

Calcareous nannofossil and dinoflagellate stratigraphy of the Cretaceous-Tertiary boundary, Alabama and Georgia

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ABSTRACT: Calcareous nannofossils and dinocysts date the base of the Clayton Formation in south-central Alabama as Danian in age. The first occurrences of *Biantholithus sparsus*, *Cruciplacolithus primus*, *Senoniasphaera inornata*, *Danea californica* and *Membranilarnacia tenella* in the basal sands at Mussel Creek indicate that the Cretaceous-Tertiary (KT) boundary lies virtually at the disconformity (type 1 sequence boundary) which separates the Clayton Formation from the underlying Prairie Bluff Chalk. The presence of the latest Maestrichtian *Micula prinsii* nannofossil zone in the uppermost 30-50cm of the Prairie Bluff unit closely constrains the hiatus to within several hundred thousand years. In the Braggs roadcut, the base of the *Micula prinsii* zone lies well within the one-meter thick magnetically unstable interval below polarity Chron C29R. This boundary indicates that the unstable interval is equivalent in age to the earlier part of this chron.

In the section from southeastern Georgia, Cretaceous nannofossil taxa disappear below the KT boundary in a shallowing upward sequence of progradation to nearshore environments. Dinoflagellate taxa are potentially valuable for distinguishing third-order cycles of coastal onlap. Species are fewest in lowstand deposits directly above the KT boundary, and then increase rapidly in number in the shelf facies transgressive tract. They then decrease in number systematically from the upper part of the transgressive tract into the next prograding highstand tract. This pattern of dinoflagellate diversity is calibrated from the sequence stratigraphy of the early Danian Pine Barren member of the Clayton Formation, and correlates with third-order cycles published for the late Campanian, early Maestrichtian and late Maestrichtian as well. Dinoflagellate species of Cretaceous origin flourished in the early Danian, at a time when the calcareous-shelled biota was still impoverished by extinction.

INTRODUCTION

Research concerning events associated with the Cretaceous-Tertiary boundary (KT) in various parts of the world has been rekindled recently by new information which attempts to explain the cause of mass extinctions. Alvarez et al. (1980) attributed the anomalously high concentrations of iridium in KT boundary clays to the major impact of one or more asteroids at the earth's surface. These bombardments would have disrupted the ecosystem of widely diverse groups of organisms, such as dinosaurs, ammonites and various groups of calcareous-shelled plankton, which caused their extinction. Given the renewed interest in the origin of the extinction event, we present biostratigraphic evidence which precisely dates the KT boundary in three sections sampled in the area around Braggs, in south-central Alabama. A fourth section, located near the Georgia coast, was studied to compare the stratigraphy across the boundary in a section with clearly higher sedimentation rates (text-fig. 1).

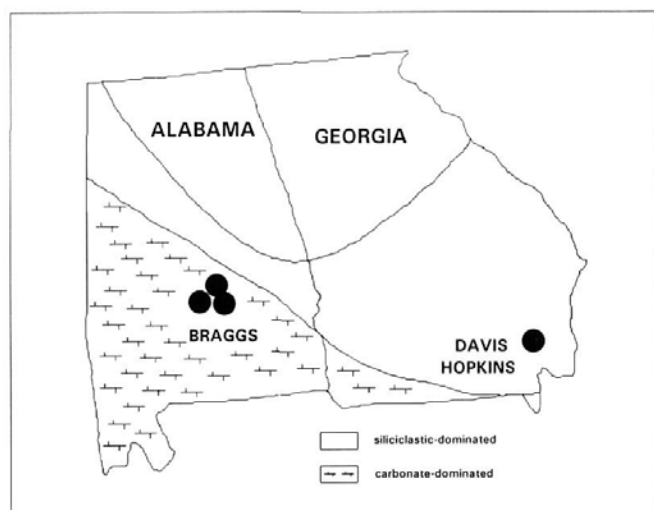
The Alabama sections are ideal for precise biostratigraphic dating. They have been studied extensively recently from a number of scientific disciplines and have been calibrated with respect to lithostratigraphy (Copeland and Mancini 1986), sequence stratigraphy (Donovan et al. 1988; Baum and Vail 1988), polarity-reversal magnetic stratigraphy (Channell and Dobson 1989) and high-resolution biotic-extinction stratigraphy (Bryan and Jones 1989). The biostratigraphic evidence for the precise position of the KTB, and its stratigraphic relationship with an important disconformity, has been somewhat ambiguous, however. This was due in part to interpretation of evidence that was published before there was a refined calcareous nannofossil zonation across the KT boundary in the Braggs area.

For example, previous studies placed the KT boundary at a level coincident with an iridium spike but stratigraphically above the major biotic extinction event. Others placed the boundary at the extinction datum but indicated a hiatus of as much as 3.5 my, with most of the upper part of the Maestrichtian section missing. In addition, a general problem with the Coastal Plain stratigraphy adjacent to the boundary is the absence of the latest Maestrichtian index planktonic foraminiferal species, *Abathomphalus mayaroensis* (Bolli) (Mancini, Tew and Smith 1989).

Our study is based on the stratigraphy of calcareous nannofossils and dinocysts. The dinocyst stratigraphy is presented in the context of sequence stratigraphy, which accounts for the occurrences of many dinoflagellate species. The fates of the two groups of microplankton in the mass extinction event are compared. Bramlette and Martini (1964) included samples from the Prairie Bluff Chalk and Clayton Formation in Alabama, among many others, to show that there was a major extinction of nannoplankton taxa between the Maestrichtian and the Danian. Conversely, the cyst-producing dinoflagellate plankton did not participate in the mass extinction (Hultberg 1986; Brinkhuis and Zachariasse 1988; Habib, Kramer and Miller 1990), but flourished during the first episode of sea level rise in the earliest Danian when the nannoplankton (Habib, Moshkovitz and Kramer 1992) and the invertebrate macrofauna (Bryan and Jones 1989) were still impoverished by extinction.

GEOLOGIC SETTING

Text-figure 2 illustrates the three sections in Alabama that were studied. The Braggs section is exposed in a roadcut on the southwestern side of Alabama Route 263, approximately 7.4km



TEXT-FIGURE 1

Location map, showing the relative geographic positions of the Braggs and Davis-Hopkins sections. Major lithofacies in the late Maestrichtian *Hauastator bilira* biozone after Sohl and Koch (1986).

southeast of the town of Braggs in Lowndes County. The sampled interval is approximately 6m thick, and ranges from the uppermost 60cm of bed 2 to the top of bed 13. The lithology of each bed in this outcrop was described by Copeland and Mancini (1986), who also established their numerical nomenclature in the area around Braggs. The nannofossil and dinocyst stratigraphy is compared directly with the polarity-reversal magnetic stratigraphy that Channell and Dobson (1989) prepared for this section. Two formations are present. The Prairie Bluff Chalk is Maestrichtian in age and is represented by bed 2 in the investigated sections. It consists of dark gray, carbonaceous, calcareous clay which becomes sandy at the top. The formation grades laterally in eastern Alabama and Georgia into the upper part of the Providence Sand. In the subsurface of eastern Georgia, sandy and marly beds of Maestrichtian age have been informally named depositional "Sequence 6" by Owens and Gohn (1985) and "Peedee equivalent" by Habib and Miller (1989). Sohl and Koch (1986) thought that the gradation from carbonates and marls in western Alabama (and eastern Mississippi) to chiefly clastics in eastern Alabama and Georgia represented deposition in a nearshore to offshore trend. The carbonates were considered to be the more offshore equivalents of the clastic deposits (text-fig. 1). Beds 3-13 are included in the Pine Barren Member of the Clayton Formation. These beds are early Danian in age, and consist of interbedded hard limestones, calcareous siltstones and sandy mudstones. Glauconite is locally abundant. Bed 3 possesses an unusual lithology which can be traced in the area around Braggs. It is a hard, highly argillaceous, carbonate rock which partially disaggregates in water. Various detrital particles are easily removed. They consist of phosphatic pebbles, angular to subangular quartz sand and granules, subangular dark rock fragments and both dark and light-colored micas. This suggests some higher energy influx of terrigenous sediment in the carbonate shelf.

Channell and Dobson (1989, fig. 1) identified polarity zone C29R in the Braggs roadcut section, in the interval from the middle of bed 9 down to the middle of bed 3. The lower

boundary of the reversed polarity zone was poorly defined, due to unstable magnetization in the upper part of bed 2. Polarity zone C30N was identified lower in bed 2, approximately 1.0m beneath the contact with bed 3.

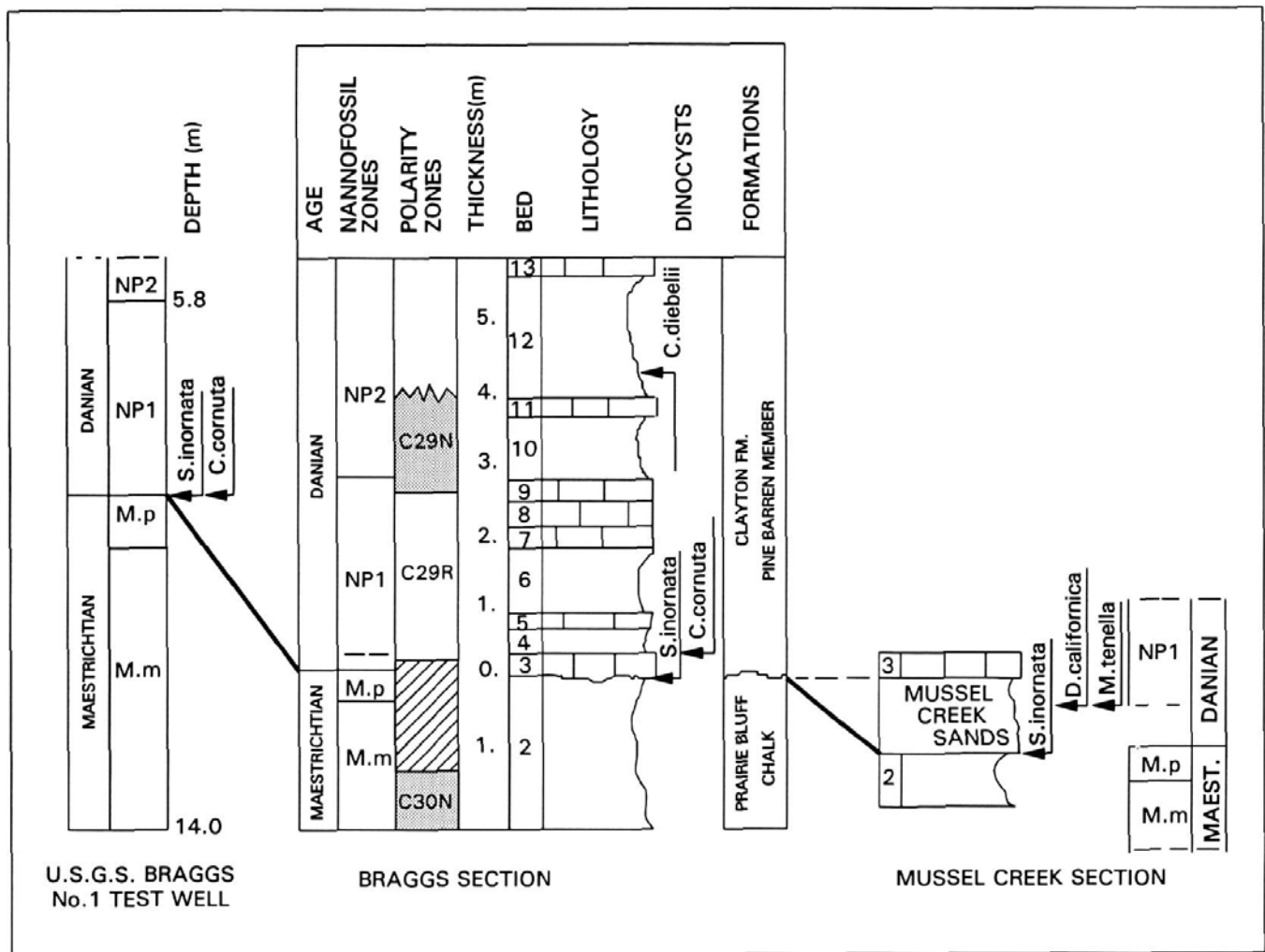
The sampled interval in the Mussel Creek section is approximately 1.5m thick (text-fig. 2). This section is important because it contains an 80cm-thick sand body wedged between beds 2 and 3. The section is exposed along Mussel Creek, approximately 3.2km south of the Braggs section. The sand is clayey and carbonaceous, and displays the parallel-laminated cross-bedding characteristic of the estuarine lithofacies. The distribution of these sands in the base of the Clayton Formation is discontinuous but widespread in central and western Alabama (Mancini, Tew and Smith 1989), and they represent filled channels incised into the Prairie Bluff Chalk. In westernmost Alabama, along the Tombigbee River at Moscow Landing, these channel deposits contain pebbles and boulders of Prairie Bluff lithology containing Maestrichtian nannofossils.

The U.S. Geological Survey Braggs No. 1 Test Well was drilled adjacent the Braggs roadcut section (Donovan et al. 1988). The sampled interval is approximately 8.2m thick. It extends from the lithologic equivalents of bed 2 to bed 9 (text-fig. 2) in the subsurface from 5.8m to 14.0m. The distinctive rubble zone in the lower part of bed 3 occurs at a depth of 7.8m (table 1), directly above the KT boundary. Donovan et al. (1988, fig. 10) illustrated the stratigraphy of this section, as well as the electric and gamma-ray log responses.

The sequence stratigraphy of the Prairie Bluff Chalk and Clayton Formation was published by Donovan et al. (1988), who interpreted the upper part of the Prairie Bluff as representing the prograding Highstand Systems Tract. An important disconformity occurs at the contact between the two formations, which they interpreted to be a Type 1 sequence boundary developed from a eustatic fall of sea level. This episode exposed the land surface and developed the locally incised topography. The subsequent initial rise of sea level deposited the basal sands and gravels of the Clayton Formation as the incised-valley-fill Lowstand Systems Tract (Donovan et al. 1988). When these channels were filled, the rising sea spread across the shelf, forming the retrogradational transgressive deposits of the Transgressive Systems Tract. The maximum flooding surface occurs at the top of bed 9, and maximum sediment starvation is represented in the condensed section of bed 10. Highstand prograding regressive sediments occur in the directly overlying beds.

The sequence boundary between beds 2 and 3, and below the estuarine sands at Mussel Creek, is significant because it represents an abrupt and severe biotic extinction event (Bryan and Jones 1989). The invertebrate macrofossils of the Prairie Bluff Chalk reveal consistently high diversity of taxa with widespread and long-ranging clades. Fifty percent of these terminal Cretaceous species drop out at this boundary. The relationship between the sequence stratigraphy and the number of macrofossil taxa per bed is illustrated in text-figure 3.

A thick section of late Maestrichtian (includes middle and late Maestrichtian in its tripartite division) to Danian age was distinguished in a well drilled by the U.S. Geological Survey in Wayne County, Georgia (Habib and Miller 1989). The C. D. Hopkins No. 1 Test Well (hereafter named Davis-Hopkins) was



TEXT-FIGURE 2

Braggs sections in south-central Alabama. Polarity-reversal stratigraphy of the roadcut section after Channell and Dobson (1989); diagonal pattern represents magnetically unstable interval. Biostratigraphic evidence of age illustrated for each section. Correlation line between sections is the boundary between the Prairie Bluff Chalk and Clayton Fm. Lithostratigraphy and bed nomenclature after Copeland and Mancini (1986). M.m. = *Micula murus* zone, M.p. = *Micula prinsii* zone.

drilled near the center of the southeast Georgia embayment, a subsiding marine basin which during the Late Cretaceous opened seaward to merge with the Blake Plateau basin (Gohn 1988). The late Maestrichtian-Danian age was determined from dinocysts in the interval from the subsurface depth of 949.1m to 649.1m. Because of the thickness of the section, and the increased rate of sediment accumulation relative to that of the Alabama sections, the interval from 806.4m to 649.1m was restudied in order to compare the nannofossil stratigraphy with the published dinocyst stratigraphy across the KT boundary in an expanded stratigraphic section.

Three lithologic units were distinguished, based on the examination of the samples that were studied for microfossils and on the lithologic log that was provided by J. A. Miller (U.S. Geological Survey, Norcross, Georgia). The uppermost unit extends from 649.1m to 661.9m. It consists of light to medium gray, porous, calcareous sandstone with abundant shell fragments. The skeletal material is fragmented thin molluscan shells, most of which are sand-sized. Larger clasts of broken shells are interspersed. The sand is indurated but is highly

porous. There is very little organic matter, mostly detrital invertebrate, and few dinoflagellate species. This interval was defined palynologically as the coastal invertebrate organic facies (Habib, Eshet and van Pelt, in press). The next lower unit extends from 669.5m to 689.3m. It is a finer-grained calcareous sandstone which is better sorted. The sandstone is indurated and dense; it is heavier than similar-sized samples of the overlying unit. The color is medium to dark gray. It is carbonaceous and contains many dinoflagellate species and abundant well preserved fecal amorphous debris (Habib and Miller 1989). Nannofossils are virtually absent in both of the sandstone units. The lowest unit in the investigated interval extends from 713.4m to 806.4m. It consists of soft to semi-indurated, dark gray to greenish gray, glauconitic calcareous muds and sandy muds which are highly carbonaceous and rich in amorphous debris. Both dinocysts and nannofossils are numerous and represent many species.

The lowest unit represents open shelf environments, which shallow progressively in ascending order to the uppermost unit representing nearshore environments above wave base.

