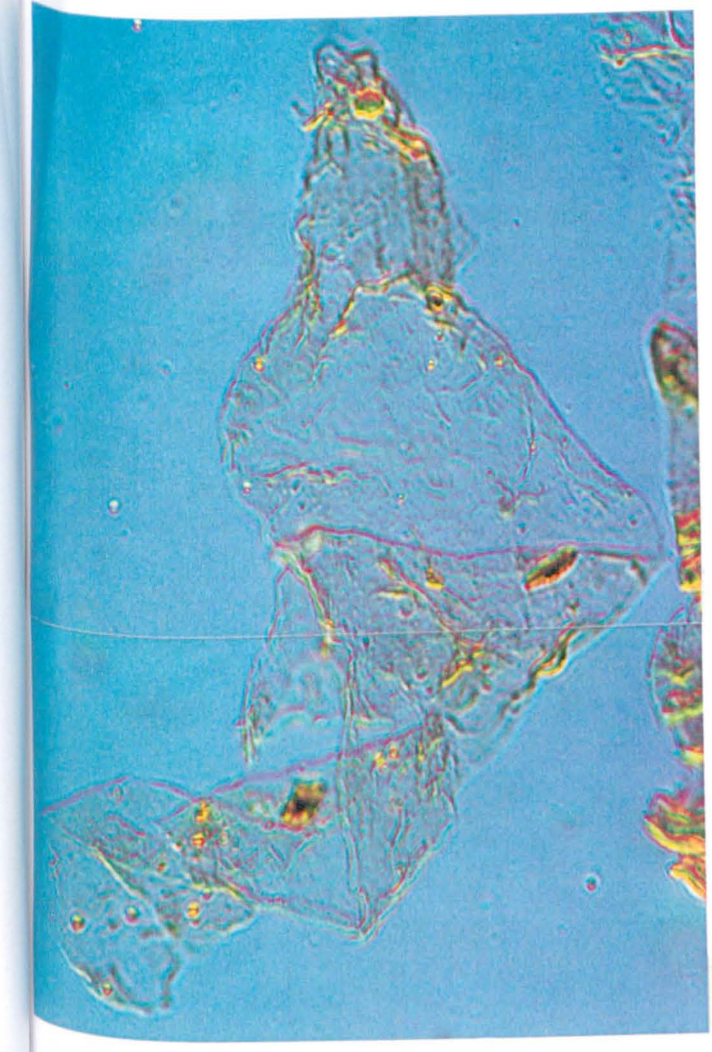
Plate 29

Plate 30

1. *Odontochitina* sp. A
   Rebecca K. Bounds Core, Sample 1128', AMOCO Loc. 15129, Slide 103, England Finder Reference: D413
2. *Nyktericysta* sp. A
   Rebecca K. Bounds Core, Sample 1128', AMOCO Loc. 15129, Slide 103, England Finder Reference: P431
3. *Nyktericysta* sp. A
   Rebecca K. Bounds Core, Sample 1128', AMOCO Loc. 15129, Slide 103, England Finder Reference: D443/4
4. ***Pseudoceratium eisenackii***
   Rebecca K. Bounds Core, Sample 1128', AMOCO Loc. 15129, Slide 103, England Finder Reference: T434
5. ***Pseudoceratium eisenackii***
   Rebecca K. Bounds Core, Sample 1128', AMOCO Loc. 15129, Slide 103, England Finder Reference: T434
6. ***Pseudoceratium eisenackii***
   Blue Point Section, Sample BMS4/38E-38F, Slide PRCIES 3152.2, England Finder Reference: T511



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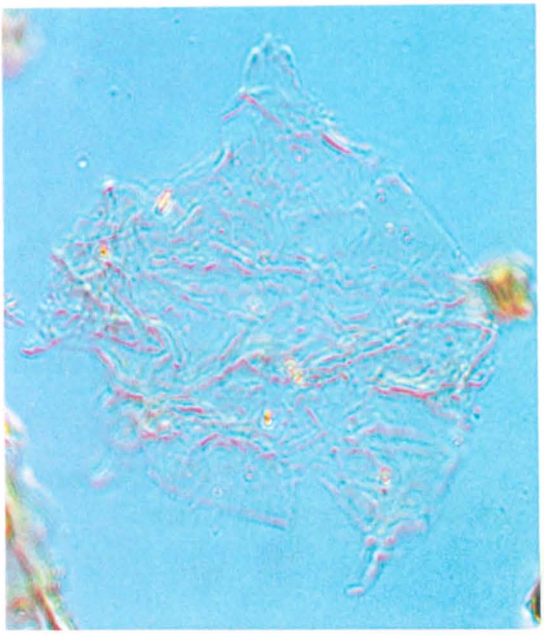

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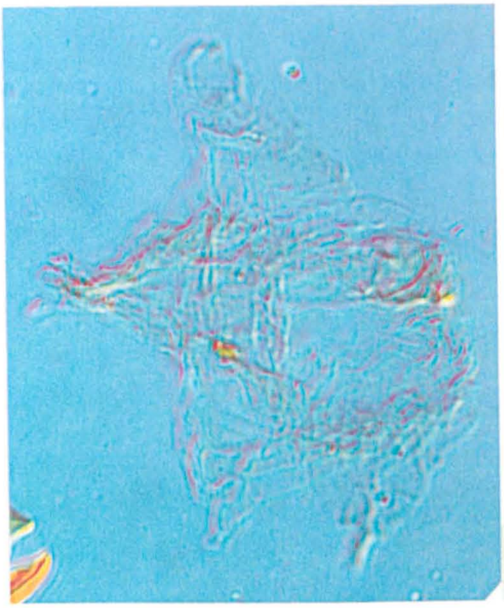

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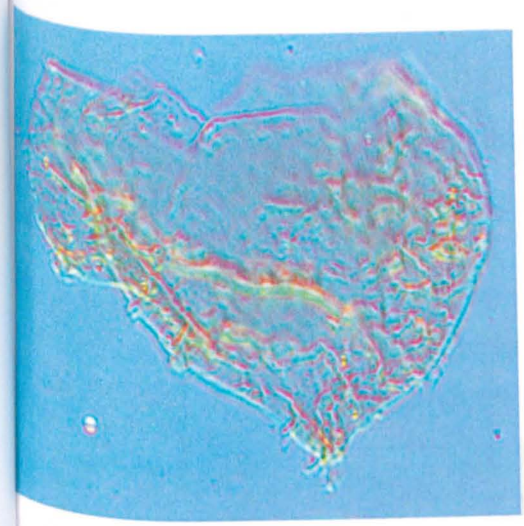

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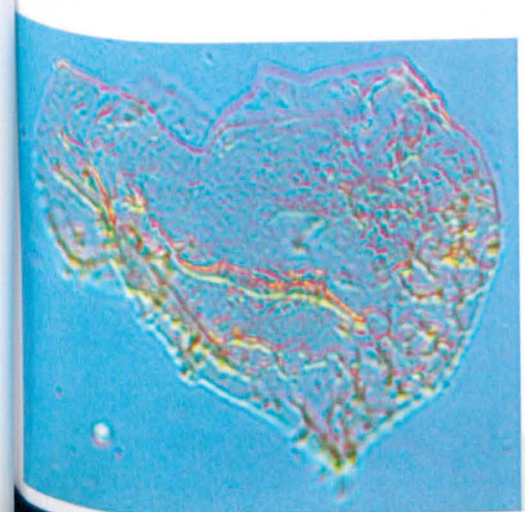

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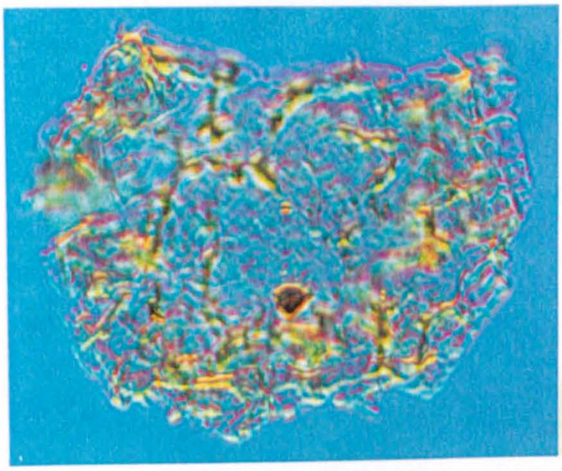

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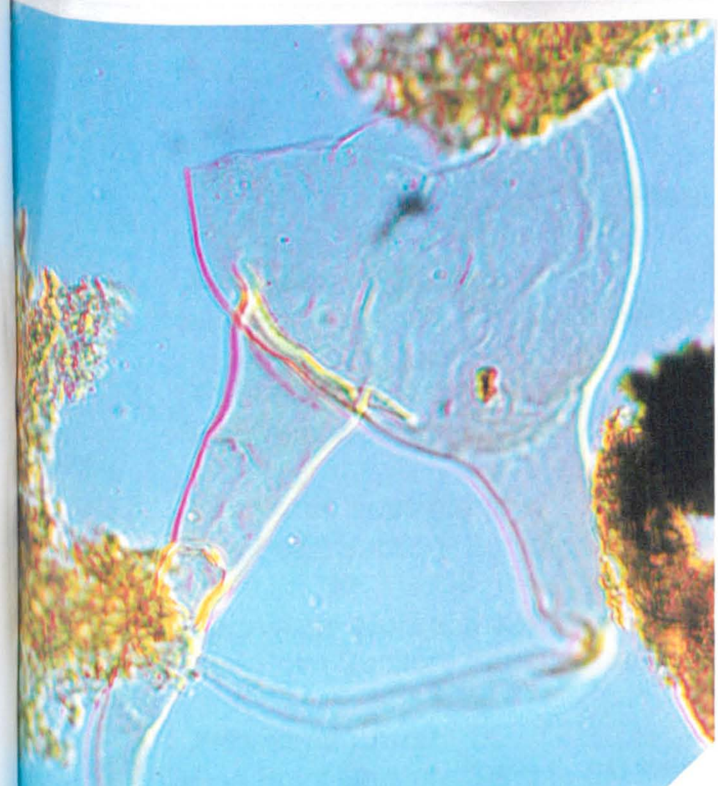
Plate 30

Plate 31

1. ***Odontochitina operculata***
   Rebecca K. Bounds Core, Sample 980', AMOCO Loc. 15129, Slide 88, England Finder Reference: R403
2. ***Odontochitina rhakodes***
   Blue Point Section, Sample BMS4/38I-39A, Slide PRCIES 3154.4, England Finder Reference: F261
3. ***Odontochitina costata***
   Blue Point Section, Sample BMS4/16B-18A, Slide PRCIES 3139.2, England Finder Reference: U303



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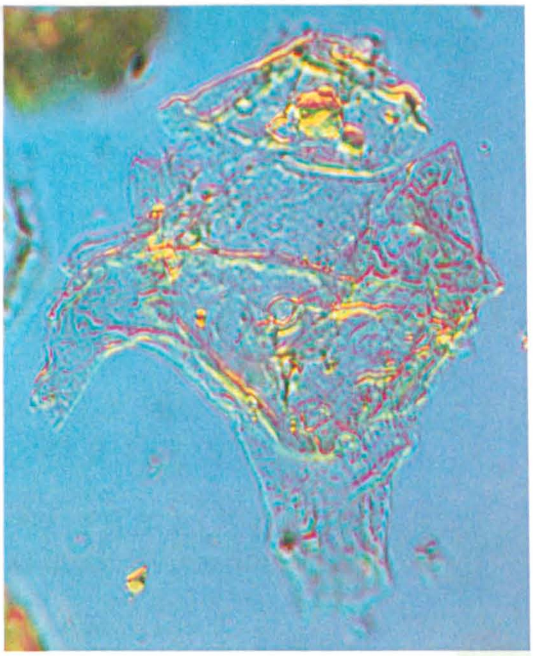

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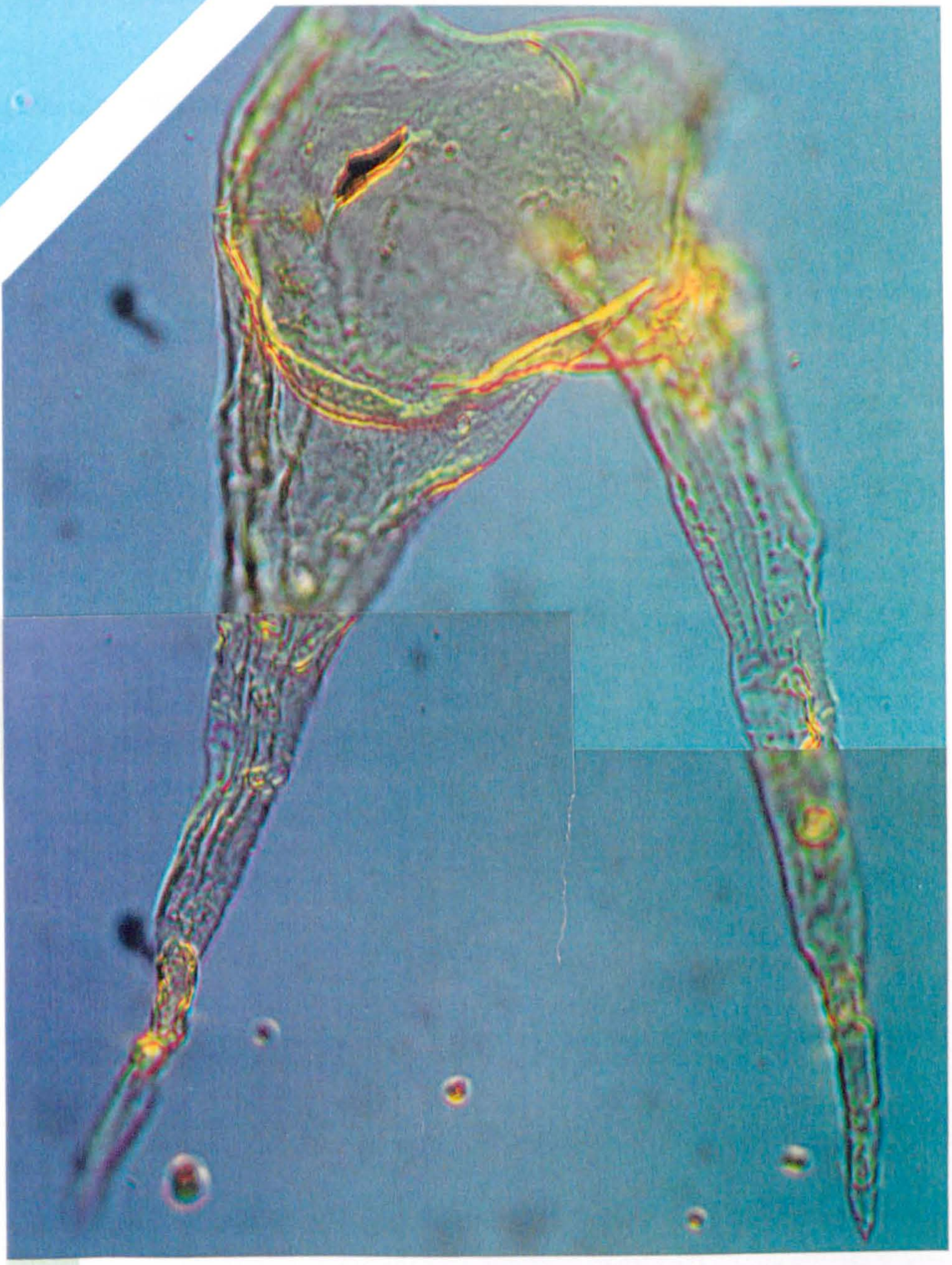

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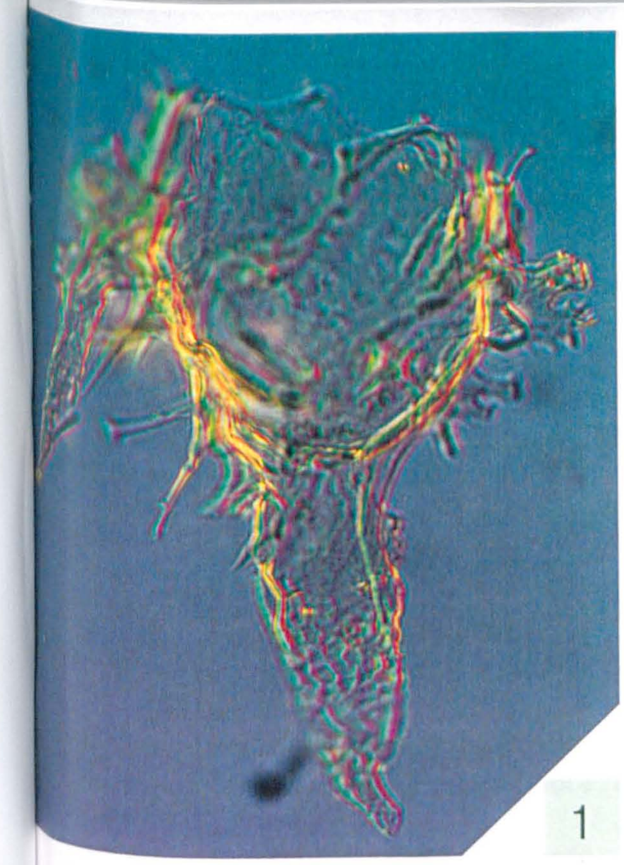
Plate 31

Plate 32

1. ***Xenascus perforatus***
   Blue Point Section, Sample BMS4/16B-18A, Slide PRCIES 3139.2, England
   Finder Reference: X381
2. ***Xenascus australensis***
   Blue Point Section, Sample BMS4/14B-16A, Slide PRCIES 3138.2, England
   Finder Reference: P202
3. ***Xenascus australensis***
   Blue Point Section, Sample BMS4/14B-16A, Slide PRCIES 3138.2, England
   Finder Reference: P202
4. ***Xenascus australensis***
   Blue Point Section, Sample BMS4/18B-20A, Slide PRCIES 3140.2, England
   Finder Reference: H464
5. ***Xenascus plotei***
   Blue Point Section, Sample BMS4/16B-18A, Slide PRCIES 3139.2, England
   Finder Reference: D382
6. ***Xenascus plotei***
   Blue Point Section, Sample BMS4/34B-36A, Slide PRCIES 3149.2, England
   Finder Reference: E261



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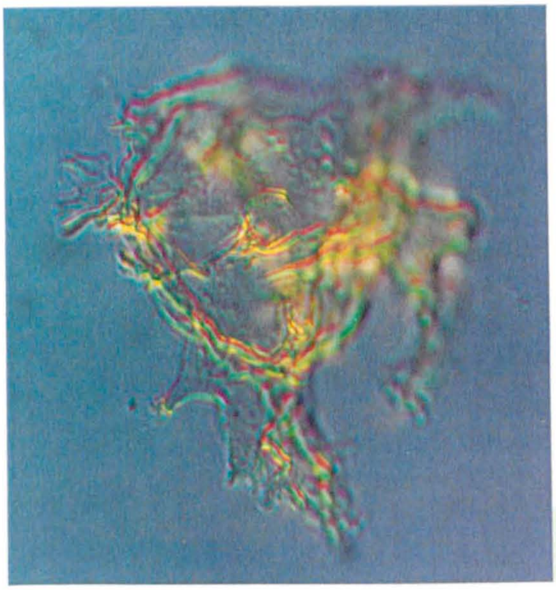

