Chapter 2

DIRECT CORRELATION OF BARREMIAN-APTIAN (MID-CRETACEOUS) DINOFLAGELLATE CYST ASSEMBLAGES FROM THE TETHYAN AND AUSTRAL REALMS

Abstract

More than a decade ago a comprehensive dinoflagellate zonation was established for stratigraphic correlation of a wide variety of Jurassic-Cretaceous marine sections in Australia. Since then the zonal scheme is extensively applied and it has proven its value as a solid tool for pan-Australian biostratigraphic correlation. However, in addition to the limited potential for cross-hemisphere correlation, only very few levels could be calibrated to the stratigraphic standard of stages and substages. For the strongly facies dependent zones, like the *Ovoidinium cinctum* Zone in presumed Barremian (Lower Cretaceous), any calibration is even excluded.

This study attempts to directly correlate an Australian Barremian-Aptian marine section with European ammonite controlled standard successions, based on corresponding stratigraphic events in the compositional development of the dinoflagellate assemblages. The paper outlines the correlation between the Barremian-Aptian part of a section of DSDP site 263 (cores 5-18) in NW Australia, and the Aptian Stage boundary in the Barremian stratotype section at Angles, SE France. The correlation provides a suit of nine dinoflagellate cyst (dinocyst) index events, which are useful for cross-hemisphere comparisons. The nine dinocyst events are: LO of *Kleithriasphaeridium fasciatum*, LO of *Muderongia staurota*, FO of *Odontochitina operculata*, LO of *Phoberocysta neocomica*, FO of *Prolixosphaeridium parvispinum*, FO of *Pseudoceratium retusum* var. *retusum*, FO of *Tehamadinium sousensis*, FO of *Tehamadinium tenuiceras*, and LO of *Valensiella magna*.

These dinocyst events further show that at least the upper portion of the Australian *Muderongia testudinaria* dinoflagellate Zone is Early Barremian in age, the succeeding *Muderongia australis* Zone is of Late Barremian to earliest Aptian, and the younger *Odontochitina operculata* Zone is Aptian in age. The *Ovoidinium cinctum* Zone, normally positioned between the *M. australis* and *O. operculata* zones, could not be recognized incontrovertibly and this part of the section is incorporated within the upper part of the *M. australis* Zone.

Palaeoenvironmental evaluation of the encountered dinoflagellate assemblages supports the view that the NW Australian margin was affected by cool water-currents during the Barremian-Aptian.

1. Introduction

The late Early Cretaceous was characterised by several profound changes in biogeochemical cycling, climate and evolution (e.g. Hay, 1995; Erbacher et al., 1996; Mutterlose, 1998; Premoli Silva and Sliter, 1999). For the understanding of the processes underlying these perturbations, global biostratigraphic correlation is of vital importance. During the last decade a number of studies on late Early Cretaceous Tethyan and Boreal sequences have shown that organic-walled dinoflagellate cysts offer a powerful tool for stratigraphic correlation of widely separated marine sections (e.g. Prauss, 1993; Hoedemaeker and Leereveld, 1995; Wilpshaar, 1995; Hoedemaeker, 1999; Torricelli, 2000), even on a global scale (Leereveld, 1997).

Helby et al. (1987) proposed a Mesozoic dinoflagellate zonal scheme for the Australian region. This scheme has become the standard palynological correlation tool for marine Cretaceous sequences in Australia. However, a lack of reference to other biostratigraphic zonations such as provided by ammonites taken as the global standard (Gradstein et al., 1998) and other chronostratigraphic methods such as magnetic polarity events, hampers the scheme.

For the mid-Cretaceous Helby et al. (1987) defined five successive zones, in ascending order: *Muderongia testudinaria* Zone, *Muderongia australis* zone, *Ovoidinium cinctum* Zone, *Odontochitina operculata* Zone and *Diconodinium davidii* Zone. They noted a strong facies dependence for the *O. cinctum* Zone and observed that in many sequences the *O. operculata* Zone directly overlies the *M. australis* Zone. However, the calibration of these Australian zones, and the dinocyst events on which they are based, to the Barremian-Aptian biostratigraphic standard zonation has remained unclear. The present paper examines correlation of dinocyst events from a reference, ammonite calibrated, Barremian-Aptian transition interval at Angles, SE France, with a corresponding stratigraphic interval sampled at Deep Sea Drilling Project (DSDP) site 263 located on the NW Australian continental margin (Figure 1a). Although, the sites represent widely disparate Tethyan and Austral realms, the biostratigraphic results from this study provide a sound basis for interregional correlation.

2. Study areas, lithology and relevant stratigraphic data

2.1 *Angles, southeast France*

The type section for the Barremian is located along the road to Angles in southeastern France (Birkelund et al., 1984; Figure 1b). The total section comprises ~94m of Barremian and Aptian sedimentary rocks and was originally described by Busnardo (1965). The 15m across the Barremian-Aptian boundary are the focus of this study.

During the Early Cretaceous, Angles was located in the Vocontian Basin, which formed part of the western border of the northern continental margin of the Tethys (Figure 1a). The setting received considerable amounts of terrigenous detritus and pelagic carbonate (Bréhéret, 1994). The lithological succession involved in the present study (beds 186-205 of Busnardo) consists of an ammonite-rich alternation of limestone with subordinate, hemipelagic marls (Figure 2). The Barremian deposits (beds 186-196) show a regular alternation between the limestones and subordinate marls. However, in the Aptian deposits (beds 197-205) the alternation becomes more irregular, the limestones thicken at the cost of the marls, which are sometimes reduced to thin, laminated beds.

Traditionally the Barremian-Aptian boundary is based on the ammonite distribution within the section. Busnardo (1965) placed the boundary at the base of bed 197, marked by the appearance of *Pseudohaploceras matheroni*. In more recent ammonite zonal schemes the base of the Aptian is considered to be marked by the first appearance of *Deshayesites* (e.g. Delanoy, 1997; Hoedemaeker and Rawson, 2000). However, due to poor ammonite recovery in the Angles section this particular level cannot precisely be identified. According to Delanoy (1995): a "non-characterised zone" of three beds occurs between the appearance of *Deshayesites* sp. (bed 200) and the top of the latest Barremian *Pseudocrioceras waagenoides* ammonite Zone in bed 196 as documented by Kakabadze and Kotetishvili (1995). The Barremian part of the studied section here comprises the *Colchidites sarasini* and *Pseudocrioceras waagenoides* ammonite Chronozones (Delanoy, 1995; Kakabadze and Kotetishvili, 1995). The top of the interval corresponds to the upper part of the lowest Aptian *Deshayesites tuarkyricus* ammonite Chronozone (Delanoy, 1995).

Thierstein (1973) studied the nannofossils from the Angles section and proposed nannofossil events to mark the Barremian-Aptian boundary. However, according to Erba (1996) these nanno-events are unreliable at low latitudes. Erba (1994) proposed magnetic polarity Chron M0 as base for the Aptian and states that the first distinct global nanno event (the "nannoconid crisis") occurred 640 Kyr later. In their chemostratigraphical evaluation of the Angles section, Wissler et al. (2002) demonstrated that a negative ^{13}C excursion preceding Chron M0 can also be observed at Angles and coincides with the top of bed 197.

Quantitative dinocyst data has been published previously for the Angles section (De Renéville and Raynaud, 1981; Srivastava, 1984). However, their work indicated relatively poorly diversified assemblages in contrast to the results presented below. This discrepancy probably reflects different processing techniques and advances in taxonomic concepts.

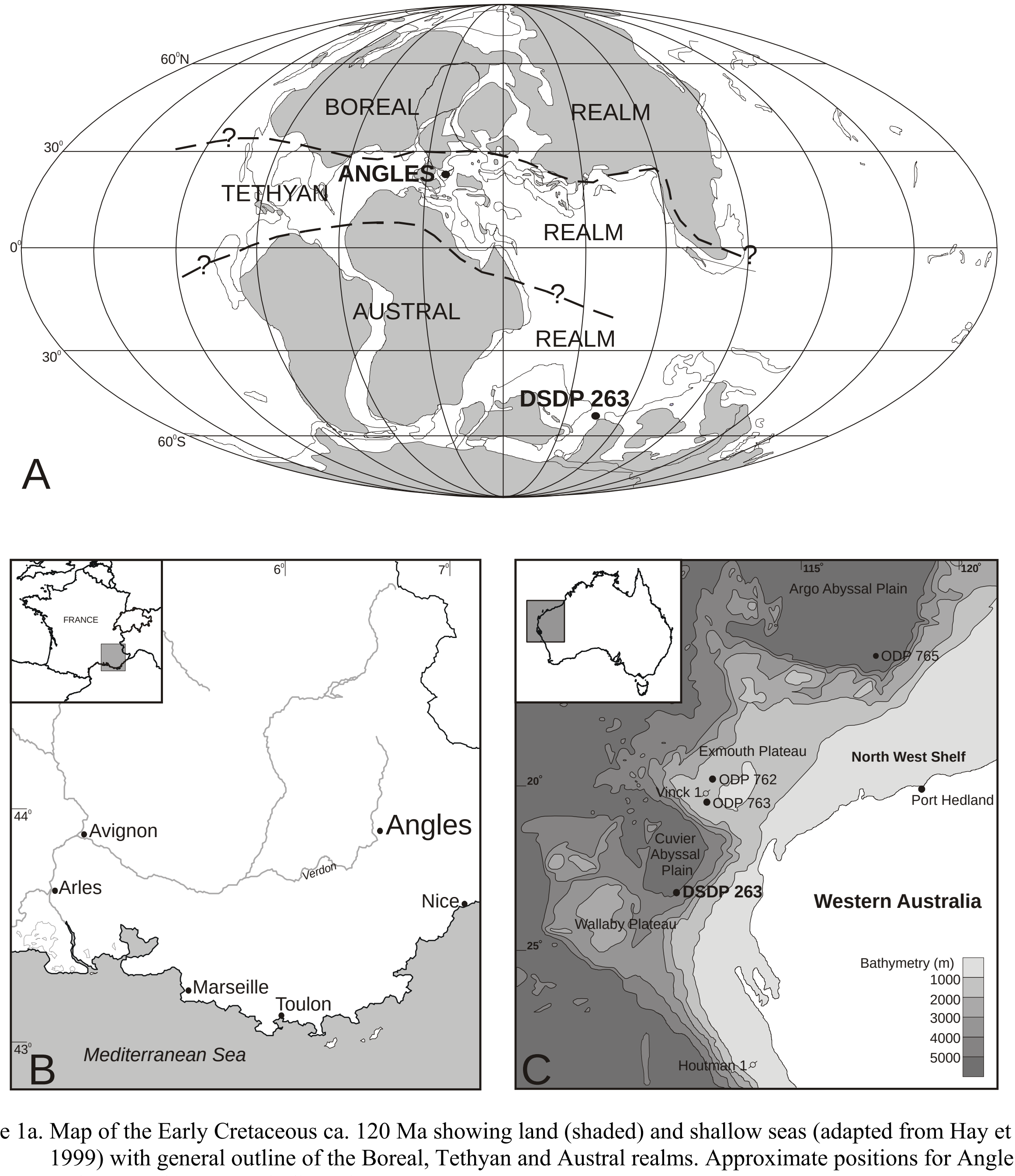

Figure 1a. Map of the Early Cretaceous ca. 120 Ma showing land (shaded) and shallow seas (adapted from Hay et al., 1999) with general outline of the Boreal, Tethyan and Austral realms. Approximate positions for Angles and DSDP site 263 are indicated.

1b. Map with present coastline of France showing the location of the Angles section, SE France.

1c. Map of present western margin of Australia showing DSDP site 263, ODP sites 762, 763, 765, Houtman-1 well and Vinck-1 well (adapted from Holbourn and Kaminski, 1995).