PREVIOUS BIOSTRATIGRAPHIC STUDIES

Since the study by Bramlette and Martini (1964), there have been many nannofossil investigations of the KT boundary interval in various parts of the world. Included among these are the works by Edwards (1966) Hay and Mohler (1967) Perch-Nielsen (1969, 1981) Worsley (1974) Percival and Fischer (1977) Romein (1977) Gartner and Keany (1978) Thierstein (1981) Magaritz et al. (1985) and Jiang and Gartner (1986). Recent papers which have addressed the nannofossil stratigraphy of the Braggs sections have been relatively few (Jones et al. 1987; Donovan et al. 1988; Mancini, Tew and Smith 1989) and have for the most part compared these fossils with other microfossils (planktonic foraminifera), polarity-reversal magnetic stratigraphy, sequence stratigraphy and/or iridium anomaly patterns. There has been some disagreement both among nannofossil stratigraphers and among foraminiferal stratigraphers, with respect to 1) the exact age of the uppermost part of the Prairie Bluff Chalk near Braggs and elsewhere in Alabama, 2) the stratigraphic position of the KT boundary and 3) the position of nannofossil zonal boundaries within the overlying Clayton Formation. Some reasons for the different positions of these boundaries may be due to the various interpretations of the pioneering work by Worsley (1974) on the Braggs section (e.g. see discussion in Bryan and Jones 1989; Zachos, Arthur and Dean 1989) and to the presence or absence of important index species (Smith and Pessagno 1973; Mancini, Tew and Smith 1989; see also Cepek et al. 1968). For example, Mancini, Tew and Smith (1989) reported the absence of the latest Maestrichtian foraminifer *Abathomphalus mayaroensis* (Bolli) and of the earliest Danian species *Parvularugoglobigerina eugubina* (Luterbacher and Premoli Silva) in the Braggs section, and suggested that the upper interval of the Prairie Bluff Chalk contains foraminifera (and nannofossils) which range down into the middle Maestrichtian *Globotruncana gansseri* zone. More recently, however, Olsson and Liu (1991) reported the presence of the earliest Danian PO (*Guembelitra cretacea*) and P α (*P. eugubina*) zones within the basal sands of the Clayton Formation at Millers Ferry, just west of Braggs in western Alabama. Habib, Moshkovitz and Kramer (1992) subsequently reported the presence of the Danian dinoflagellate species *Danea californica* and *Membranilarnacia tenella* in the two samples from the uppermost 20cm of the basal sands at Mussel Creek. *A. mayaroensis* is absent in sections ranging from Alabama to New Jersey. This phenomenon may be due to hiatus, or to the shallow water inner neritic facies of this interval. This species appears in continental margins in the middle part of the neritic zone (Brinkhuis and Zachariasse 1988; Eshet et al. 1992).

Dinocysts and other palynomorphs from within the Maestrichtian-Danian interval have been reported extensively from sections in the Coastal Plain ranging from New Jersey to Texas. These include the earlier efforts by Zaitzeff and Cross (1971), Benson (1976), Koch and Olsson (1977) and Jarzen (1978) and the more recent efforts by Whitney (1984), Firth (1987), Aurisano (1989) and Habib and Miller (1989). Hansen (1977, 1979) published a dinoflagellate zonation across the KT boundary in the Danish stratotype sections, and was the first to document the stratigraphic value of the dinoflagellate species *Danea californica* (as *D. mutabilis*), *Carpatella cornuta* and *Membranilarnacia tenella*. Hultberg (1986) refined this stratigraphy and indicated that *Senoniasphaera inornata* is also valuable for distinguishing the KT boundary, after his restudy of this species and its more restricted definition. Recent studies

TABLE 1

List of Samples. Samples in the Braggs and Mussel Creek sections (text-figure 2) are keyed to the bed nomenclature published by Copeland and Mancini (1986). Core samples from the Braggs No. 1 and Davis-Hopkins wells were collected according to subsurface depths in the English scale, and were changed to the metric scale using 3.28 ft/m. Samples in which dinocysts alone were studied are marked with an asterisk; those in which nannofossils only were studied are marked with an 'N'. Most samples are 3 or 4cm thick, unless otherwise noted.

Sample	Location	Sample	Location
I. BRAGGS ROADCUT SECTION			
1. Clayton Formation			
13.2	bed 13, top 5cm	6.4	bed 6, 44cm above base
13.1	bed 13, basal 5cm	6.3	bed 6, 37cm above base
12.3*	bed 12, 138cm above base	6.3N	bed 6, 30cm above base
12.2	bed 12, 30cm above base	6.2N	bed 6, 21cm above base
12.1*	bed 12, basal 3cm	6.2	bed 6, 10cm above base
11.2	bed 11, top 2cm	6.1	bed 6, basal 5cm
11.1	bed 11, top 4cm	5.5	bed 5, top 4cm
10.4	bed 10, 64cm above base	5.4*	bed 5, 27cm above base
10.3	bed 10, 45cm above base	5.3*	bed 5, 17cm above base
10.2	bed 10, 25cm above base	5.2*	bed 5, 11cm above base
10.1	bed 10, basal 4cm	5.1	bed 5, 5cm above base
9.1	bed 9, basal 2cm	4.3	bed 4, top 4cm
8.2*	bed 8, 40cm above base	4.2	bed 4, 10cm above base
8.1	bed 8, basal 4cm	4.1	basal 4cm
7.1	bed 7, basal 8cm	3.2	bed 3, top 3cm
6.5	bed 6, top 3cm	3.1	bed 3, basal 3cm
2. Prairie Bluff Chalk			
2.7	bed 2, 4cm below top	2.3	bed 2, 32cm below top
2.6	bed 2, 10cm below top	2.2	bed 2, 45cm below top
2.5	bed 2, 11cm below top	2.1	bed 2, 60cm below top
2.4	bed 2, 15cm below top		
II. MUSSEL CREEK SECTION			
1. Clayton Formation			
MC15	bed 3, top 2cm	MC10	sands, 38cm above base
MC14	bed 3, 10cm above base	MC9	sands, 25cm above base
MC13	sands, top 2cm	MC8	sands, 12cm above base
MC12	sands, 60cm above base	MC7	sands, basal 4cm
MC11	sands, 48cm above base		
2. Prairie Bluff Chalk			
MC6	bed 2, top 2cm	MC3	bed 2, 2cm below top
MC5	bed 2, 10cm below top	MC2	bed 2, 31cm below top
MC4	bed 2, 18cm below top	MC1	bed 2, 45cm below top
III. U.S. GEOLOGICAL SURVEY BRAGGS NO. 1 TEST WELL			
1. Clayton Formation			
18	5.8m (19.0 ft)	15	7.6m (25.0 ft)
17	5.9m (19.35 ft)	14	7.8m* (25.5 ft)
16	6.7m (22.0 ft)		
2. Prairie Bluff Chalk			
13	8.0m (26.1 ft)	06	11.6m (38.0 ft)
12	8.4m (27.6 ft)	05	12.0m (39.5 ft)
11	8.7m (28.4 ft)	04	12.8m (42.0 ft)
10	9.3m (30.5 ft)	03	13.4m (44.0 ft)
09	9.5m (31.2 ft)	02	13.7m (45.0 ft)
08	10.1m (33.0 ft)	01	14.0m (46.0 ft)
07	10.6m (34.8 ft)		
IV. U.S. GEOLOGICAL SURVEY C. D. HOPKINS NO. 1 TEST WELL			
24	649.4m (2130 ft)	12	716.2m (2349 ft)
23	653.4m (2143 ft)	11	722.6m (2370 ft)
22	657.6m (2157 ft)	10	750.6m (2462 ft)
21	661.3m (2169 ft)	09	760.0m (2492 ft)
20	661.9m (2171 ft)	08	767.1m (2516 ft)
19	669.5m (2196 ft)	07	775.0m (2480 ft)
18	678.7m (2226 ft)	06	776.8m (2548 ft)
17	679.0m (2227 ft)	05	786.9m (2573 ft)
16	685.9m (2250 ft)	04	792.7m (2600 ft)
15	689.3m (2261 ft)	03	799.7m (2623 ft)
14	713.4m (2340 ft)	02	806.4m (2645 ft)
13	714.0m (2342 ft)	01	815.9m* (2668 ft)

TABLE 2

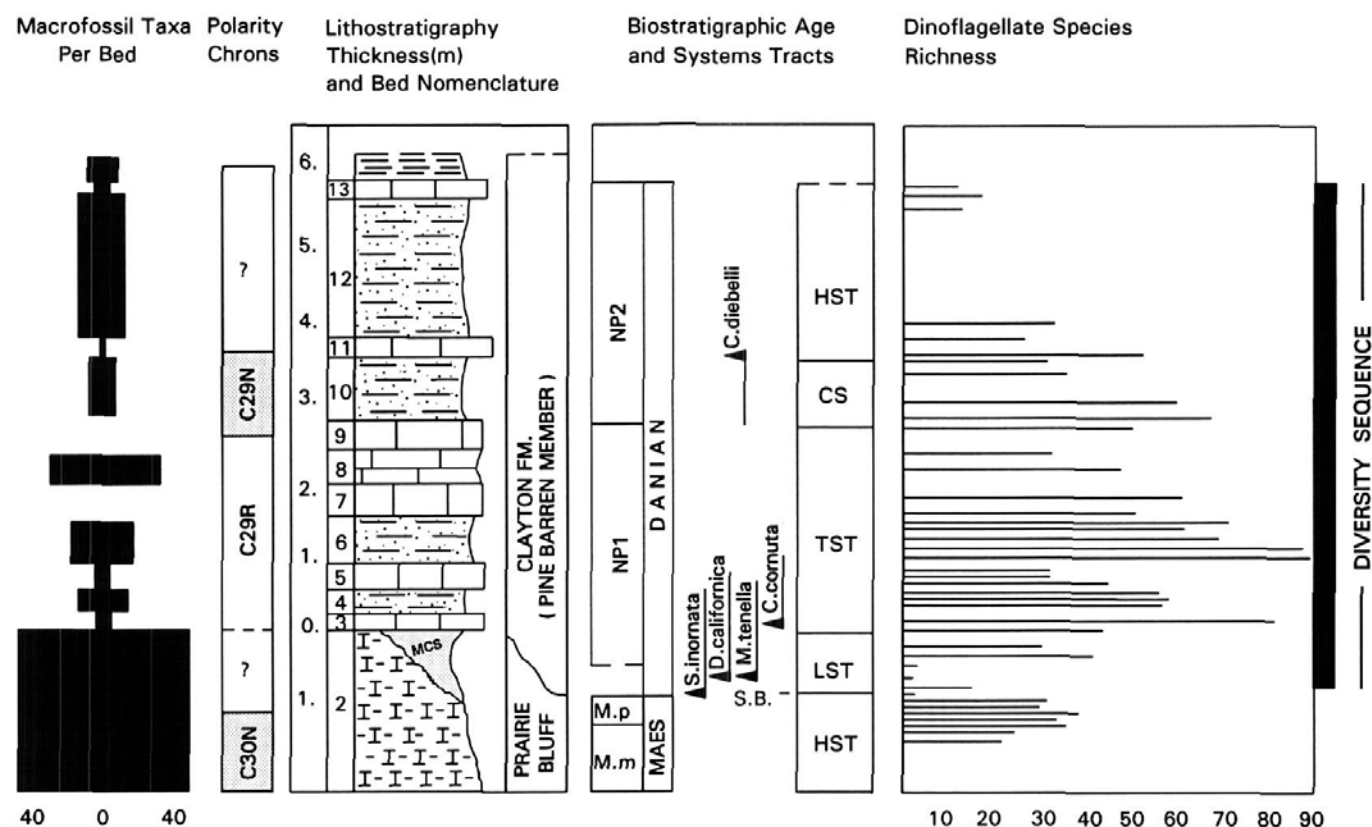
List of calcareous nannoplankton taxa.

1. *Ahmuerella octoradiata* (Gorka) Reinhardt (1966). Widespread during the Late Cretaceous, especially in the Campanian and Maestrichtian. Its abundance decreases in the late Maestrichtian.
2. *Ahmuerella regularis* (Gorka) Verbeek (1977) (Plate 2, figure 15). Widespread, especially in the latest Maestrichtian (*M. prinsii* zone).
3. *Arkhangelskiella cymbiformis* Vekshina (1959) (Plate 1, figure 1). Widespread in the latest Maestrichtian. It ranges up to 16µm in length.
4. *Biantholithus sparsus* Bramlette and Martini (1964) (Plate 2, figures 16-17). One of the most reliable species that first occurs in the earliest Danian. The first occurrence of this species is in sample MC12 (table 1) in the basal sands of the Clayton Formation at Mussel Creek.
5. *Biscutum constans* (Gorka) Black, in Black and Barnes (1959).
6. *Biscutum* sp. 1, cf. *B. coronum* Wind and Wise, in Wise and Wind (1977).
7. *Biscutum?* *parvulum* Romein (1979) (Plate 2, figure 21). Small forms (2-3µm) are distinguished between crossed-nicols by the central birefringent area. Under light microscopy, it is not always possible to distinguish the individual species. Both *B.?* *parvulum* and *B.?* *romeinii* occur at the same level, thus the zonation based on these small nannofossils is impractical.
8. *Biscutum?* *romeinii* Perch-Nielsen (1981) (Plate 2, figure 20). Small elliptical rings, 1-3µm in diameter. It is difficult to determine with light microscopy whether the open central area is a natural structure or is due to dissolution. They occur in the lower beds of the Clayton Formation with small *Biscutum* spp. and with *B.?* *parvulum*.
9. *Biscutum* spp. Very small nannofossils (1-3µm) rare in the lower part of the Clayton Formation.
10. *Braarudosphaera bigelowi* (Gran and Braarud) Deflandre (1947) (Plate 1, figure 7).
11. *Braarudosphaera* sp. 1, cf. *B. bigelowi*. Large nannofossils with concave rims.
12. *Braarudosphaera discula* Bramlette and Riedel (1954).
13. *Braarudosphaera regularis* Black (1973).
14. *Chiastozygus amphipons* (Bramlette and Martini) Gartner (1968) (Plate 2, figure 18).
15. *Cretarhabdus conicus* Bramlette and Martini (1964).
16. *Cretarhabdus crenulatus* Bramlette and Martini (1964).
17. *Cribrosphaerella ehrenbergii* (Arkhangelsky) Deflandre (1952). (Page 1, figure 8). Forms up to 14µm and more in length are quite common in the upper part of the Prairie Bluff Chalk.
18. *Cruciplacolithus primus* Perch-Nielsen (1977) (Plate 2, figure 22).
19. *Cruciplacolithus tenuis* (Stradner) Hay and Mohler (1967) (Plate 2, figures 23-24).
20. *Cyclagelosphaera alta* Perch-Nielsen, in Birkelund and Bromley (1979) (Plate 2, figure 14). This species is somewhat smaller than *C. reinhardtii*, and its central area is wider. It may have originated in the Maestrichtian but is typical, albeit rare, in the earliest Danian. It is one of the rarest species found in bed 3 in the Braggs section.
21. *Cyclagelosphaera margerelii* Noel (1965) (Plate 2, figure 12). This species is long-ranging, but has been reported in the early Paleocene. It is very rare in the *Micula prinsii* zone in the Davis-Hopkins well.
22. *Cyclagelosphaera reinhardtii* (Perch-Nielsen) Romein (1977) (Plate 2, figure 13). It is rare to very rare in the Prairie Bluff Chalk and Clayton Formation.
23. *Cylindralithus serratus* Bramlette and Martini (1964) (Plate 2, figure 11).
24. *Eiffelolithus turrisseiffeli* (Deflandre) Reinhardt (1965) (Plate 1, figures 2-3).
25. *Gartnerago obliquum* (Stradner) Reinhardt (1970).
26. *Helicolithus trabeculatus* (Gorka) Verbeek (1977).
27. *Kamptnerius magnificus* Deflandre (1959).
28. *Lithraphidites carniolensis* Deflandre (1963).
29. *Lithraphidites grossopectinatus* Bukry (1969). Very few specimens were found, in the uppermost samples of the of the Prairie Bluff Chalk.
30. *Lithraphidites quadratus* Bramlette and Martini (1964) (Plate 2, figure 10). This species is common in the Prairie Bluff Chalk in all the investigated sections. Specimens with highly developed blades occur in both the *M. murus* and *M. prinsii* zones.
31. *Manivitella pemmatoidea* (Deflandre) Thierstein (1971). Very rare in the latest Maestrichtian.
32. *Markalius inversus* (Deflandre) Bramlette and Martini (1964) (Plate 2, figures 8-9). This species is rare, but occurs in the Maestrichtian and Danian in the Alabama sections. Jiang and Gartner (1986) showed that forms with circular birefringent centers are best developed in the Maestrichtian (Plate 2, figure 8) and the smaller nannofossils with elliptical centers occur in the Paleocene (Plate 2, figure 9).
33. *Microrhabdulus decoratus* Deflandre (1959).
34. *Micula decussata* Vekshina (1959).
35. *Micula murus* (Martini) Bukry (1973) (Plate 1, figures 9-11).
36. *Micula prinsii* Perch-Nielsen (1979) (Plate 2, figures 1-7). This species is rare, but occurs consistently in the uppermost samples of the Prairie Bluff Chalk, as well as in the latest Maestrichtian in the Davis-Hopkins well, where it is widespread.
37. *Neocrepidolithus?* *neocrassus* (Perch-Nielsen) Romein (1979) (Plate 1, figure 19). Very rare in the early Danian, this species is questionably identified due to its small size.
38. *Nephrolithus frequens* Gorka (1957) (Plate 1, figure 12).
39. *Parahbdolithus embergeri* (Noel) Stradner (1963) (Plate 1, figure 4).
40. *Prediscosphaera cretacea* (Arkhangelsky) Gartner (1968) (Plate 1, figure 14).
41. *Prediscosphaera spinosa* (Bramlette and Martini) Gardner (1968) (Plate 1, figure 13).
42. *Prediscosphaera quadripunctata* (Gorka) Verbeek (1977) (Plate 1, figure 15). This species is common in the latest Maestrichtian.
43. *Prolatipatella multicarinata* Gartner (1968) (Plate 1, figure 16). This species is rare in the Maestrichtian. Few specimens were found in the uppermost samples of bed 2 in the Braggs section.
44. *Rhagadodiscus elongatus* Stover (1966).
45. *Thoracosphaera operculata* Bramlette and Martini (1964) (Plate 1, figures 5-6).
46. *Thoracosphaera* spp. Occur as broken particles.
47. *Toweius?* *petaloides* Ellis and Lohman (1973). A few badly preserved specimens were found in bed 10.
48. *Vekshinella crux* (Deflandre) Shafik and Stradner (1971) (Plate 2, figure 19).
49. *Watznaueria biporta* Bukry (1969).
51. *Zygodiscus spiralis* Bramlette and Martini (1964) (Plate 1, figure 17).
52. *Zygodiscus sigmoides* Bramlette and Sullivan (1961) (Plate 1, figure 18).
53. *Zygodiscus* spp. Small unidentifiable forms were grouped together. They occur most frequently in the latest Maestrichtian.

of the Tunisian stratotype sections (Brinkhuis and Zachariasse 1988; Brinkhuis and Leereveld 1988) strongly support the results of Hansen (1977). For example, in the El Haria section, *D. californica* appears in the boundary clay very near the base of the Danian and within the *Guembelitra cretacea* foraminiferal zone. At El Kef, it first occurs 10cm above this boundary. *S. inornata* was not reported from Tunisia, and it is apparently absent in Israel as well (Eshet et al. 1992). The geographic range

of this species may not have extended into the eastern Tethys province.