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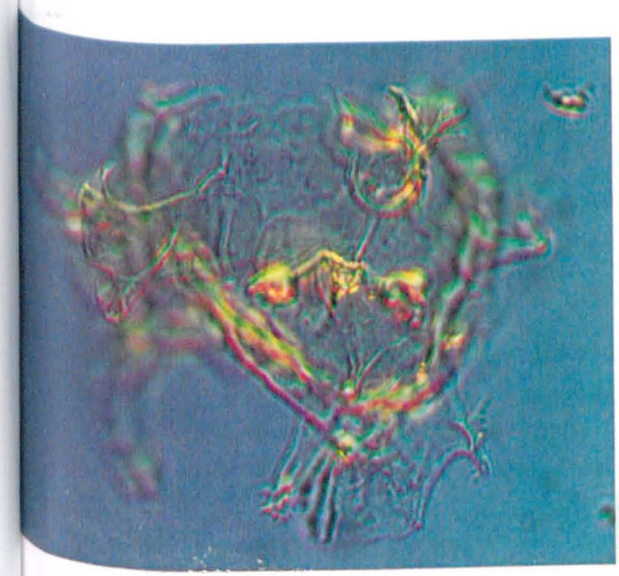

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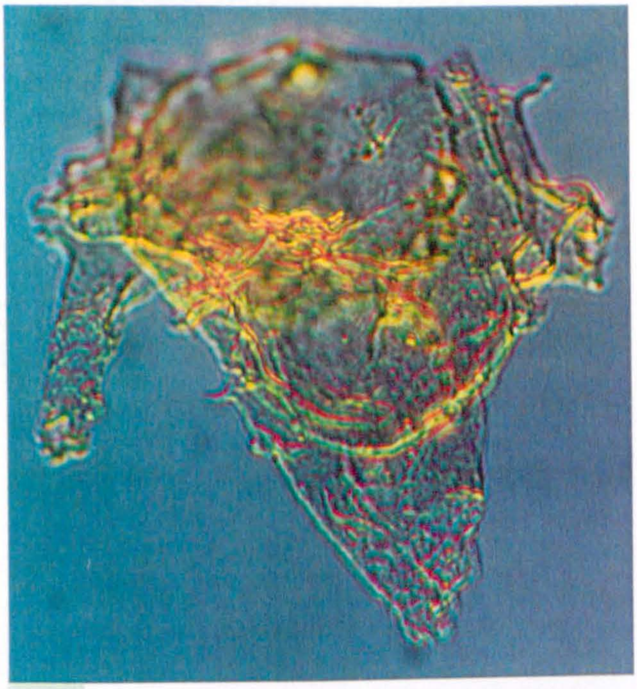

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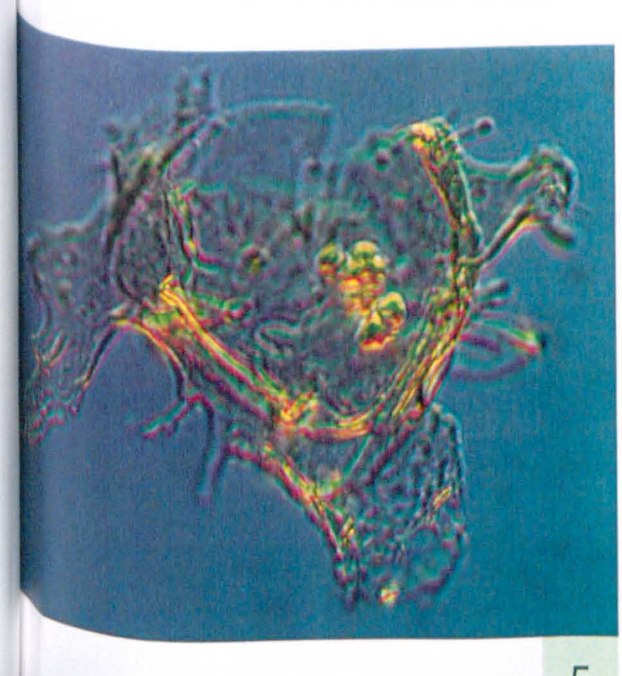

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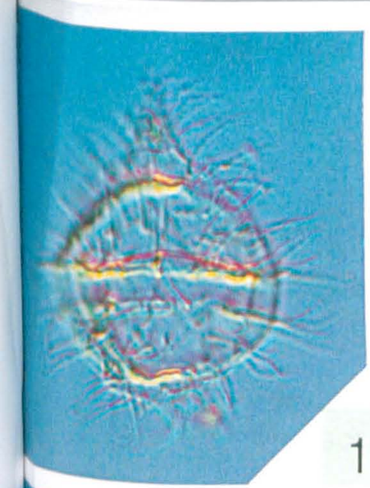
Plate 32

Plate 33

1. ***Palaeohystrichophora infusorioides***
Blue Point Section, Sample BMS4/3-5, Slide PRCIES 3134.1, England Finder Reference: G351
2. ***Palaeohystrichophora infusorioides***
Blue Point Section, Sample BMS4/3-5, Slide PRCIES 3134.1, England Finder Reference: G351
3. ***Subtilisphaera cheit***
Pueblo Section, Sample PH3, Slide PRCIES 3398.1, England Finder Reference: V211
4. ***Subtilisphaera cheit***
Rebecca K. Bounds Core, Sample 930', AMOCO Loc. 15129, Slide 83, England Finder Reference: L401/3
5. ***Subtilisphaera? inaffecta***
Rebecca K. Bounds Core, Sample 870 (1)', AMOCO Loc. 15129, Slide77, England Finder Reference: C443
6. ***Subtilisphaera? inaffecta***
Rebecca K. Bounds Core, Sample 850', AMOCO Loc. 15129, Slide 75, England Finder Reference: M513/4
7. ***Subtilisphaera pontis-marie***
Rebecca K. Bounds Core, Sample 950', AMOCO Loc. 15129, Slide 85, England Finder Reference: N431
8. ***Subtilisphaera pontis-marie***
Bunker Hill Section, Sample BH37, Slide PRCIES 2725.15, England Finder Reference: C464
9. ***Subtilisphaera zawia***
Wahweap Wash Section, Sample NBU/23-24, Slide PRCIES 3131.4, England Finder Reference: H283/J281
10. ***Subtilisphaera pirnaensis***
Rebecca K. Bounds Core, Sample 1000', AMOCO Loc. 15129, Slide90, England Finder Reference: K311
11. ***Subtilisphaera hyalina***
Rebecca K. Bounds Core, Sample 1100', AMOCO Loc. 15129, Slide 100, England Finder Reference: E341/D343
12. ***Subtilisphaera hyalina***
Rebecca K. Bounds Core, Sample 1100', AMOCO Loc. 15129, Slide 100, England Finder Reference: E341/D343
13. ***Subtilisphaera foliacea***
Rebecca K. Bounds Core, Sample 910', AMOCO Loc. 15129, Slide 81, England Finder Reference: D414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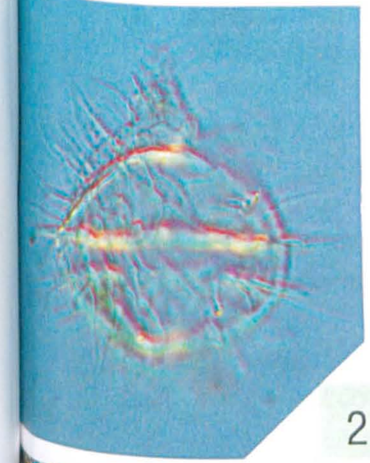
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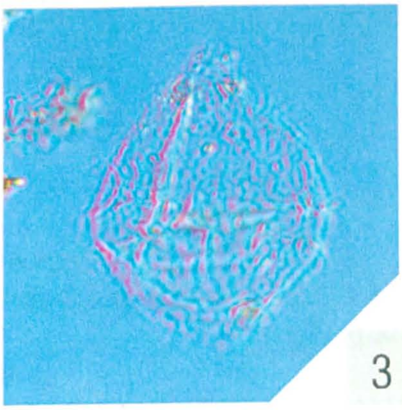
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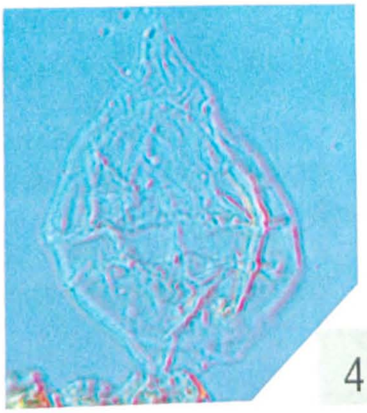
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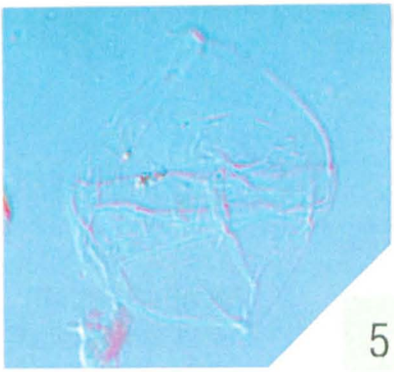
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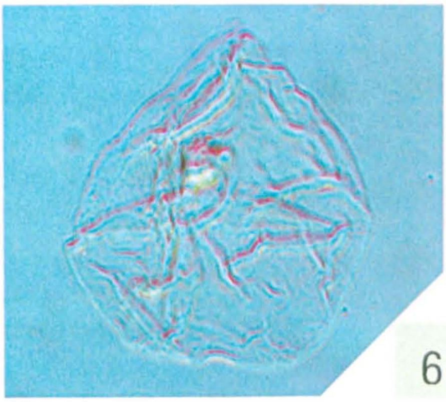
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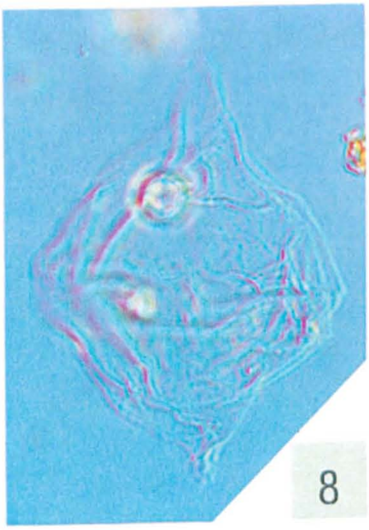
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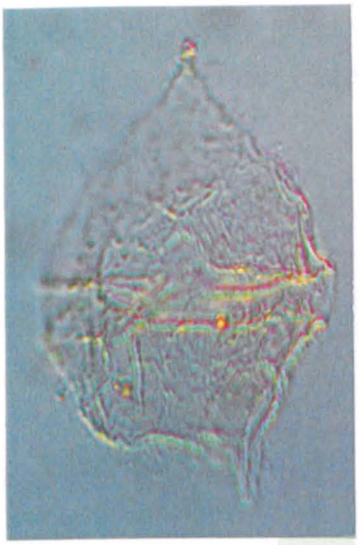
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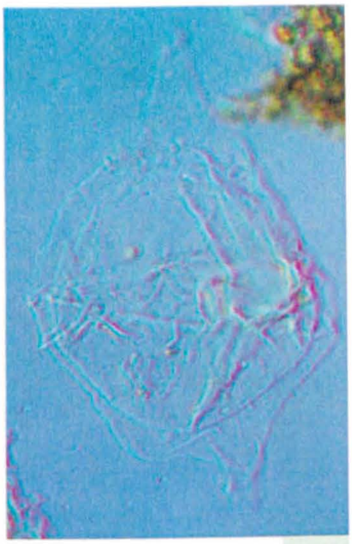
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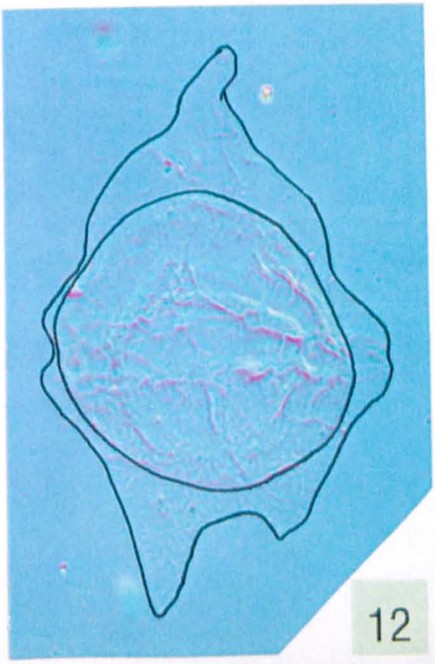
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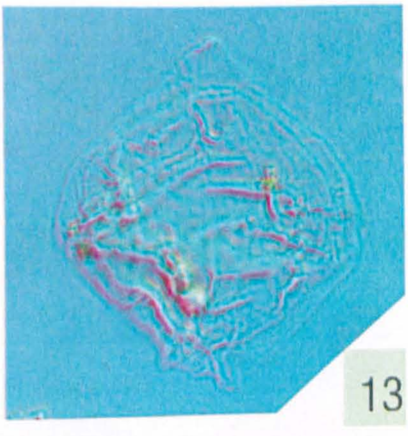
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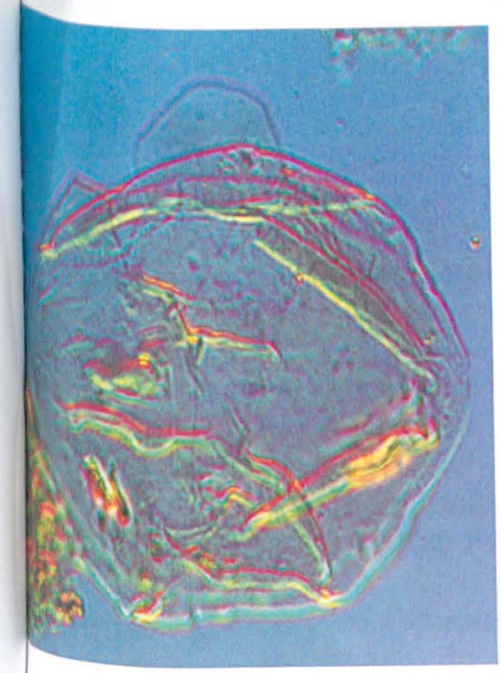
Plate 33

Plate 34

1. ***Isabelidinium? globosum***
   Rebecca K. Bounds Core, Sample 950', AMOCO Loc. 15129, Slide 85, England Finder Reference: N393
2. ***Eurydinium ingramii***
   Rebecca K. Bounds Core, Sample 820', AMOCO Loc. 15129, Slide 72, England Finder Reference: L381
3. ***Eurydinium glomeratum***
   Rebecca K. Bounds Core, Sample 860 (1)', AMOCO Loc. 15129, Slide76, England Finder Reference: J504
4. ***Eurydinium saxoniensis***
   Rebecca K. Bounds Core, Sample 930', AMOCO Loc. 15129, Slide 83, England Finder Reference: C513
5. ***Eurydinium eyrensis***
   Rebecca K. Bounds Core, Sample 780', AMOCO Loc. 15129, Slide 68, England Finder Reference: K352
6. ***Eurydinium eyrensis***
   Pueblo Section, Sample PUB4, Slide PRCIES 2385.2, England Finder Reference: L423/M421
7. ***Eurydinium eyrensis***
   Blue Point Section, Sample BMS4/42B-44A, Slide PRCIES 3156.6, England Finder Reference: O262/4



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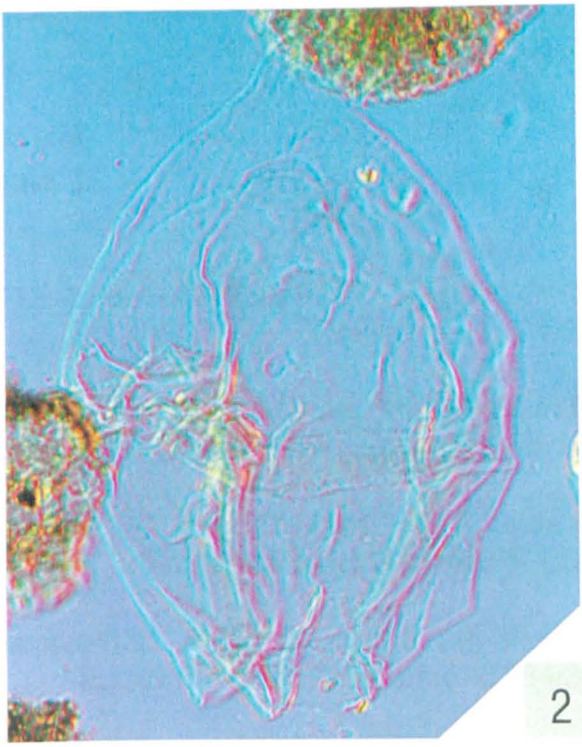

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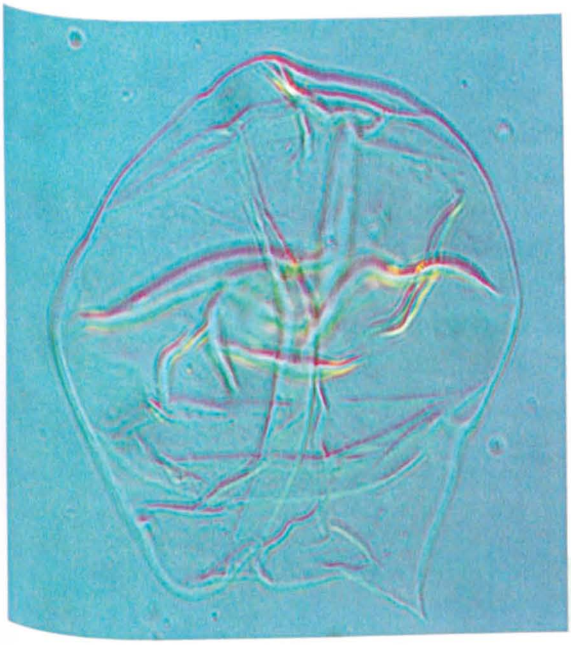

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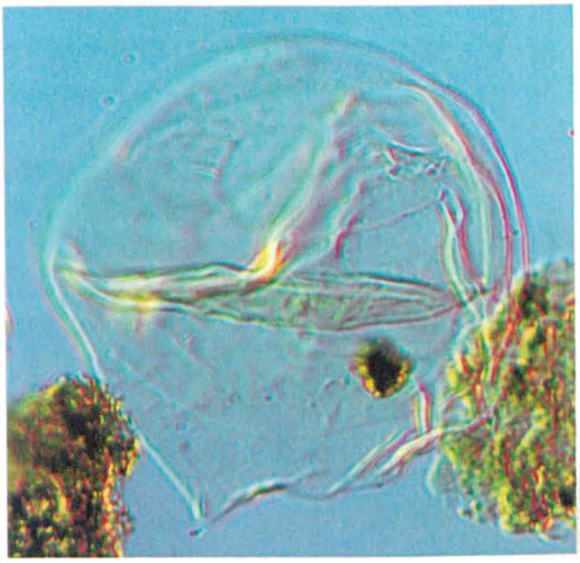

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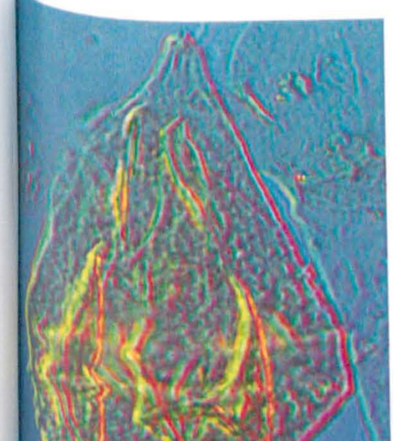