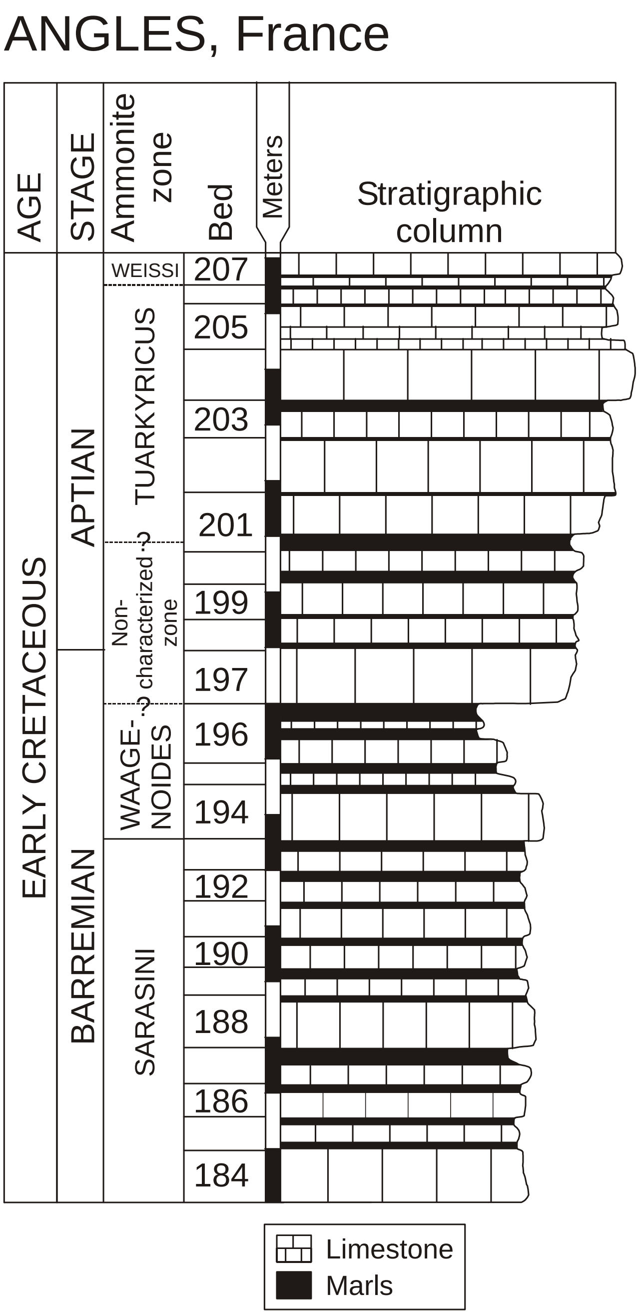

Figure 2. The stratigraphic column for the Angles section (modified after Delanoy, 1995). Position of the Barremian-Aptian boundary after Wissler et al. (2002).

2.2 *DSDP site 263, northwest Australian margin*

DSDP site 263 is located at 23º19.43'S and 110º58.81'E on the eastern edge of the Cuvier Abyssal Plain off the northwest margin of Australia (Figure 1c). Twenty-nine cores were recovered from the corehole, which penetrated approximately 646m of late Early Cretaceous marine sediments. About half of the material recovered between 128.5 and 746m below sea floor was retained (for details see Shipboard Scientific Party, 1974). The Lower Cretaceous section has been divided into three units (Figure 3; Shipboard Scientific Party, 1974): Unit 2 (cores 5, 6 and upper half of 7) consists of dark-greenish-grey to olive-black, stiff nannofossil bearing clay with the proportion of nannofossils increasing upward; Unit 3 (cores lower half of 7-18) comprises greenish-black clay stone with clay content generally exceeding 90%; Unit 4 (cores 19-29) consists of olive-black quartz-rich claystone. Cores within the sedimentary sequence show no evidence of internal disruption.

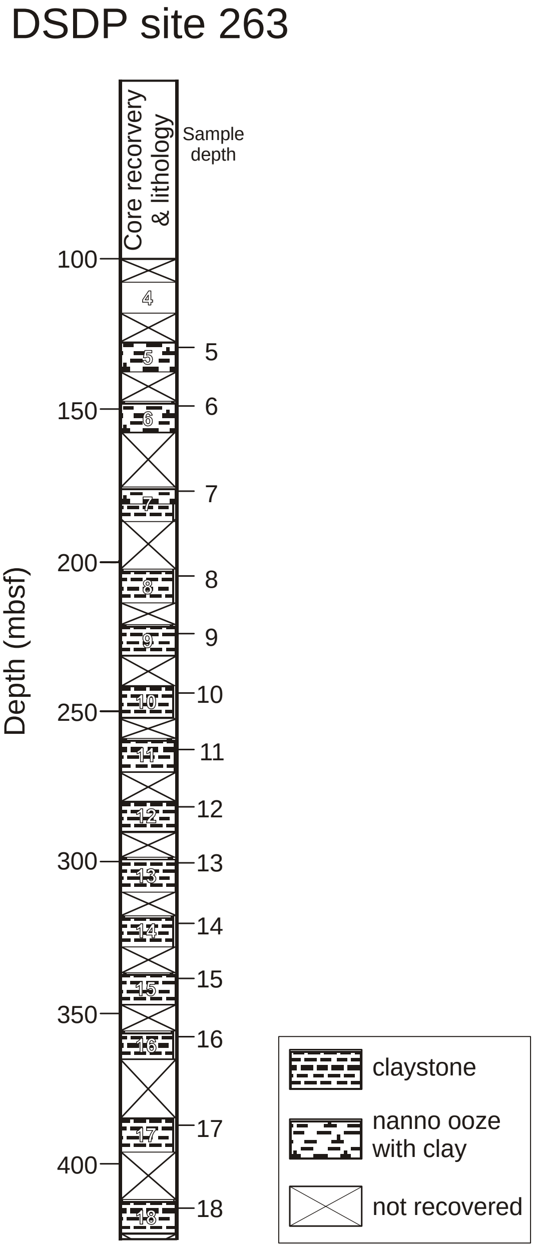

Figure 3. The stratigraphic column at DSDP site 263 (adapted from the Shipboard Scientific Party, 1974).

The Cretaceous sedimentary package was deposited on the outer continental shelf or upper continental slope (Shipboard Scientific Party, 1974), although the depositional depth remains uncertain and may have deepened through time (Scheibnerova, 1974; Holbourn and Kaminski, 1995). Besides the controversy over depositional environment the precise age of the Lower Cretaceous section at DSDP site 263 remains controversial (Figure 4) as well. Wiseman and Williams (1974) initially assigned an Aptian to Early Albian age to cores 5-18 and a Barremian age to cores 19-29 based on dinocyst assemblages. Wiseman (as cited by Morgan, 1980a) later indicated that the dinocysts support a slightly older age. Scheibnerová (1974) suggested that the benthic foraminiferal assemblages supported a late Albian age for cores 5-10, and an Aptian or older age for cores 11-29. After re-examining the benthic foraminifera, Holbourn and Kaminski

(1995) assigned an Albian age for cores 5-6, an Aptian to Albian age for cores 7-18, and a Valanginian to Barremian age for cores 19-29. On the basis of ostracods, Oertli (1974) assigned a Late Albian to Aptian or older age to cores 17-29. Proto Decima (1974) also assigned an Albian age to cores 5-28 based on a preliminary nannofossil study and a Tethyan zonation. However, P.R. Bown (as cited by Holbourn and Kaminski, 1995) suggested that the nannofossils supported a Hauterivian to Aptian age for cores 4-21. Although none of the stratigraphic work at DSDP site 263 is recent, the discrepancy in age assignments highlights the intrinsic difficulty of dating Lower Cretaceous marginal marine sections in the Austral realm without systematic comparisons to Tethyan assemblages.

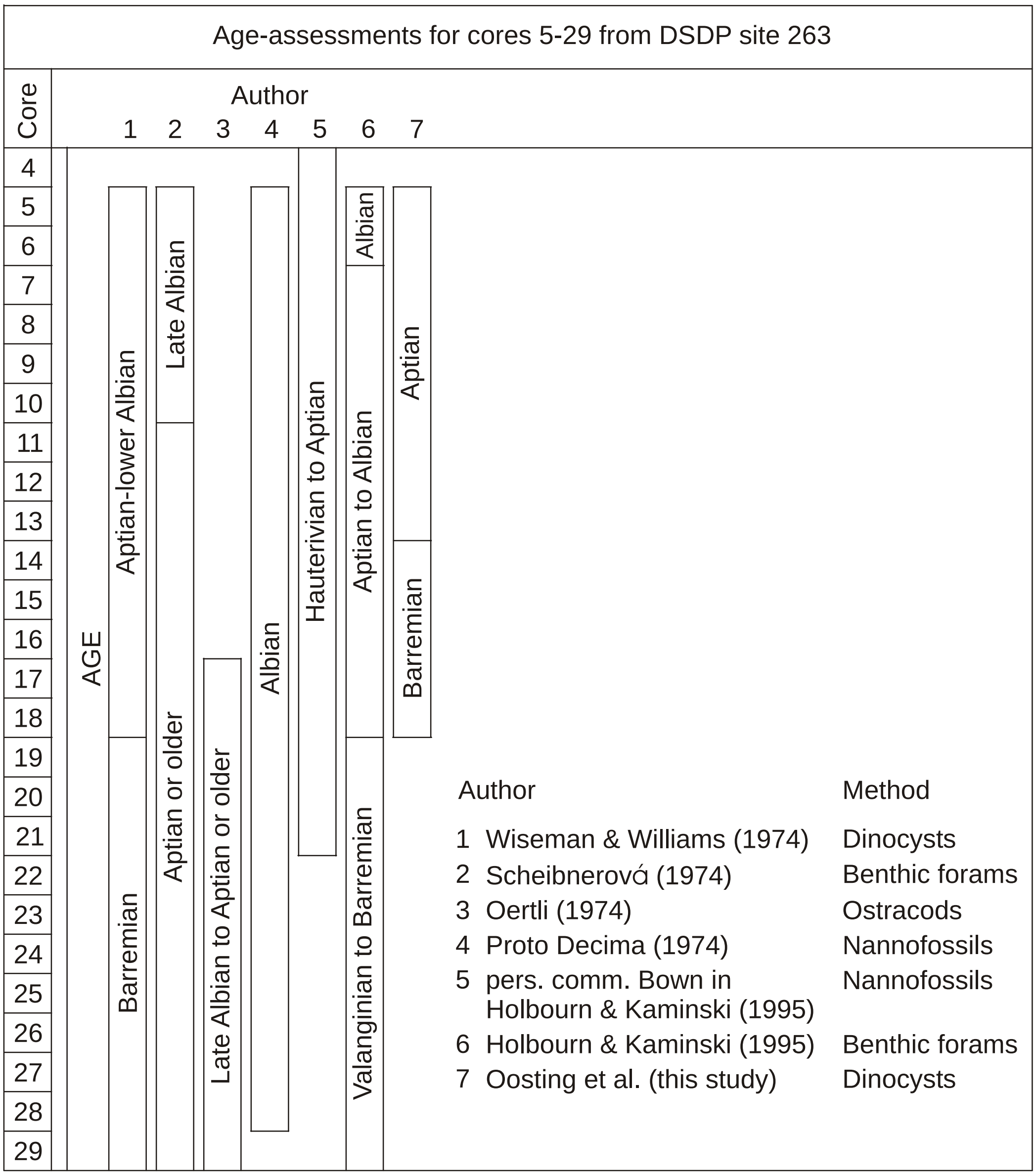

Figure 4. Age assessment of cores 5-29 from DSDP site 263 based on biostratigraphical studies.

3. Samples and methods

This study examines 23 samples of Barremian-Aptian sediment from the Angles section, and 14 samples of inferred Barremian-Aptian sediment from DSDP site 263. One sample was collected from each marl interval of beds 186-205 at the Angles section (Figure 2). For DSDP site 263, one 10 cm^3 “plug” of sediment was taken from each of cores 5-18 (Figure 3).

All 37 samples were processed for palynology at the Laboratory of Palaeobotany and Palynology (LPP, Utrecht University, The Netherlands) according to standard procedures (see Wilpshaar and Leereveld, 1994; Wilpshaar, 1995). Briefly, this procedure involved sequential digestion of samples with 30% HCL and 38% HF to remove carbonates and silicates, respectively. The residues were then sieved at 20 µm and stored in glycerine water. For each sample, two slides were made by mounting portions of the residue in glycerine gelatine. The palynomorph assemblages were quantified using three successive steps. Firstly, 100 palynomorphs (mainly dinocysts, spores, pollen, acritarchs) and acid-resistant foraminiferal linings were randomly counted on one slide. Secondly, 200 identifiable dinocysts were counted in the same slide to quantify the abundance of dinocyst taxa. Counting was started at the same reference position on each slide. Thirdly, both slides of each sample were scanned for the presence of additional taxa. Slides and sample residues from the Angles section and DSDP site 263 are currently stored in the LPP collection.

The identification and nomenclature of dinoflagellate taxa follows the Lentin and Williams Index (Williams et al., 1998). Taxa not included therein are treated in the systematics appendix. Light photomicrographs of characteristic taxa (Figures 6-8) were taken from the permanent scatter mounts.

The data for Angles and DSDP site 263 is compared to the ammonite calibrated dinocyst zonation schemes for the Tethyan and Boreal realms (Leereveld, 1995) and to the Helby et al. (1987) composite dinocyst zonation scheme for the Australian Mesozoic.