Dinoflagellate diversity (species richness + most abundant species) is a parameter which has been used to interpret marine transgression-regression and eustatic sea level change. Partridge (1976) reported high dinoflagellate species diversity in areas of marine inundation, in his study of the Gippssland basin in



TEXT-FIGURE 3

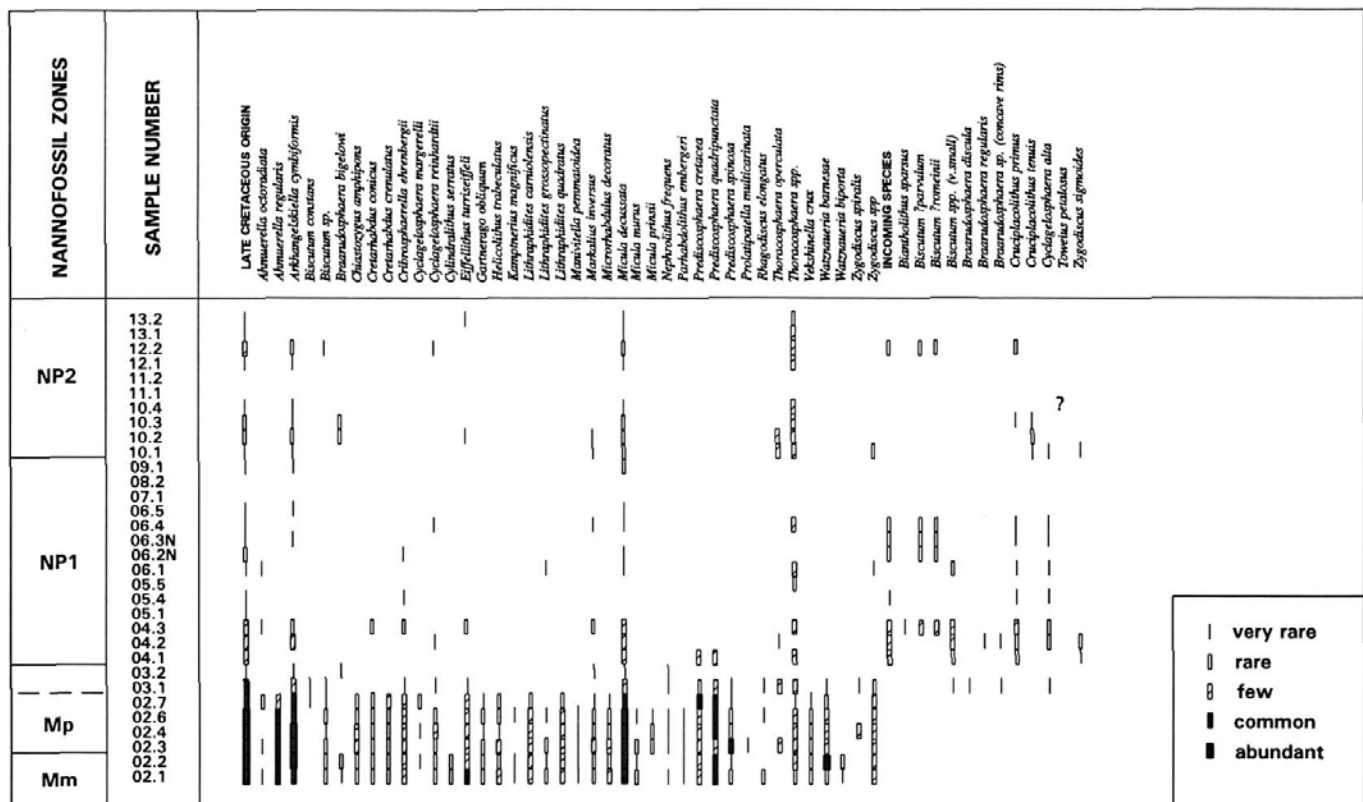
Integrated stratigraphy of 3 sections in Alabama. Macrofossil taxa histogram in roadcut after Bryan and Jones (1989). We consider the magnetically uncertain interval in the Prairie Bluff Chalk to be biostratigraphically equivalent in age to the earlier part of chron C29R. Systems tract components (LST, TST, CS, HST) after Donovan et al. (1988); S.B. = sequence boundary. The dinoflagellate species richness curve is a composite of the 3 sections (Habib, Moshkovitz and Kramer 1992); bar to the right represents dinoflagellate diversity pattern for third-order depositional sequence in Pine Barren member. M.C.S. = Mussel Creek sands.

Australia. He concluded that the dramatic influx of species resulted from rapid eustatic sea level rise. Edwards, Goodman and Witmer (1984) and Edwards (1989) used species richness to interpret coastal versus open marine shelf paleoenvironments in sections of Paleocene age in Virginia and Maryland. Many specimens of a single species in an assemblage of few species indicated coastal estuarine or brackish water environments, whilst a diverse dinoflagellate biota (in the order of 70 species) represented the marine shelf. Habib and Miller (1989) interpreted the dramatic influx of dinoflagellate species to be the first palynological evidence of marine transgression in their study of two wells in South Carolina and one well in Georgia. In the study of a South Carolina well (U.S. Geological Survey St. George Test Well, Dorchester 211), three such discrete dinoflagellate episodes of transgression were dated late Campanian-earliest Maestrichtian, early Maestrichtian and late Maestrichtian, respectively (Habib and Moshkovitz 1991). The relative percentages of terrigenous organic matter have also been used to interpret sedimentary cycles. The higher frequencies of land plant particles and recycled palynomorphs correspond to the lowstand and highstand systems tracts, whereas the higher frequency of marine microplankton corresponds to the transgressive tract (Gregory and Hart 1992). Eshet et al. (1988) had previously indicated that there was a larger amount of reworked palynomorphs in regressive intervals, in their study of sedimentary cycles of Triassic age. In his study of the pollen assemblages in the Bragg roadcut section, Jarzen (1978, fig. 3)

showed that pollen grains increase in relative percentage in the uppermost few centimeters of the Prairie Bluff Chalk, and that the dinoflagellate biota becomes most frequent at the base of the Clayton Formation. Other palynological studies concern the systematic study of dinoflagellates in the Clayton Formation, including that of *Danea californica* in the McBryde member (Drugg 1970). Habib, Moshkovitz and Kramer (1992) used dinoflagellate diversity to interpret sea level change in the Bragg sections.

MATERIALS AND METHODS

Table 1 lists the 95 samples from Alabama and Georgia that were studied. Of these, both nannofossils and dinocysts (and acritarchs) were analyzed together in 85 samples. Dinocysts and acritarchs alone were analyzed in eight, and nannofossils alone were analyzed in two. Both groups of microfossils were studied with the optical microscope. Further study of the small acritarchs in the sections will require the use of the scanning electron microscope (Habib and Knapp 1982). Nannofossils were prepared for microscope study using the standard suspension method. This includes separation of the heavy fraction after 1 minute, and concentration of the suspended material after 15 minutes of settling in distilled water. The relative abundance of each species was then noted (Moshkovitz and Ehrlich 1976). Samples for palynological study were prepared so that both species diversity and the composition of the total organic matter could be measured. Each sample was treated with 5% HCl and



TEXT-FIGURE 4

Calcareous nannofossil stratigraphy, Braggs roadcut.

subsequently with concentrated 48% laboratory grade HF. However, prior to acid treatment the sand samples were first swirled to separate the clay and organic particles from the sand. The finer, suspended particles were then treated with HCl and HF. Four microscope slides were prepared from each recovered residue. The first was prepared from the raw residue so that the predominant organic particles could be identified. Commonly, this material masked the representative dinoflagellate and acritarch biota in the sample. Consequently, the residue was then filtered through a 15µm screen to concentrate these palynomorphs. A fourth slide was prepared from the fraction smaller than 15µm. At least 300 dinocysts and acritarchs were counted, in order to estimate the total number of species in the sample. In two cases, there were too few specimens so that despite the preparation of additional slides from the + 15µm fraction only about 40 specimens were counted, i.e. samples MC8 and MC10 in the Mussel Creek section (table 1). The relative abundance of each species is described as very rare if only one or two specimens were counted from the average 300, rare if 3-5 specimens were counted, few if 6-15, common if 16-25 and abundant if more than 25 specimens were counted.

CALCAREOUS NANNOPLANKTON STRATIGRAPHY

Fifty-three species or groups of species were identified in the Alabama and Georgia sections (table 2). Four zones were distinguished. These are the *Micula murus* zone (late Maestrichtian) *Micula prinsii* zone (latest Maestrichtian), *Markalius inversus* zone (NP1, earliest Danian) and *Cruciplacolithus tenuis* zone (NP2, early Danian).

1) *Micula murus* Zone. Bukry and Bramlette (1970), emended Perch-Nielsen (1983). Interval zone defined from the first occurrence of *M. murus* to the first occurrence of *M. prinsii*.

Discussion: This zone occurs in all of the investigated sections. In the Braggs roadcut section (text-fig. 4), it occurs in the lowest two samples of the Prairie Bluff Chalk (table 1). At Mussel Creek (text-fig. 5), it was found in the lowest sample (MC1) only, 45cm below the contact with the Clayton Formation. The *Micula murus* zone extends in the studied section in the Braggs well (text-fig. 6), from the depth of 14.0m up to 9.3m, and in the section in the Davis-Hopkins well, from 806.4m to 767.1m.

Nannofossils are abundant and moderately to well preserved. The assemblages are diverse and include up to 50 species. These include *M. murus*, *M. decussata*, the large forms of *Arkhangelskiella cymbiformis*, *Watznaueria barnesae*, *Lithraphidites quadratus* with developed blades, *Prediscosphaera cretacea*, *P. spinosa*, *P. quadripunctata*, *Cribratosphaerella ehrenbergii*, *Ahmuerella regularis*, *A. octoradiata*, *Nephrolithus frequens*, *Chiastozygus amphipons*, *Eiffellithus turrisseiffeli*, *Zygodiscus spiralis* and the calcareous-cyst-based dinoflagellates *Thoracosphaera* spp. The important index species, *M. murus* and *N. frequens*, are rare. On the other hand, *A. regularis* is common but *A. octoradiata* is rare. The latter species is the dominant of the two in the middle part of the Maestrichtian. *Markalius inversus* is rare, and there are very few braarudosphaerids. Only the upper (late Maestrichtian) part of the *Micula murus* zone is present in the investigated sections.

TABLE 3

List of dinoflagellate, acritarch and other algal taxa in the Alabama sections.

1. *Achilleodinium latispinosum* (Davey and Williams) Bujak, Downie, Eaton and Williams (1980).
2. *Achomosphera ramulifera* (Deflandre) Evitt (1963).
3. *Achomosphera* sp. A. This species resembles the specimen illustrated by Manum et al. (1989, pl. 17, fig. 2) as *Spiniferites* sp. 2. *Achomosphera* sp. A is rare but is distinctive. It is restricted to the Danian in both the Braggs roadcut section and Braggs well.
4. *Alisocysta circumtabulata* (Drugg) Stover and Evitt (1978).
5. *Alterbidinium acutulum* (Wilson) Lentin and Williams (1985).
6. *Alterbidinium? pentaradiatum* (Cookson and Eisenack) Lentin and Williams (1985). This species is rare. It is restricted to the Danian.
7. *Alterbidinium* sp. A. This species is restricted to the interval of beds 2-4. It is relatively large, and is distinguished by scattered rounded baculae distributed over the pericyst.
8. *Andalusiella polymorpha* (Malloy) Lentin and Williams (1977).
9. *Andalusiella rhombohedra* (Benson) Stover and Evitt (1978).
10. *Areoligera senonensis* Lejeune-Carpentier (1938).
11. *Batiacasphaera* sp. A, cf. *B. baculata* Drugg (1970).
12. *Batiacasphaera?* spp. Species not distinguished.
13. *Caligidinium amiculum* Drugg (1970). This species ranges from the *Micula prinsii* nannofossil zone into bed 11 in the Alabama sections. Although it occurs in a frequency of 1-8 specimens (in 300), it was observed in all the beds in this interval.
14. *Canningia minor* Cookson and Hughes (1964). Observed only in beds 12 and 13 in the Braggs section.
15. *Cannosphaeropsis utinensis* Wetzel (1933). Very well preserved specimens of this species were found in two samples (MC 10, MC 12) only, in the basal sands of the Clayton Formation at Mussel Creek.
16. *Carpatella cornuta* Grigorovich (1969). Thicker walled specimens of this species predominate in the Alabama sections. It ranges from the level of sample 4.3 (bed 4) to that of 9.1 (bed 9). It becomes most abundant towards the top of this range, where 41 specimens (13.7%) were counted in sample 8.1 (bed 8) in the Braggs section. It is restricted to nannofossil zone NP1 in the Alabama sections, and is considered to be an important guide species for the early Danian (Plate 3, figure 3).
17. *Carpatella?* sp. A. Three specimens of this species were observed in sample 9.1 in the Braggs section. It is distinguished by the presence of rounded pores in the periphragm.
18. *Cassidium?* spp. Species not distinguished.
19. *Cerodinium boloniense* (Riegel) Lentin and Williams (1989). This species occurs in the *Micula murus* and *Micula prinsii* zones in the Prairie Bluff Chalk. However, it was also observed in the lowermost sample (MC 7) of the basal sands of the Clayton Formation at Mussel Creek. It is considered to be a valuable species in the Maestrichtian.
20. *Cerodinium cordiferum* (May) Lentin and Williams (1987).
21. *Cerodinium diebelii* (Alberti) Lentin and Williams (1987). This subspecies occurs in the *Micula murus* and *Micula prinsii* zones. It ranges up to the level of sample 11.2 in the Braggs sections (Plate 4, figures 7,10).
22. *Cerodinium diebelii* subsp. A. This subspecies is distinguished by its larger size, extending to 185µm in length. It is restricted to the Danian in the Braggs section and in the Braggs core.
23. *Cerodinium depressum* (Morgenroth) Lentin and Williams (1987).
24. *Cerodinium pannuceum* (Stanley) Lentin and Williams (1987).
25. *Cerodinium speciosum* (Alberti) Lentin and Williams (1987). This species is rare in the Danian in the Alabama sections. It first occurs in the basal sands at Mussel Creek (MC12).
26. *Cerodinium striatum* (Drugg) Lentin and Williams (1987).
27. *Cerodinium* sp. cf. *C. obliquipes* (Deflandre and Cookson) Lentin and Williams (1987).
28. *Cerodinium* sp. A. Bicavate cysts with tapering, rounded, apical and antapical horns, and with rounded tubercles aligned subparallel with the cingulum. Antapical horns subparallel.
29. *Chlamydothorella discreta* Clarke and Verdier (1967).
30. *Chlamydothorella urna* Cookson and Eisenack (1960).
31. *Chlamydothorella* sp. A. Rounded cysts and larger, otherwise similar to *C. discreta*.
32. *Chytroisphaeridia baetica* Riegel (1974).
33. *Conneximura fimbriata* (Morgenroth) May (1980). This species is one of the more common elements of the Mussel Creek sands.
34. *Cordosphaeridium fibrospinosum* Davey and Williams (1966).
35. *Cordosphaeridium inodes* (Klump) Eisenack (1963).
36. *Cribroperidinium wetzelii* (Lejeune-Carpentier) Helenes (1984).
37. *Cyclapophysis monmouthensis* Benson (1976). This species first occurs in the latest Maestrichtian *Micula prinsii* zone in the Alabama sections as well as in the Davis-Hopkins well in Georgia (Plate 3, figure 4).
38. *Cyclopsella vieta* Drugg and Loeblich (1967).
39. *Danea californica* (Drugg) Stover and Evitt (1978). Rare in the sections, this species did not ever exceed one percent (Plate 3, figure 1).
40. *Deflandrea galeata* (Lejeune-Carpentier) Lentin and Williams (1973).
41. *Deflandrea* sp. A. Large bicavate cysts with long tapering epicyst (Plate 5, figure 5).
42. Dinocyst sp. A. Specimens resemble *Eocladopyxis*.
43. Dinocyst sp. B.
44. Dinocyst sp. C. Species characterized by long acuminate spines, precingular archeopyle and a bifid apical process.
45. Dinocyst sp. D. Cavate cysts with gonyaulacoid tabulation and with apical archeopyle. This species first occurs in the basal sands at Mussel Creek (Plate 4, figure 3).
46. Dinocyst sp. E. Larger proximate cysts with relatively short, broad epicysts. Combination archeopyle. Polygonal outline in dorsoventral view.
47. *Pervosphaeridium truncigerum*. The species become abundant in samples from beds 9 and 12 in the Braggs section.
48. Dinocyst sp. F. Small oval cysts with short apical horn. Combination archeopyle involving apical and precingular series. Precingular pieces attached at the cingulum. Similar to dinocyst sp. E. except that it is smaller and more rounded.
49. Dinocyst sp. G. Oval cysts with precingular archeopyle involving at least three plates. Nontabular arrangement of sparse, short, flat-topped processes. Restricted to the lower part of the basal sands at Mussel Creek.
50. *Dinogymnium acuminatum* Evitt, Clarke and Verdier (1967). This species was observed in samples from the Braggs well only. It ranges up to the lowermost sample (8.7m.) of the *Micula prinsii* zone.
51. *Dinogymnium westralium* (Cookson and Eisenack) Evitt, Clarke and Verdier (1967). This species is rare in the Mussel Creek sands and in bed 3 near Braggs and at Mussel Creek.
52. *Diphyes colligerum* (Deflandre and Cookson) Cookson (1965).
53. *Distatodinium* sp. A.
54. *Exochosphaeridium* spp. Species not distinguished.
55. *Fibradinium annetorpense* Morgenroth (1968).
56. *Fibrocysta bipolaris* (Cookson and Eisenack) Stover and Evitt (1978).
57. *Florentinia* sp. A.

2) *Micula prinsii* Zone. Perch-Nielsen (1981a, 1981b, 1983, 1985). Interval zone defined from the first occurrence of the nominate species to the first common occurrence of *Thoracosphaera operculata* and/or *Braarudosphaera bigelowii*. In this study, the sudden disappearance of the majority of Maestrichtian species is used as the upper boundary of this zone.

Discussion: The *Micula prinsii* zone occurs in the uppermost 32cm of the Prairie Bluff Chalk in the Braggs roadcut section, directly below the disconformable contact with the Clayton Formation. An exception is the uppermost sample, representing the uppermost 4cm of the Prairie Bluff Chalk (Sample 2.7 in table 1), which contains very poorly preserved, partly recrystal-

TABLE 3
Continued.