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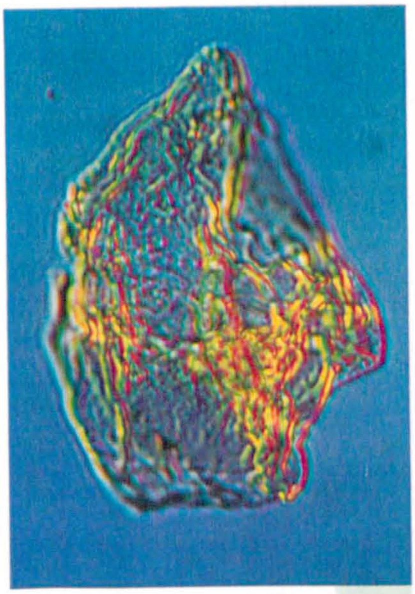

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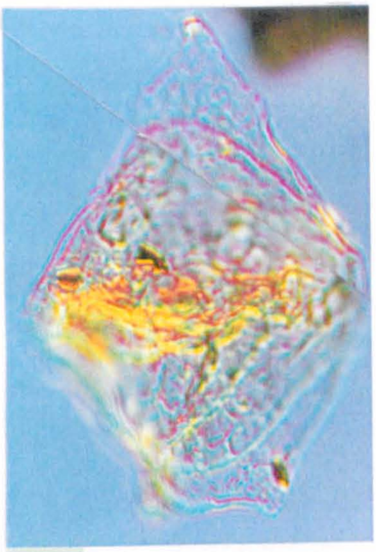

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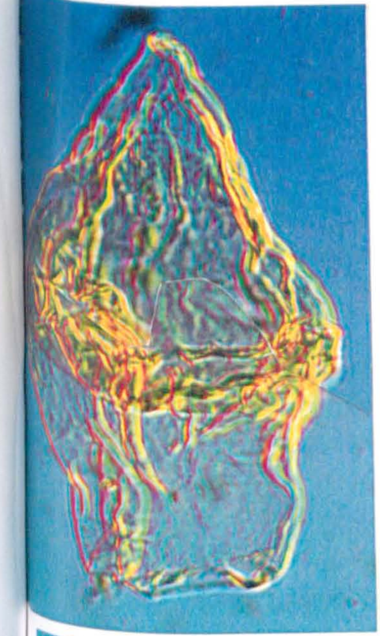
Plate 34

Plate 35

1. ***Isabelidinium magnum***
   Pueblo Section, Sample PUB12, Slide PRCIES 2403.2, England Finder Reference: L504/513
2. ***Isabelidinium magnum***
   Rebecca K. Bounds Core, Sample 790', AMOCO Loc. 15129, Slide 69, England Finder Reference: B511/3
3. ***Isabelidinium cooksoniae***
   Rebecca K. Bounds Core, Sample 780', AMOCO Loc. 15129, Slide 68, England Finder Reference: C331
4. ***Chatangiella spectabilis***
   Rebecca K. Bounds Core, Sample 820', AMOCO Loc. 15129, Slide 72, England Finder Reference: C384/393
5. ***Chatangiella spectabilis***
   Rebecca K. Bounds Core, Sample 820', AMOCO Loc. 15129, Slide 72, England Finder Reference: C384/393
6. ***Chatangiella victoriensis***
   Rebecca K. Bounds Core, Sample 760', AMOCO Loc. 15129, Slide 66, England Finder Reference: H412
7. ***Alterbidinium emulatum***
   Wahweap Wash Section, Sample NBU/54B-54C, Slide PRCIES 3347.5, England Finder Reference: G183/H181
8. ***Alterbidinium emulatum***
   Rebecca K. Bounds Core, Sample 900', AMOCO Loc. 15129, Slide 80, England Finder Reference: G364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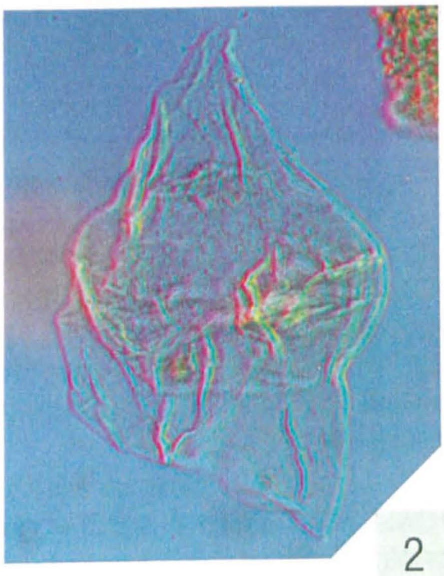
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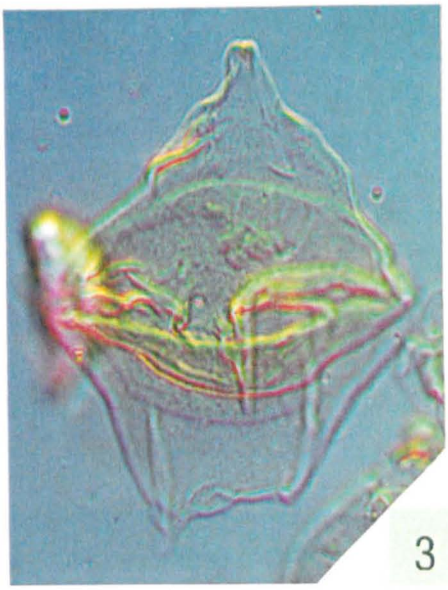
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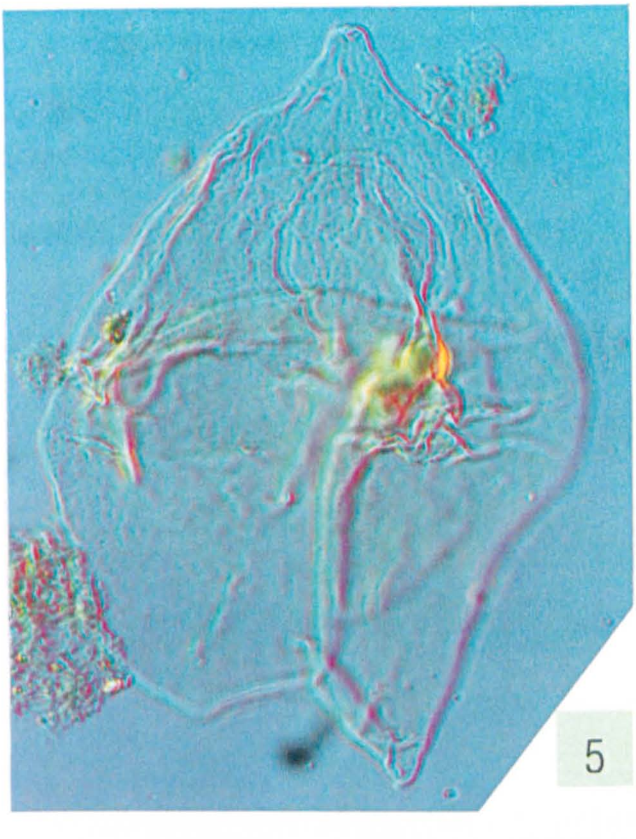
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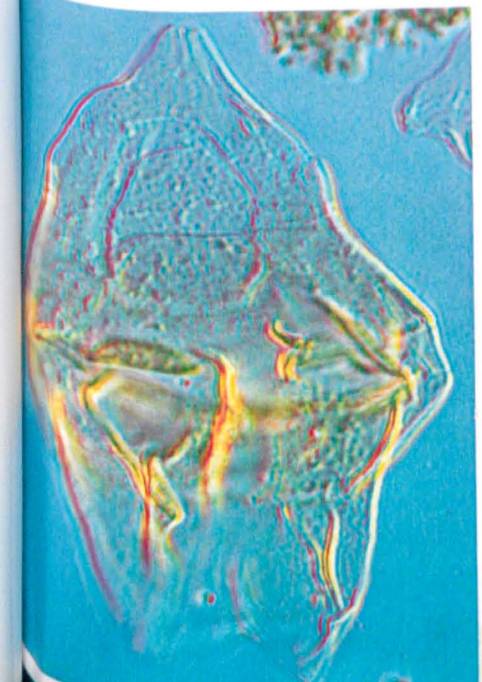
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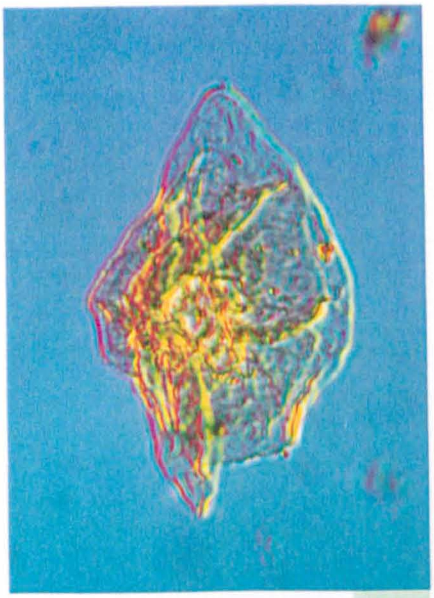
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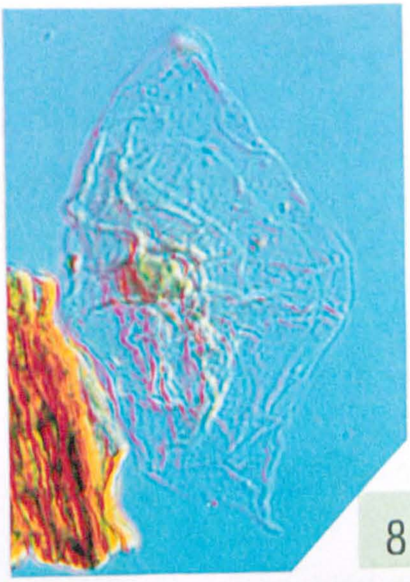
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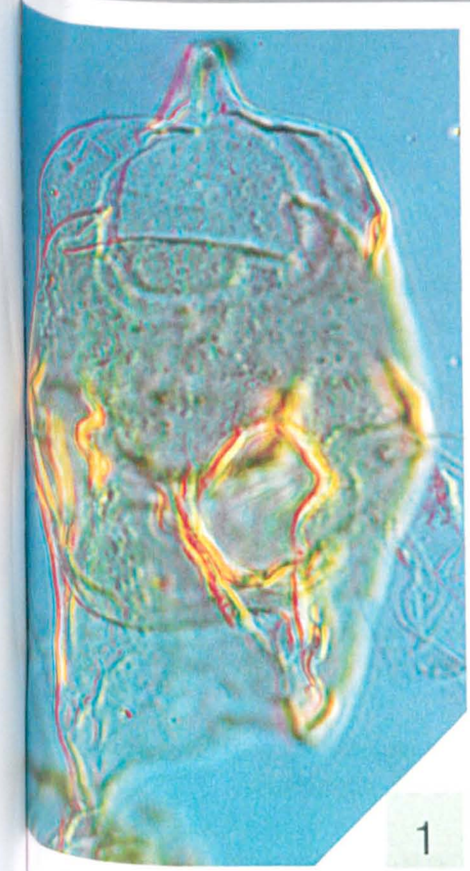
Plate 35

Plate 36

1. ***Chatangiella granulifera***
   Rebecca K. Bounds Core, Sample 760', AMOCO Loc. 15129, Slide 66, England Finder Reference: H492
2. ***Chatangiella granulifera***
   Rebecca K. Bounds Core, Sample 760', AMOCO Loc. 15129, Slide 66, England Finder Reference: H492
3. ***Chatangiella granulifera tenuis***
   Rebecca K. Bounds Core, Sample 840', AMOCO Loc. 15129, Slide 74, England Finder Reference: L431
4. ***Chatangiella granulifera tenuis***
   Rebecca K. Bounds Core, Sample 820', AMOCO Loc. 15129, Slide 72, England Finder Reference: G501
5. ***Alterbidinium rhombovale***
   Rebecca K. Bounds Core, Sample 770', AMOCO Loc. 15129, Slide 67, England Finder Reference: F504/G501
6. ***Alterbidinium rhombovale***
   Rebecca K. Bounds Core, Sample 970', AMOCO Loc. 15129, Slide 87, England Finder Reference: L462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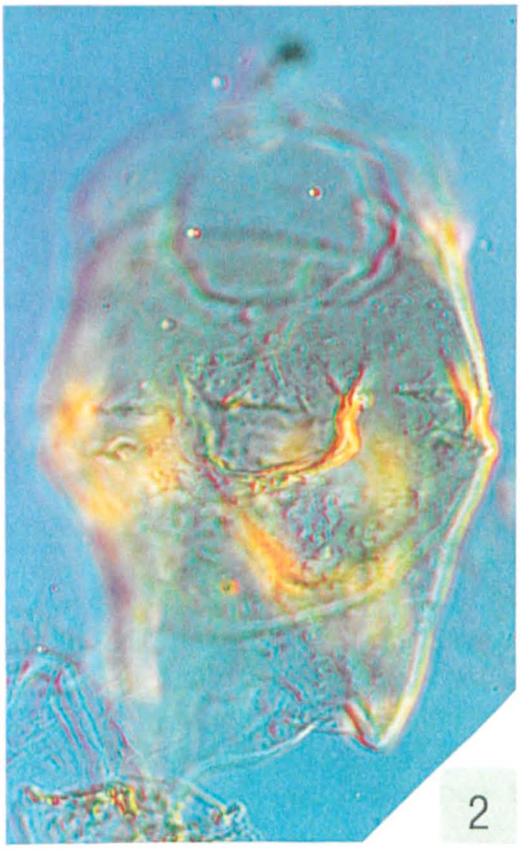
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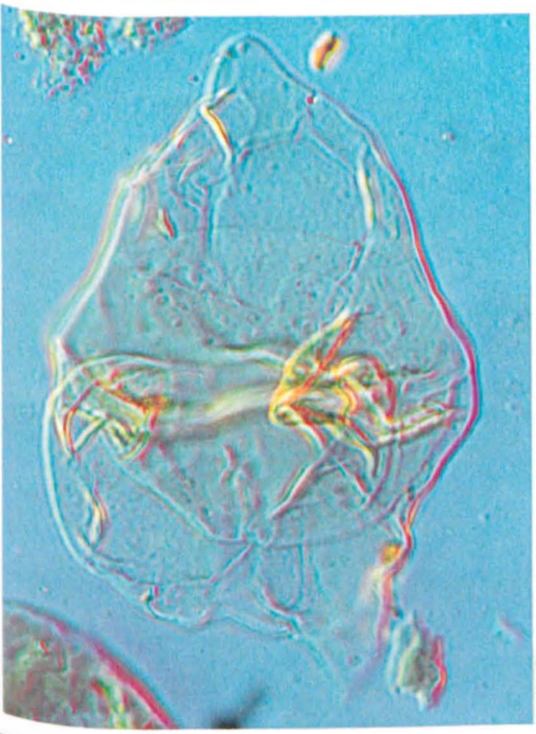
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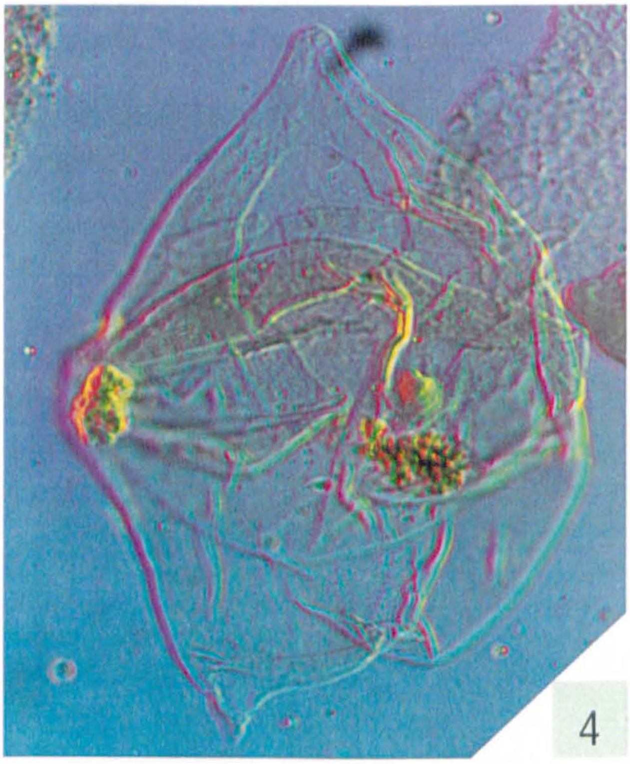
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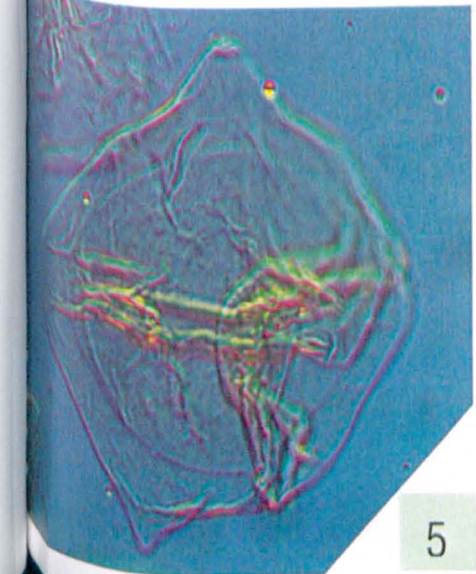
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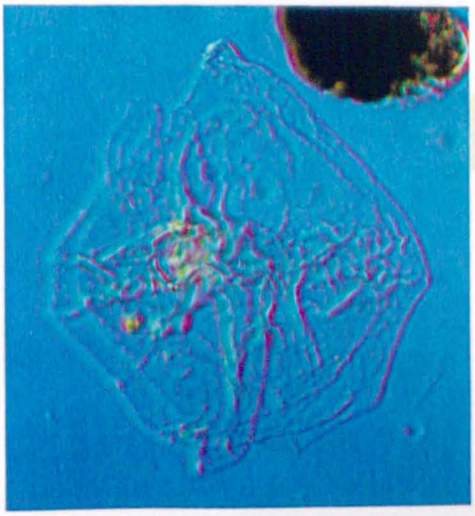
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Plate 36

Plate 37

1. ***Trithyrodinium dubium***
   Rebecca K. Bounds Core, Sample 790', AMOCO Loc. 15129, Slide 69, England Finder Reference: D443
2. ***Trithyrodinium dubium***
   Rebecca K. Bounds Core, Sample 790', AMOCO Loc. 15129, Slide 69, England Finder Reference: D443
3. ***Trithyrodinium dubium***
   Rebecca K. Bounds Core, Sample 800', AMOCO Loc. 15129, Slide 70, England Finder Reference: G441
4. ***Trithyrodinium suspectum***
   Rebecca K. Bounds Core, Sample 970', AMOCO Loc. 15129, Slide 87, England Finder Reference: U431
5. ***Trithyrodinium suspectum***
   Rebecca K. Bounds Core, Sample 770', AMOCO Loc. 15129, Slide 67, England Finder Reference: E441/3
6. ***Trithyrodinium* sp. cf. *T. evittii***
   Rebecca K. Bounds Core, Sample 880', AMOCO Loc. 15129, Slide 78, England Finder Reference: L382
7. ***Trithyrodinium* sp. cf. *T. evittii***
   Rebecca K. Bounds Core, Sample 1000', AMOCO Loc. 15129, Slide90, England Finder Reference: M472
8. ***Ginginodinium evittii***
   Rebecca K. Bounds Core, Sample 1119.5', AMOCO Loc. 15129, Slide 102, England Finder Reference: B433