4. Results

4.1 *Dinoflagellate cyst assemblages at Angles, SE France*

The samples generally contain relatively well-preserved palynomorphs; acritarchs are rare, sporomorphs and dinocysts are abundant. The diversity of the dinocyst assemblages is moderate throughout the studied section with between 35 and 67 taxa identified for each sample (Table 1). Throughout the entire studied interval, *Spiniferites* and *Oligosphaeridium* species dominate the dinocyst assemblages; *Impagidinium* is also consistently present. Biostratigraphically important taxa occur in low numbers. The distribution of these key taxa is recorded in terms of first occurrence (FO) and last occurrence (LO). Reworked dinocysts are rare and include the following species: *Chytroeisphaeridia chytroeides*, *Cymososphaeridium validum*, *Exiguisphaera phragma*, *Gonyaulacysta exsanguia*, *G. perforobtusa*, *Kleithriasphaeridium corrugatum* and *Tanyosphaeridium magneticum*. These taxa are all considered to be of Neocomian (pre-Late Barremian) age.

4.2 *Dinoflagellate cyst assemblages at DSDP site 263*

In general, the palynomorphs of the studied interval are moderately well preserved, a finding consistent with previous work (Wiseman and Williams, 1974). The palynological assemblages are mainly composed of dinocysts, sporomorphs, acritarchs and acid-resistant formaminiferal linings (with an upward increase of the marine palynomorph proportion relative to spores/pollen; see also Wiseman and Williams, 1974, figure 3). Dinocysts dominate the assemblages in the investigated interval and show a moderate diversity (between 36 and 62 identified taxa, with a trend of gradual upward increase). The quantitative distribution chart of dinoflagellate cysts is given in Table 2.

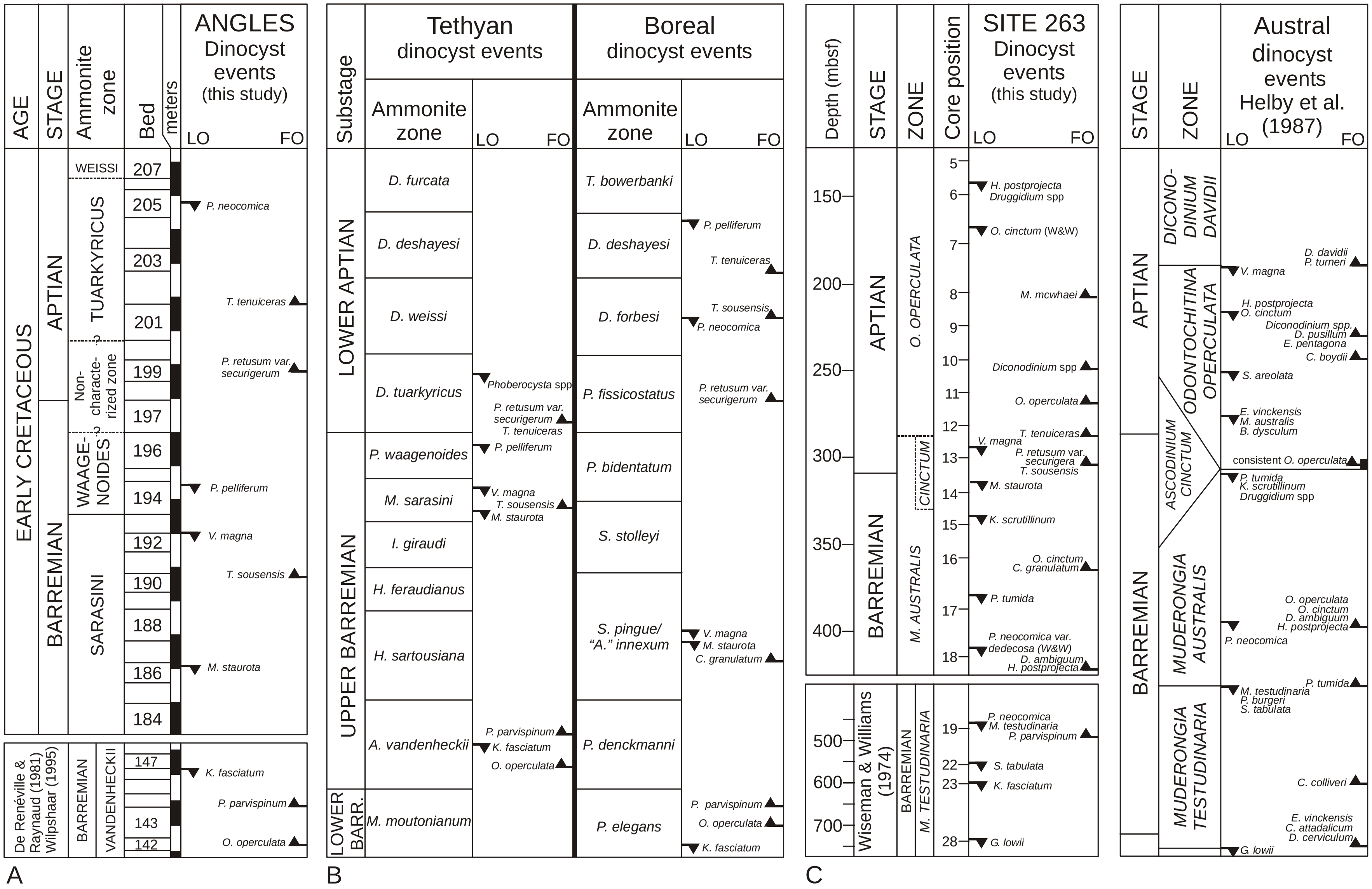

Figure 5a. Selected dinocyst events (this study) at Angles, SE France. Correlated to the ammonite calibrated standard Tethyan and Boreal schemes (adapted from Leereveld, 1995). ▼ = LO (Last Occurrence) ▲ = FO (First Occurrence)

5b. The Tethyan and Boreal ammonite calibrated dinocyst events (adapted from Leereveld, 1995).

5c. Selected dinocyst events from DSDP site 263 (this study) and Australian dinocyst events recognised by Helby et al. (1987)

Apart from the overall dominance of simple spherical cysts (chorate as well as proximate), *Spiniferites* spp quantitatively characterises the dinoflagellate assemblages throughout the studied interval, and *Impagidinium* (including forms previously assigned to *Pterodinium* and *Leptodinium*) are consistently well represented. Marine palynomorphs relative to terrigenous constituents, and dinocyst diversity, both show a general upward increase.

The dinocyst data obtained in this study are comparable with that reported by Wiseman and Williams (1974) and represents three of the dinocyst zones defined by Helby et al. (1987). In ascending order these zones are: *Muderongia testudinaria* Zone, *Muderongia australis* Zone, and *Odontochitina operculata* Zone. A fourth, the *Ovoidinium cinctum* Zone, could not be identified incontrovertibly and instead of its normal positioned between the *M. australis* and *O. operculata* it correlates to the upper part of the *M. australis* Zone.

4.3 *Comparison of dinoflagellate assemblages from Angles and DSDP site 263*

Nine dinocyst events recognised at Angles are also present at DSDP site 263 (Figure 5). These dinocyst events can be linked to ammonite controlled European Tethyan and Boreal sections. In ascending order the events at Angles are (Figure 5a): FO of *O. operculata*, FO of *P. parvispinum*, LO of *K. fasciatum*, LO of *M. staurota*, FO of *T. sousensis*, LO of *V. magna*, FO of *P. retusum* var. *securigera*, FO of *T. tenuiceras*, and LO of *P. neocomica.* At DSDP site 263 the order is: (Figure 5c): LO of *K. fasciatum*, FO of *P. parvispinum*, LO of *P. neocomica*, LO of *M. staurota*, FO of *T. sousensis*, FO of *P. retusum* var. *securigera*, LO of *V. magna*, FO of *T. tenuiceras*, and FO of *O. operculata.*

5. Discussion

5.1 *Barremian-Aptian dinocyst events at Angles.*

Leereveld (1995) determined diagnostic dinostratigraphical events in the Lower Cretaceous based on comparison of the first and last occurrences of taxa, exclusively in ammonite-controlled European Tethyan and Boreal sections. The present study amplifies this scheme with the determination of several additional key events in the Barremian-Aptian boundary interval that are of wide significance, also being represented at the DSDP site 263. The key events at Angles, summarised in Table 1 and Figure 5, are listed as:

1) LO of *Muderongia staurota*

This event is found in Bed 186 in the middle of the *sarasini* ammonite Chronozone. This biostratigraphic position agrees with its LO in the Spanish Rio Argos section (Leereveld, 1997). In NW Germany (Prössl, 1990) and in E England (H. Leereveld, unpublished) its LO is in an interval corresponding to the middle of the *Oxytheuthis germanica* belemnite Zone (middle Upper Barremian).

2) FO of *Tehamadinium sousensis*

The FO of this relatively rare species is found in Bed 190 in the middle of the *sarasini* ammonite Zone. In borehole sections from NW Germany its appearance is associated with the extinction of *Phoberocysta neocomica*, i.e., corresponding to the *forbesi* ammonite Zone (Lister and Batten, 1995; Heilmann Clausen and Thomsen, 1995).

3) LO of *Valensiella magna*

The LO occurs in Bed 192 in the uppermost *sarasini* ammonite Chronozone. In NW Germany (Prössl, 1990) and in E England (H. Leereveld, unpublished). Its LO is in an interval corresponding to the middle of the *O. germanica* belemnite Zone (middle Upper Barremian).

4) FO of *Pseudoceratium retusum* var. *securigera*

This event is found in Bed 199 in the interval without diagnostic ammonites. Previously, its first appearance in ammonite controlled Tethyan sections, was reported by Davey and Verdier (1974) and Masure (in Rasplus et al., 1987). Boreal records indicate its appearance in the *fissicostatus* ammonite Zone (Duxbury, 1983).

5) FO of *Tehamadinium tenuiceras*

The FO of the species is found in Bed 202 in the *tuarkyricus* ammonite Chronozone. However, in England its FO is in the *deshayesi* ammonite Zone (Duxbury, 1983).

6) LO of *Phoberocysta neocomica*

This event is found in Bed 205 in the upper *tuarkyricus* ammonite Chronozone; this position is confirmed by its LO in the lower part of magnetic polarity chron M0 in N Italy (Torricelli, 2000). In the European Boreal it is documented from the *forbesi* ammonite Zone (Isle of Wight: Duxbury, 1983).

Previous studies carried out on the lower part of the Angles section provided three additional dinocyst events of biostartigraphic significance (Figure 5a). These events in ascending order are:

7) FO of *Odontochitina operculata*

This event was encountered in Bed 142 in the lower *vandenheckii* ammonite Chronozone by Wilpshaar (1995).

8) FO of *Prolixosphaeridium parvispinum*

De Renéville and Raynaud (1981) identified its FO within Bed 143/144, in the middle *vandenheckii* ammonite Chronozone.

9) LO of *Kleithriasphaeridium fasciatum*

This event was found in Bed 146/147 in the middle *vandenheckii* ammonite Chronozone by De Renéville and Raynaud (1981).

It is interesting to note that one more diagnostic event around the Barremian-Aptian boundary in the Angles section may have significance for biostratigraphic correlation. To date its significance has been exclusive to the Northern Hemisphere. The taxon concerned is:

Pseudoceratium pelliferum

The LO is documented from Bed 194 in the *waagenoides* ammonite Chronozone. In the European Boreal its extinction is reported to occur in the *deshayesi* ammonite Zone (Duxbury, 1983).

A comparison of diagnostic dinoflagellate events around the base of the Aptian Stage for the Angles section with those recognized in NW European successions, suggests that the boundary assigned on the basis of the Tethyan ammonite succession is slightly younger than that based on the Boreal ammonite zonation (compare left and right column in Figure 5b for this particular interval).

5.2 *Correlation between DSDP site 263 and European standard successions.*

Nine successive dinocyst events have been recognised here to correlate the studied section at DSDP site 263 with the ammonite controlled global reference section at Angles (Figure 5). Listed in ascending stratigraphic order the events at DSDP site 263 are:

1) LO of *K. fasciatum*

This event was reported by Wiseman and Williams (1974) to lie in core 263-23: middle of the *vandenheckii* ammonite Chronozone (lowermost Upper Barremian).

2) FO of *P. parvispinum*

The FO was documented by Wiseman and Williams (1974) to lie in core 263-19: upper *vandenheckii* ammonite Chronozone (lower Upper Barremian). In support of this the species is also reported to appear near the base of magnetic chron M1 in Italy (Torricelli, 2000).