58. *Fromea fragilis* (Cookson and Eisenack) Stover and Evitt (1978).
59. Genus A (Benson 1976).
60. *Gerdicysta cassicus* (Drugg) Liengjærn, Costa and Downie (1980). This species first occurs as a rare constituent in the latest Maestrichtian (*Micula prinsii* zone) in Georgia (Habib and Miller 1989). In the Braggs section, this species becomes particularly abundant in beds 12 (upper part) and 13, forming as much as 81 percent (243/300) in an assemblage of 11 species. It may represent nearshore shelf environments (Plate 4, figure 8).
61. *Glaphyrocysta perforata* Hultberg (1986).
62. *Glaphyrocysta retintexta* (Cookson) Stover and Evitt (1978). Counted together with *G. reticulosa* (Gerlach) Stover and Evitt (1978). The species is common to abundant in sediments of late Maestrichtian age in both Alabama and Georgia. In both areas, its abundance drops sharply across the KT boundary (Plate 4, figures 4,5).
63. *Glaphyrocysta semitecta* (Bujak) Lentin and Williams (1981).
64. *Hystriocholpoma bulbosum* (Ehrenberg) Morgenroth (1968).
65. *Hystriocholpoma rigaudae* Deflandre and Cookson (1955).
66. *Hystriocholpoma palmatum* (White) Downie and Sarjeant (1965).
67. *Hystriocholpoma tubiferum* (Ehrenberg) Deflandre (1937).
68. *Hystriocholpoma ovum* Deflandre (1935).
69. *Hystriocholpoma*? sp. A. Present in bed 13 in the Braggs section.
70. *Impagidinium cristatum* (May) Lentin and Williams (1981).
71. *Impagidinium ovum* (Sah, Kar and Singh) Stover and Evitt (1978).
72. *Impagidinium patulum* (Wall) Stover and Evitt (1978).
73. *Impagidinium* sp. A. Large, robust cysts with densely granulate yellow periphragm and high, transparent, serrated septa.
74. *Kallosphaeridium granulosum* (Norvick) Stover and Evitt (1978). Counted together with *K. brevis* DeConinck (1969).
75. *Kleithrisphaeridium truncatum* (Benson) Stover and Evitt (1978).
76. *Lanternosphaeridium lanosum* Morgenroth (1966).
77. *Lanternosphaeridium reinhardtii* Habib, n. sp. (Plate 5, figures 1-5).
78. *Lejeunecysta hyalina* (Gerlach) Artzner and Dorhofer (1978).
79. *Lejeunecysta* sp. A. Small to medium cysts, broader than long, with broadly tapering epicyst. Broad anterior intercalary archeopyle. Restricted to the Danian.
80. *Manumiella seelandica* (Lange) Bujak and Davies (1983). Firth (1987) indicated that this species shows considerable variation in form, which was observed also in the Alabama samples (Plate 3, figure 5).
81. *Membranilarnacia tenella* Morgenroth (1968) (Plate 3, figure 2).
82. *Micrhystridium*? sp., cf. *M. fragile* Deflandre (1947). This acritarch species is rare in the latest Maestrichtian, but becomes common to abundant in the transgressive systems tract. Reference to *Micrhystridium* is provisional, based on the presence of plugs within the projections (Plate 4, figure 6).
83. *Oligosphaeridium complex* (White) Davey and Williams (1966).
84. *Operculodinium/Xenodinium* spp. Species not distinguished.
85. *Ophiolobus lapidarius* Wetzel (1933).
86. *Palaeocystodinium gabowense* Stover and Evitt (1978).
87. *Palaeocystodinium gonzowense* Alberti (1961).
88. *Palaeoperidinium pyrophorum* (Ehrenberg) Sarjeant (1967).
89. *Palambages morulosa*.
90. *Palynodinium grillator* Gocht (1970). This species ranges from the latest Maestrichtian (upper part of *Micula murus* zone) into the earliest Danian (NP1) (Plate 3, figure 6).
91. *Paralecaniella indentata* (Deflandre and Cookson) Cookson and Eisenack (1970).
92. *Phelodinium magnificum* (Stanley) Stover and Evitt (1978).
93. *Pierceites pentagona* (May) Habib and Drugg (1987).
94. *Pterodinium cingulatum* (Wetzel) Below (1981).
95. *Pterodinium* sp. A.
96. *Pterospermella* spp.
97. *Pyxidinospis*? sp. A.
98. *Renidinium membraniferum* Morgenroth (1968).
99. *Renidinium vitilare* (Cookson) Stover and Evitt (1978).
100. *Riculacysta* sp. A. This species resembles *Riculacysta perforata* Stover (1977) sensu Brinkhuis and Zachariasse (1988). *Riculacysta* sp. A is most frequent in the *Micula prinsii* zone and then decreases numerically across the KT boundary (Plate 4, figures 1,2).
101. *Rottmestia borussica* (Eisenack) Cookson and Eisenack (1961).
102. *Senegalinium bicavatum* Jain and Millipied (1973).
103. *Senegalinium dilwynense* (Cookson and Eisenack) Stover and Evitt (1978).
104. *Senegalinium obscurum* (Drugg) Stover and Evitt (1978).
105. *Senoniasphera inornata* (Drugg) Stover and Evitt (1978). This species first occurs stratigraphically just below the first occurrence of *Danea californica* in both Alabama and Georgia. At Mussel Creek it first occurs in the basal sands of the Clayton Formation, in sample MC9 just 25cm above the contact with the Prairie Bluff Chalk. It becomes common in sample MC12, 35cm higher, at the same level as the first occurrence of *Danea californica*. *S. inornata* ranges through the interval of bed 3 (3.2) to bed 10 (10.3). It is most frequent in beds 5, 6 and 10 (Plate 3, figure 7,8).
106. *Sentusidinium* spp. Species not distinguished.
107. *Spinidinium densispinatum* Stanley (1965).
108. *Spinidinium ornatum* (May) Lentin and Williams (1981).
109. *Spiniferites cornutus* (Gerlach) Sarjeant (1970). This species first occurs in the *Micula prinsii* zone in the Braggs section.
110. *Spiniferites cornutus* subsp. A (Firth 1987, pl. 3, fig. 13). This subspecies first occurs in the latest Maestrichtian (2.6) and ranges up to bed 12 (12.1).
111. *Spiniferites fluens* (Hansen) Stover and Williams (1987).
112. *Spiniferites granomembraneus* (Davey and Williams) Lentin and Williams (1973).
113. *Spiniferites multibrevis* (Davey and Williams) Below (1982).
114. *Spiniferites ramosus granosus* (Davey and Williams) Lentin and Williams (1973).
115. *Spiniferites ramosus* (Ehrenberg) Loeblich and Loeblich (1966).
116. *Spiniferites supparus* (Drugg) Sarjeant (1970).
117. *Spiniferites* sp. cf. *S. pseudofurcatus* (Klump) Sarjeant (1970). This species is most frequent in bed 2, and then becomes rare in the Clayton Formation. It commonly occurs in fragments.
118. *Spiniferites* sp. A. Elongate-elliptical species.
119. *Spongodinium delitiense* (Ehrenberg) Deflandre (1936). A single specimen was observed in sample 6.2.
120. *Systematophora placacantha* (Deflandre and Cookson) Davey, Downie, Sarjeant and Williams (1969).
121. *Tanyosphaeridium xanthiopyxides* (Wetzel) Stover and Evitt (1978).
122. *Tectatodinium* sp. A.
123. *Thalassiphora pelagica* (Eisenack) Eisenack and Gocht (1960). This species is rare in the Braggs section. It first occurs in the *Micula prinsii* zone.
124. *Triblastula nuda* Wetzel (1961).
125. *Trithyrodinium evittii* Drugg (1967) (Plate 4, figure 9).
126. *Turbiosphaera filosa* (Wilson) Archangelsky (1969).
127. *Xenikoon australis* Cookson and Eisenack (1960) sensu Edwards, Goodman and Witmer (1984).

lized nannofossils. In the Mussel Creek section, it extends in the Prairie Bluff Chalk from 31cm below the contact with the Clayton Formation (estuarine facies) up to 7cm below this contact. It was not found in sample MC6, representing the uppermost 2cm of the Prairie Bluff Chalk (text-fig. 5). In the Braggs well, it extends from the depth at 8.7m up to 8.4m. Again, it was not found in the highest available sample of the

Prairie Bluff Chalk, at 8.0m. In the Davis-Hopkins well, it extends from a depth of 767.1m to 713.4m, above which the majority of Cretaceous nannoplankton species disappear.

The nannofossil assemblages are rich and well preserved, and the nannoplankton taxa are as diverse as they are in the *Micula murus* zone. The presence of *M. prinsii*, and the common

occurrence of very large specimens of *A. cymbiformis* together with specimens of *L. quadratus* with very wide blades, all point to a latest Maestrichtian age for the investigated sections. The presence of specimens of *L. quadratus* with very wide blades indicates that this species was in the later stage of its evolution. *P. quadripunctata* is as common as it is in the upper part of the *Micula murus* zone. *A. regularis* is much more common, and *A. octoradiata* has now become virtually absent. The rich and varied assemblages of this zone are interpreted to represent normal marine conditions of the open shelf in the latest Maestrichtian.

In the present study, the upper limit of the *Micula prinsii* zone is defined by the disappearance of most Maestrichtian species. The KT boundary is not precisely defined by the nannoplankton, due to the absence of diagnostic characteristics such as blooms of thoracosphaerids or braarudosphaerids. Instead, the sediment directly above this zone contains delicate and broken nannofossils, which may be the result of unfavorable conditions related to shallow water depths and to concomitant diagenetic processes such as dissolution and recrystallization. Nannofossils are very poorly preserved in the lowest bed (bed 3) of the Clayton Formation, due to their diagenetic alteration. In both the Braggs and Mussel Creek sections, the *Micula prinsii* zone is approximately 30cm thick. This stands in sharp contrast to the Davis-Hopkins well, where it is about 50m thick.

3) *Markalius inversus* (NP1) Zone. Mohler and Hay, in Hay et al. (1967), emended Martini (1970). Zone defined from the last occurrence of Cretaceous nannoplankton or the first occurrence and acme of *Thoracosphaera* spp. or the first common occurrence of *Braarudosphaera bigelowi*, to the first occurrence of *Cruciplacolithus tenuis*. In this study the lower boundary of the *Markalius inversus* zone is taken above the massive disappearance of Maestrichtian nannofossils.

Discussion: This zone was distinguished in the Alabama sections, but was not identified in the investigated section from the Davis-Hopkins well. In the Braggs roadcut section, it is known to range from the base of bed 4 (sample 4.1) into bed 9 (sample 9.1). This interval contains *Biantholithus sparsus*, *Cruciplacolithus primus*, and small specimens included in *Biscutum* (with the questionable presence of *B. romeinii* and *B. parvulum*). These taxa identify the early Danian NP1 zone. The 20cm-thick underlying limestone (bed 3) at the base of the Clayton Formation near Braggs is nearly devoid of nannofossils, except for a few reworked Maestrichtian forms and very rare specimens of *Braarudosphaera*. In general, the preservational state of the nannofossils is usually poor throughout the NP1 zone. Worsley (1974) suggested that a small hiatus exists at the boundary between the Prairie Bluff Chalk and Clayton Formation in the Braggs roadcut section. This may account in part for the absence of nannofossil blooms. In the Braggs well, the NP1 zone was distinguished in the interval from 7.6m through 5.9m. This section is generally devoid of nannofossils, except for reworked Maestrichtian forms. However, the lowest sample (7.6m) contains very rare specimens of *B. sparsus* and *Braarudosphaera* sp. *B. sparsus* identifies the earliest Danian age of this sample. There is no other positive evidence of the NP1 zone in this core. *Cruciplacolithus tenuis* first occurs at 5.8m, which marks the base of the NP2 zone. In the Mussel Creek section, nannofossils first occur within the basal estuarine sands of the Clayton Formation at a level 60cm (sample MC12) above the contact with the underlying Prairie Bluff Chalk. Although rare, *B.*

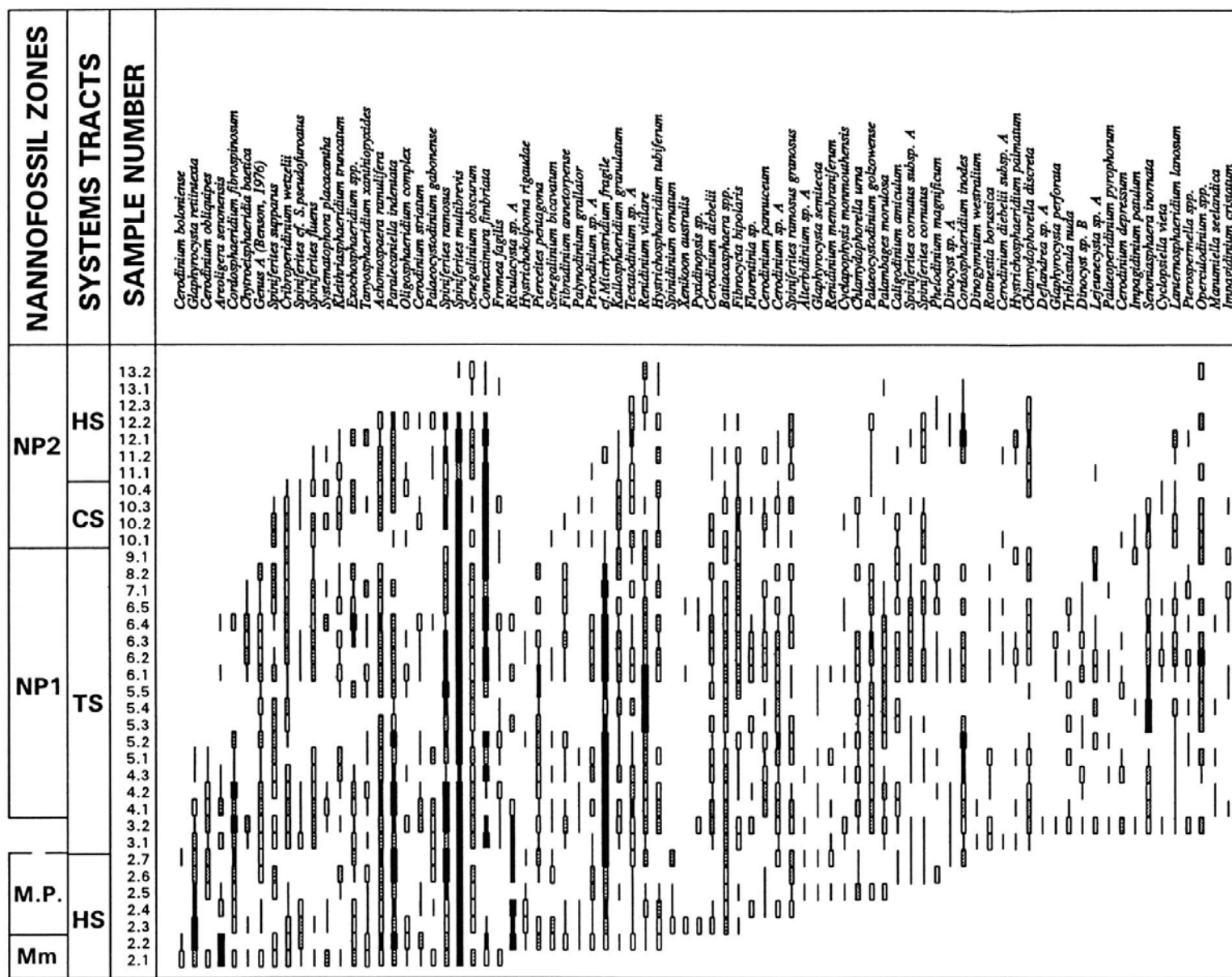
Table 4

Characteristic taxa of the latest Maestrichtian-early Danian interval (*Micula prinsii*-NP2 nannofossil zones).

Latest Maestrichtian	
Nannoplankton	
<i>Arkhangelskiella cymbiformis</i>	(larger forms, fossils up to 16µm in length).
<i>Lithraphidites quadratus</i>	(fossils with highly developed blades).
<i>Micula decussata</i> .	
<i>Micula murus</i> .	
<i>Micula prinsii</i>	(first occurrence defines the <i>Micula prinsii</i> zone).
<i>Nephrolithus frequens</i> .	
Dinoflagellates	
<i>Cerodinium boloniense</i>	(last occurrence in <i>Micula prinsii</i> zone).
<i>Cyclapophysis monmouthensis</i>	(first occurrence in <i>Micula prinsii</i> zone).
<i>Palynodinium grallator</i>	(first occurrence in the uppermost <i>Micula murus</i> zone).
<i>Thalassiphora pelagica</i>	(first occurrence in <i>Micula prinsii</i> zone).
Early Danian	
Nannoplankton	
<i>Cruciplacolithus primus</i>	(first occurrence within NP1 zone).
<i>Biantholithus sparsus</i>	(first occurrence within NP1 zone).
<i>Cyclagelosphaera alta</i>	(first occurrence within NP1 zone).
<i>Cruciplacolithus tenuis</i>	(first occurrence defines NP2 zone).
Dinoflagellates	
<i>Danea californica</i>	(first occurrence in basal Danian).
<i>Carpateella cornuta</i>	(first occurrence in basal Danian).
<i>Membranilarnacia tenella</i>	(first occurrence in basal Danian).
<i>Senoniasphaera inornata</i>	(first occurrence immediately above KT boundary).
<i>Micrhystridium?</i> cf. <i>M. fragile</i>	(acme in early Danian).
<i>Cerodinium diebelii diebelii</i>	(last occurrence in NP2 zone).

sparsus, *Biscutum* sp., *C. primus* and *Cyclagelosphaera altus* occur and identify the NP1 zone. These species occur also in the uppermost sample of the basal sands (sample MC13) and in the overlying limestone (bed 3) in this section. The lowermost 50cm of the sands are nearly devoid of nannofossils.