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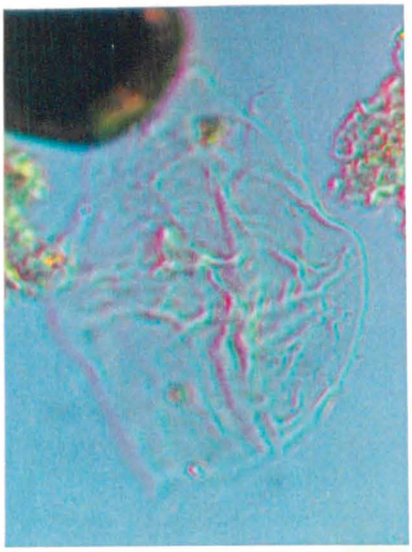

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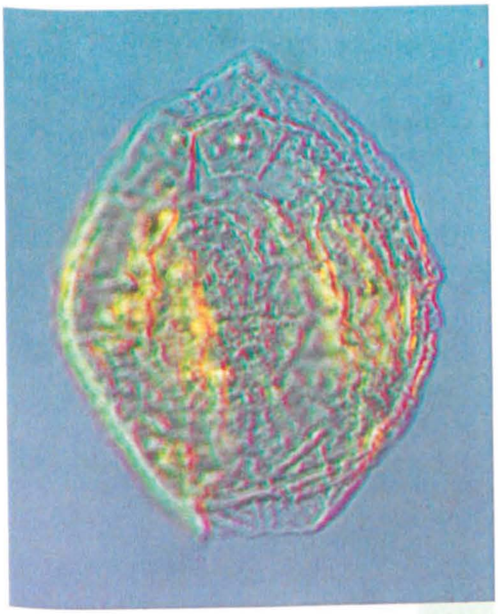

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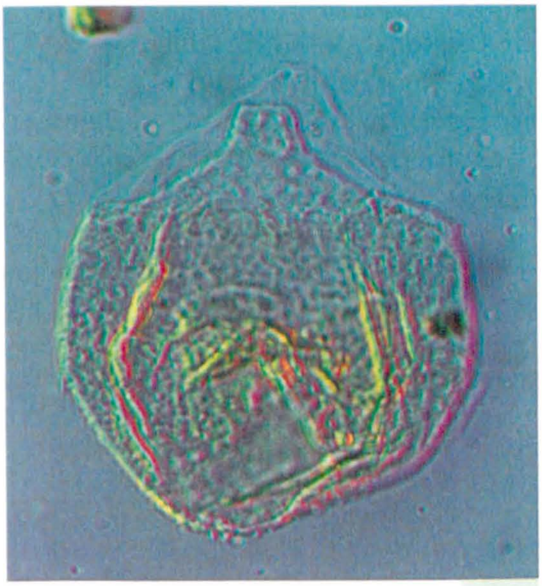

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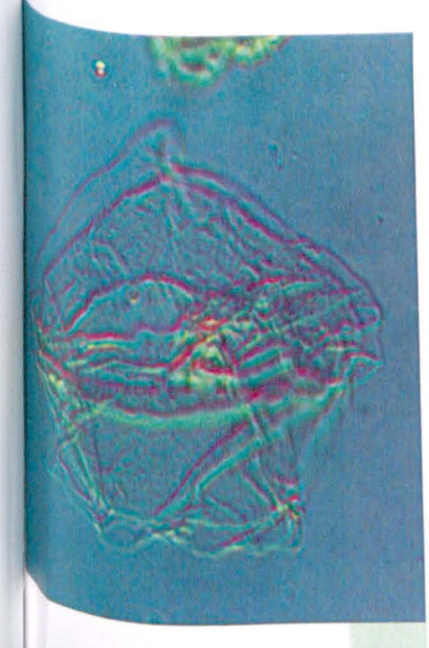

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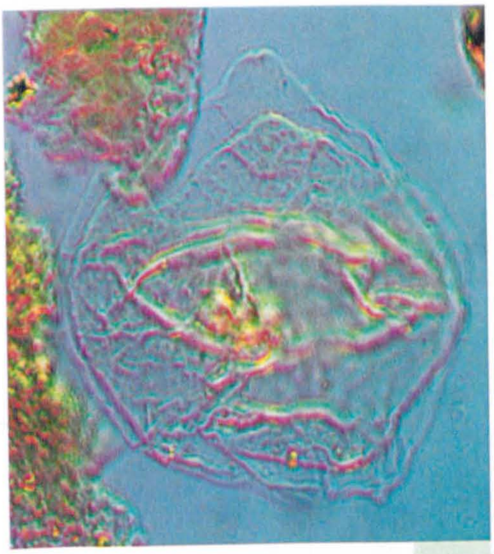

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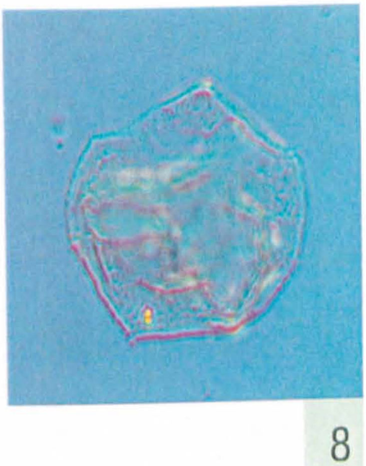

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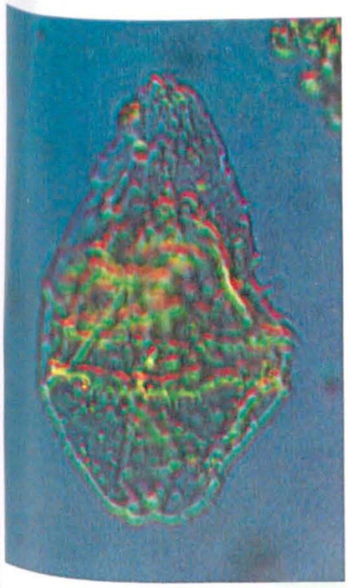
Plate 37

Plate 38

1. ***Chichaouadinium vestitum***
Rebecca K. Bounds Core, Sample 990', AMOCO Loc. 15129, Slide 89, England Finder Reference: W523
2. ***Chichaouadinium boydii***
Rebecca K. Bounds Core, Sample 990', AMOCO Loc. 15129, Slide 89, England Finder Reference: N391
3. ***Chichaouadinium boydii***
Rebecca K. Bounds Core, Sample 990', AMOCO Loc. 15129, Slide 89, England Finder Reference: N391
4. ***Nelsoniella aceras***
Rebecca K. Bounds Core, Sample 1119.5', AMOCO Loc. 15129, Slide 102, England Finder Reference: B354
5. ***Palaeoperidinium cretaceum***
Blue Point Section, Sample BMS4/26-27A, Slide PRCIES 3144.3, England Finder Reference: L312
6. ***Epelidosphaeridia spinosa***
Pueblo Section, Sample PUB19, Slide PRCIES 2410.2, England Finder Reference: Y444
7. ***Ovoidinium verrucosum***
Rebecca K. Bounds Core, Sample 1119.5', AMOCO Loc. 15129, Slide 102, England Finder Reference: M412
8. ***Ovoidinium scabrosum***
Rebecca K. Bounds Core, Sample 1119.5', AMOCO Loc. 15129, Slide 102, England Finder Reference: F371



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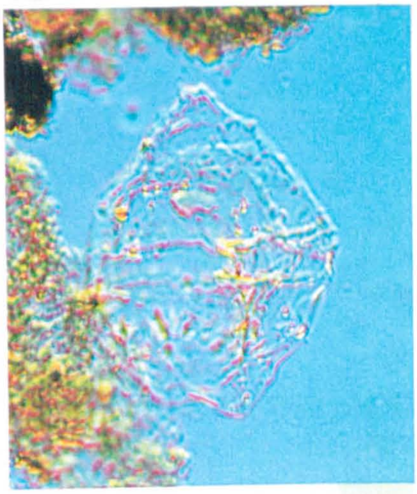

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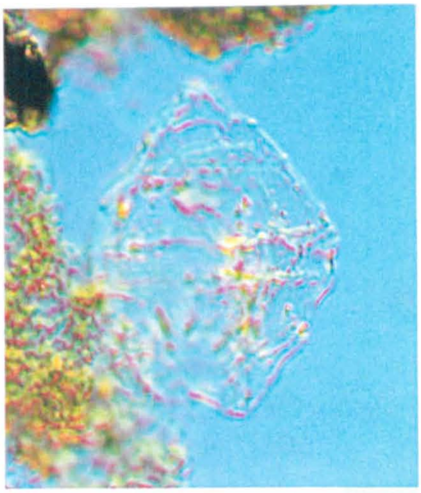

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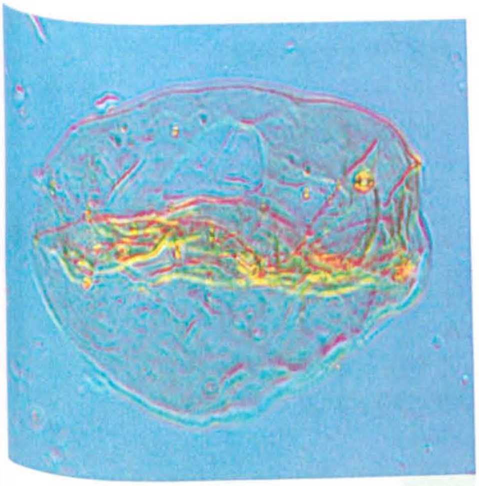

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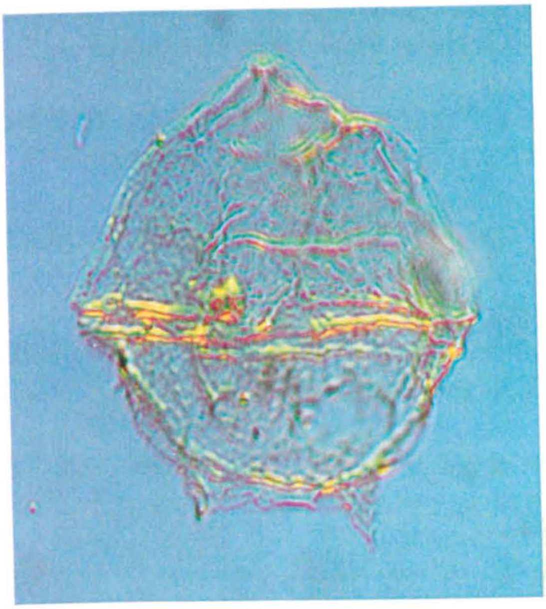

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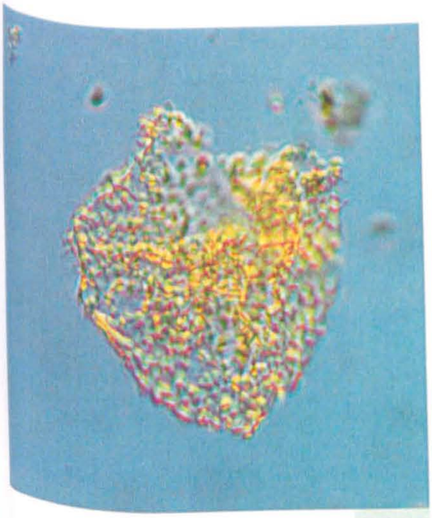

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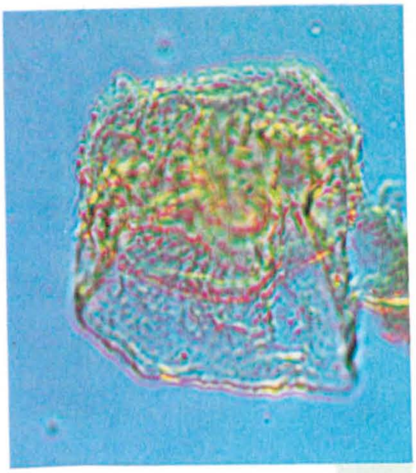

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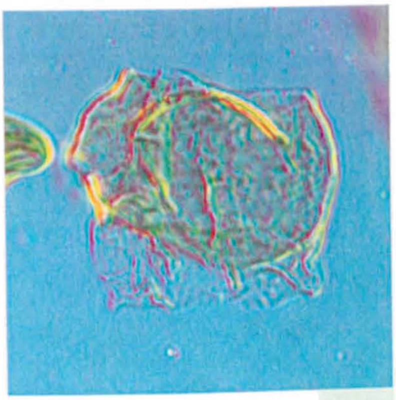

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Plate 38

Plate 39

1. ***Pareodinia ceratophora***
   Blue Point Section, Sample BMS4/16B-18A, Slide PRCIES 3139.2, England Finder Reference: M533
2. ***Palaeotetradinium silicorum***
   Rebecca K. Bounds Core, Sample 900', AMOCO Loc. 15129, Slide 80, England Finder Reference: D392
3. ***Dinogymnium vozzhennikovae***
   Rebecca K. Bounds Core, Sample 990', AMOCO Loc. 15129, Slide 89, England Finder Reference: C491
4. ***Wallodinium anglicum***
   Rebecca K. Bounds Core, Sample 1060', AMOCO Loc. 15129, Slide 96, England Finder Reference: D323
5. ***Trigonopyxidia ginella***
   Rebecca K. Bounds Core, Sample 910', AMOCO Loc. 15129, Slide 81, England Finder Reference: O451/2
6. ***Wallodinium luna***
   Wahweap Wash Section, Sample NBU/30, Slide PRCIES 3321.1, England Finder Reference: M231
7. ***Wallodinium luna***
   Blue Point Section, Sample BMS4/42B-44A, Slide PRCIES 3156.6, England Finder Reference: K304
8. ***Fromea amphora***
   Rebecca K. Bounds Core, Sample 960'-961', AMOCO Loc. 15129, Slide 86, England Finder Reference: N362
9. ***Fromea fragilis***
   Rebecca K. Bounds Core, Sample 800', AMOCO Loc. 15129, Slide 70, England Finder Reference: B373
10. ***Dorocysta litotes***
    Rebecca K. Bounds Core, Sample 970', AMOCO Loc. 15129, Slide 87, England Finder Reference: H412

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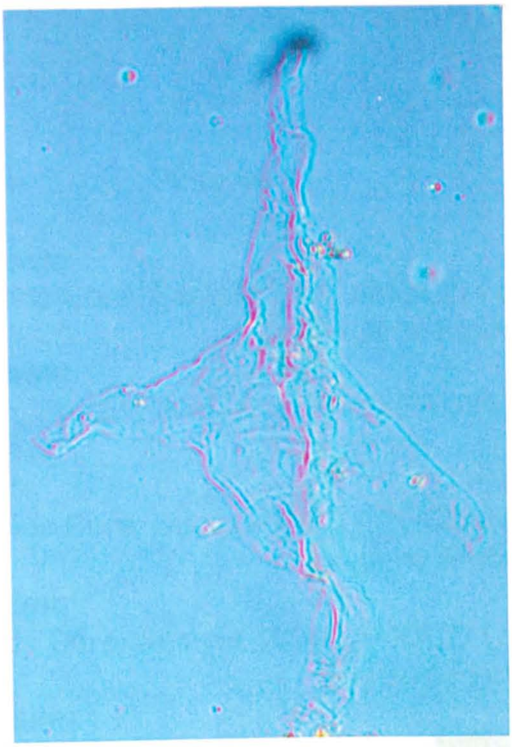

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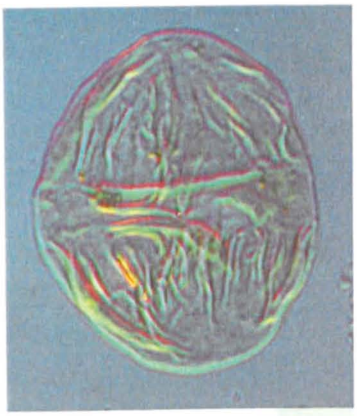

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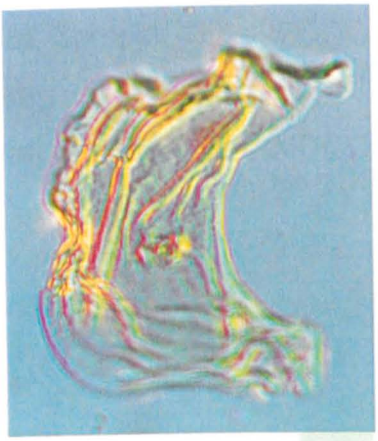

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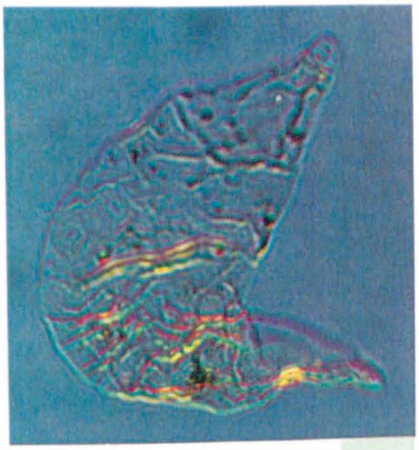

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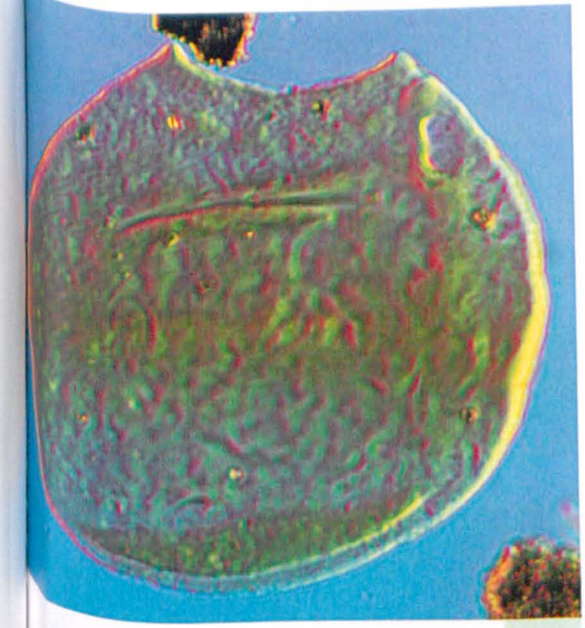

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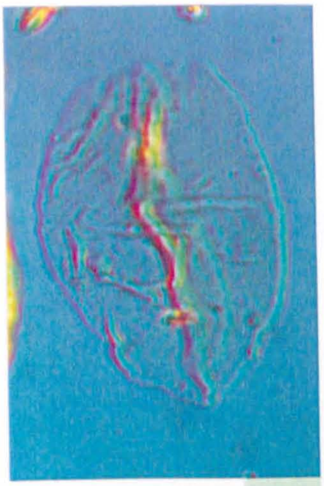

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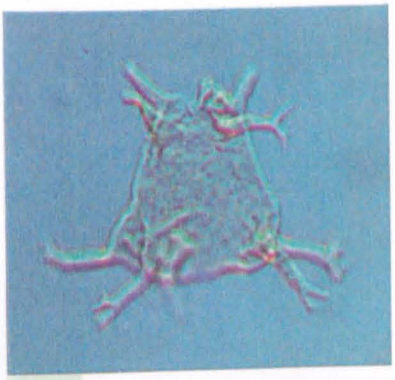