3) FO of *P. neocomica*

This event was encountered by Wiseman and Williams (1974) in core 263-19: the FO of *Phoberocysta* spp lies in the upper *tuarkyricus* ammonite Chronozone (lowermost Aptian).

4) LO of *M. staurota*

In the present study this event is found in core 263-14: *sarasini* ammonite Chronozone (uppermost Barremian).

5) LO of *V. magna*

The LO is found in core 263-13: *sarasini* ammonite Chronozone (uppermost Barremian).
In Australian sequences *V. magna* shows a high degree in morphological diversity and may be confused morphologically similar form, e.g. *Circulodinium vermiculatum* (see taxonomical section). Therefore, the LO of *V. magna* in Australian sequences should be applied with caution.

6) Presence of *P. retusum* var. *securigera*

Although this taxon has a single presence (in core 263-13) it is consistently reported to appear in the lowermost Aptian.

7) FO of *T. sousensis*

This event is found in core 263-13: middle *sarasini* ammonite Chronozone (uppermost Barremian).

8) FO of *T. tenuiceras*

The species appears in core 263-12: Tethyan *tuarkyricus* ammonite Chronozone (lowermost Aptian).

9) FO of *Odontochitina operculata*

This event occurs in core 263-11: Tethyan lower *vandenheckii* ammonite Chronozone (lower Upper Barremian).

According to the above assessments, the interval represented by cores 5-13 (128.5-300.5 m) correlates with the Early Aptian and cores 14-19 (319-461 m) with the Late Barremian part of the Angles section and other European successions.
The age assignments agree well with those provided for this site by Bown (as cited by Holbourn and Kaminski, 1995) based on nannofossils. They conflict with the age assessment of Holbourn and Kaminski (1995), based on benthic foraminifera. These authors place the Barremian-Aptian boundary between cores 18 and 19, cores 7-17 were placed as Aptian-Albian, and the interval comprising cores 4-6 were assigned an Albian or younger age. In their initial palynological study Wiseman and Williams (1974) tentatively assigned a Barremian-Early Albian age to the interval of cores 5-29. Although this is in general agreement with the results presented here, Wiseman (in Morgan, 1980a) later reassigned an older Barremian age than originally inferred in Wiseman and Williams (1974).

Remarkable differences in contemporaneous dinoflagellate assemblages from European standard successions and Australia are apparent in their ceratioid associations, implying limited utility for this group in global biostratigraphic correlation:

1. The stratigraphic range of *Muderongia* spp reach higher stratigraphic intervals in Australia than in Europe. Conversely *Phoberocysta* spp are restricted to Lower Barremian and older intervals in Australia but range up into the Aptian in Europe.
2. Typical European Barremian-Aptian *Pseudoceratium* such as *P. pelliferum* and *P. retusum* (including *P. retusum* var. *anaphrissum* and *P. retusum* var. *securigera* of Leereveld, 1997) are virtually absent in Australian dinoflagellate assemblages. As an exception to this, the presence of P. *retusum* var. *securigera* in DSDP 263 enabled a more precise assignment of the Barremian-Aptian boundary. However, due to the rare presence of this taxon, the FO of *T. tenuiceras,* which can be found in most Australian sequences, seems to be a more appropriate marker to approximate the stage boundary.

Although there is an overall dominance of cosmopolitan taxa, Australian dinoflagellate assemblages also show a strong regional character. The typical Austral forms are a complementary tool for a regional correlation. The continuous presence of *V. magna*, *C. granulatum* (a species hitherto not documented from typical Tethyan assemblages) and representatives of *Batioladinium* in the studied interval at DSDP site 263 suggest a Boreal rather than Tethyan affinity for the Australian assemblages. For instance, the FO of *C. granulatum*, found in core 263-16, corresponds to the Boreal *germanica* belemnite Zone (compare with Heilmann-Clausen and Thomson, 1995), and to the Boreal *Pingue/Innexum* ammonite Zone (Mutterlose, 1992; middle Upper Barremian). Similarly, the stratigraphic gap between the disappearance of *K. fasciatum* (core 23) and appearance of *P. parvispinum* (core 19) is a typical Boreal pattern. In NW European successions this gap almost spans the entire *elegans* ammonite Zone, whereas in the western Mediterranean Tethys both events occur in the middle *vandenheckii* ammonite Zone (Leereveld, 1995).

5.3 *Australian dinocyst zones at DSDP site 263 and their calibration*

Documentation of the dinocyst succession at DSDP site 263 across the Barremian-Aptian transition, augmented by the broader study of Wiseman and Williams (1974), which investigated the entire Lower Cretaceous section at this site, has allowed a re-evaluation of the dinoflagellate biostratigraphic scheme proposed by Helby et al. (1987) for Australia across this time interval.
The diagnostic dinocyst events relevant for defining the zonal boundaries in Australia (see Figure 6) and encountered at DSDP site 263 have also been reported from contemporaneous sequences in the region (Backhouse, 1988; Stover and Helby, 1987a and b; Brenner, 1992; Helby and McMinn, 1992) (Figure 7). The events important for recognition of the Australian dinocyst zones are:

1) LO of *M. testudinaria*

Reported by Wiseman and Williams (1974) in core 19. The extinction of the species defines the base of the *M. australis* Zone.

2) 'Acme' of *O. cinctum*

This species is found consistently but in low numbers in cores 263-16 to 13. Based on the definitions in Helby et al. (1987) the upper boundary of the *M. australis* Zone could be placed at the base of an acme of *O. cinctum*. However, no true acme was apparent at this site. This is in agreement with observations by Brenner (1992) who states that at ODP site 763, the *O. cinctum* Zone could not be recognised in between the *M. australis* and *O. operculata* zones because of lack of diagnostic stratigraphic dinocyst events in this interval. Instead he applied the zonal concept for the Carnarvon Basin: omission of the strongly facies controlled *O. cinctum* Zone, i.e., FO *M. mcwhaei* defines the top of the *M. australis* Zone. Applying this concept to the data of the present study (with the FO of *M. mcwhaei* in core 263-8) would introduce discrepancies in the ranges shown by other taxa important in the zonal scheme by Helby et al. (1987; Figure 2). Namely, the LO of *O. cinctum* (core 263-10) and the FO of *Diconodinium* spp (core 263-10) would lie below the *O. operculata* Zone instead of their normal position in the middle of the zone (Helby et al., 1987, figure 26). An extensive review on the problem concerned is also provided by Loutit et al. (1997).

3) First consistent occurrence of *O. operculata*

The first consistent occurrence of *O. operculata* lies in core 263-9. Applying the Australian zonal concept of Helby et al. (1987) for the base of the *O. operculata* Zone (the consistent occurrence of *O. operculata*) the boundary would lie between cores 9 and 10. However, definition of the zonal boundary based in this taxon, as proposed by Helby et al. (1987), is considered here to be unreliable.

The FO of *O. operculata*

This event was found in core 263-11. In the Australian zonation scheme (Helby et al., 1987) this event lies in the middle *M. australis* Zone but in DSDP site 263 it is considerably later, i.e. it occurs in the upper part of this zone. Its first appearance in DSDP site 263 is also considerably later than in Europe (i.e., in the Aptian rather than in the middle Barremian).

However, in Australia the FO of *O. operculata* has been observed coeval with the FOs of *H. postprojecta*, *O. cinctum* and *D. ambiguum* (Helby et al., 1987, figure 26). In DSDP 263, the FO of *O. operculata* is considerably later than those of *H. postprojecta* and *D. ambiguum* (Figure 5c) but these latter two occur prior to the global events of LO of *P. neocomica*, FO of *C. granulatum*, FO of *T. sousensis*, and after the FO of *P. parvispinum*. This would imply that the FO of *O. operculata* in Australian sequences is younger than the FO of *P. parvispinum*, but older than the other three mentioned global events.

4) The LO of *Kaiwaradinium scrutillinum*

This event occurs in core 263-15. In the Helby et al. (1987) scheme this taxon is considered not to range above the *M. australis* Zone, implying that the top of this zone in DSDP site 263 would lie between cores 263-14 and 15. The consistent presence of *O. cinctum* would in this case start at the top of the assigned zone, corresponding with its normal position within the Helby et al. (1987) zonation scheme. However, since there is no true acme in *O. cinctum* at DSDP site 263, a sound definition of this zone is not possible. Furthermore, due to the lack of diagnostic, stratigraphic dinocyst events between cores 263-11 and 14, recognition of the base of the succeeding *O. operculata* Zone remains a problem. The only event recognized in this interval is the last consistent occurrence of *O. cinctum* itself. In this study is therefore chosen to tentatively define the base of the *O. operculata* Zone at the last consistent occurrence of *O. cinctum* in core 263-13. Such a zonal assignment for this site would further agree with the Helby et al. (1987) zonation scheme because the LO of *O. cinctum*, and the FO of *Diconodinium* spp would then have their events higher up in the *O. operculata* Zone. The *O. cinctum* Zone itself was not differentiated independently but was rather incorporated within the upper part of the *M. australis* Zone.

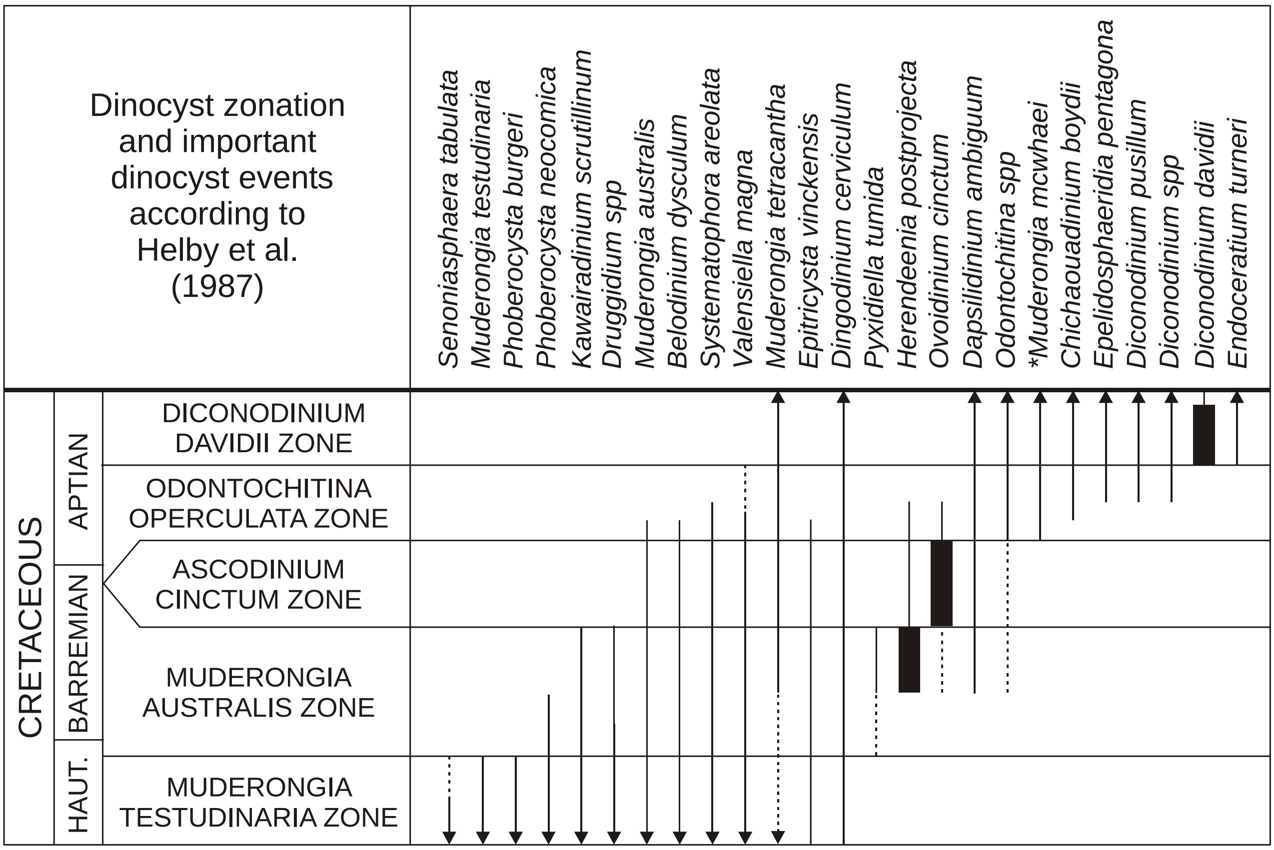

Figure 6. Zonal framework for Hauterivian-Aptian time, adapted from Helby et al. (1987). * M. mcwhaei not originally incorporated in Helby et al. (1987).