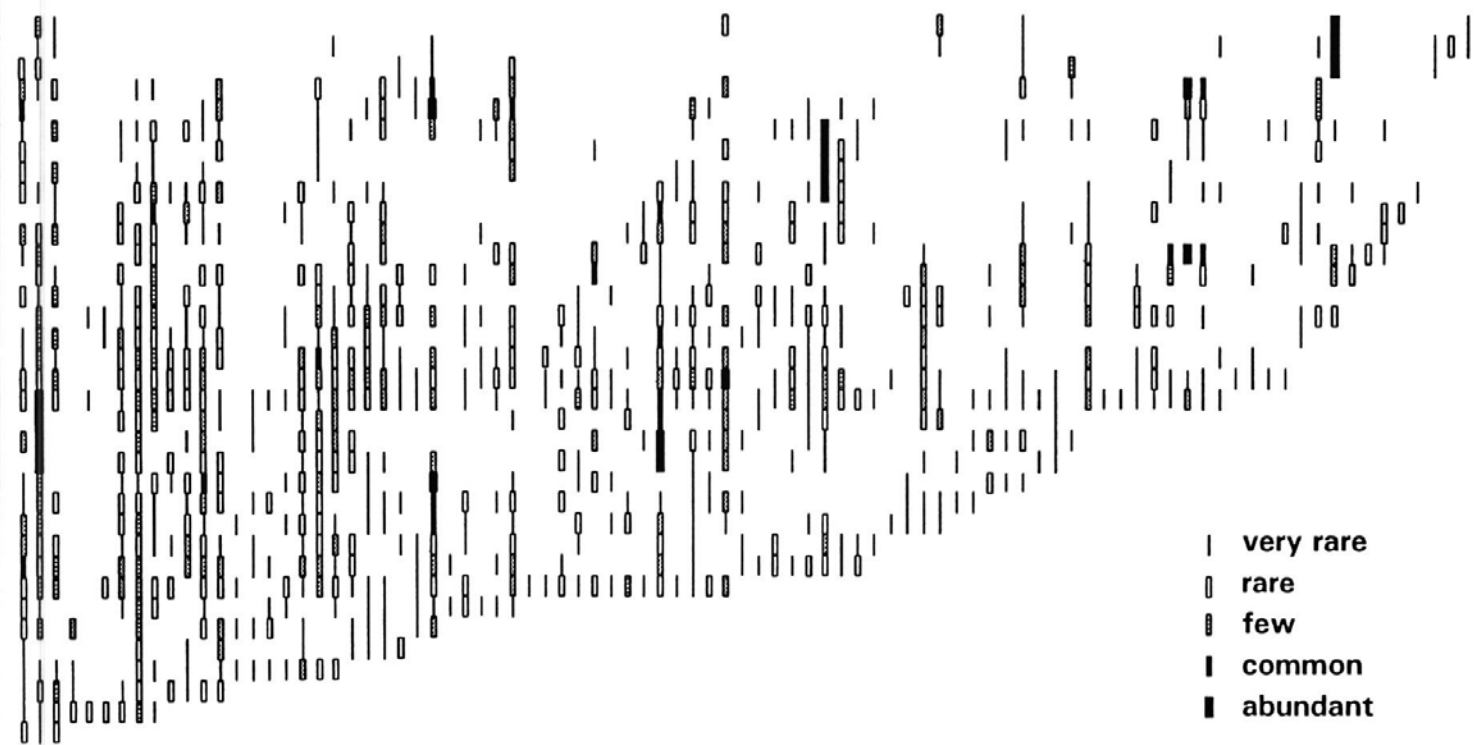
4) *Cruciplacolithus tenuis* (NP2) Zone. Mohler and Hay, in Hay et al. (1967), emended Martini (1970). Interval zone defined from the first occurrence of *C. tenuis* to the first occurrence of *Chiasmolithus danicus* (Brotzen) Hay and Mohler. The NP2 zone was distinguished in the Braggs section and in the Braggs well. In the Braggs roadcut section it ranges from the base of bed 10 (sample 10.1) to the top of the investigated section at the top of bed 13. Nannofossils are few in this interval, and occur mostly in the clayey beds. Most fossils are poorly preserved. *C. tenuis*, *C. primus* and *Zygodiscus sigmoides* were distinguished, in addition to a few Maestrichtian species which were reworked. In the Braggs well, the NP2 zone was distin-

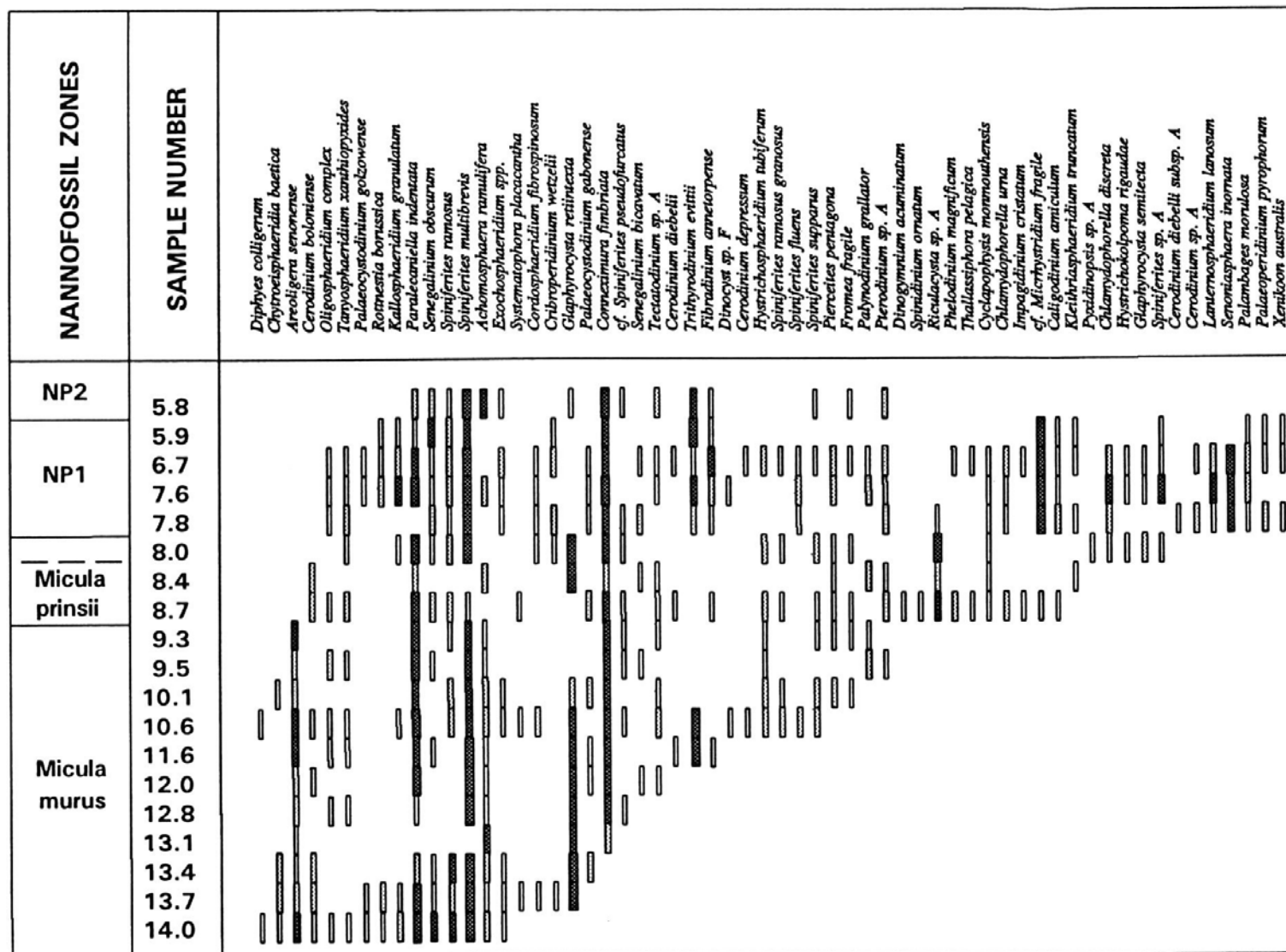


TEXT-FIGURE 7

Dinoflagellate-acritarch stratigraphy, Braggs roadcut.

Ictadocinium sp. A
Rensselaeria vitellaria
Hysterochaetidium tubiferum
Spinidinium ornatum
Xenikoon australis
Pyralidopsis sp.
Cerodinium diebelii
Batiacosphæra spp.
Fibrocysta bipolaris
Florentinia sp.
Cerodinium parvum
Cerodinium sp. A
Spiniferites ramosus gransus
Alterbidinium sp. A
Glaphyrocysta semilecta
Rensselaeria membraniferum
Cyclapophysis mammuliferum
Chlamydothorella urna
Palaeocystodinium golzowense
Palaeobacis morulusa
Caliodinium amiculum
Spiniferites cornutus subsp. A
Phalodinium magnificum
Dinocyst sp. A
Conosphaeridium inodes
Dinocystidium westralium
Rosetta sp.
Cerodinium diebelii subsp. A
Hysterochaetidium palmatum
Chlamydothorella discreta
Deflandrea sp. A
Glaphyrocysta perforata
Tribasina nuda
Dinocyst sp. B
Lejeuncysta sp. A
Palaeoperidinium pyrophorum
Cerodinium depressum
Impagidinium paulum
Senoniasphaera thornala
Cyclopsiella vieta
Lanierosphaeridium lanosum
Pterospermella spp.
Operculodinium spp.
Manutella seelandica
Impagidinium cristatum
Cassidium spp.
Turbosphaera filosa
Pterodinium angulatum
Trihyrodinium evittii
Spiniferites sp. A
Senasidinium spp.
Lejeuncysta hyalina
Cerodinium speciosum
Dinocyst sp. C
Carpateia cornuta
Hysterochaetidium bulbosum
Alterbidinium ? pentaradiale
Dinocyst sp. D
Andalutella rhomboida
Membranularia tenella
Lanierosphaeridium rethardii
Ophiletes laudatus
Dinocyst sp. E
Disaodinium sp. A
Deflandrea galeata
Alterbidinium aculeum
Thalassophora pelagica
Hysterochaetopsis ovum
Achomosphaera sp. A
Chlamydothorella sp. A
Dinocyst sp. F
Achilodinium latiporosum
Alisocysta circumscutata
Spongodinium delitense
Andalutella polymorpha
Impagidinium ovum
Cerodinium confertum
Danea californica
Spiniferites granomembraceus
Gerdicysta casticulus
Spinidinium densispinum
Carpateia sp. A
Diphyes colligerum
Impagidinium sp. A
Dinocyst sp. G
Canningia minor
Batiacosphæra baculata
Hysterochaetopsis sp.



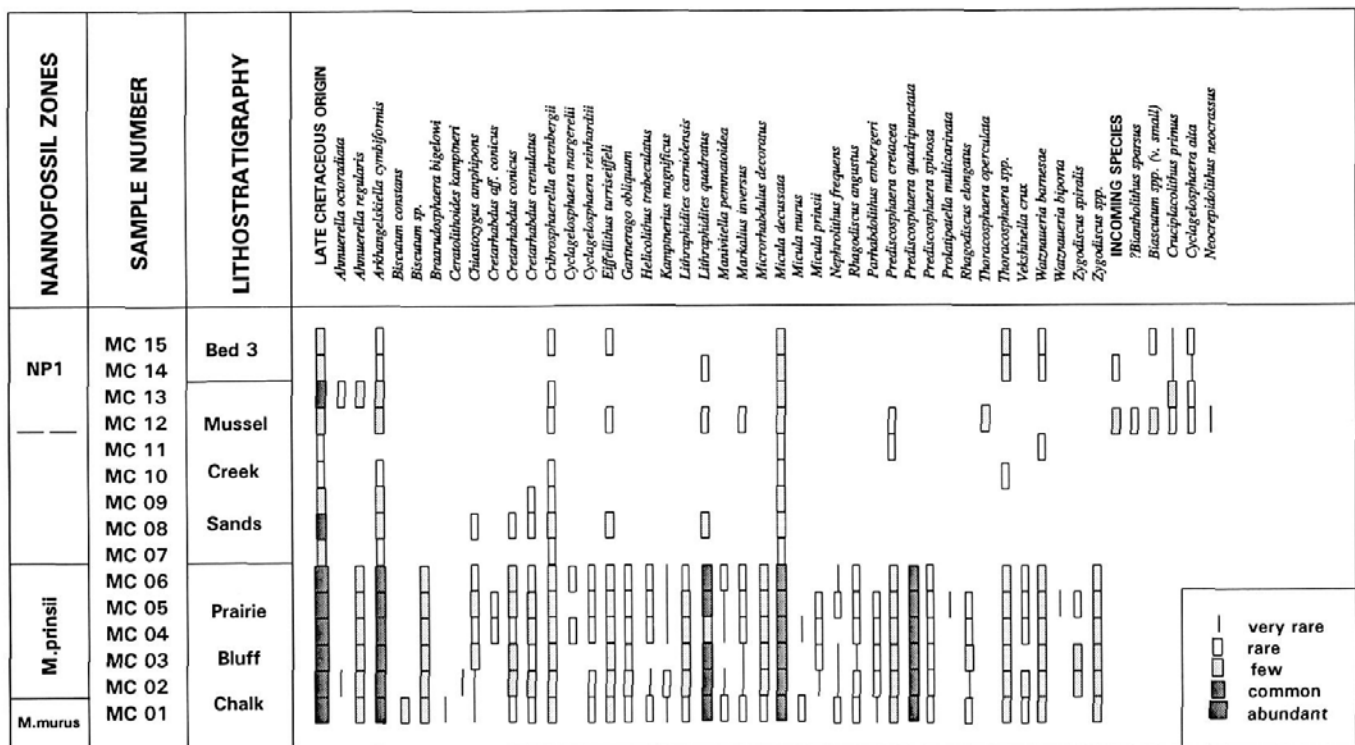


TEXT-FIGURE 9
Dinoflagellate stratigraphy, Braggs well.

Cerodinium diebelii
Trihydradinium evittii
Fibradinium annetorpense
Dinocyst sp. F
Cerodinium depressum
Hystriochloaeridium tubiferum
Spiniferites ramosus granosus
Spiniferites fluens
Spiniferites supparus
Pterocites penagone
Fromea fragile
Polynodinium grillator
Pterodinium sp. A
Dinogymnium acuminatum
Spinidinium ornatum
Riculacysta sp. A
Phelodinium magnificum
Thalassiphora pelagica
Cyclapophysis mormouthensis
Chlamydothorella urna
Impagidinium cristatum
cf. Microhydradinium fragile
Caligodinium amiculum
Kleithrasphaeridium truncatum
Pyxidopsis sp. A
Chlamydothorella discreta
Hystriochloa rigaudae
Glaphyrocysta semilecta
Spiniferites sp. A
Cerodinium diebelii subsp. A
Cerodinium sp. A
Lanternosphaeridium lanosum
Senoniasphaera inornata
Palambages morulosa
Polaeoperidinium pyrophorum
Xenitocoon australis
Corlosphaeridium inodes
Cerodinium striatum
Cerodinium parvum
Andaliella rhombohedra
Pterodinium cingulatum
Cerodinium cordiferum
Chlamydothorella sp. A
Cycloptella vieta
Membranilamacia tenella
Fibrocysta bipolaris
Alterbidinium ? pentaradiatum
Cladopyxidium saeptum
Lanternosphaeridium reinhardtii
Triblastula nuda
Carpacella cornuta
Achomosphaera sp. A
Alisocysta circumabulata
Dinocyst sp. B
Genus A
Glaphyrocysta perforata
Hystriochloa bulbosum
Impagidinium aculeatum
Impagidinium sp. A
Lejaneucysta sp. A
Operculodinium spp.
Senegalinium alwynense
Turbiosphaera filosa
Deflandrea galeata
Pterospermella spp.
Cerodinium speciosum
Spiniferites cornutus subsp. A
Lejaneucysta hyalina
Spiniferites cornutus
Spiniferites granomembranacea
Spinidinium densispinatum



rare
 few
 common
 abundant



TEXT-FIGURE 5

Calcareous nannofossil stratigraphy, Mussel Creek section.

guished in the uppermost sample, at 5.8m, based only on the first occurrence of *C. tenuis*.

DINOFLAGELLATES AND ACRITARCHS

Census

Table 3 lists the 127 species, subspecies and species-groups of dinoflagellates and acritarchs that were distinguished in the Alabama sections. All but four were observed in the Braggs roadcut section. *Cannosphaeropsis utinensis* and dinocyst sp. H were observed in the basal sands at Mussel Creek only, and *Dinogymnium acuminatum* was found only in the Prairie Bluff Chalk in the Braggs well. *Senegalinium dilwynense* was observed in the Danian interval in the Mussel Creek sands and Braggs well. As much as 24% of the total taxa listed in table 3 are not validly named or formally described. Nevertheless, it was considered to be important to include these fossils so that the entire recovered record could be used for paleoenvironmental interpretation. These include examples from the literature considered to be conspecific with our fossils, such as *Xenikoon australis* (sensu Edwards, Goodman and Witmer 1984). On the other hand, other species were counted together because it was not always possible to distinguish them as separate taxa, e.g. *Glaphyrocysta reticulata* and *G. reticulosa*. Yet other fossils occurred as single specimens. Although they represent more than one species, these fossils were grouped together in their common genus, e.g. *Batiacasphaera* spp.