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Plate 39

Plate 40

1. ***Veryhachium europeum***
   Rebecca K. Bounds Core, Sample 750', AMOCO Loc. 15129, Slide 65, England Finder Reference: N404
2. ***Veryhachium europeum***
   Pueblo Section, Sample PH2, Slide PRCIES 3397.4, England Finder Reference: F432
3. ***Veryhachium valiente***
   Rebecca K. Bounds Core, Sample 780', AMOCO Loc. 15129, Slide 68, England Finder Reference: U473
4. ***Veryhachium collectum***
   Rebecca K. Bounds Core, Sample 1090', AMOCO Loc. 15129, Slide 99, England Finder Reference: J431
5. ***Veryhachium formosum***
   Rebecca K. Bounds Core, Sample 1090', AMOCO Loc. 15129, Slide 99, England Finder Reference: D383
6. ***Veryhachium rhomboideum***
   Rebecca K. Bounds Core, Sample 1010', AMOCO Loc. 15129, Slide 91, England Finder Reference: D472
7. ***Veryhachium reductum***
   Rebecca K. Bounds Core, Sample 790', AMOCO Loc. 15129, Slide 69, England Finder Reference: H354
8. ***Veryhachium irregulare***
   Rebecca K. Bounds Core, Sample 820', AMOCO Loc. 15129, Slide 72, England Finder Reference: N492

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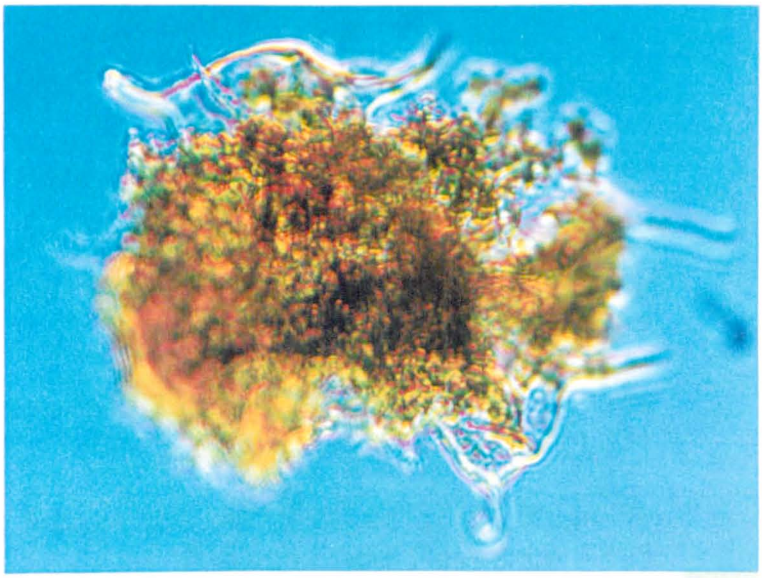

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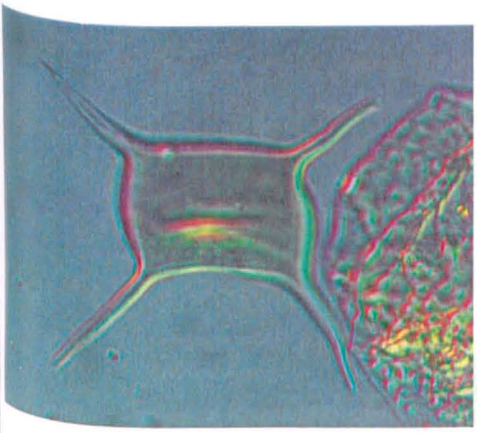

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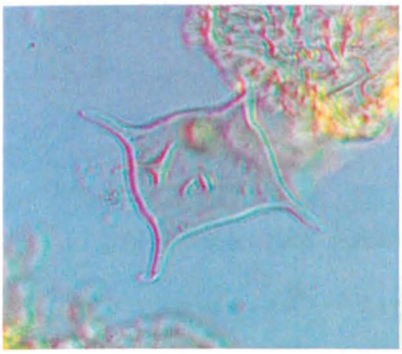

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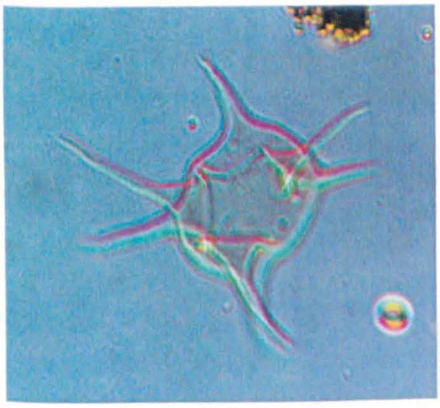

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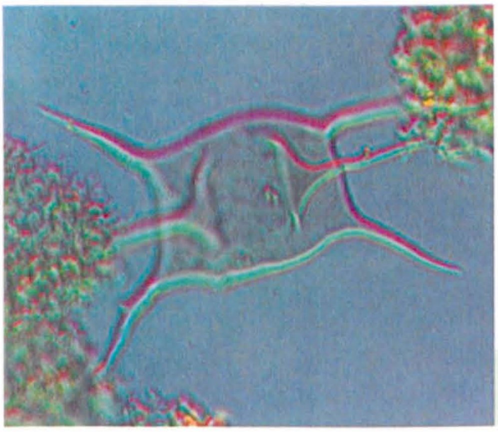

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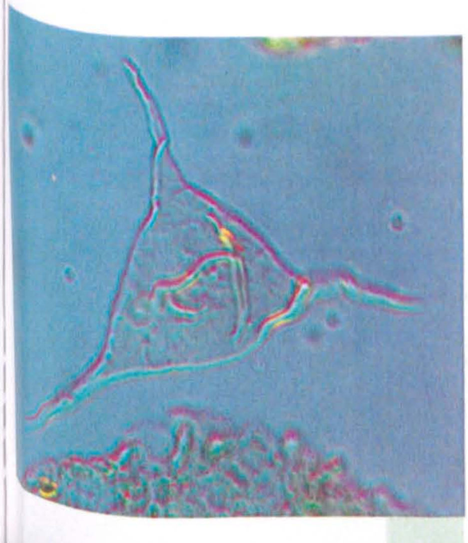

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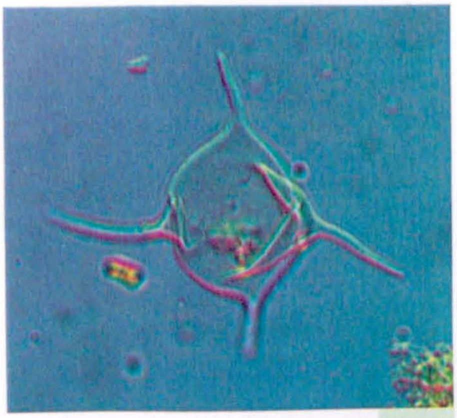

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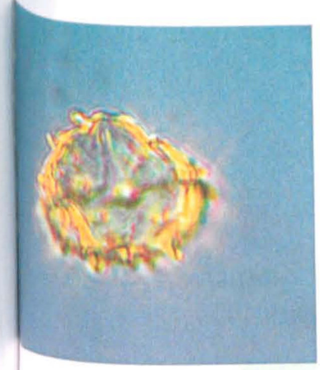
Plate 40

Plate 41

1. ***Micrhystridium minutispinum***
Blue Point Section, Sample BMS4/11B-14A, Slide PRCIES 3137.3, England Finder Reference: D331
2. ***Micrhystridium recurvatum***
Wahweap Wash Section, Sample NBU/30, Slide PRCIES 3321.1, England Finder Reference: L301
3. ***Micrhystridium stellatum***
Rebecca K. Bounds Core, Sample 880', AMOCO Loc. 15129, Slide 78, England Finder Reference: F493
4. ***Baltisphaeridium crameri***
Rebecca K. Bounds Core, Sample 1070', AMOCO Loc. 15129, Slide 97, England Finder Reference: D334
5. **Acritarch sp. A**
Rebecca K. Bounds Core, Sample 1110', AMOCO Loc. 15129, Slide 101, England Finder Reference: C432
6. ***Platycystidia diptera***
Rebecca K. Bounds Core, Sample 1000', AMOCO Loc. 15129, Slide90, England Finder Reference: B384
7. ***Tetraporina* sp. A**
Rebecca K. Bounds Core, Sample 1050', AMOCO Loc. 15129, Slide 95, England Finder Reference: K393
8. ***Schizocysta laevigata***
Rebecca K. Bounds Core, Sample 1080', AMOCO Loc. 15129, Slide 98, England Finder Reference: F363
9. ***Tetraedron* sp. A**
Bunker Hill Section, Sample BH38, Slide PRCIES 2726.14, England Finder Reference: D462
10. ***Petalosporites quadrangulus***
Rebecca K. Bounds Core, Sample 1128', AMOCO Loc. 15129, Slide 103, England Finder Reference: C382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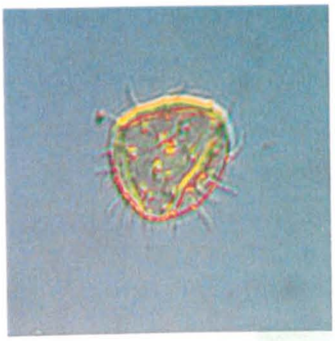
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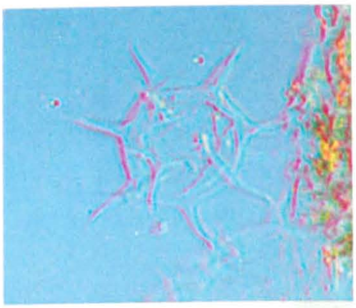
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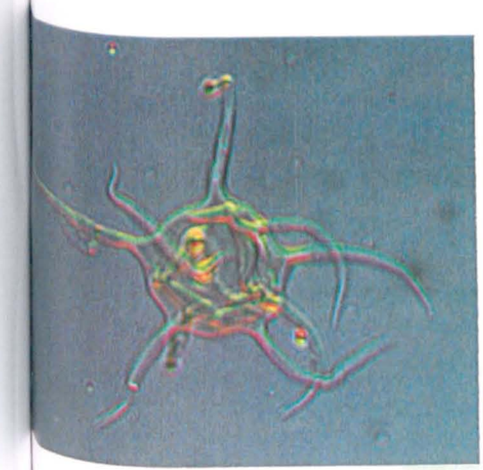
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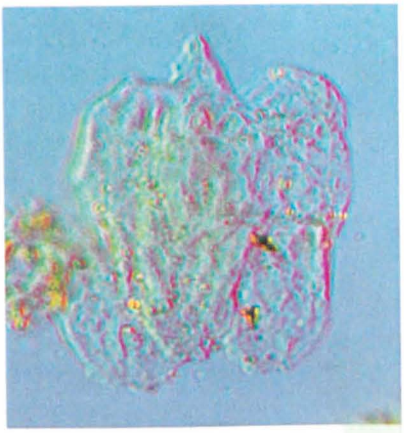
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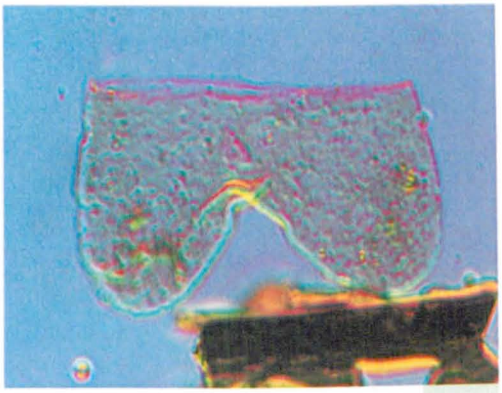
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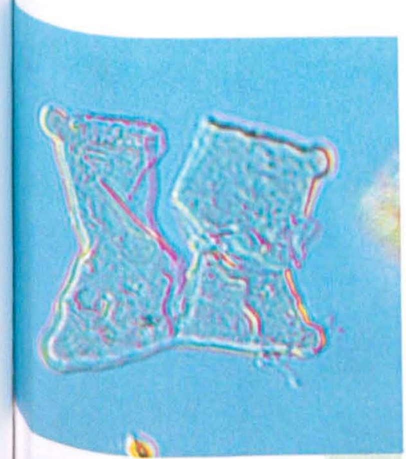
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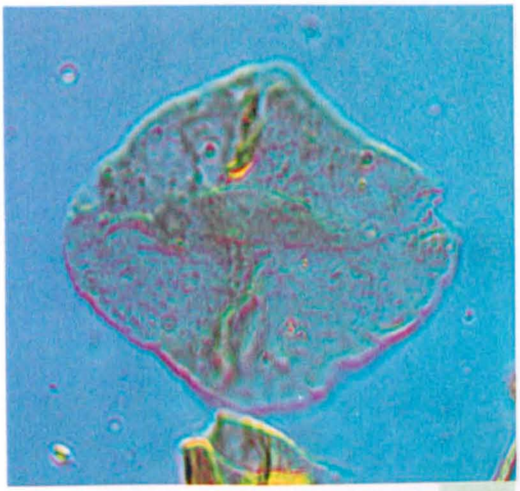
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Plate 41

Plate 42

1. ***Diplofusa gearlensis***
   Wahweap Wash Section, Sample NBU/48N-480, Slide PRCIES 3342.6, England Finder Reference: G301/3
2. ***Leiofusa jurassica***
   Wahweap Wash Section, Sample NBU/30, Slide PRCIES 3321.1, England Finder Reference: L482
3. **Acritarch sp. C**
   Rebecca K. Bounds Core, Sample 1128', AMOCO Loc. 15129, Slide 103, England Finder Reference: Q314
4. **Acritarch sp. C**
   Rebecca K. Bounds Core, Sample 1128', AMOCO Loc. 15129, Slide 103, England Finder Reference: V494
5. ***Wuroia* sp. A**
   Rebecca K. Bounds Core, Sample 1040', AMOCO Loc. 15129, Slide 94, England Finder Reference: G424
6. ***Wuroia* sp. A**
   Rebecca K. Bounds Core, Sample 990', AMOCO Loc. 15129, Slide 89, England Finder Reference: Q522

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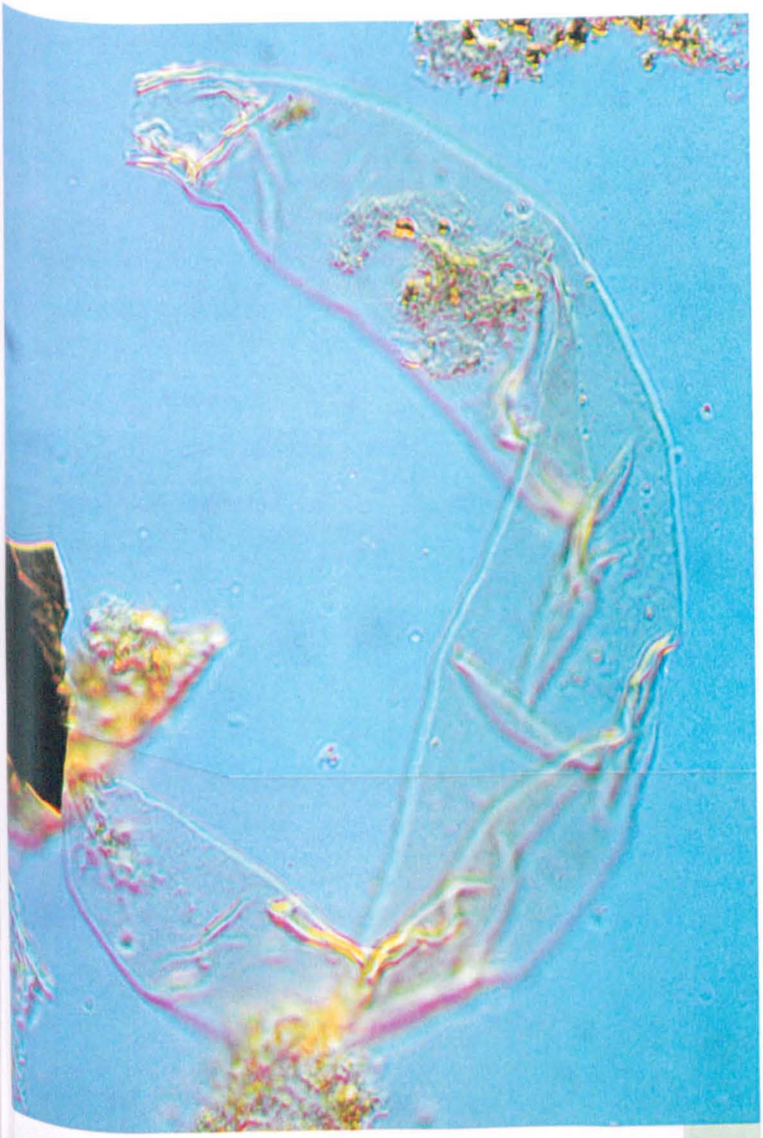

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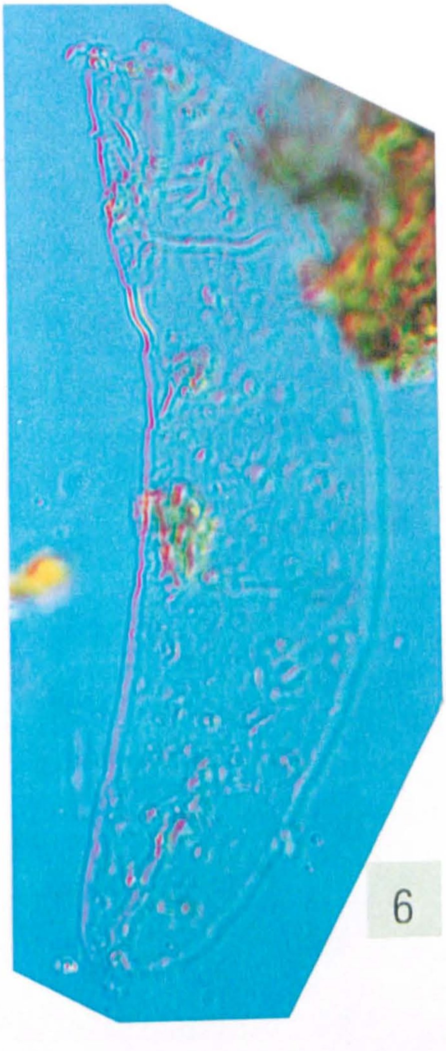

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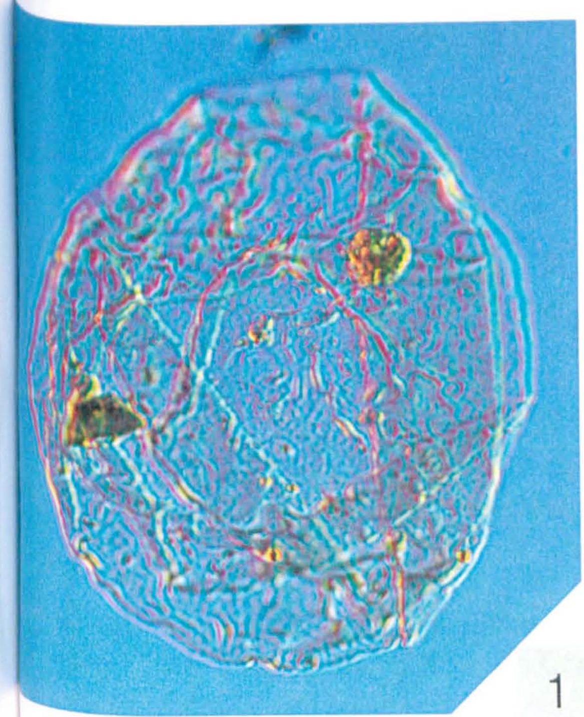
Plate 42