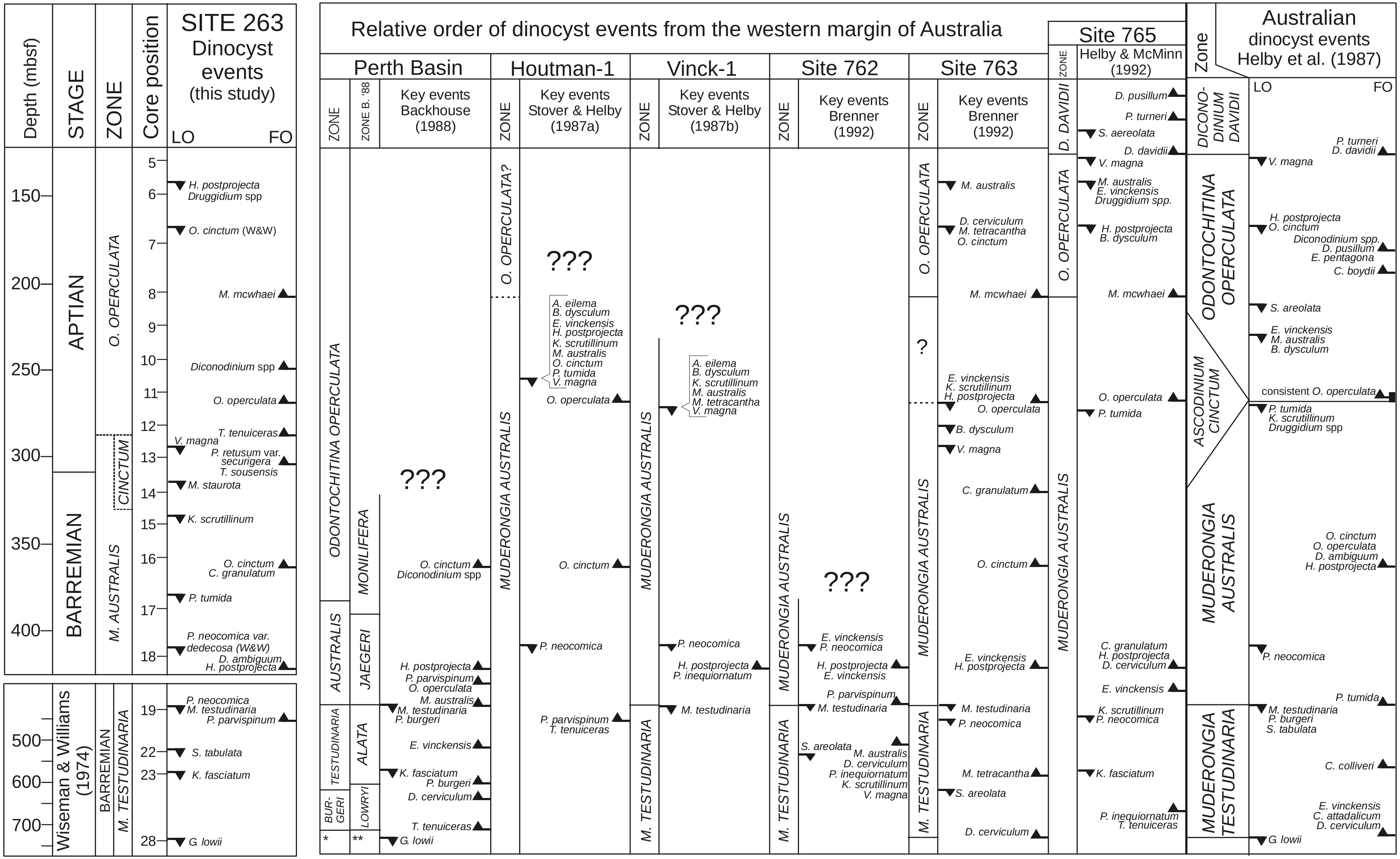

Figure 7. Correlation of DSDP site 263 with other core-based records from western Australia and the Australian composite biostratigraphic scheme (Helby et al., 1987). (* = *S. tabulata* Zone (Helby et al., 1987), ** = *K. scrutillinum* Zone (Backhouse, 1988). ▼ LO (Last Occurrence) ▲ FO (First Occurrence).

Species considered not to range above the lower *O. operculata* Zone in the zonal scheme of Helby et al. (1987) range above this level in the sequence at DSDP site 263: *B. dysculum*, *M. australis* and *E. vinckensis*. Apart from the presence of *Diconodinium* spp no taxa considered characteristic of the higher part of the *O. operculata* Zone of Helby et al. (1987) were observed in the present study. The presence of *Druggidium* spp in cores 6 and 7 is unexpectedly high, viz. above the *M. australis* Zone. But its extinction at the top of this zone as suggested by Helby et al. (1987) is suspect because this taxon was reportedly noted in association with *M. mcwhaei* (e.g. Wiseman and Williams, 1974; Helby and McMinn, 1992).

Two events documented from lower intervals by Wiseman and Williams (1974) support placement of the base of the *M. australis* Zone between cores 18 and 19 (Figure 6): 1) the LO of *Senoniasphaera tabulata* in core 22. Wiseman and Williams (1974) recorded the species as *Senoniasphaera* sp. A but their description of it allows assignment to *S. tabulata* (Backhouse and Helby in Helby, 1987). The uppermost consistent presence of this species lies within the middle *M. testudinaria* Zone. 2) the LO of *Gardodinium lowii* (recorded as *G. elongatum*) from core 28. According to Helby et al. (1987) the extinction of the species lies at the base of the *M. testudinaria* Zone.

Based on the biostratigraphic correlation of cores 5-18 from DSDP site 263 with the Angles section as presented in this study, the Aptian Stage boundary is placed within the upper *M. australis* Zone, between samples 13 and 14 of this study. Utilising data presented by Wiseman and Williams (1974) for this succession, the base of the zone is between samples taken from cores 18 and 19. Dinoflagellate events suggest that this level corresponds to the *vandenheckii* ammonite Chronozone (lowermost Upper Barremian). Consequently, the *M. australis* Zone in DSDP site 263 is Late Barremian-earliest Aptian in age and is represented by approximately 130m of section. The *O. operculata* Zone measures at least 150 meters in thickness, and because Upper Aptian or younger markers are absent it is inferred to correspond to Lower Aptian strata.

In conclusion it can be stated that, subject to strict application of comparative taxonomical and nomenclatural concepts, the selected diagnostic dinocyst events can be used to calibrate successions from different Australian basins. The extinction of *K. fasciatum* and appearances of *C. granulatum*, *P. parvispinum* and *T. tenuiceras*, for example, are frequently reported in similar mutual stratigraphic compositions from the Perth Basin (Backhouse, 1988) and Argo Abyssal Plain (Helby and McMinn, 1992) (Figure 6).

5.4 *Palaeoenvironmental evaluation of DSDP site 263*

In modern environments *Spiniferites* has its highest abundance in open marine, neritic environments (e.g. Davey and Rogers, 1975; Harland, 1983). Representatives of *Impagidinium* are associated with open ocean waters (e.g. Wall et al., 1977). The quantitative composition of the dinocyst assemblages reflects open marine environments with a continuous and distinct influence of oligotrophic waters at the location of DSDP site 263 during the Barremian-Aptian. The parallel general upward increase in marine palynomorphs versus terrigenous constituents, and dinocyst diversity indicates a progressive development towards more offshore conditions. This conclusion agrees with the palaeoenvironmental assessment based on benthic foraminifera by Holbourn and Kaminski (1995). The gradual shift from open marine neritic to hemipelagic depositional environments almost certainly reflects thermal subsidence of the Cuvier Abyssal Plain after the continental separation along the Cape Range Fracture Zone in the Valanginian-Hauterivian (Exon and Buffler, 1992).

Cool-temperate elements consistently present in the dinocyst assemblages from DSDP site 263 of Barremian-Aptian age doubtless reflect palaeotemperature. The implication of cooler water conditions prevailing on the western Australian margin during this time, compared to those in the

western Mediterranean Tethys is consistent with the Early Cretaceous palaeolatitudinal position inferred for this site, based on global palaeogeographic reconstructions (Figure 1a; Hay et al., 1999). Based on micro-palaeontological studies (e.g. nannofossils and foraminifera) similar water conditions were inferred by Baumgartner et al. (1992). According to them cooler water conditions developed in the Barremian-Aptian, probably indicating that a circumfluent current system existed around the Antarctic-Australian landmass at this time.
In agreement with Wiseman and Williams (1974) a considerable degree of reworking was noted through the studied interval. Palaeontological evidence of some reworking was also noted by the Shipboard Scientific Party (1974), although they state there is no lithological evidence indicating mass transport at this site at the time of deposition. However, it necessitates a critical analysis of the highest occurrences of taxa that seemingly have their range top in the studied interval.

Conclusions

Dinoflagellate cyst biostratigraphy can be applied for direct correlation of Barremian-Aptian Australian sequences with European ammonite controlled standard successions like at Angles. However, to accomplish this on the basis of previously published information, a critical re-evaluation of the used taxonomical and nomenclatural concepts for those studies is of vital importance.

Based on a succession of nine key dinoflagellate events in DSDP site 263, the interval of cores 18-14 correlates with Upper Barremian and the interval of cores 13-5 with the Lower Aptian (although direct proof from the upper cores is missing). This stratigraphic assessment is in general agreement with the initial palynological results of Wiseman and Williams (1974) and with that based on nannoflora by Bown (pers. comm. in Holbourn and Kaminski, 1995), but contrasts that of other biostratigraphic studies (e.g. by Holbourn and Kaminski, 1995); see figure 3.

Direct dinoflagellate stratigraphic correlation indicates that the Aptian Stage boundary (traditionally defined on ammonites at the base of the *tuarkyricus* ammonite Chronozone, and approximating the base of magnetic polarity Chron M0) is situated between cores 13 and 14 in DSDP site 263.
The Lower-Upper Barremian boundary (corresponding to a level just below the base of magnetic polarity Chron M1) is assessed to lie somewhere between cores 23 and 19. It is inferred to reflect the situation in NW Europe where the boundary lies between the stratigraphic appearance of the dinoflagellate *P. parvispinum* and the extinction of the dinoflagellate *K. fasciatum*, rather than the Tethyan situation where these events co-occur in the lowermost Upper Barremian.

Combining complementary data of Wiseman and Williams (1974) with that of this study, three successive Barremian-Aptian dinoflagellate zones from the Australia zonal scheme of Helby et al. (1987) can be identified in the interval of cores 5-19 from DSDP site 263. Based on diagnostic stratigraphic dinoflagellate events the following zones could be recognised in descending order: *O. operculata* Zone in a deviating definition (base defined by the last consistent occurrence of *O. cinctum*) in cores 5-12; *M. australis* Zone in cores 13-18; (top of) *M. testudinaria* Zone in core 19.
The *O. cinctum* Acme Zone, by Helby et al. (1987) defined as being intermediate between the *O. operculata* and *M. australis* zones could not be determined at that particular position but was instead incorporated within the upper part of the *M. australis* Zone.

Depending on the definition of its top, the Australian *M. australis* dinoflagellate Zone in DSDP site 263 extends into the Aptian, with the stage boundary positioned in its upper part. As a consequence, the overlying *O. operculata* dinoflagellate Zone is considerably younger in Australia (viz. Aptian) than the *O. operculata* Zone defined in ammonite controlled western Mediterranean (Leereveld, 1997: Late Barremian) and NW European successions (Davey, 1987: Barremian).

The lithological shift in core 7 of DSDP site 263 from greenish grey clay with 5% nannoplankton to (downward) greenish black clay with only trace amounts of nannos is inferred to be situated in Lower Aptian.

Barremian-Aptian palynological distribution patterns of DSDP site 263 are indicative of open marine neritic environments with a continuous and distinct influence of oligotrophic waters and a progressive shift towards more open marine conditions. This setting agrees with the palaeoenvironmental assessment based on benthic foraminifera by Holbourn and Kaminski (1995). The progressive development from open marine neritic to hemipelagic depositional environments probably was in response to thermal subsidence of the Cuvier Abyssal Plain after the marginal collapse of the Cape Range Fracture Zone area in the Valanginian-Hauterivian (Exon and Buffler, 1992).
The cool-temperate affinity of the encountered dinoflagellate assemblages confirms the middle Cretaceous latitudinal position of DSDP site 263 at around 50°S (e.g. Hay et al*.,* 1999) and supports the view advanced by Baumgartner et al. (1992) that a circum-Antarctic-Australian current system affected the western Australian margin during the Barremian-Aptian.