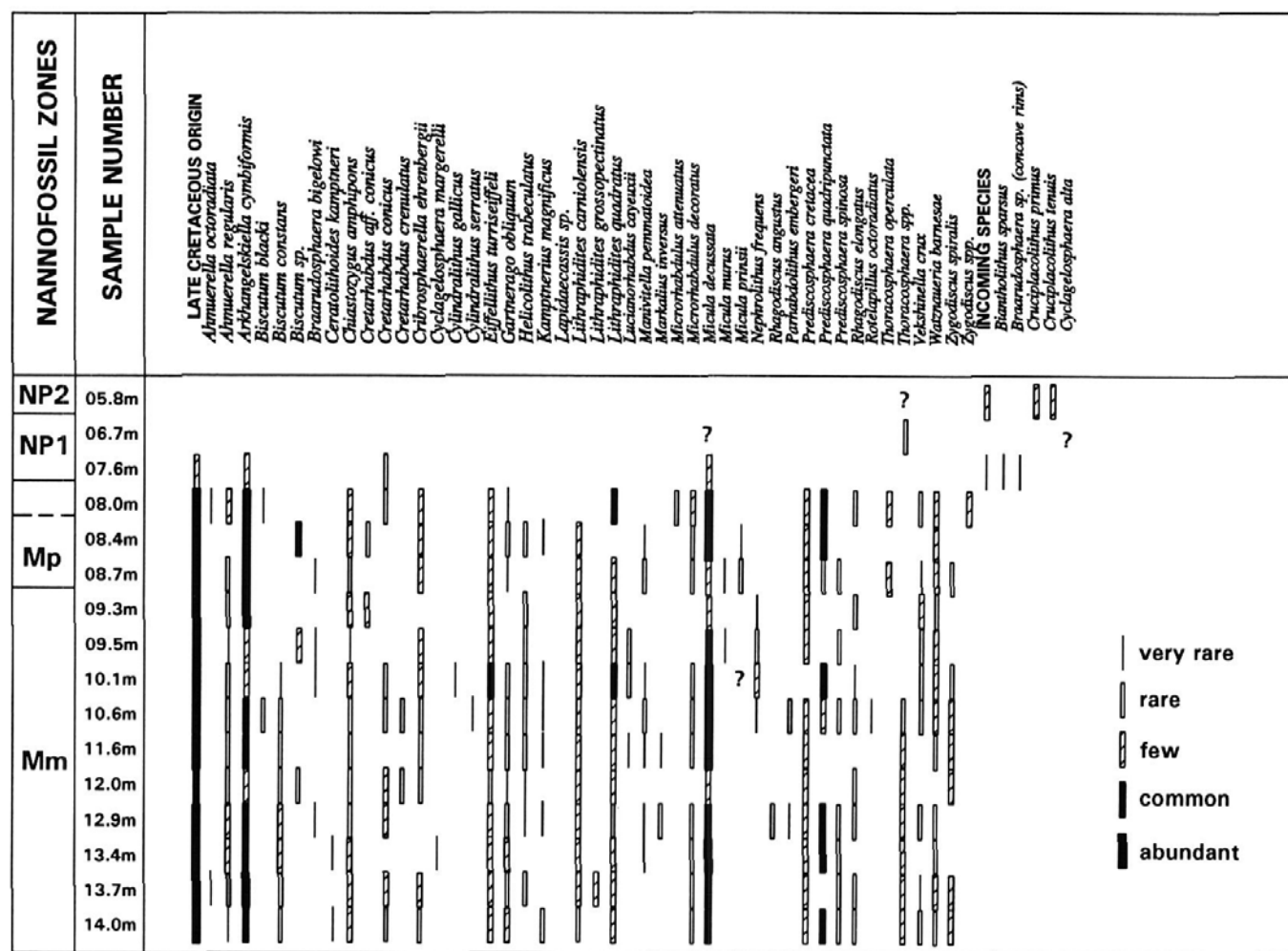
Dinocysts and acritarchs predominate over sporomorphs and other land plant particles through most of the section in the Clayton Formation. However, in several specific thin intervals, and in the upper part of this section, i.e. within bed 12 of the

roadcut section, the landplant materials are more numerous. In these cases, there is a clear separation of the populations based on preservation. Dinocysts are well preserved in contrast to the land plant particles which, based on their darker color and evidence of corrosion, evidently suffered from reworking or other detrital effects. Land plant particles are most numerous in the upper part of the Prairie Bluff Chalk. Dinoflagellate species are fewer than in the overlying Clayton Formation, but the fossils are equally well preserved in most samples. Dinocysts are fewer in the Mussel Creek sands. They are very well preserved, and are associated with land plant particles comprised mostly of dark brown to black inertinite detritus. Pollen grains and spores are very few, and consist mostly of bisaccate pollen grains, e.g. *Rugubivesiculites reductus* Pierce, which are well preserved.

Biostratigraphy

Of the 127 taxa that were distinguished in the Alabama sections, 103 have a history in the Maestrichtian, based on the literature or their presence in the Maestrichtian nannofossil zones. In the Braggs roadcut (text-fig. 7), this includes many species which have their lowest occurrences in the Danian nannofossil zones. This suggests that their distribution was determined to a large extent by change in paleoenvironment. There is no evidence in the investigated sections to indicate that the dinoflagellate and acritarch flora participated in the extinction event which impoverished the calcareous-shelled biota. Twenty-four taxa are restricted to the Danian. However, many of these are new and rare and, thus, require further study.

Danea californica, *Membranilarnacia tenella* and *Carpatella cornuta* are the three most valuable dinoflagellate species for



TEXT-FIGURE 6

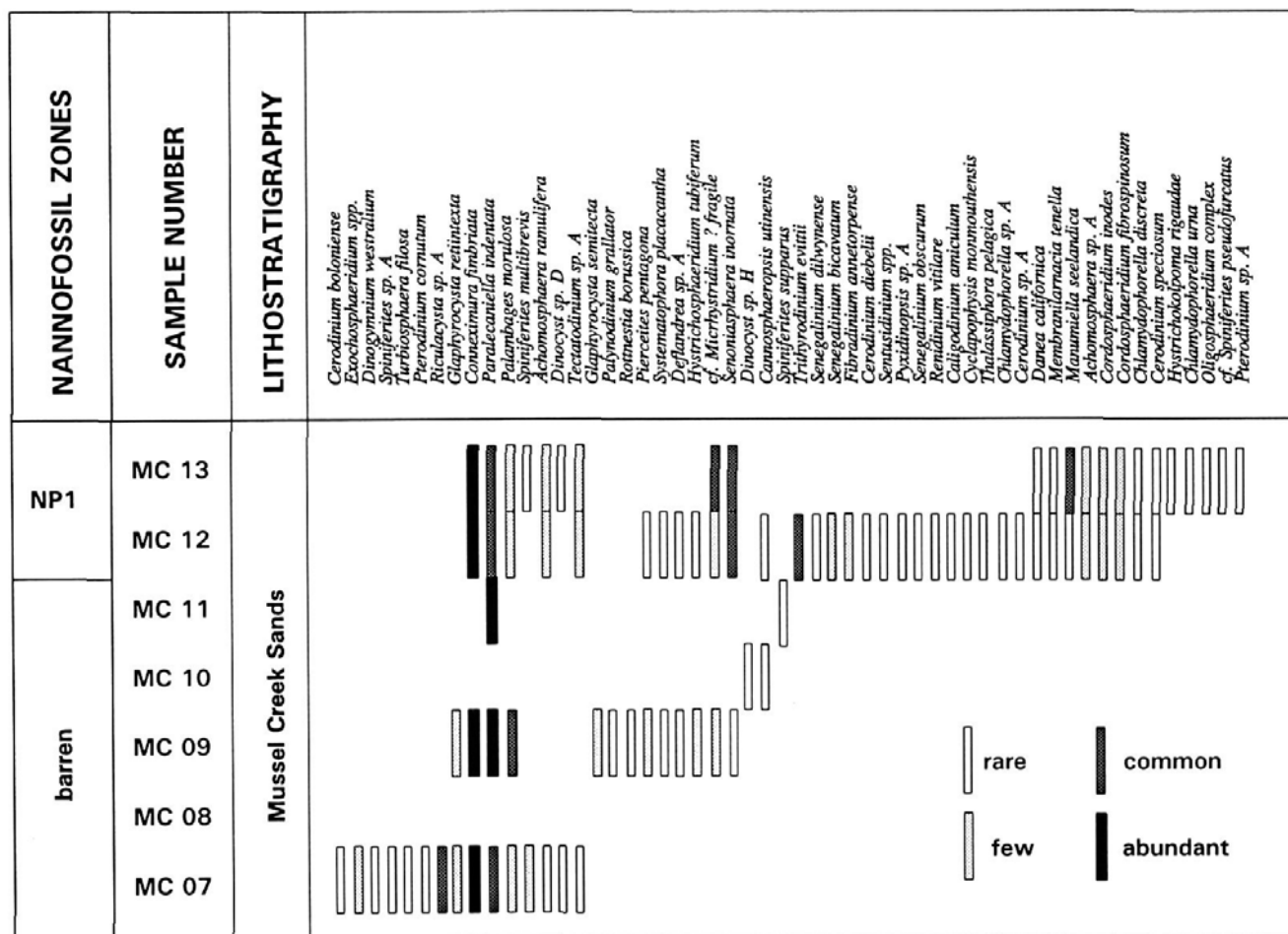
Calcareous nannofossil stratigraphy, Braggs well.

identifying the KT boundary. They first occur in the basal Danian in biostratigraphically calibrated sections ranging from Denmark to Tunisia, in various paleobiogeographic regions, and in the deep ocean basin stratigraphy. In the Mussel Creek section (text-fig. 8), *D. californica* and *M. tenella* first occur in the carbonaceous estuarine sands 60cm (sample MC12 in table 1) above the base of the Clayton Formation. Since this evidence was first reported (Habib, Moshkovitz and Kramer 1992), we have observed that this sample also contains the first occurrences of the basal Danian nannofossil species *Biantholithus sparsus* and *Cruciplacolithus primus*. The first occurrences of these four species provide firm evidence that the basal sands of the Clayton Formation are Tertiary in age. The paucity of dinoflagellate fossils in the lower part of these sands, and the lack of indigenous nannofossils, is attributed to aqueous coastal environments not yet sufficiently influenced by sea level rise (Habib, Moshkovitz and Kramer 1992). However, the presence of *Senoniasphaera inornata* at 25cm (sample MC9) indicates that the lower part is already Danian. This conclusion is based on the occurrence of foraminiferids in splits of the same samples of the sand at Mussel Creek that were studied initially for dinocysts. Olsson and Liu (1993) reported the PO foraminiferal zone in the interval below 48cm of the basal sands and the P α

zone in the interval beginning at 48cm. This places FO *S. inornata* within the PO zone and FO *D. californica* within P α at Mussel Creek.

Senoniasphaera inornata first occurs just below the first occurrence of *D. californica* in the Davis-Hopkins well in Georgia as well. In the Mussel Creek sands, it first occurs just 25cm above the base of the Clayton Formation, 35cm below the first occurrence of *D. californica*. In the Braggs well and roadcut, it first occurs in the rubble zone in the lower part of bed 3. In the expanded section of the Davis-Hopkins well, *S. inornata* first occurs below the first occurrence of *D. californica*. Although this species does not have the global distribution of the three other species, *S. inornata* is considered to be valuable for dating sediments at the KT boundary (Hultberg 1986; Firth 1987).

Carpatella cornuta first occurs in the Mussel Creek section in the limestone (bed 3) directly overlying the basal sands. It was not observed in the sand interval. *D. californica* was not observed in the Braggs well (text-fig. 9). However, *C. cornuta* and *M. tenella* appear stratigraphically in the upper part of bed 3 (sample 15 at 7.6m depth) which identifies the Danian. In the Braggs roadcut, *C. cornuta* and *M. tenella* have their lowest



TEXT-FIGURE 8
Dinoflagellate-acritarch stratigraphy, Mussel Creek sands.

occurrences in bed 4 of the Clayton Formation. *D. californica* appears in bed 5.

When calibrated against the nannofossil zonation, the biostratigraphic datums of other species are valuable for dating the latest Maestrichtian and Danian, respectively. *Cyclapophysis monmouthensis* and *Thalassiphora pelagica* first occur within the *Micula prinsii* zone in both Braggs sections, although the latter species is very rare. Habib and Miller (1989) reported the first occurrences of these species approximately 61m and 88m, respectively, below the first occurrence of *D. californica* in the Davis-Hopkins Well. This study now indicates that these species first occur within the *Micula prinsii* zone in the Georgia section as well. *Palynodinium grallator* first occurs earlier within the latest Maestrichtian (uppermost part of the *Micula murus* zone).

The dinoflagellate *Cerodinium diebelii diebelii* last occurs within the NP2 nannofossil zone in both Braggs sections. This datum may be valuable for dating the coastal plain sections. Stover, in Haq, Hardenbol and Vail (1988, fig. 14), correlated this datum within the top of the NP2 zone.

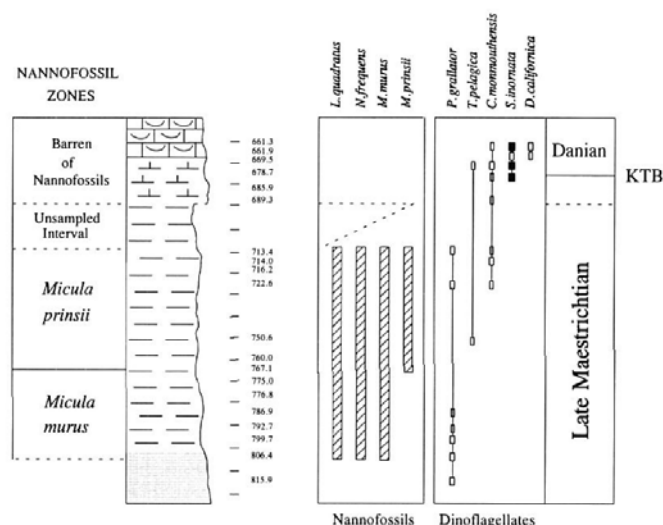
There are other palynological events which appear to correlate between Alabama and Georgia. *Glaphyrocysta retiintexta* (*G. retiintexta*-*G. reticulosa*) is common to abundant in the latest Maestrichtian in both areas, but then declines numerically

rapidly just below the KT boundary. *Riculacysta* sp. A similarly declines in abundance in Alabama, just above the boundary. Conversely, in both areas (Firth 1987) the acritarch species cf. *M. fragile* first occurs in the latest Maestrichtian but becomes a dominant element at or just above the KT boundary. Other species, e.g. *Gerdiocysta cassiculus* and *Trithyrodinium evitti*, become abundant in localized parts of the sections.

CONCLUSIONS

The first occurrences of two nannofossil species (*Biantholithus sparsus*, *Cruciplacolithus primus*) and four dinoflagellate species (*Senoniasphaera inornata*, *Danea californica*, *Membranilarnacia tenella*, *Carpatella cornuta*) date the base of the Clayton Formation in south-central Alabama as early Danian. The first five species appear just 25cm-60cm above the formation boundary in estuarine sand at Mussel Creek. *C. cornuta* first occurs in the immediately overlying shelf facies, in the lowermost limestone (bed 3) in the Braggs well. The presence of the *Micula prinsii* zone in the three Alabama sections closely constrains the duration of the hiatus represented in the disconformity between the Clayton Formation and underlying Prairie Bluff Chalk. This erosion surface must have formed during a fall of sea level very close to, or at, the end of the Maestrichtian.

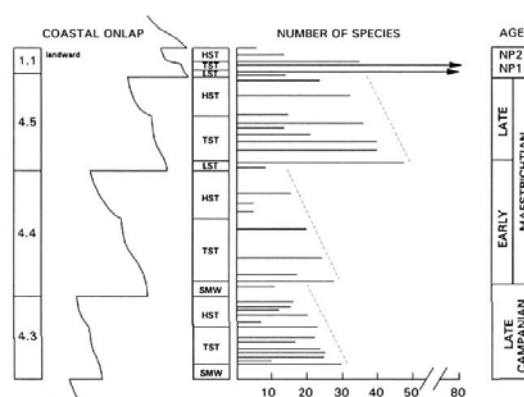
The nannofossil stratigraphy provides further evidence of the geologically short period of time in which the disconformity



TEXT-FIGURE 10

Age-diagnostic nannofossil and dinoflagellate taxa in the Davis-Hopkins well, compared against the lithofacies succession and nannofossil zonation. Depths in meters.

developed, specifically when compared against the magnetic reversal stratigraphy of the roadcut section (text-fig. 2). In pelagic ocean basin sections with a stable magnetic record and complete sequence of nannofossil zones, and with a single predominant lithology (nannofossil ooze) which implies only slight variations in sedimentation rate, there is a constant stratigraphic relationship between the biozonal boundaries and the polarity chrons. This relationship can be seen in widely distributed sections from the South Atlantic (Manivit and Feinberg 1984; Poore et al. 1984) and the western Pacific



TEXT-FIGURE 11

Coastal onlap cycles compared against dinoflagellate diversity patterns of late Campanian, early Maestrichtian, late Maestrichtian and early Danian ages, respectively. Onlap cycles after Haq, Hardenbol and Vail (1988). Late Campanian-late Maestrichtian species richness curve from Dorchester well; latest Maestrichtian-earliest Danian from Davis-Hopkins well (Habib and Miller 1989); early Danian curve from Braggs sections.

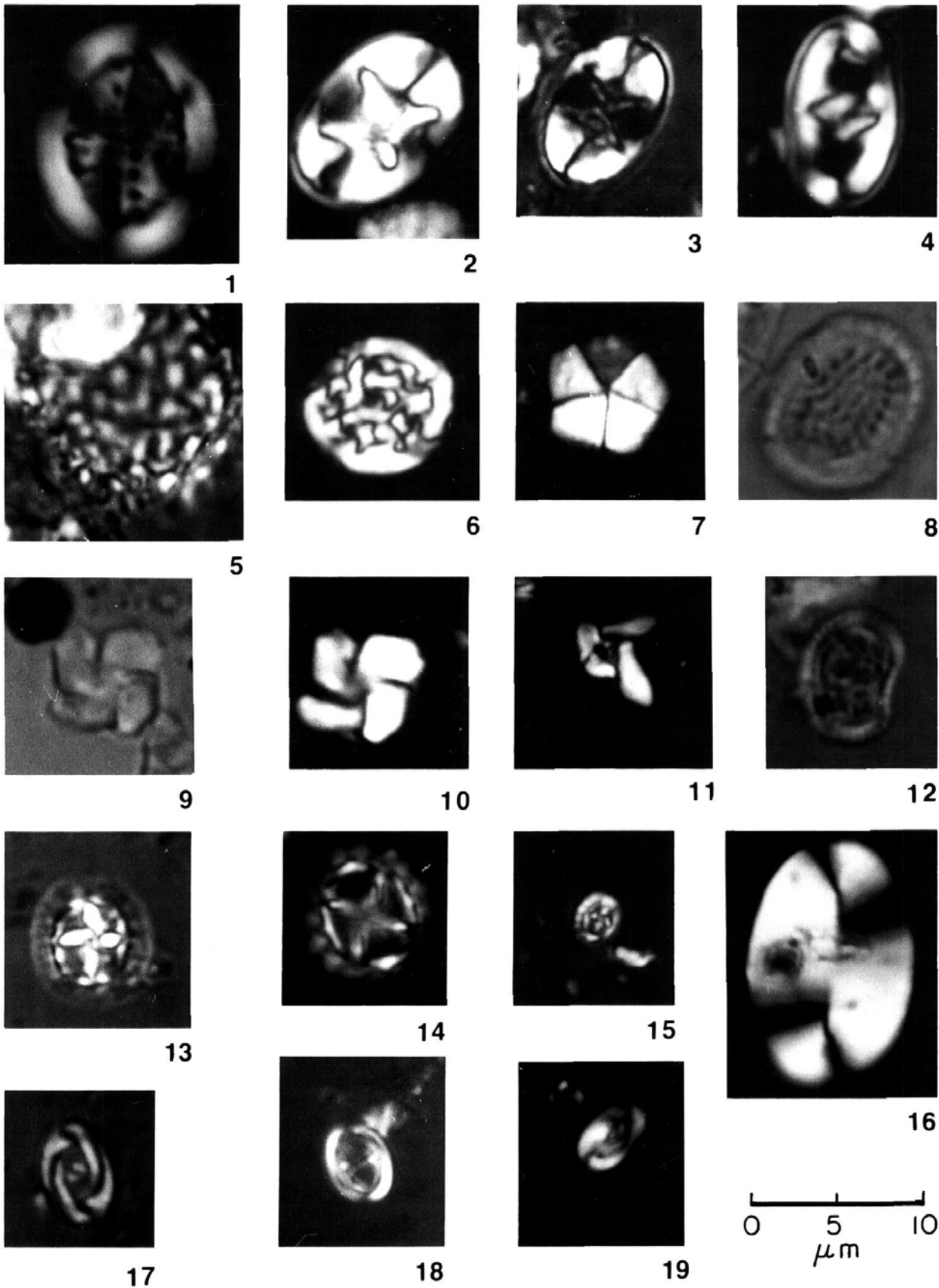
(Monechi, Bleil and Bachman 1985). Based on the first occurrences of age-diagnostic zonal species, the boundary between the *Micula murus* and *Micula prinsii* zones is situated within the lower half of chron C29R. The nannofossil KT boundary occurs in the middle or in the upper half of C29R, and the boundary between the NP1 and NP2 zones occurs in chron C29N. These correlations can also be found in selected land sections.