Plate 43

1. ***Leiosphaeridia* sp.**
   Pueblo Section, Sample PH2, Slide PRCIES 3397.9, England Finder Reference: L382/391
2. ***Leiosphaeridia* sp.**
   Rebecca K. Bounds Core, Sample 1020', AMOCO Loc. 15129, Slide 92, England Finder Reference: M374/383
3. ***Palambages morulosa***
   Rebecca K. Bounds Core, Sample 800', AMOCO Loc. 15129, Slide 70, England Finder Reference: F394/G392
4. ***Scuticabolus lapidaris***
   Pueblo Section, Sample PUB15, Slide PRCIES 2406.4, England Finder Reference: D454
5. ***Eyrea nebulosa***
   Blue Point Section, Sample BMS4/16B-18A, Slide PRCIES 3139.2, England Finder Reference: E321/2
6. ***Eyrea nebulosa***
   Blue Point Section, Sample BMS4/16B-18A, Slide PRCIES 3139.2, England Finder Reference: E321/2. Scale ×450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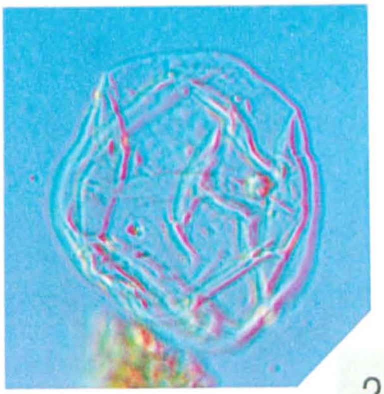
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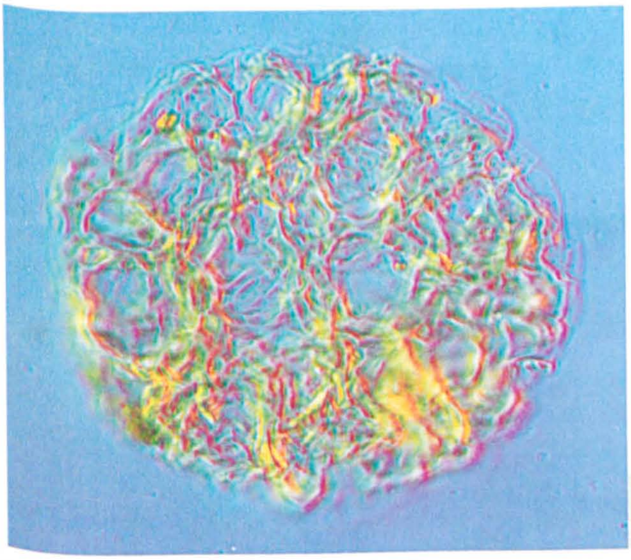
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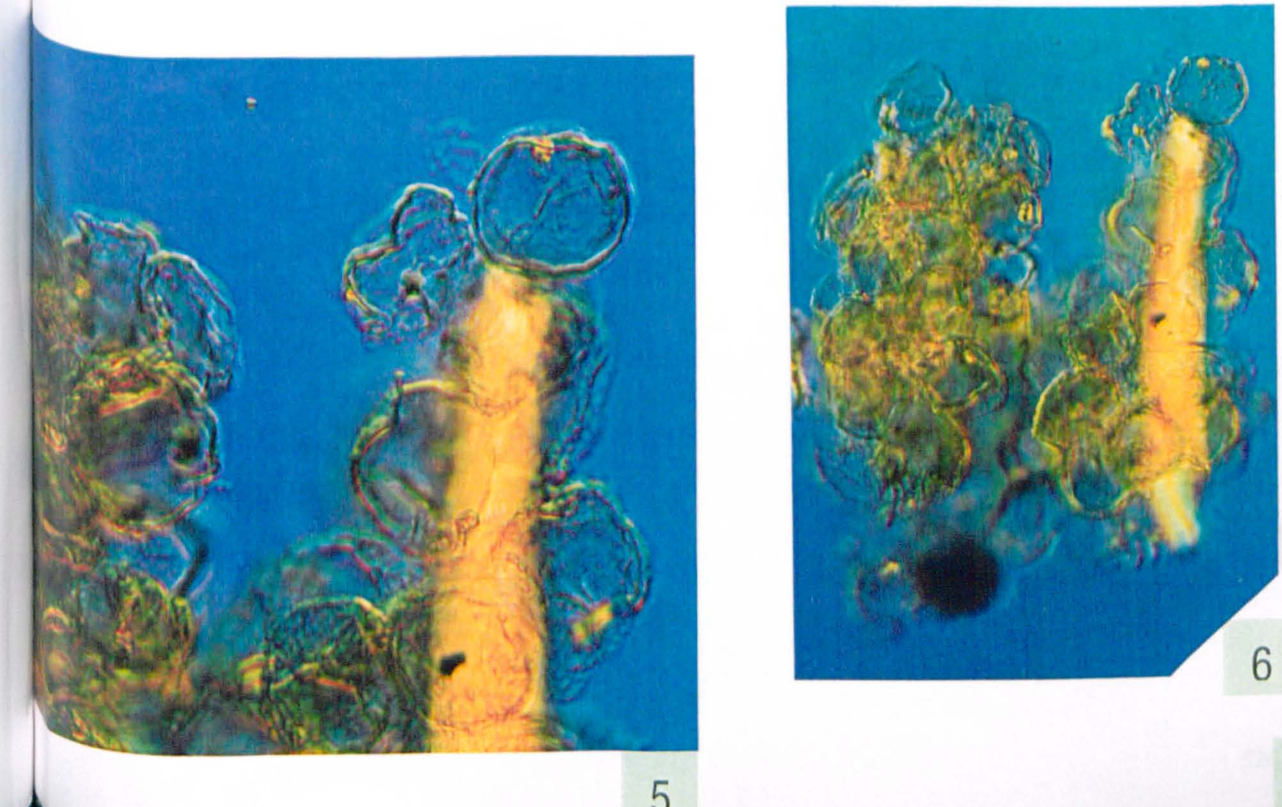
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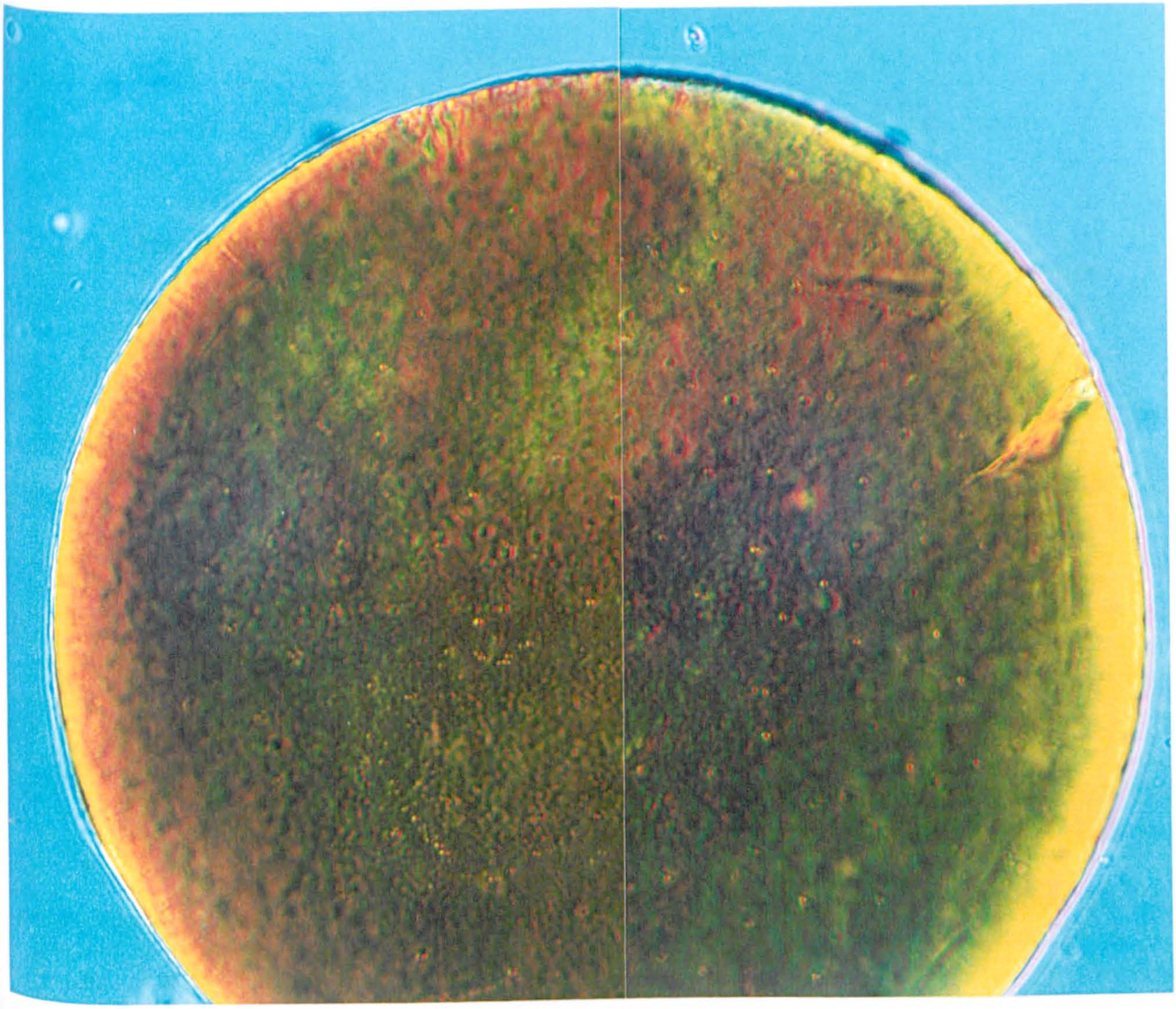
6

Plate 43

Plate 44

1. ***Tasmanites* sp.**
   Pueblo Section, Sample PH3, Slide PRCIES 3398.2, England Finder Reference: M563
2. ***Tasmanites* sp.**
   Pueblo Section, Sample PH3, Slide PRCIES 3398.2, England Finder Reference: M563. Scale ×225
3. ***Pterosphaeridia pachytheca***
   Rebecca K. Bounds Core, Sample 820', AMOCO Loc. 15129, Slide 72, England Finder Reference: H494
4. ***Crassosphaera papillata***
   Rebecca K. Bounds Core, Sample 920', AMOCO Loc. 15129, Slide 82, England Finder Reference: K553
5. ***Lecaniella foveata***
   Rebecca K. Bounds Core, Sample 1128', AMOCO Loc. 15129, Slide 103, England Finder Reference: N322
6. ***Paralecaniella indentata***
   Blue Point Section, Sample BMS4/38E-38F, Slide PRCIES 3152.2, England Finder Reference: S401
7. ***Cymatiosphaera costata***
   Rebecca K. Bounds Core, Sample 870' (1), AMOCO Loc. 15129, Slide 77, England Finder Reference: C330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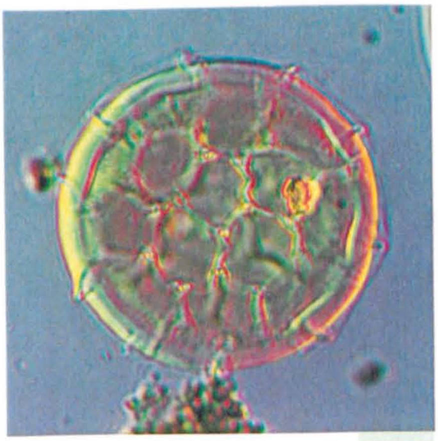
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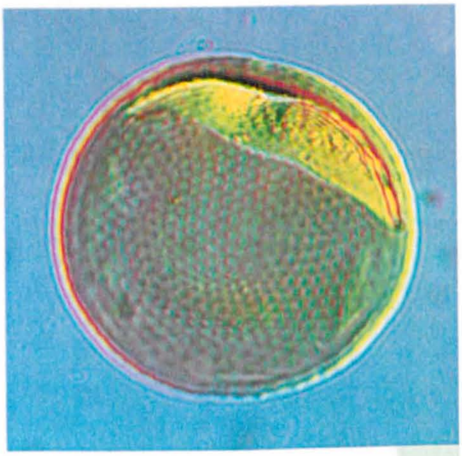
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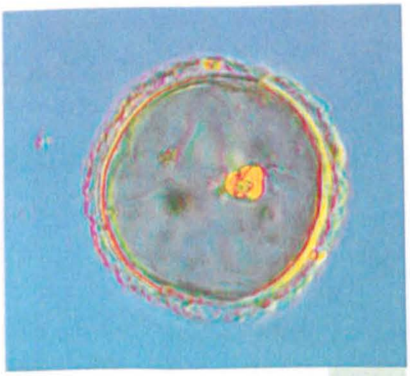
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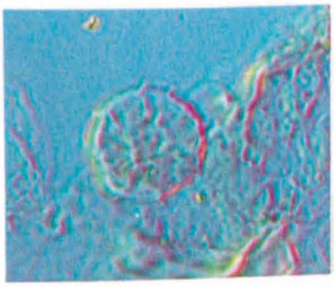
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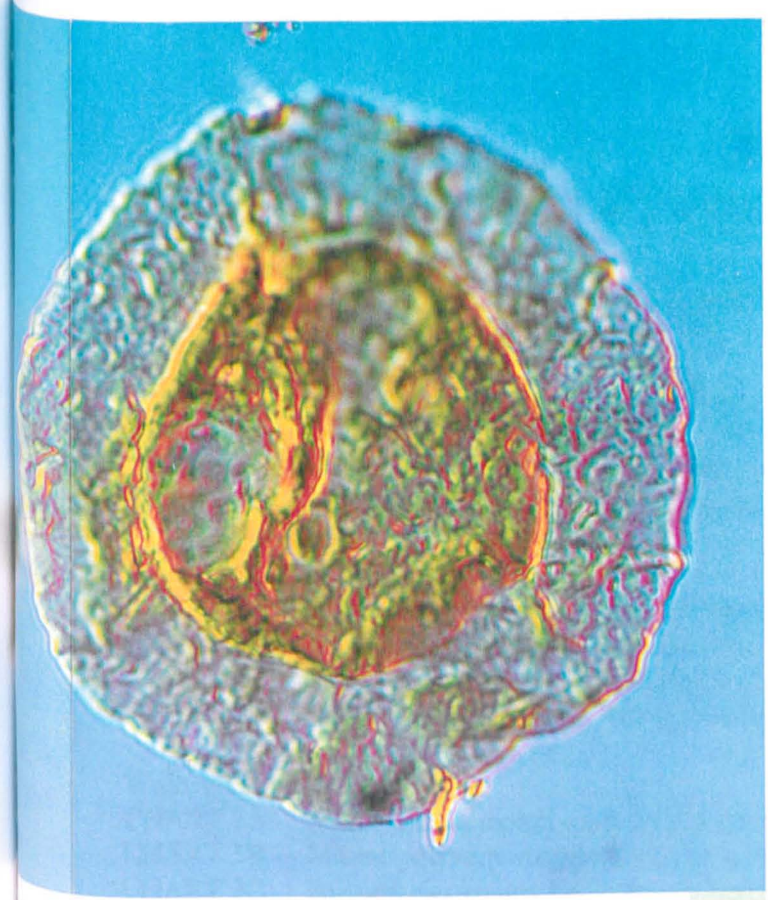
Plate 44

Plate 45

1. ***Pterospermella aureolata***
   Pueblo Section, Sample PUB4, Slide PRCIES 2385.2, England Finder Reference: P423
2. ***Pterospermella centrata***
   Rebecca K. Bounds Core, Sample 1060', AMOCO Loc. 15129, Slide 96, England Finder Reference: H512
3. ***Pterospermella australiensis***
   Pueblo Section, Sample PH1, Slide PRCIES 3396.1, England Finder Reference: R351
4. ***Pterospermella* sp. A**
   Rebecca K. Bounds Core, Sample 1070', AMOCO Loc. 15129, Slide 97, England Finder Reference: D353
5. **Acritarch sp. B**
   Rebecca K. Bounds Core, Sample 1020', AMOCO Loc. 15129, Slide 92, England Finder Reference: G423
6. **Acritarch sp. B**
   Rebecca K. Bounds Core, Sample 1020', AMOCO Loc. 15129, Slide 92, England Finder Reference: G423
7. **Acritarch sp. B**
   Rebecca K. Bounds Core, Sample 1020', AMOCO Loc. 15129, Slide 92, England Finder Reference: D452
8. **Foraminiferal test lining**
   Blue Point Section, Sample BMS4/36B-38B, Slide PRCIES 3150.2, England Finder Reference: H232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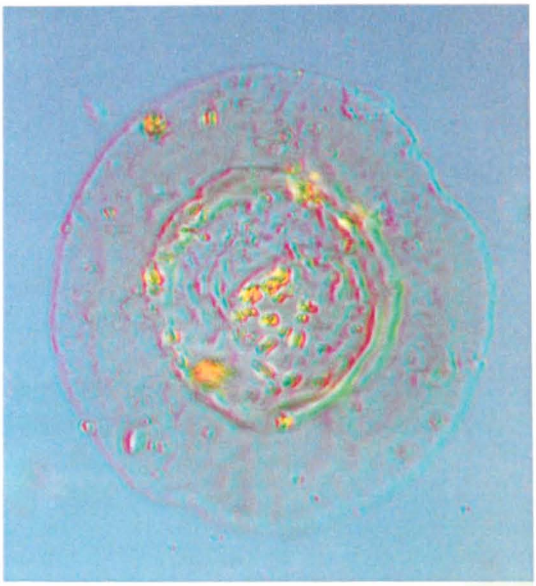
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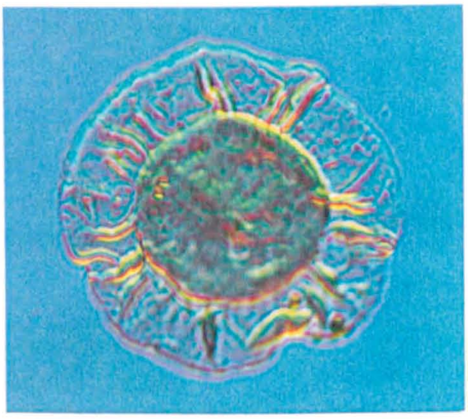
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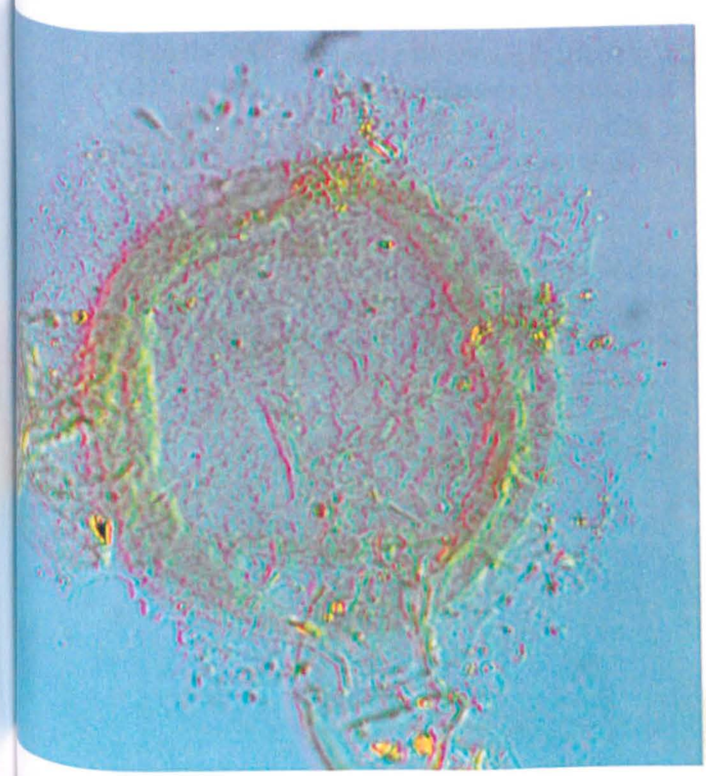
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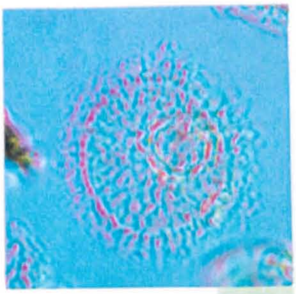
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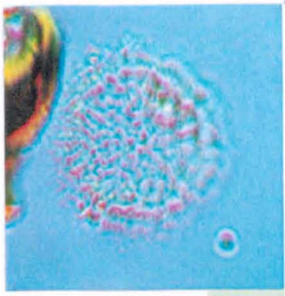
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Plate 45