Dinoflagellate cyst species list and taxonomic remarks for Angles and DSDP site 263

List of identified taxa

For documentation of the taxa identified in the present study, see the Lentin and Williams Index (Williams et al., 1998). A selection of taxa is illustrated in Plates 1 to 4 where sample codes, preparation slide numbers, size of the specimens and England Finder Co-ordinates are indicated. Reference is made to figure numbers where applicable. Numbers refer to the order in the distribution data in Table 1 (Angles) and Table 2 (DSDP site 263).

	Table 1	Table 2	Plate
Acanthaulax spp Sarjeant, 1968	51		
Achomosphaera spp Evitt, 1963	1	153	
Adnatosphaeridium tutulosum (Cookson and Eisenack, 1960) Morgan, 1980		161	
Alterbidinium spp Lentin and Williams, 1985		190	
Aprobolocysta eilema Backhouse, 1987		113	
Aprobolocysta sp. A *sensu* Stover and Helby, 1987		134	
Aprobolocysta spp Duxbury, 1977		135	
Apteodinium granulatum Eisenack, 1958		91	
Apteodinium maculatum Eisenack and Cookson, 1960		173	
Apteodinium sp. A *sensu* Stover and Helby, 1987		151	
Avellodinium lepidum Backhouse, 1988		131	
Batiacasphaera reticulata (Davey, 1969) Davey, 1979		158	
Batiacasphaera spp Drugg, 1970		101	
Batioladinium jaegeri (Alberti, 1961) Brideaux, 1975		185	
Batioladinium micropodum (Eisenack and Cookson, 1960) Brideaux, 1975	77	126	
Batioladinium spp Brideaux, 1975		147	
Belodinium dysculum Cookson and Eisenack, 1960		92	
Callaiosphaeridium asymmetricum (Deflandre and Courteville, 1939) Davey and Williams, 1966		34	
Canningia reticulata Cookson and Eisenack, 1960		168	3i
Canningia spp Cookson and Eisenack, 1960		87	
Canninginopsis colliveri (Cookson and Eisenack, 1960) Backhouse, 1988		166	3a-c
Carpodinium granulatum Cookson and Eisenack, 1962		154	1h, l

	Table 1	Table 2	Plate
Carpodinium spp Cookson and Eisenack, 1962		178	
Cerbia cf. *tabulata* (Davey and Verdier, 1974) Below, 1981		189	3j
Cerbia tabulata (Davey and Verdier, 1974) Below, 1981	10		3k, l
Cernicysta helbyi (Morgan, 1980) Stover and Helby, 1987		187	
Cernicysta spp Stover and Helby, 1987		180	
cf. *Hystrichosphaeridium tubiferum* (Ehrenberg, 1838) Deflandre, 1937		84	
Chlamydophorella spp Cookson and Eisenack, 1958	27		
Chlamydophorella trabeculosa (Gocht, 1959) Davey, 1978	48		
Chytroeisphaeridia chytroeides (Sarjeant, 1962) Downie and Sarjeant, 1965	73		
Circulodinium spp Alberti, 1961		167	
Circulodinium vermiculatum Stover and Helby, 1987		155	3d-h
Cleistosphaeridium spp Davey *et al.*, 1966	22	94	
Cometodinium habibii Monteil, 1991	20		
Cometodinium spp Deflandre and Courteville, 1939		149	
Cometodinium? comatum Srivastava, 1984	24		
Coronifera albertii Millioud, 1969	63		
Coronifera oceanica Cookson and Eisenack, 1958	13	152	
Cribroperidinium spp Neale and Sarjeant, 1962	11	110	
Ctenidodinium elegantulum Millioud, 1969	30		
Cyclonephelium intonsum Duxbury, 1983	70		
Cyclonephelium spp Deflandre and Cookson, 1955	2	95	4a-d
Cymososphaeridium validum Davey, 1982	66		
Dapsilidinium ambiguum (Deflandre, 1937) Wheeler and Sarjeant, 1990		93	4f
Dapsilidinium spp Bujak *et al.*, 1980	14	162	
Diconodinium micropunctatum Backhouse, 1988		181	4h
Dingodinium cerviculum Cookson and Eisenack, 1958	45	96	
Dingodinium europaeum Eisenack, 1958	53		
Discorsia nanna (Davey, 1974)	52	115	
Dissiliodinium globulus Drugg, 1978	12		
Druggidium apicopaucicum Habib, 1973	40		4i
Druggidium apicopaucicum Habib, 1973 /*deflandrei* Millioud, 1969	83		4j
Druggidium deflandrei Millioud, 1969	46		4k
Druggidium deflandrei Millioud, 1969 /*rhabdoreticulatum* Habib, 1973		177	
Elytrocysta circulata (Clarke and Verdier, 1967) Stover and Helby, 1987	69		
Endoscrinium bessebae Below, 1981	89	171	
Endoscrinium campanula (Gocht, 1959) Vozzhennikova, 1967		49	127
Endoscrinium spp (Klement, 1960) Vozzhennikova, 1967		157	
Epitricysta vinckensis Stover and Helby, 1987		116	
Escharisphaeridea spp Erkmen and Sarjeant 1980	3	182	
Exiguisphaera phragma Duxbury, 1979	78		
Exochosphaeridium phragmites Davey *et al.*, 1966	31		
Exochosphaeridium spp Davey *et al.*, 1966		104	
Florentinia cooksoniae (Singh, 1971) Duxbury, 1980		56	
Florentinia interrupta Duxbury, 1980	59		
Florentinia mantellii Davey and Williams, 1966	50		
Florentinia resex Davey and Verdier, 1976		188	
Florentinia spp Davey and Verdier, 1973	60	191	
Fromea monilifera Backhouse, 1987		124	
Gonyaulacysta cassidata Eisenack and Cookson, 1960	47		
Gonyaulacysta cretacea (Neale and Sarjeant, 1962) Sarjeant, 1969	90		
Gonyaulacysta helicoidea (Eisenack & Cookson 1960) Sarjeant 1966	25		
Gonyaulacysta perforobtusa Duxbury 1977	79		
Gonyaulacysta spp Deflandre, 1964		105	
Herendeenia postprojecta Stover and Helby, 1987		129	4l
Heslertonia heslertonensis (Neale and Sarjeant, 1962) Sarjeant, 1966	28		
Heslertonia spp Sarjeant, 1966		186	
Heterosphaeridium? heteracanthum (Deflandre and Cookson, 1955) Eisenack and Kjellström, 1971	35	183	
Heterosphaeridium spp Cookson and Eisenack, 1968		144	
Histiocysta outananensis Below, 1981	26		

	Table 1	Table 2	Plate
Hystrichodinium pulchrum Deflandre, 1935	18	111	4q
Hystrichodinium spp Deflandre, 1935		117	
Hystrichogonyaulax spp Sarjeant, 1969	71		
Hystrichosphaeridium recurvatum (White 1842) Lejeune-Carpentier, 1940	54		
Impagidinium phlyctaena Stover and Helby, 1987		150	
Impagidinium spp Stover and Evitt, 1978		98	
Kaiwaradinium scrutillinum Backhouse, 1987		160	4p
Kiokansium spp Stover and Evitt, 1978	4		
Kiokansium unituberculatum (Tasch, 1964) Stover and Evitt, 1978		122	
Kleithriasphaeridium corrugatum Davey, 1974	85		
Kleithriasphaeridium eoinodes (Eisenack, 1958) Davey, 1974		33	107
Leiosphaera spp Eisenack, 1938		106	
Leptodinium spp Klement, 1960		109	
Lithodinia amlasis (Below, 1981) Williams *et al.*, 1993	75		
Lithodinia psora (Davey and Verdier, 1974) Gocht, 1976		175	
Lithodinia sp. cf. *helbyi* (Morgan, 1980)		192	
Lithodinia sp. cf. *L. bulloidea* (Cookson and Eisenack, 1960) Gocht, 1976		139	
Lithodinia spp Eisenack, 1935		136	
Lithodinia stoveri Millioud, 1969	21		
Lithodinia stoveri Millioud, 1969 */amlasis* (Below, 1981) Williams *et al.*, 1993	72		
Microdinium spp Cookson and Eisenack, 1960		141	
Muderongia australis Monteil, 1991		99	4n
Muderongia crusis Neale and Sarjeant, 1962; emend. Monteil, 1991		137	
Muderongia mcwhaei Monteil, 1991		184	4o
Muderongia simplex Monteil, 1991		43	
Muderongia staurota Monteil, 1991	44	138	1o, p
Muderongia tabulata Raynaud, 1978	86		
Muderongia tetracantha Monteil, 1991		114	
Occisucysta tentorium Duxbury, 1977	74		
Odontochitina operculata (O.Wetzel, 1933) Deflandre and Cookson, 1955	5	176	1c, d
Oligosphaeridium complex (White, 1842) Davey and Williams, 1966	6	100	
Ovoidinium cinctum (Cookson and Eisenack, 1958) Davey, 1970		159	4m
Ovoidinium diversum Davey, 1979	55		
Palaeoperidinium cretaceum Pocock, 1962	32		
Pareodinia ceratophora Deflandre, 1947	39	165	
Pareodinia spp Deflandre, 1947		133	
Pentafidia punctata Backhouse, 1988		128	
Pervosphaeridium truncatum (Davey, 1969) Below, 1982		119	4e
Phoberocysta neocomica (Gocht, 1957) Millioud, 1969; emend. Helby, 1987	37		1m,n
Phoberocysta tabulata Raynaud, 1978	61		
Platycystidia eisenackii (Mehrota and Sarjeant, 1984) Backhouse, 1988		143	
Polystephanephorus euryanthus Cookson and Eisenack, 1974	67		
Proloxisphaeridium parvispinum (Deflandre, 1937) Davey *et al.* 1969	36	142	1a, b
Proloxisphaeridium spp Davey *et al.*, 1966	68	146	
Protoellipsodinium spinosum Davey and Verdier, 1971		120	
Protoellipsodinium spp Davey and Verdier, 1971	29	123	
Protoellipsodinium touile Below, 1981	64		
Pseudoceratium pelliferum Gocht, 1957	41		1j
Pseudoceratium retusum Brideaux, 1977	58		1i
Pseudoceratium retusum var. *securigera* (Davey & Verdier, 1974) Leereveld, 1997	76	170	1k
Pterodinium spp Eisenack, 1958	15	121	
Pyxidiella tumida Stover and Helby, 1987		148	4g
Rhombodella natans Cookson and Eisenack, 1962		132	
Rhynchodiniopsis fimbriata (Duxbury, 1980) Sarjeant, 1982	7		
Scriniodinium attadalense (Cookson and Eisenack, 1958) Eisenack, 1967		140	
Scriniodinium? campanula Gocht, 1959	57		
Sentusidinium spp Sarjeant and Stover, 1978		16	102
Spiniferites spp Mantell, 1850	8	97	
Stiphrosphaeridium anthophorum (Cookson and Eisenack, 1958) Lentin and Williams, 1985		145	

	Table 1	Table 2	Plate
Stiphrosphaeridium dictyophorum (Cookson and Eisenack, 1958) Lentin and Williams, 1985	88	112	
Subtilisphaera spp Jain and Millepied, 1973	9	130	
Systematophora areolata Klement, 1960		179	
Systematophora spp Klement, 1960		65	
Tanyosphaeridium spp Davey and Williams, 1966	19	103	
Tehamadinium coummia Below, 1981	82		
Tehamadinium sousensis (Below, 1981) Jan du Chêne *et al.* in Jan du Chêne *et al.*, 1986	62	169	2a-c
Tehamadinium tenuiceras (Eisenack, 1958) Jan du Chêne *et al.* in Jan du Chêne *et al.*, 1986	81	172	2d-f
Tenua spp Eisenack, 1958		108	
Tetrachacysta allenii Backhouse, 1988		164	
Trichodinium castanea (Deflandre, 1935) Clarke and Verdier, 1967	17	156	
Trichodinium ciliatum (Gocht, 1959) Eisenack, 1964	80		
Valensiella magna (Davey, 1974) Courtinat, 1989	42	163	1e-g
Valensiella pygmaea (Stevens, 1987) Lentin and Williams, 1993		118	
Valensiella reticulata (Davey, 1969) Courtinat, 1989	23		
Valensiella spp Eisenack, 1963		125	
Wallodinium krutzschii (Alberti, 1961) Habib, 1972	38		
Wallodinium luna (Cookson and Eisenack, 1960) Lentin and Williams, 1973		174	

Taxonomic remarks

Canningia

This genus is two layered and bears no signs of paratabulation besides its archeopyle margin.

Canningia reticulata

The present material did not allow observation of the wider ectocoel below horns and paracingulum as described by Helby (1987, p. 322).