In the Braggs roadcut section (text-fig. 2) there is agreement on the position of the NP1/NP2 boundary within C29N. However, the position of the *M. murus*/*M. prinsii* boundary lies below the

PLATE 1

Calcareous nannofossils, $\times 3000$.

- 1 *Arkhangelskiella cymbiformis*. Cross-polarized light. Sample 2.3, Braggs.
- 2, 3 *Eiffellithus turriseiffeli*. Cross-polarized light. 2, Sample 2.4N, Braggs. 3, Davis-Hopkins well No. 1, 713.4m.
- 4 *Parhabdolitus embergeri*. Cross-polarized light. Sample 2.3 Braggs.
- 5-6 *Thoracosphaera operculata*. Cross-polarized light. 5, sample 12, Mussel Creek; 6, sample 2.3, Braggs.
- 7 *Braarudosphaera bigelowi*. Cross-polarized light. Sample 10.3, Braggs.
- 8 *Cribrosphaerella ehrenbergii*. Cross-polarized light. Sample 2.4N, Braggs.
- 9-11 *Micula murus*. 9, Ordinary light; 10, cross-polarized light. Sample Davis Hopkins well No. 1 713,4m depth; 11, sample 2.4N, Braggs.
- 12 *Nephrolithus frequens*. Cross-polarized light. Sample 3.2, Braggs.
- 13 *Prediscosphaera spinosa*. Cross-polarized light. Sample Davis Hopkins well No. 1, 713.4m depth.
- 14 *Prediscosphaera cretacea*. Cross-polarized light. Sample 2.4N, Braggs.
- 15 *Prediscosphaera quadripunctata*. Cross-polarized light. Sample 2, Mussel Creek.
- 16 *Prolatipatella multicarinata*. Cross-polarized light. Sample 2.3, Braggs.
- 17 *Zygodiscus spiralis*. Cross-polarized light. Sample 2.4N, Braggs.
- 18 *Zygodiscus sigmoides*. Cross-polarized light. Sample 4.3, Braggs.
- 19 *Neocrepidolithus ?neocrassus*. Cross-polarized light. Sample 12, Mussel Creek.



identified chron C29R, within the magnetically unstable interval. Channell and Dobson (1989) indicated that the thickness of C29R in the roadcut section is 2.91 (± 0.48) m. It extends from the stratigraphic level of the middle of bed 9 down to the middle of bed 3. The next lower interval, from the middle of bed 3 down into the uppermost part of the underlying Prairie Bluff Chalk, is approximately 1.2m thick. This interval was not classified due to its unstable magnetization. Chron 30N was distinguished in the section immediately below the unstable interval. This undefined interval in the Prairie Bluff Chalk is interpreted on nannofossil evidence to represent the time of the earlier half of C29R. This conclusion is based on the stratigraphic position of the zonal boundary between the *Micula murus* and *Micula prinsii* zones, 32cm below the upper boundary of the Prairie Bluff Chalk and well within the magnetically unstable interval. In order for this zonal boundary to lie within C29R at all, it is required that the magnetically unstable interval of the Prairie Bluff Chalk be classified in time with C29R. By lowering the base of the time of C29R approximately 1.2m into the Prairie Bluff Chalk the nannofossil boundary would be situated well within the lower half of C29R. Further, the position of the KT boundary would be relatively higher within the chron. This would be closer in position to that recorded in the pelagic sections, and suggested for the Gubbio stratotype (Rocchia et al. 1990).

The hiatus at (or very close to) the KT boundary is estimated to be not greater than several hundred thousand years in duration. Based on numerical age data published by Berggren et al. (1985), Monechi, Bleil and Backman (1985) estimated the duration of C29R to be 570,000 years, lasting from 66.74 Ma to 66.17 Ma. The *Micula prinsii* zone lies entirely within C29R

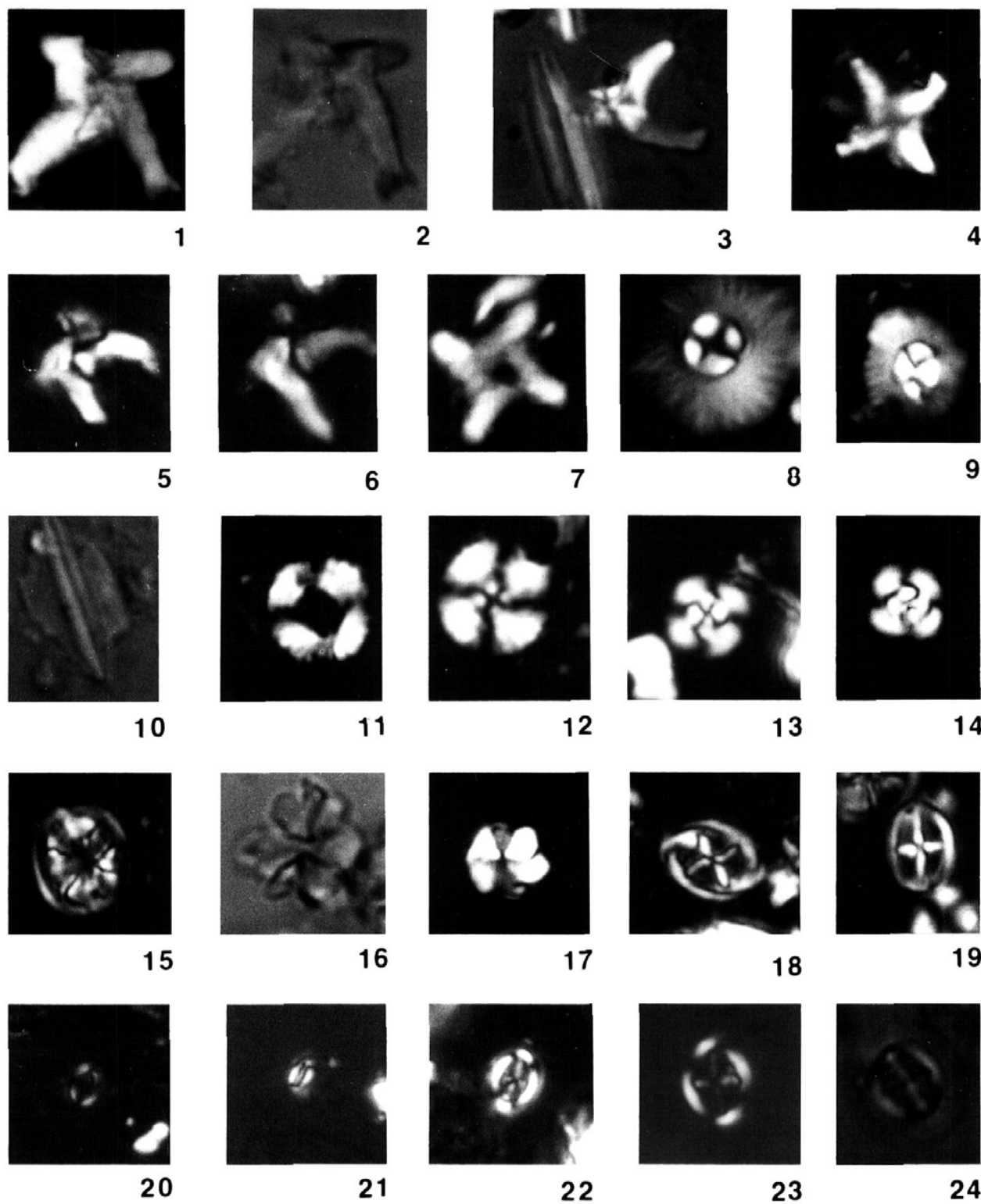
and appears to represent about one-half of the 570,000-year period. The presence of earliest Tertiary microfossils directly above this zone (and above the disconformity) at Braggs suggests that less than one-half (ca. 200,000 years) of this time period is missing in the record there. The nannofossil KT boundary lies within the middle or upper half of C29R but would be lowered in those sections with a boundary hiatus, such as in the Braggs section. This would be the result of the erosion, at the end of the Maestrichtian, of sedimentary deposits of latest Maestrichtian age, i.e. sediments of the *Micula prinsii* zone. The resultant downward relative displacement of the KT boundary within C29R appears to be not greater than one-third of its total 570,000-year total time period or, again, approximately 200,000 years of sea level fall. In the Braggs area, the *Micula prinsii* zone varies between 30cm and 50cm in thickness. This thin interval most likely represents the erosion of sediments of latest Maestrichtian age at the top of the Prairie Bluff Chalk.

The disconformity between the Prairie Bluff Chalk and Clayton Formation in the Braggs area is close in age to the KT boundary and may accentuate the extinction datum of the invertebrate macrofossil and nannofossil taxa. In contrast, the *Micula prinsii* zone is more than 50m thick in the Davis-Hopkins well, in siliclastic mudstones deposited at a high rate of sedimentation in a shallowing upwards conformable sequence (text-fig. 10). The top of the zone occurs at 713.4m, although it may have extended through the unsampled interval of 24m. The overlying 28m-thick interval from 689.3m through 661.3m is barren of nannofossils. It is within this interval, in porous calcareous sandstones, that the KT boundary (at 678.7m) is distinguished by the first occurrence of *Senoniasphaera inornata*. The disappearance of Cretaceous nannofossils at least through the interval

PLATE 2

Calcareous nannofossils, $\times 3000$.

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| <p>1-7 <i>Micula prinsii</i>. 1, cross-polarized light; 2, ordinary light, sample 2.4N, Braggs; 3, cross-polarized light, sample 2.3, Braggs; 4, cross-polarized light, sample Braggs core #1, 8.38m depth; 5, cross-polarized light, sample 4, Mussel Creek; 6, cross-polarized light, Davis Hopkins well No. 1, 722.6m depth; 7, cross-polarized light, sample 2.4N, Braggs.</p> <p>8-9 <i>Markalius inversus</i> Cross-polarized light. 8, sample 2.4N, Braggs; 9, sample 10.1, Braggs (with elliptical center).</p> <p>10 <i>Lithraphidites quadratus</i>. Ordinary light, sample 2.4N, Braggs.</p> <p>11 <i>Cylindralithus serratus</i>. Cross-polarized light, Davis-Hopkins well No. 1, 713.4m depth.</p> <p>12 <i>Cyclagelosphaera margerelii</i>. Cross-polarized light, Davis-Hopkins well No. 1, 713.4m depth</p> <p>13 <i>Cyclagelosphaera reinhardtii</i>. Cross-polarized light, sample 2.3, Braggs.</p> | <p>14 <i>Cyclagelosphaera alta</i> Cross-polarized light, sample 4.3, Braggs.</p> <p>15 <i>Ahmuerella regularis</i>. Cross-polarized light, sample 2, Mussel Creek.</p> <p>16 <i>Biantholithus sparsus</i>. Ordinary light, sample 4.3, Braggs.</p> <p>17 <i>Biantholithus sparsus</i>. Cross-polarized light, sample 12, Mussel Creek.</p> <p>18 <i>Chiastozygus amphipons</i>. Cross-polarized light, sample 2, Mussel Creek.</p> <p>19 <i>Vekshinella crux</i>. Cross-polarized light, ample 2, Mussel Creek.</p> <p>20 <i>Biscutum ?romeinii</i>. Cross-polarized light, sample 4.3, Braggs.</p> <p>22 <i>Cruciplacolithus primus</i>. Cross-polarized light, sample 4.1, Braggs.</p> <p>23-24 <i>Cruciplacolithus tenuis</i>. Cross-polarized light, sample 10.2, Braggs.</p> |
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0 5 10
μm

of 661.9m to 689.3m suggests that paleoecological conditions were the controlling factors, possibly due to the regression at the end of the Maestrichtian.

Dinoflagellate (and acritarch) taxa fluctuate in numerical abundance in the Prairie Bluff Chalk and Clayton Formation, which correlates with the sequence stratigraphy published by Donovan et al. (1988) for those sections. In a composite dinoflagellate richness curve (text-fig. 3) drawn from the study of the three Alabama sections (Habib, Moshkovitz and Kramer 1992), dinoflagellate taxa are few in the prograding highstand systems tract in the uppermost part of the Prairie Bluff Chalk. The species are fewest in the lowstand sands directly above the KT boundary and above the sequence boundary (disconformity) representing the latest Maestrichtian fall in sea level. The smaller number of species in the lowstand systems tract and its association with blackish detrital inertinite is characteristic of coastal paleoenvironments of Late Cretaceous and Danian ages in the Atlantic Coastal Plain (Habib, Eshet and van Pelt, in press). In the Davis-Hopkins well in Georgia, and in Alabama, *D. californica* first occurs in this depositional organic facies.

Dinoflagellate evidence of sea level rise across the Danian paleoshelf is based on the rapid influx of species near the base of the transgressive tract (text-fig. 3). The maximum diversity of dinoflagellates is associated with well-preserved, abundant, amorphous debris. *Senoniasphaera inornata*, *Carpatella cornuta*, and the acritarch cf. *Michrystidium? fragile* increase in relative frequency in the transgressive tract. The large number of species and the abundance of amorphous debris, presumably of fecal origin, suggest an episode of high organic productivity at a time in the early Danian (NP1 nannofossil zone) when the calcareous-shelled biota (except for the calcareous shelled-dinoflagellate *Thoracosphaera*) remained impoverished by mass extinction. Dinoflagellates become progressively less diverse through the highstand tract. At the level of bed 13 in the Braggs roadcut, an assemblage of 11 species is dominated (81%) by a single species, *Gerdicysta cassicus*.

The dinoflagellate pattern of few species in the lowstand deposits, maximum number of species in the lowest part of the transgressive tract and then a systematic reduction in number of species into and through the highstand tract correlates in age with third-order cycles of coastal onlap for the late Campanian-early Danian as illustrated by Haq, Hardenbol and Vail (1988). In the Dorchester well, in South Carolina, Habib and Miller

(1989, fig. 3) show a few species in the late Campanian interval (lowstand deposits?), and then a rapid diversification of the dinoflagellate biota (lower transgressive tract) amidst abundant fecal amorphous debris. This interval is followed by a continuous reduction in number of species through the late Campanian-earliest Maestrichtian in an episode of deltaic progradation of land plant detritus. This cycle correlates in age with third-order cycle 4.3 in supercycle UZA4 (Haq, Hardenbol and Vail 1988, fig. 15). The dinoflagellate pattern is repeated in the interval from late Campanian-earliest Maestrichtian to early Maestrichtian (4.4 in UZA4) when, in the Dorchester well, the organic facies changes from deltaic progradation to coastal inertinite. It is repeated again in the late Maestrichtian, this time in an interval dominated by amorphous debris. The cycles of dinoflagellate diversity are somewhat independent of the dominant depositional organic matter, but do follow the palynological evidence of regression following initial expansion of the biota. The diversity pattern in the Braggs roadcut section correlates in age with the Danian third-order cycle 1.1 in supercycle TA1. Text-figure 11 shows the correlation of the dinoflagellate patterns with the onlap cycles of the late Campanian-early Danian interval (Habib and Miller 1989, fig. 3; Habib, Moshkovitz and Kramer 1992, figs. 1-3; Haq, Hardenbol and Vail 1988, figs. 14-15). For each diversity pattern, there is a close match with the corresponding onlap cycle. The systematic decrease in number of dinoflagellate species, beginning from the lower part of transgressive tract, matches the landward onlap of facies during a cycle of sea level rise and progradation (regression in the highstand tract).

SYSTEMATIC PALEONTOLOGY

Genus **LANTERNOSPHAERIDIUM** Morgenroth 1966 emend. Stover and Evitt 1978

Type species: *Lanternosphaeridium lanosum* Morgenroth 1966.

***Lanternosphaeridium reinhardtii* Habib, n. sp.**

Plate 5, figures 1-4

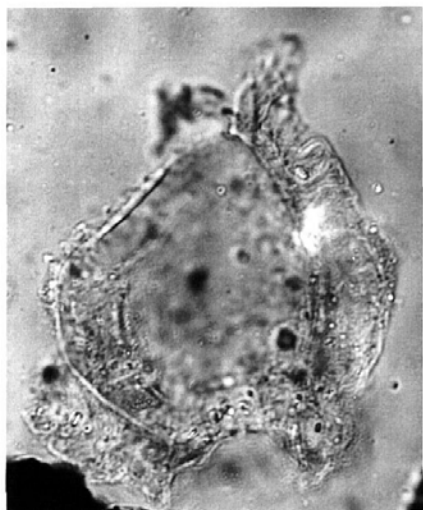
Holotype: Sample 5.4, collected 27cm above the base of bed 5 in the Braggs roadcut section. Slide 5.4C. England Finder coordinates W67.1. Plate 5, text-figure 1a-c. 164µm x 126µm; endocyst 157µm x 81µm; apical spike 34µm long; antapical spike 23µm. Repository at Queens College of the City University of New York.

PLATE 3

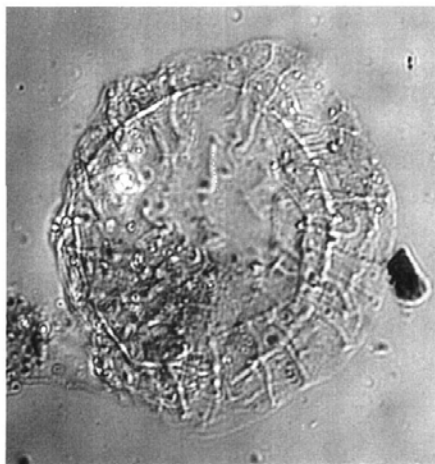
Dinoflagellates, approximately x650.