APPENDIX E

RANGE CHARTS

Rebecca K. Bounds core, Kansas

CHART 1A	Marine palynomorph species (in order of first appearance datum)
CHART 1B	Marine palynomorph species (in order of last appearance datum)
CHART 1C	Palynofacies counts (including marine amorphous organic matter)
CHART 1D	Palynofacies counts (excluding marine amorphous organic matter)

Blue Point, Arizona

CHART 2A	Marine palynomorph species (in order of first appearance datum)
CHART 2B	Marine palynomorph species (in order of last appearance datum)
CHART 2C	Palynofacies counts (including marine amorphous organic matter)
CHART 2D	Palynofacies counts (excluding marine amorphous organic matter)

Wahweap Wash, Utah

CHART 3A	Marine palynomorph species (in order of first appearance datum)
CHART 3B	Marine palynomorph species (in order of last appearance datum)
CHART 3C	Palynofacies counts (including marine amorphous organic matter)
CHART 3D	Palynofacies counts (excluding marine amorphous organic matter)

Pueblo, Colorado

CHART 4A	Marine palynomorph species (in order of first appearance datum)
CHART 4B	Marine palynomorph species (in order of last appearance datum)
CHART 4C	Palynofacies counts (including marine amorphous organic matter)
CHART 4D	Palynofacies counts (excluding marine amorphous organic matter)

Bunker Hill, Kansas

CHART 5A	Marine palynomorph species (in order of first appearance datum)
CHART 5B	Marine palynomorph species (in order of last appearance datum)
CHART 5C	Palynofacies counts (including marine amorphous organic matter)

Well Name : Rebecca K. Bounds Core
Well Code : AMOCO 15129, Kansas
Interval : 750.00' - 1128.00'
Scale : 1:750

CHART 1A
Style : Numeric Abundance Saw Tooth
Author : Anthony J. Harris
Date : 28-August-1996

Marine Palynomorph Distribution Chart 1A

Palynology Lab., I. E. S.
Aberystwyth

Palynology Lab., I. E. S.
Aberystwyth

Well Name : Rebecca K. Bounds Core
Well Code : AMOCO 15129, Kansas
Interval : 750.00' - 1128.00'
Scale : 1:750

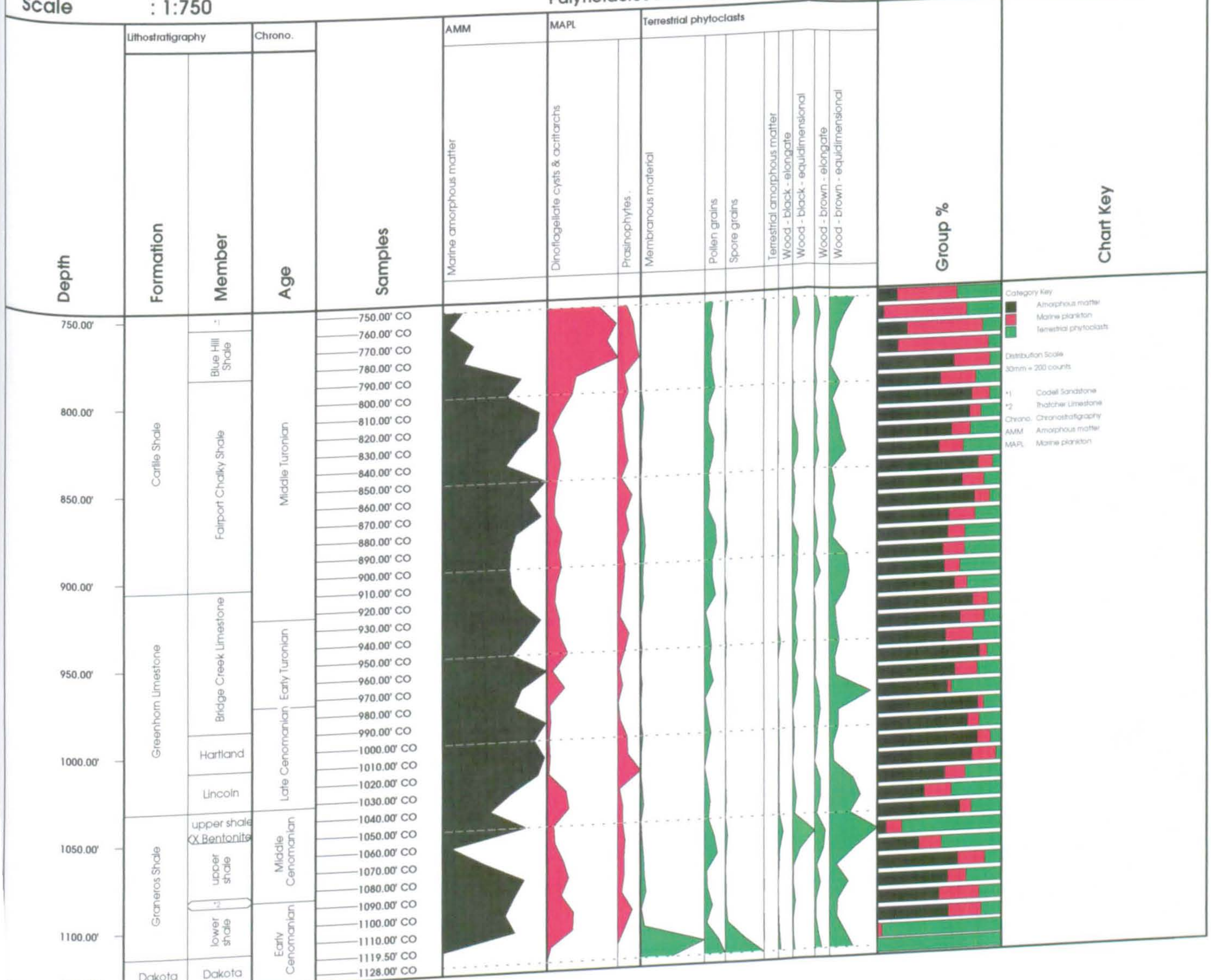
CHART 1B
Style : Semi Quantitative Symbols
Author : Anthony J. Harris
Date : 28-August-1996

Marine Palynomorph Distribution Chart 1B

Well Name : Rebecca K. Bounds Core
Well Code : AMOCO 15129, Kansas
Interval : 750.00' - 1128.00'
Scale : 1:750

CHART 1C
Style : Numeric Abundance Saw Tooth
Author : Anthony J. Harris
Date : 28-August-1996

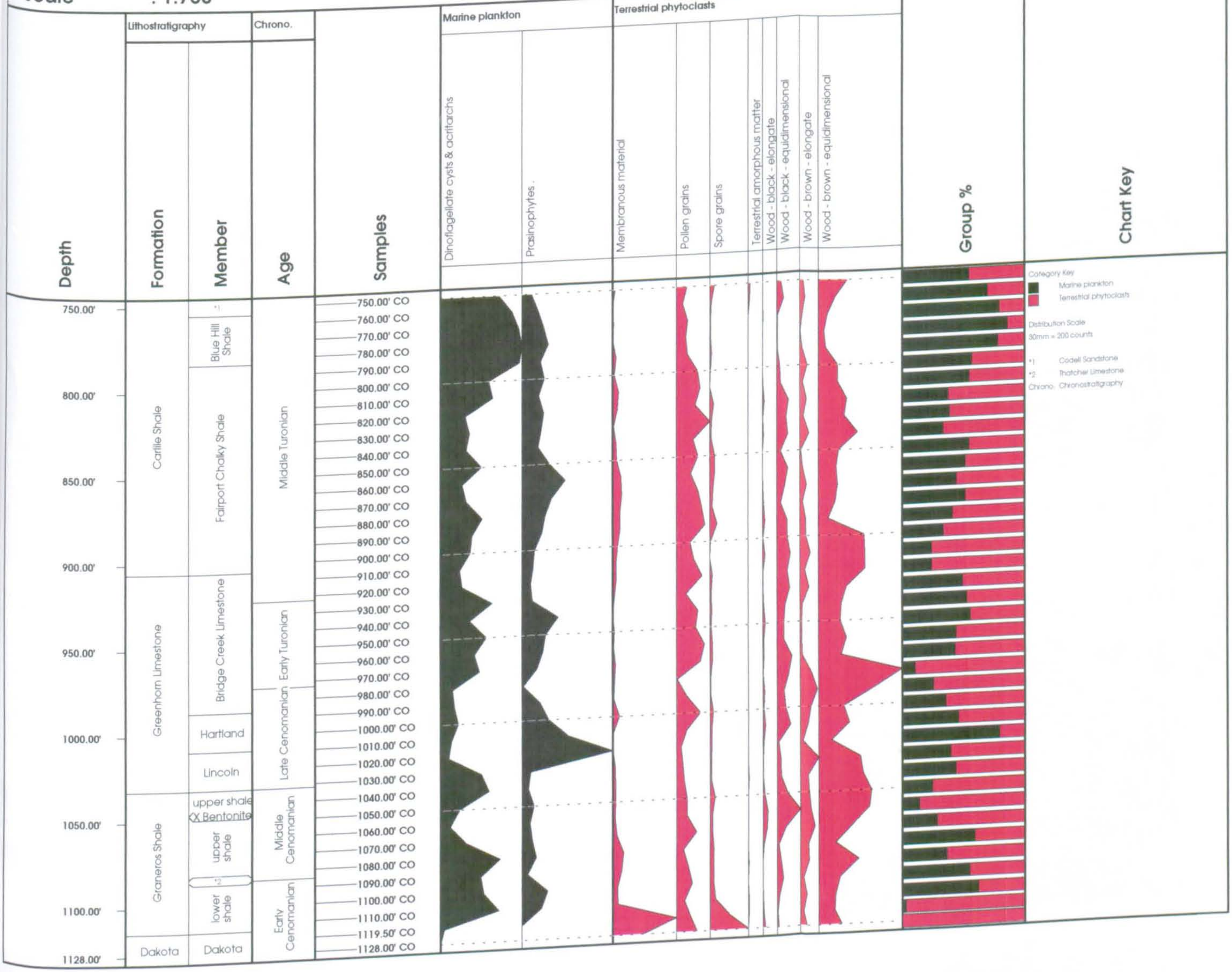
Palynofacies Distribution Chart 1C



Well Name : Rebecca K. Bounds Core
Well Code : AMOCO 15129, Kansas
Interval : 750.00' - 1128.00'
Scale : 1:750

CHART 1D
Style : Numeric Abundance Saw Tooth
Author : Anthony J. Harris
Date : 28-August-1996

Palynofacies Distribution Chart 1D



Well Name : Blue Point
Well Code : Arizona
Interval : 1.00m - 33.42m
Scale : 1:250

CHART 2A
Style : Numeric Abundance Saw Tooth
Author : Anthony J. Harris
Date : 28-August-1996

Marine Palynomorph Distribution Chart 2A

Palynology Lab., I. E. S.
Aberystwyth

Well Name : Blue Point
Well Code : Arizona
Interval : 1.00m - 33.42m
Scale : 1:250

CHART 2B
Style : Semi Quantitative Symbols
Author : Anthony J. Harris
Date : 28-August-1996

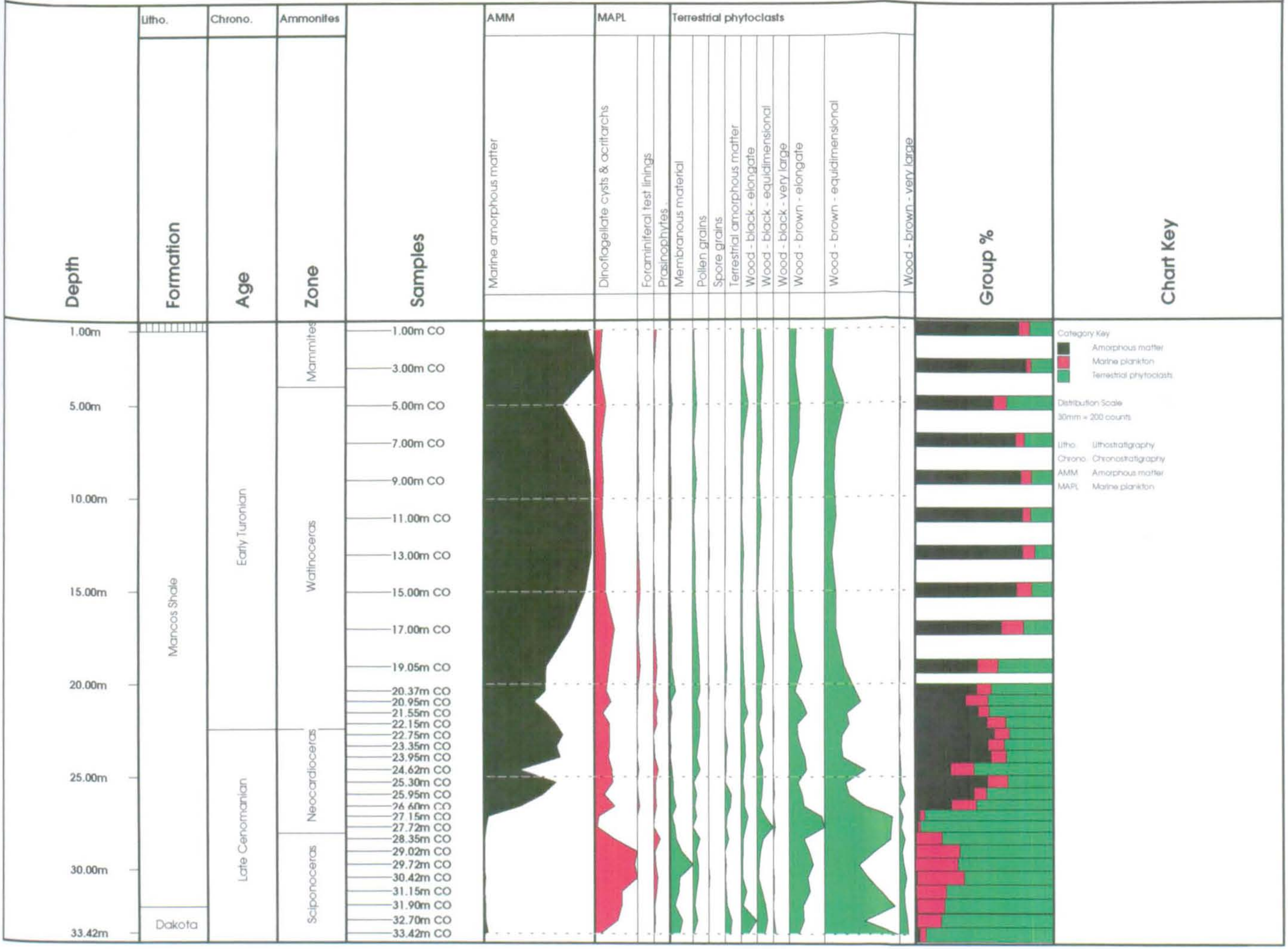
Marine Palynomorph Distribution Chart 2B

Palynology Lab., I. E. S.
Aberystwyth

Well Name : Blue Point
Well Code : Arizona
Interval : 1.00m - 33.42m
Scale : 1:250

CHART 2C
Style : Numeric Abundance Saw Tooth
Author : Anthony J. Harris
Date : 28-August-1996

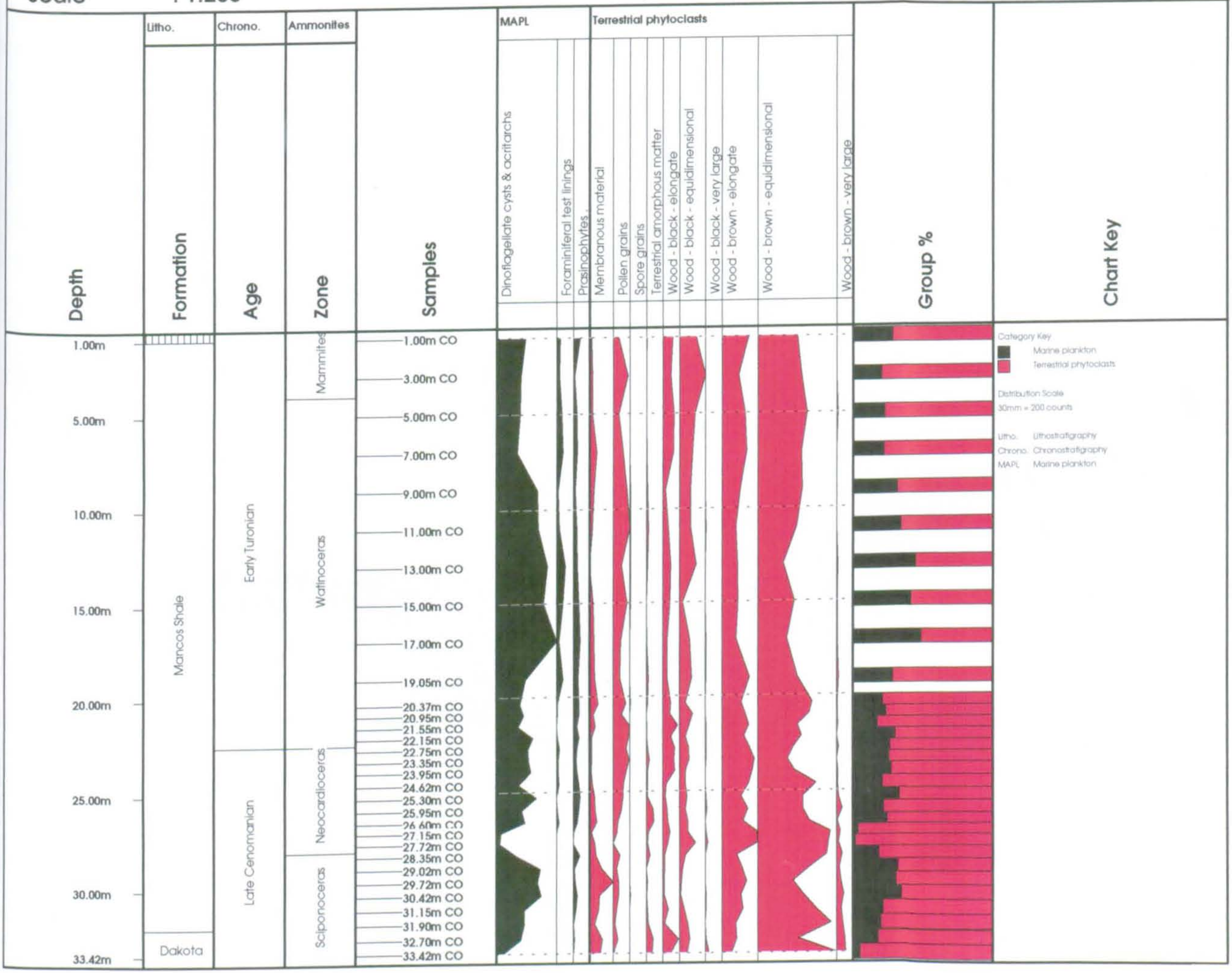
Palynofacies Distribution Chart 2C



Well Name : Blue Point
Well Code : Arizona
Interval : 1.00m - 33.42m
Scale : 1:250