Canninginopsis

This genus differs from *Canningia* in being single instead of two layered, and in displaying paratabulation by alignment of low parasutural features.

Canninginopsis colliveri

Wall ornamentation displayed by the specimens examined varies from being smooth to finely granular. Paratabulation, when present, is very hard to discern. On the granular forms it is incomplete or lacking and the smooth forms display no evidence of this feature.

Cerbia cf. *tabulata*

Specimens encountered show the parasutural characteristics of *Cerbia tabulata,* but still bear minor intratabular spinelike features rather than being smooth. They are therefore assigned to *Cerbia* cf. *tabulata*. Wiseman and Williams (1974) recorded *Canninginopsis denticulata* from core 7. However, the specimens we have noted show the processes being peritabular as in *Cerbia tabulata* rather than parasutural as in *C. denticulata*. It is therefore likely that the specimens noted by Wiseman and Williams (1974) as *C. denticulata* are variations of *Cerbia* cf. *tabulata*.

Chlamydophorella spp

No attempt has been made to distinguish (sub)spherical to ovoidal forms of *Chlamydophorella* with randomly distributed pillars and without other diagnostic features.

Circulodinium vermiculatum
Cysts with highly variable shapes: spherical, subspherical, with one median antapical bulge or ceratioid with one or two antapical lobes. Parasutural features, apart from the archeopyle suture, are absent. Wall ornamentation within each specimen varies from being vermiculate to finely reticulate. This combined variation, of shape and wall structure, can be found in the genera: *Canningia*, *Cyclonephelium* and *Circulodinium*. However, light-microscopic analysis of the present material did not allow conclusive identification of the existence of a two layered wall as in, e.g. *Canningia? rotundata*.
The dorso-ventral areas, which show up darker in light-microscopic analysis, are caused by the vermiculate pattern becoming more dense in these areas and not because of a reduction in ornamentation, like in *Cyclonephelium*, with a subsequent thickening in these areas. Therefore, all the encountered specimens in this study have been assigned to *Circulodinium vermiculatum*.

Cyclonephelium spp
In the present study *Cyclonephelium* spp contains all variations in number and length of spines between *C. distinctum* as one morphological end member and *C. hystrix* as the other.
Circulodinium attadalicum (= *Cyclonephelium?*) recorded by Wiseman and Williams (1974)
was not recognised because the specimens observed in this study show neither concentration of spines in certain parts, nor a strongly reduced right antapical horn.

Diconodinium micropunctatum
The observed specimens show a broad cingulum, striate surface, and posses one apical and two antapical small protrusions. It is considered that *Dinogymnium westralium* at Wiseman and Williams (1974) represent specimens of *D. micropunctatum* on which the small protrusions could not be observed.

Druggidium deflandrei/*rhabdoreticulatum*
The specimens encountered in the present study exhibit a combination of high septa as in *D. deflandrei* and the intratabular characteristics of *D. rhabdoreticulatum.* Specimens described as *Druggidium* sp. A of Wiseman and Williams (1974) have not been observed. It is noteworthy that the highest stratigraphic occurrence of *D. rhabdoreticulatum* in ammonite controlled sections is from the Upper Barremian (*vandenheckii* ammonite Chronozone in south Spain (Leereveld, 1997) and from the Sarasini ammonite Chronozone in the Angles section.

Herendeenia postprojecta
All specimens encountered in this study show the characteristic single intratabular process on the antapical paraplate and a pitted ornamentation of *H. postprojecta*, rather than showing intratabular projections as in *H. pisciformis* which was reported by Wiseman and Williams (1974).

Hystrichodinium pulchrum
The encountered specimens possess spines, which are all of similar length and show no concentration around the paracingulum or in the polar areas. *H. oligacanthum*, a species reported by Wiseman and Williams (1974), were not encountered in the present study as no specimen showed spine concentration that characterises this species. No high septa between the spines were observed as in *H. voigtii*.

Muderongia
For species assignment within *Muderongia* the concept of Monteil (1991) is strictly followed for Stages 0, I and II. Although Monteil synonymised *Phoberocysta* with *Muderongia,* the variation observed in this study does not permit emphasis on the inter-gradating nature of the features concerned.

M. mcwhaei is characterised by a postcingular extension at least twice as long as the precingular one, and a clearly oblique antapical extension. *M. australis* is characterised by a clearly oblique antapical extension, and a postcingular-precingular ratio less than two. Since none of the encountered specimens possess a strongly developed, second antapical horn, a characteristic of *M. simplex* which was recognised by Wiseman and Williams (1974), the species was not identified in the present study. *Muderongia* sp. nov. (Evans) in Wiseman and Williams (1974) corresponds to *M. testudinaria* (Burger, 1980) as emended by Monteil (1991).

Odontochitina operculata
Following Duxbury (1980), and Wilpshaar (1995), records of this species in strata older than middle Barremian are here considered to be incorrectly identified representatives of *Muderongia*.

Oligosphaeridium cpx group
The range of morphologies assigned to this taxon embraces: *O. asterigerum*, *O. complex*, *O. diastema,* and *O. pulcherrimum*.

Ovoidinium/Subtilisphaera group
In the present study specimens showing the morphological characteristics of *Ovoidinium cinctum,* (= *Ascodinium*) but in which an archeopyle could not be discerned, are here assigned to the *Ovoidinium/Subtilisphaera* group. In rare cases where an archeopyle is recognisable specimens have been assigned to *O. cinctum*.

Pervosphaeridium truncatum
This taxon reported in Wiseman and Williams (1974) as *Exochosphaeridium striolatum* var. *truncatum* is now referred to as *P. truncatum*. Specimens encountered in this study display a 2P archeopyle.

Prolixosphaeridium parvispinum.
In Austral sequences the related species *P. inequiornatum* has a similar stratigraphic first occurrence to that of *P. parvispinum*. However, *P. inequiornatum* possesses verrucae, coni and short spines in the equatorial region and has longer spines concentrated in the polar areas. Because all specimens of *Prolixosphaeridium* encountered in the present study possess spines which do not vary in shape and are evenly distributed over the body they are assigned to *P. parvispinum*.
Phoberocysta
See notes on *Muderongia*.

Pseudoceratium retusum var. *anaphrissa*
The LOD of *Pseudoceratium retusum* var. *anaphrissa* has previously been reported in the Upper Barremian. In the present study, however, the range of this species appears to overlap with that of *Pseudoceratium retusum* var. *securigerum* to which it is morphologically closely related. The latter morph has a consistent presence in Lower Aptian deposits.

Pyxidiella tumida
Pyxidiella tumida is exclusive to the Australian *Muderongia australis* Oppel Zone of Helby *et al.* (1987). In the studied material archeopyles were extremely difficult to discern, perhaps explaining why Wiseman and Williams (1974) did not identify this species.

Tanyosphaeridium spp.
In the present study no attempt has been made to distinguish species within *Tanyosphaeridium*. This category embraces morphs assigned as: *T. boletum, T. isocalamus, T. magneticum, T. regulare, T. salpinx*, and *T. variecalamus*.

Tehamadinium

For species assignment within *Tehamadinium*, the concept of Jan du Chêne et al. (1986) has been applied.

Tehamadinium sousensis

A subspherical- to ovoidal-shaped species with a thick and vacuolate autophragm showing clear but delicate parasutural septa. The cyst bears an ill-defined apical protuberance. Specimens may show a few scattered intratabular spines, especially on the precingular, postcingular and antapical plates.

Tehamadinium tenuiceras

The first specimens at DSDP 263 are robust, possess strongly developed parasutural crests, many intratabular spines, a thick wall, a clear apical protuberance, and have a somewhat ovoidal shape. At Angles *T. tenuiceras* is subspherical, possesses lower parasutural crests, minor intratabular spines and thinner walls. Such specimens have also been observed at DSDP 263 and co-occur with the more robust specimens. These thinner, more spherical specimens are therefore considered to represent variation within the species.

This species is differentiated from *T. sousensis* in displaying numerous intratabular spines on all paraplates.

The interval in which *T. tenuiceras* has been recognised for this study corresponds to the interval in which Wiseman and Williams (1974) identified *Gonyaulacysta* (now *Leptodinium*) *episoma*. Wiseman and Williams (1974) followed Sarjeant's (1966) concept for *G. episoma*, as did Morgan (1980a). The specimens illustrated by Morgan (1980a, plate 14, figure 4 and 5) however, clearly show a 2P archeopyle. *G. episoma* of Wiseman and Williams (1974), although not described or figured by these authors, almost certainly represents *Tehamadinium*.

Valensiella magna

Specimens from DSDP site 263 assigned to *V. magna* in this study are spherical, coarsely reticulate, and of considerable size. Although the specimens show all the key characteristics of *V. magna*, they appear to be slightly less robust and thick walled than typical of this species. Morgan (1980a) and Backhouse (1988) reported *V. magna* from Austral successions as showing a higher degree in morphological diversity than typical of European assemblages. They describe forms with more delicate lumina co-occurring with the 'classic' robust, coarsely reticulate forms.

Plate 1

Light photomicrographs of selected taxa from the Angles section and DSDP site 263.

a, *Prolixosphaeridium parvispinum*, body width 35 µm, 263-6(1) EFC G29/4.
b, idem, body width 30 µm, Angles 204-15 EFC J42.

c, *Odontochitina operculata*, body width 47 µm, 263-7(1) EFC U27/2.
d, idem, 47 µm, Angles 204-36 EFC G46/3.

e, *Valensiella magna*, body width 97 µm, 263-13(1) EFC J32/2.
f, idem, body width 87 µm, 263-13(1) EFC J33/3.
g, idem, body width 82 µm, Angles 190-3 EFC S36/3.

h, *Carpodinium granulatum*, body width 42 µm, 263-7(1) EFC K43/2.
l, idem, body width 33 µm, 263-7(1) EFC Q32/4.

i, *Pseudoceratium retusum*, body width 62 µm, Angles 194-16 EFC J33.

j, *Pseudoceratium pelliferum*, body width 58 µm, Angles 191-I EFC U39/4.

k, *Pseudoceratium retusum* var. *securigerum*, body width 93 µm, 263-13(1) EFC M35.

m, *Phoberocysta neocomica*, inner body width 48 µm, Angles 205-26 EFC P29/1.
n, idem, inner body width 64 µm, Angles 190-3 EFC G28/1.

o, *Muderongia simplex*, inner body width 37 µm, Angles 192-30 EFC X31.

p, *Muderongia staurota*, inner body width 53 µm, 263-17(1) EFC M29/2.

Plate 1

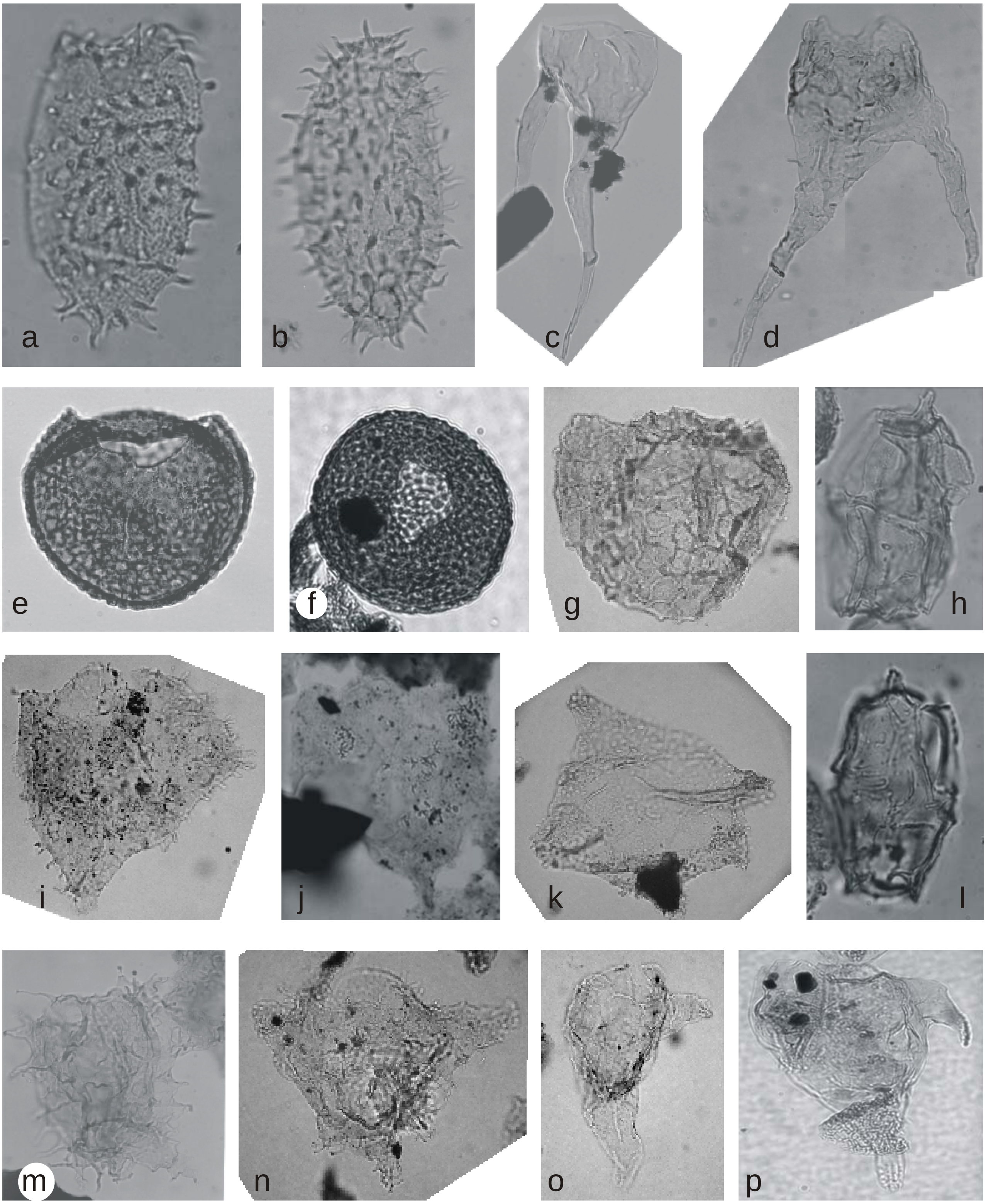

Plate 2

Light photomicrographs of selected taxa from the Angles section and DSDP site 263.

a, b, *Tehamadinium sousensis*, body width 58 µm, 263-13(1) EFC K43/3.
c, d, idem, body width 59 µm, 263-13(2) EFC D28.
e, f, idem, body width 59 µm, Angles 202-25 EFC M30/4.

g, h, *Tehamadinium tenuiceras*, body width 67 µm, 263-11(2) EFC F35.
i, j, idem, body width 64 µm, 263-9(1) EFC P32/4.
k, l, idem, body width 61 µm, Angles 202-24 EFC P37/4.

Plate 2

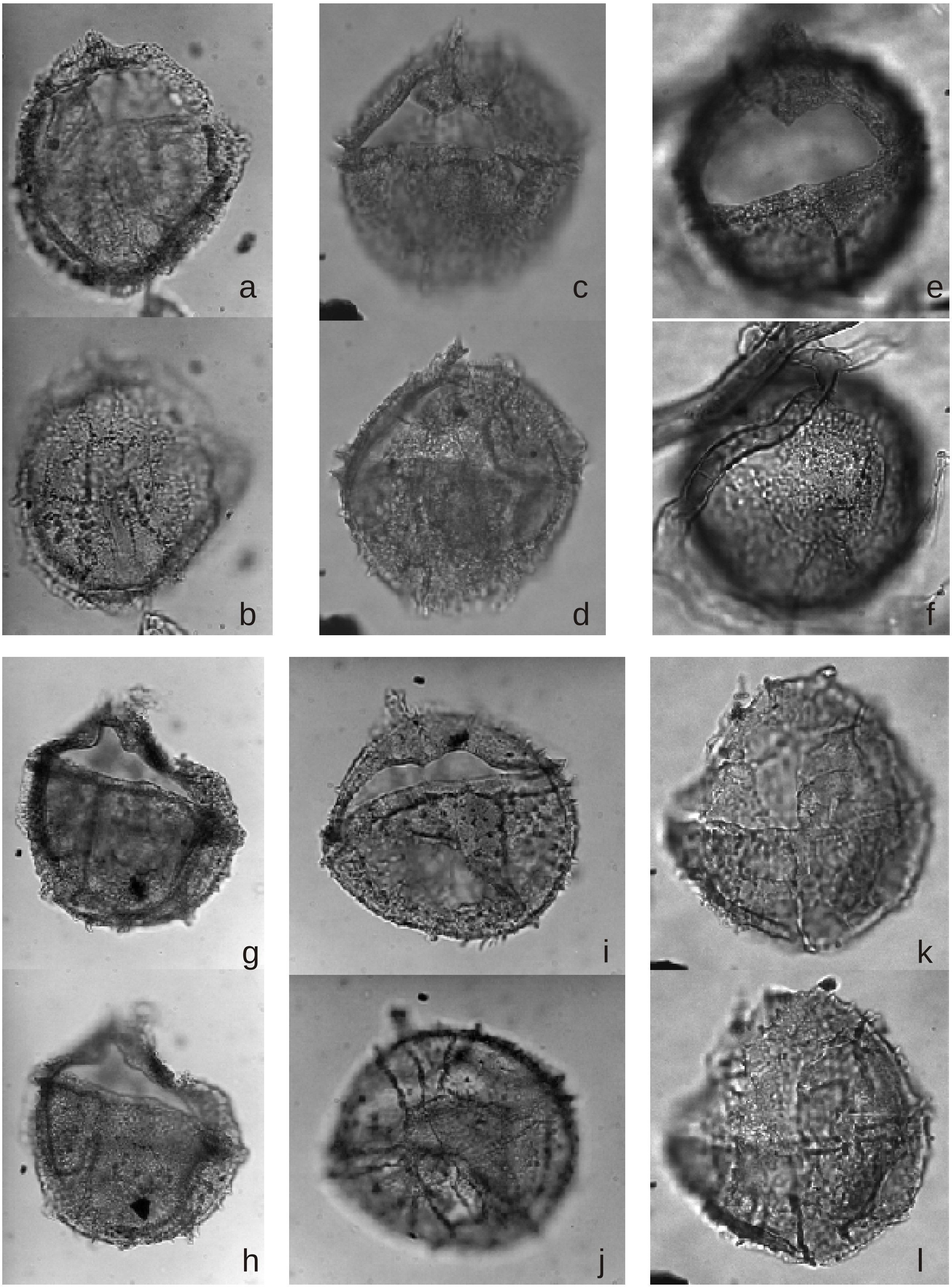

Plate 3

Light photomicrographs of selected taxa from the Angles section and DSDP site 263.

a, *Canninginopsis colliveri*, body width 71 µm, 263-8(1) EFC E42/3.
b, idem, body width 78 µm, 263-10(1) EFC P34.
c, idem, body width 88 µm, 263-11(1) EFC O33/4.

d, *Circulodinium vermiculatum*, body width 119 µm, 263-13(2) EFC L28/2.
e, idem, body width 119 µm, 263-13(1) EFC Q44.
f, idem, body width 94 µm, 263-13(1) T40/2.
g, idem, body with 91 µm, 263-13(1) EFC S32.
h, idem, body width 111 µm, 263-13(2) EFC M33.

i, *Canningia reticulata*, body width 100 µm, 263-13(2) EFC L28/2.

j, *Cerbia* cf. *tabulata*, body width 80 µm, 263-5(1) EFC D36/1.

k, *Cerbia tabulata*, body width 79 µm, Angles 203-25 EFC N31/1.
l, idem, body width 93 µm, Angles 204-35 EFC S25/4.

Plate 3

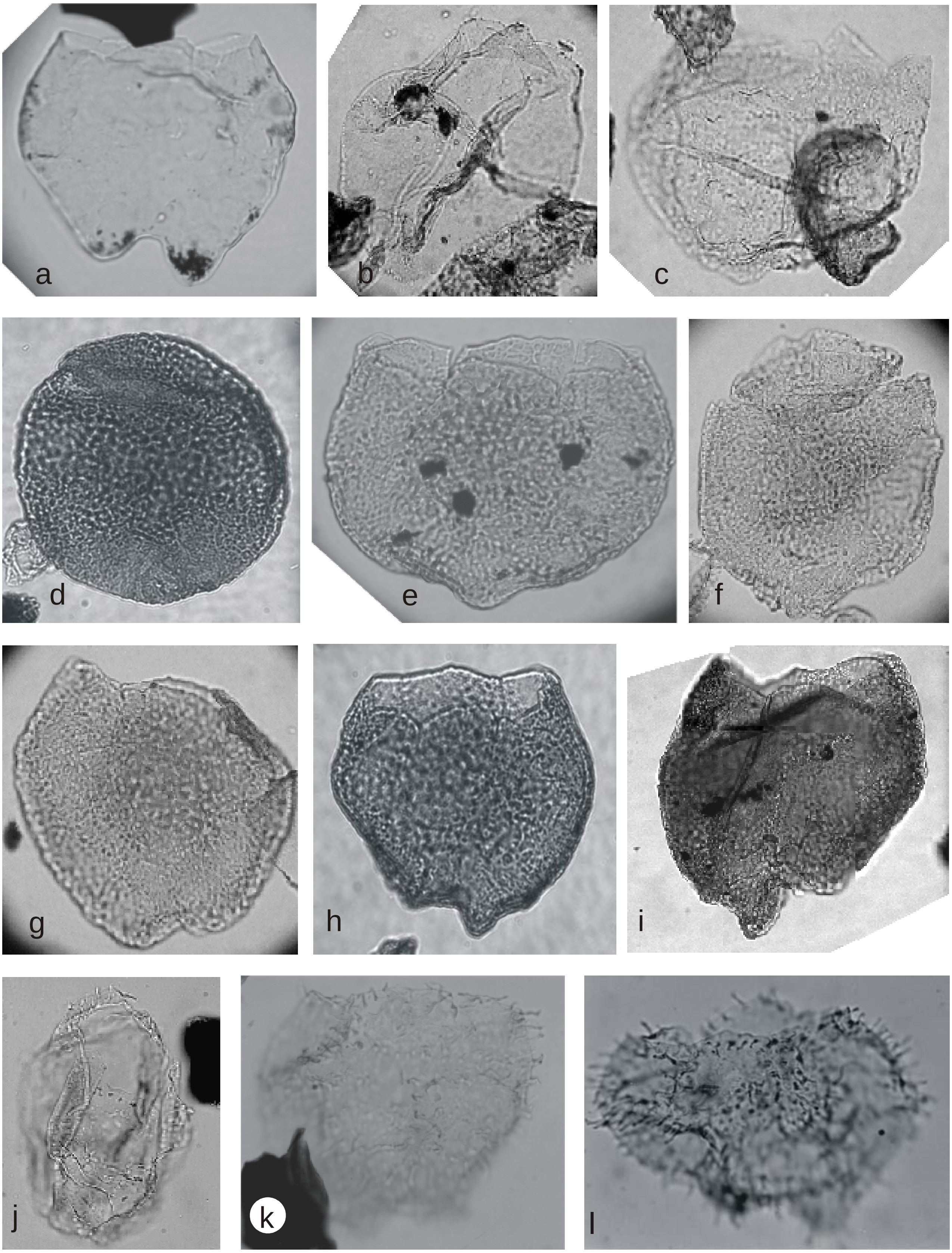

Plate 4

Light photomicrographs of selected taxa from the Angles section and DSDP site 263.

a, *Cyclonephelium* spp, body width 78 µm, 263-5(1) EFC M39/1.
b, idem, body width 83 µm, 263-18(2) EFC G42.
c, idem, body width 81 µm, 263-13(1) EFC V32/4.
d, idem, body width 70 µm, 263-9(1) EFC M36/4.

e, *Pervosphaeridium truncatum*, body width 60 µm, 263-13(1) EFC G27.

f, *Dapsilidinium ambiguum*, inner body width 36 µm, 263-6(1) EFC W34/3.

g, *Pixydiella tumida*, body width 21 µm, 263-17(1) EFC C38.

h, *Diconodinium micropunctatum*, body width 35 µm, 263-8(1) EFC P37/2.

i, *Druggidium apicopaucicum*, body width 28 µm, Angles 204-35 EFC O31.

j, *Druggidium* spp, body width 22 µm, 263-7(2) EFC M40.

k, *Druggidium deflandrei*, body width 30 µm, Angles 190-3 EFC R36/3.

l, *Herendeenia postprojecta*, body width 50 µm, 263-8(2) EFC P34.

m, *Ovoidinium cinctum*, inner body width 53 µm, 263-14(2) EFC E32.

n, *Muderongia australis*, inner body width 55 µm, 263-17(1) EFC J43/2.

o, *Muderongia mcwhaei*, inner body width 62 µm, 263-8(1) EFC D31.

p, *Kaiwaradinium scutillinum*, body width 56 µm, 263-15(2) EFC M41/2.

q, *Hystrichodinium pulchrum*, body width 50 µm, 263-6(2) EFC P37/2.

Plate 4