CHART 2D
Style : Numeric Abundance Saw Tooth
Author : Anthony J. Harris
Date : 28-August-1996

Palynofacies Distribution Chart 2D



Well Name : Wahweap Wash
Well Code : Utah
Interval : 3.87m - 44.63m
Scale : 1:250

CHART 3A
Style : Numeric Abundance Saw Tooth
Author : Anthony J. Harris
Date : 28-August-1996

Palynology Lab., I. E. S.
Aberystwyth

Marine Palynomorph Distribution Chart 3A

Well Name : Wahweap Wash
Well Code : Utah
Interval : 3.87m - 44.63m
Scale : 1:250

CHART 3B
Style : Semi Quantitative Symbols
Author : Anthony J. Harris
Date : 28-August-1996

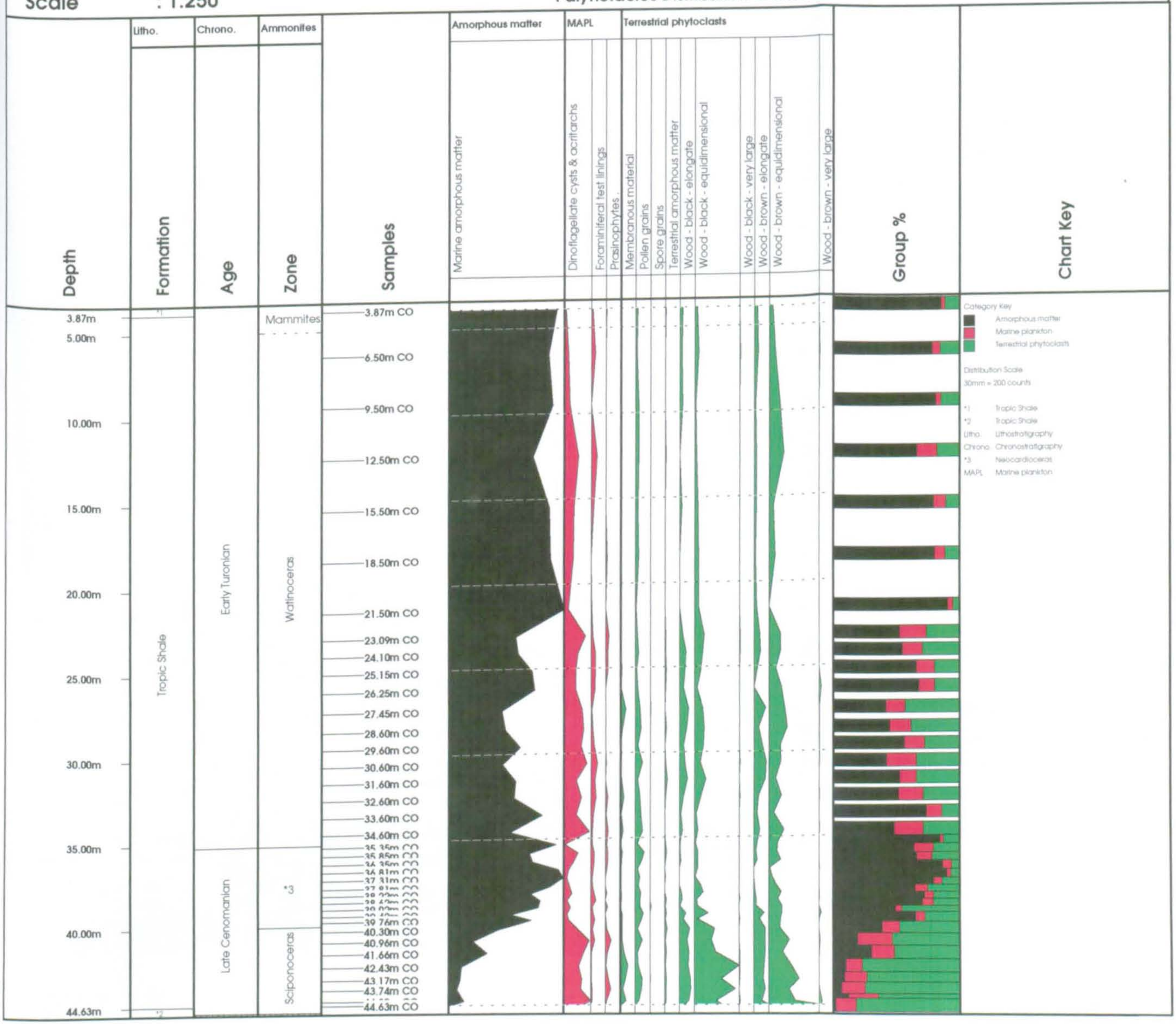
Marine Palynomorph Distribution Chart 3B

Palynology Lab., I. E. S.
Aberystwyth

Well Name : Wahweap Wash
Well Code : Utah
Interval : 3.87m - 44.63m
Scale : 1:250

CHART 3C
Style : Numeric Abundance Saw Tooth
Author : Anthony J. Harris
Date : 28-August-1996

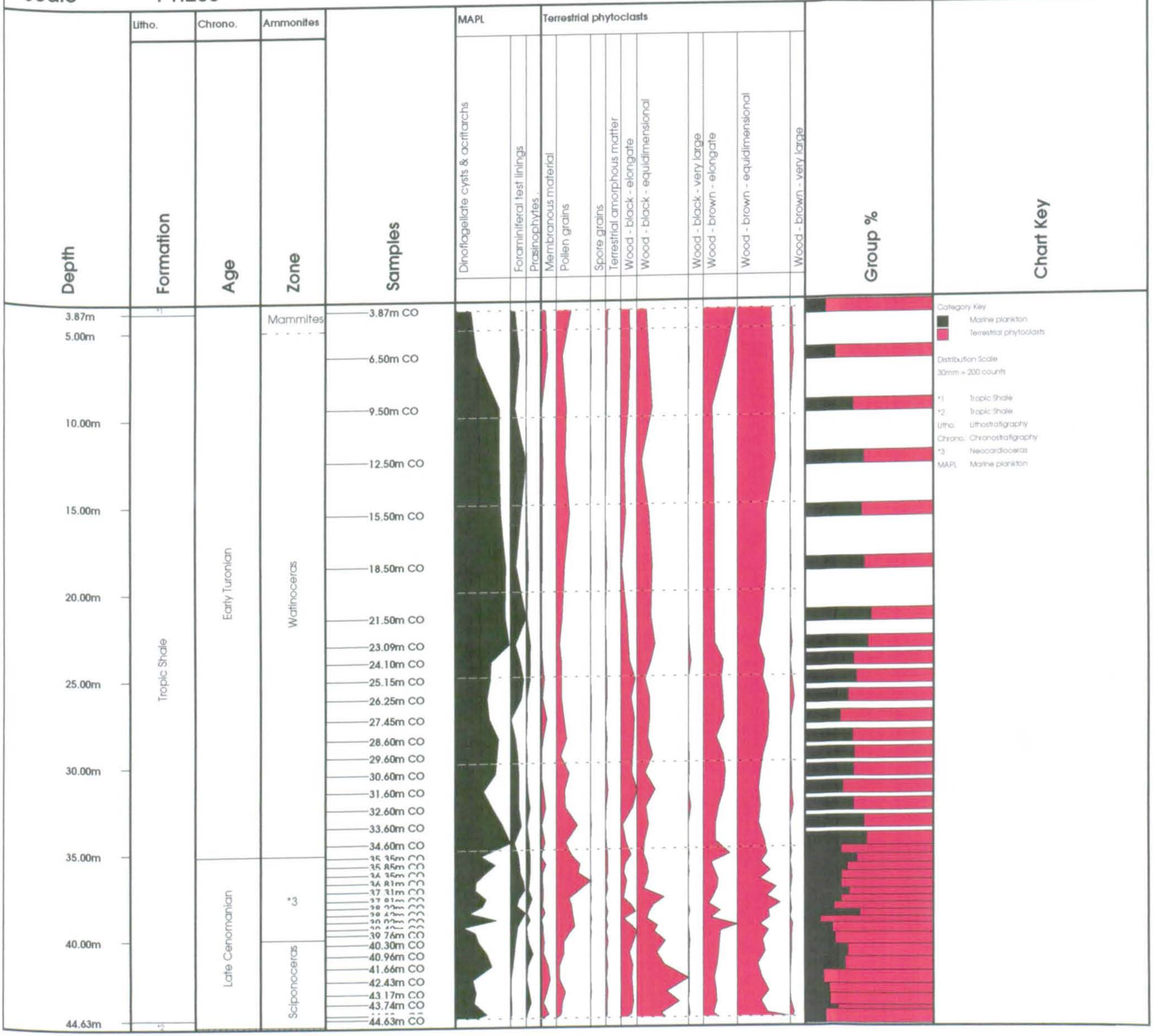
Palynofacies Distribution Chart 3C



Well Name : Wahweap Wash
Well Code : Utah
Interval : 3.87m - 44.63m
Scale : 1:250

CHART 3D
Style : Numeric Abundance Saw Tooth
Author : Anthony J. Harris
Date : 28-August-1996

Palynofacies Distribution Chart 3D



Well Name : Pueblo
Well Code : Colorado
Interval : 0.95m - 9.90m
Scale : 1:50

CHART 4A
Style : Numeric Abundance Saw Tooth
Author : Anthony J. Harris
Date : 28-August-1996

Marine Palynomorph Distribution Chart 4A

Palynology Lab., I. E. S.
Aberystwyth

Well Name : Pueblo
Well Code : Colorado
Interval : 0.95m - 9.90m
Scale : 1:50

CHART 4B
Style : Semi Quantitative Symbols
Author : Anthony J. Harris
Date : 28-August-1996

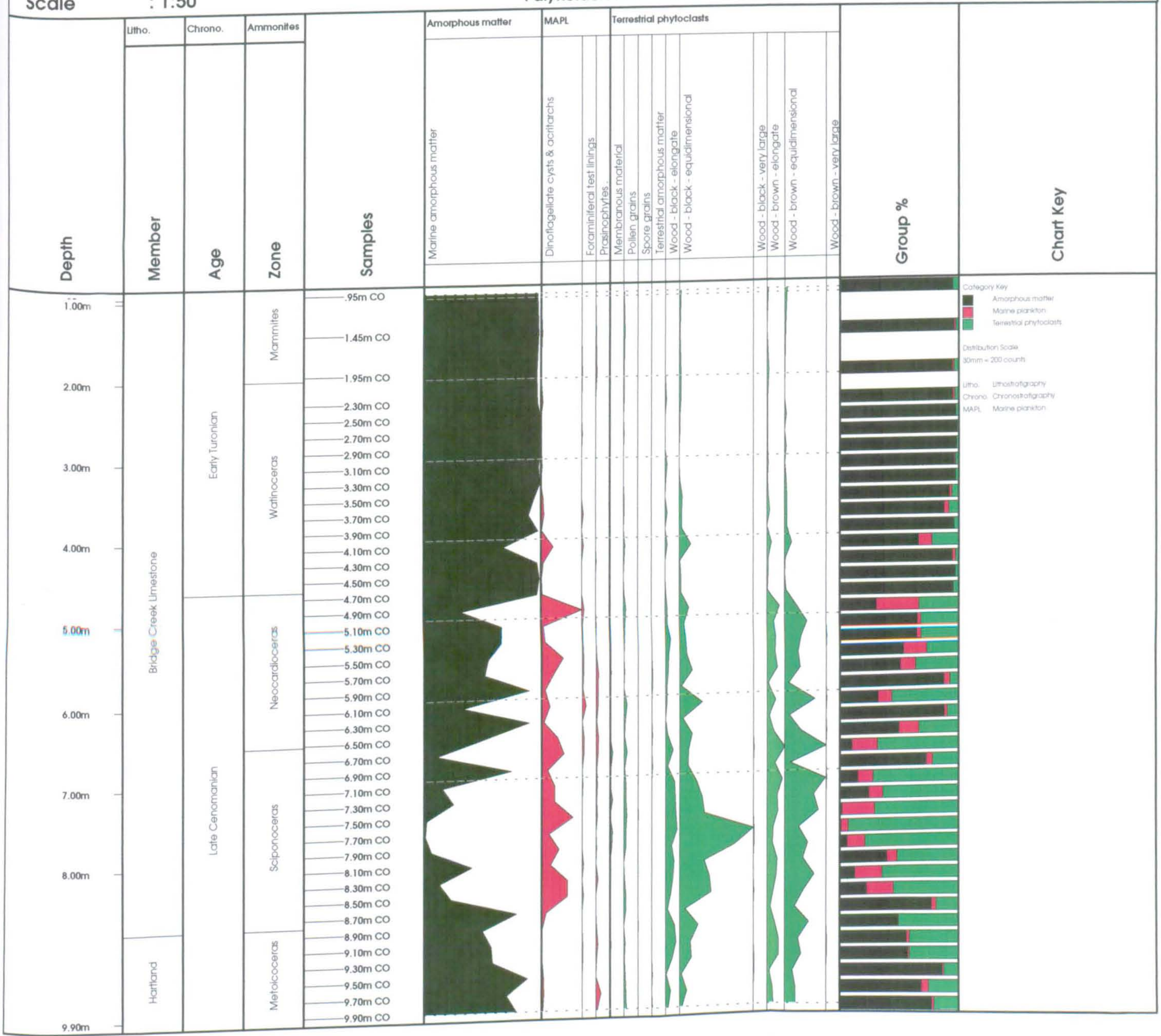
Marine Palynomorph Distribution Chart 4B

Palynology Lab., I. E. S.
Aberystwyth

Well Name : Pueblo
Well Code : Colorado
Interval : 0.95m - 9.90m
Scale : 1:50

CHART 4C
Style : Numeric Abundance Saw Tooth
Author : Anthony J. Harris
Date : 28-August-1996

Palynofacies Distribution Chart 4C



Well Name : Pueblo
Well Code : Colorado
Interval : 4.10m - 9.90m
Scale : 1:50

CHART 4D
Style : Numeric Abundance Saw Tooth
Author : Anthony J. Harris
Date : 28-August-1996

Palynofacies Distribution Chart 4D

Well Name : Bunker Hill
Well Code : Kansas
Interval : 2.30m - 9.90m
Scale : 1:50

CHART 5A
Style : Numeric Abundance Saw Tooth
Author : Anthony J. Harris
Date : 28-August-1996

Marine Palynomorph Distribution Chart 5A

Palynology Lab., I. E. S.
Aberystwyth

Category Key
🟫 Acritarchs
🟥 Dinoflagellate cysts
🟩 Foram test linings

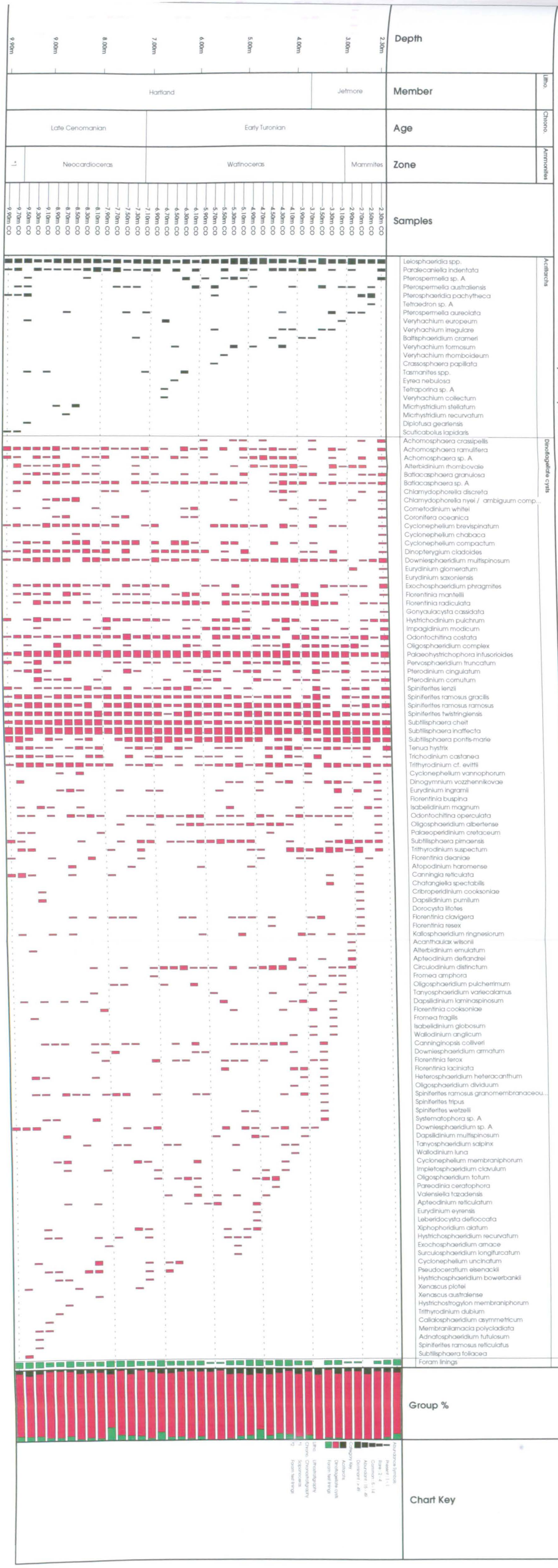
Distribution Scale
30mm = 100 counts

Litho.	Lithostratigraphy
Chrono.	Chronostratigraphy
*1	Sciponoceras
FT	Foram test linings

Well Name : Bunker Hill
Well Code : Kansas
Interval : 2.30m - 9.90m
Scale : 1:50

CHART 5B
Style : Semi Quantitative Symbols
Author : Anthony J. Harris
Date : 28-August-1996

Marine Palynomorph Distribution Chart 5B



Palynology Lab., I. E. S.
Aberystwyth

Well Name : Bunker Hill
Well Code : Kansas
Interval : 2.30m - 9.90m
Scale : 1:50

CHART 5C
Style : Numeric Abundance Saw Tooth
Author : Anthony J. Harris
Date : 28-August-1996

Palynofacies Distribution Chart 5C