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| <p>1 <i>Danea californica</i>. Sample MC12, Mussel Creek sands. Lateral view, optical section. Apical and antapical horns in focus.</p> <p>2 <i>Membranilarnacia tenella</i>. Sample MC12, Mussel Creek sands.</p> <p>3 <i>Carpatella cornuta</i>. Sample 15, Braggs No. 1 Testwell.</p> | <p>4 <i>Cyclapophysis monmouthensis</i>. Sample 6.1, Braggs roadcut.</p> <p>5 <i>Manumiella seelandica</i>. Sample MC7, Mussel Creek sands.</p> <p>6 <i>Palynodinium grallator</i>. Sample 4.2, Braggs roadcut.</p> <p>7-8 <i>Senoniasphaera inornata</i>. 7. Sample MC9, Mussel Creek sands. 8. Sample 5.5, Braggs roadcut.</p> |
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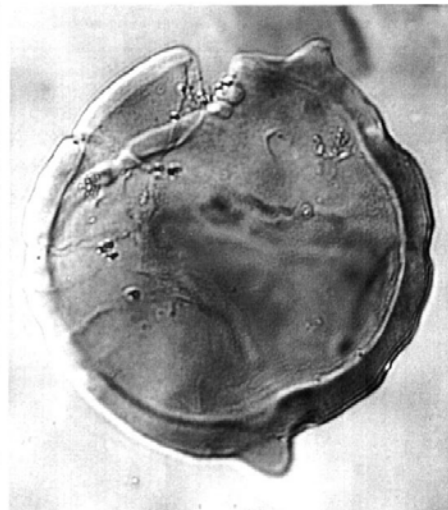
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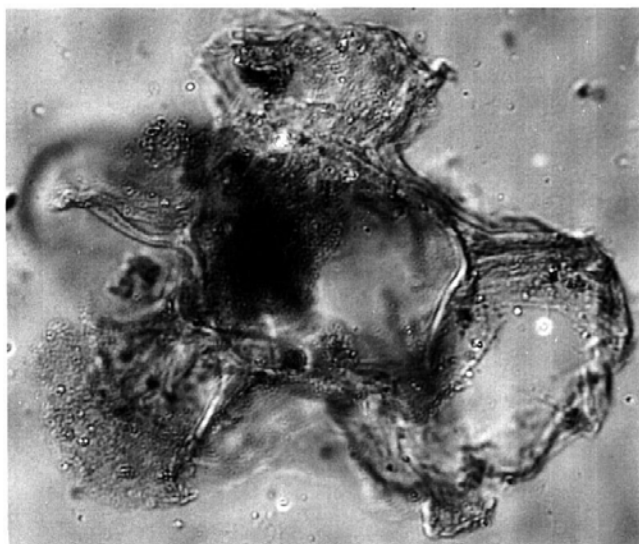
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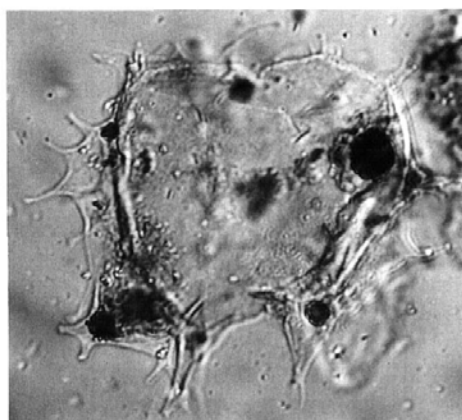
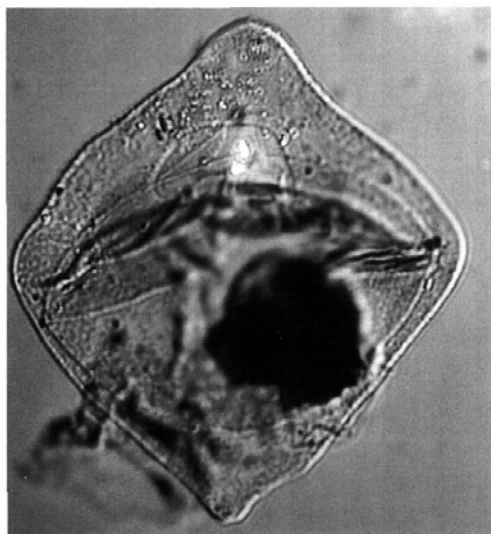
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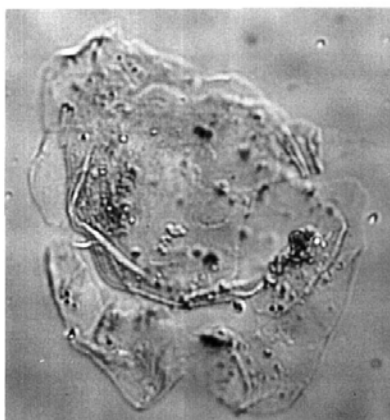
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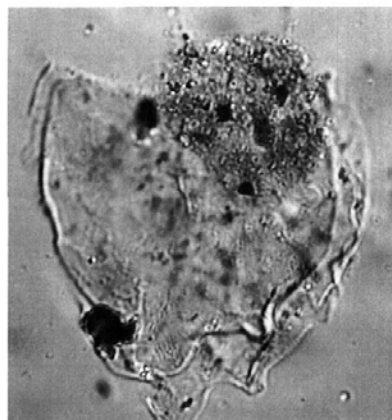
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Diagnosis: Loosely sheathed proximocavate dinoflagellate cysts. Endocyst rigidly ovoidal, with a prominent, tapering, long apical spike and somewhat shorter antapical spike. Endocyst wall relatively thick (ca. 2µm) and not tabulated. It is yellow in color and the surface is smooth or barely scabrate. Pericyst thin (<1µm) and distinctly scabrate. It is pale yellow to almost colorless. It is of variable, mostly irregular, shape in most orientations. In dorsoventral compression, the pericyst can be bilaterally symmetrical butterfly-shaped (e.g. holotype) with thin radially pointed folds. Otherwise, it has a nonsymmetrical shape regardless of orientation. In other specimens, the pericyst is sheathed close to the endocyst and displays an incomplete gonyaulacoid tabulation in which 6 postcingular and 6 pre-tingular plates are evident. The pericyst encloses both polar spikes of the endocyst. Pericystal archeopyle rounded hexagonal, broader than high, precingular Type P3". Endoarcheopyle of same shape and about the same size. Operculum simple and free. Pericystal cingulum evident at the outline by an equatorial indentation; evidence of sulcus lacking. Endocyst without cingulum or sulcus.

Dimensions of 20 measured specimens: overall length 143µm-170µm, width 105µm-126µm; endocyst length 139µm-157µm, width 81µm-111µm. Apical spike 20µm-32µm; antapical spike 14µm-25µm.

Remarks: *Lanternosphaeridium reinhardtii* is distinguished from *L. lanosum* by its thicker-walled and rigid central body and by the possession of long polar endocystal spikes. The species is potentially valuable for distinguishing the basal Danian. It first occurs in bed 4 in the Braggs roadcut section, in bed 3 at Mussel Creek, and in the subsurface depth of 7.8m (bed 3) in the Braggs well.

The species is named in memory of the deceased geologist, Juergen Reinhardt, who encouraged us in our research and first suggested that we sample the Mussel Creek section.

ACKNOWLEDGMENTS

James A. Miller (U.S. Geological Survey, Norcross, Georgia), Lucy Edwards (U.S. Geological Survey, Reston, Virginia) and Richard Olsson (Rutgers University, New Brunswick, New Jersey) reviewed the manuscript. We benefitted from discussions with Peter Sugarman (New Jersey Geological Survey, Trenton). Ernest Mancini, Berry Tew (Geological Survey of Alabama) and James A. Miller helped us in our field studies. This study was supported by National Science Foundation Grant EAR- 8903522.

REFERENCES

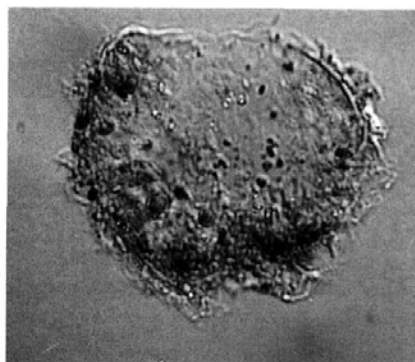
- ALVAREZ, L. W., ALVAREZ, W., ASARO, F. and MICHAEL, H. V., 1980. Extraterrestrial cause for the Cretaceous-Tertiary extinction. *Science*, 298:1095-1108.
- AURISANO, R., 1989. Upper Cretaceous dinoflagellate biostratigraphy of the subsurface Atlantic Coastal Plain of New Jersey and Delaware, U.S.A. *Palynology*, 13:143-179.
- BAUM, G. R. and VAIL, P. R., 1988. Sequence stratigraphy concepts applied to Paleogene outcrops: Gulf and Atlantic basins. In: Wilgus, C. K. et al., Ed., Sea-level changes: an integrated approach. Society of Economic Paleontologists and Mineralogists, Special Publication No. 42:309-327.
- BENSON, D. G., 1976. Dinoflagellate taxonomy and biostratigraphy at the Cretaceous-Tertiary boundary, Round Bay, Maryland. *Tulane Studies in Geology and Paleontology*, 12:169-233.
- BERGGREN, W. A., KENT, D. V., FLYNN, J. J. and VAN COUVERING, J. A., 1985. Cenozoic geochronology. *Geological Society of America Bulletin*, 96:1407-1418.
- BRAMLETTE, M. N. and MARTINI, E., 1964. The great change in calcareous nannoplankton fossils between the Maestrichtian and Danian. *Micro-paleontology*, 10:291-322.
- BRINKHUIS, H. and LEEREVELD, H., 1988. Dinoflagellate cysts from the Cretaceous-Tertiary boundary sequence of El Kef, northwest Tunisia. *Review of Palaeobotany and Palynology*, 56:5-19.

PLATE 4

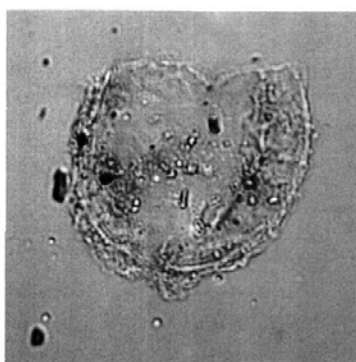
Dinoflagellates, approximately ×650.

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| <p>1-2 <i>Riculacysta</i> sp. A. 1. Sample MC7, Mussel Creek sands. 2. Sample 2.7, Braggs roadcut sections.</p> <p>3 <i>Dinocyst</i> sp. D. Species with well-developed tabulation cingulum and sulcus. Gonyaulacoid cyst tabulation. Sulcal tongue is evident in this specimen. Sample 5.1. Braggs roadcut section.</p> <p>4 <i>Glaphyrocysta retiintexta</i>. Sample MC7. Mussel Creek sands.</p> <p>5 <i>Glaphyrocysta reticulosa</i>. Sample 2.3. Braggs roadcut section.</p> | <p>6 <i>Micrystidium?</i> sp. cf. <i>M. fragile</i>. Specimen within plugs in the projections and at the base, restricting communication with the central vesicle cavity. Sample 6.1, Braggs roadcut section.</p> <p>7,10 <i>Cerodinium diebelii diebelii</i>. Chocolate brown peridinioid dinocysts. 7. Sample 6.1, Braggs roadcut section. 10. Sample 6.2, Braggs roadcut section.</p> <p>8 <i>Gerdicysta cassicus</i>. Sample 13.2, Braggs roadcut section.</p> <p>9 <i>Trithyrodinium evittii</i>. Chocolate brown peridinioid dinocyst. Sample 6.2, Braggs roadcut section.</p> |
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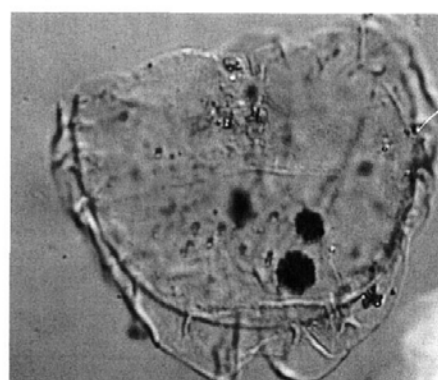
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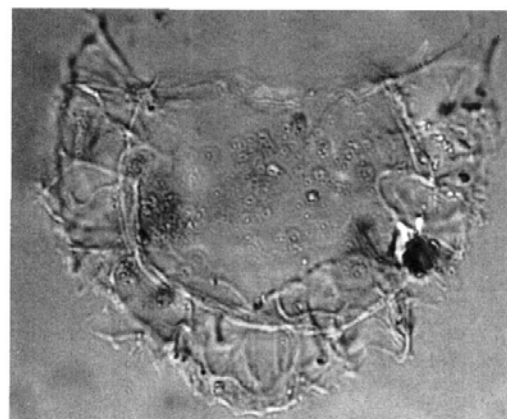
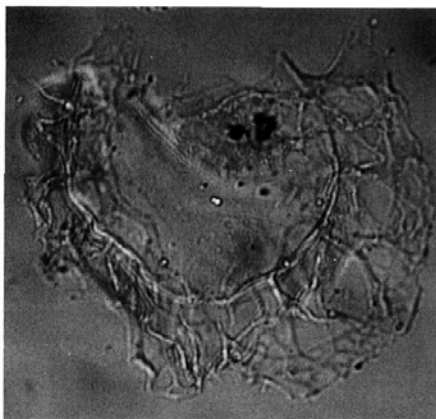
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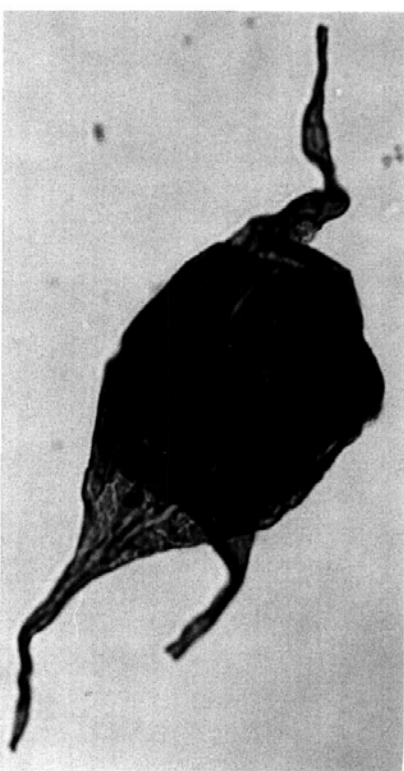


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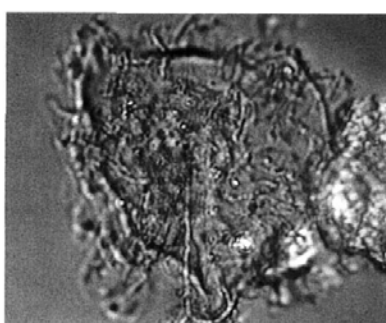
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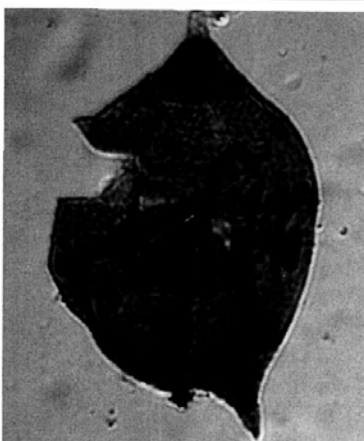


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- BRINKHUIS, H. and ZACHARIASSE, W. J., 1988. Dinoflagellate cysts, sea level changes and planktonic foraminifers across the Cretaceous-Tertiary boundary at El Haria, northwest Tunisia. *Marine Micropaleontology* 13:153-191.
- BRYAN, J. R. and JONES, D. S., 1989. Fabric of the Cretaceous-Tertiary marine macrofaunal transition at Braggs, Alabama. *Palaeogeography, Palaeoclimatology, Palaeoecology*, 69:279-301.
- BUKRY, D. and BRAMLETTE, M. N., 1970. Cocolith age determination. Leg 3, Deep Sea Drilling Project. In: Initial Reports of the Deep Sea Drilling Project, Volume 13:589-611. Washington, D.C.: U.S. Government Printing Office.
- CEPEK, P., MASTERS, B. A. and WORSLEY, T. A., 1968. Calcareous plankton in the upper Cretaceous of Alabama. In: Scott, J. C., et al., Facies changes in the Selma Group in central and eastern Alabama. Alabama Geological Society, 6th Annual Field Guidebook, pp. 27-40.
- CHANNELL, J. E. T. and DOBSON, J. P., 1989. Magnetic stratigraphy and magnetic mineralogy at the Cretaceous-Tertiary boundary section, Braggs, Alabama. *Palaeogeography, Palaeoclimatology, Palaeoecology*, 69:267-277.
- COPELAND, C. W. and MANCINI, E. A., 1986. Cretaceous-Tertiary boundary southeast of Braggs, Lowndes County, Alabama. In: Neathery, T. L., Ed., Geological Society of America, Centennial Field Guide, 6:369-372.
- DONOVAN, A. D., BAUM, G. R., BLECHSCHMIDT, G. L., LOUTIT, T., PFLUM, C. E. and VAIL, P. R., 1988. Sequence stratigraphic setting of the Cretaceous-Tertiary boundary in central Alabama. In: Wilgus, C. K., et al., Eds., Sea-level changes, an integrated approach. Society of Economic Paleontologists and Mineralogists, Special Publication No. 42:299-307.
- DRUGG, W. S., 1970. Some new genera, species and combinations of phytoplankton from the Lower Tertiary of the Gulf Coast, USA. *Proceedings, North America Paleontology Convention*, G:809-843.
- EDWARDS, A. R., 1966. Calcareous nannoplankton from the uppermost Cretaceous and the lowermost Tertiary of the mid Waipara section. South Island, New Zealand. *New Zealand Journal of Geology and Geophysics*, 9:481-490.
- EDWARDS, L. E., 1989. Dinoflagellate cysts from the Lower Tertiary formations, Haynesville cores, Richmond County, Virginia. U.S. Geological Survey Professional Paper, 1489-C:C1-C12.
- EDWARDS, L. E., GOODMAN, D. K. and WITMER, R. J., 1984. Lower Tertiary (Pamunkey Group) dinoflagellate biostratigraphy, Potomac River area, Virginia and Maryland. In: Frederiksen, N. O. and Kraft, K., Eds., Cretaceous and Tertiary stratigraphy, paleontology and structure, southwestern Maryland and northeastern Virginia. American Association of Stratigraphic Palynologists Field Trip Volume and Guidebook, pp. 137-152.
- ESHET, Y., DRUCKMAN, D., COUSMINER, H. L., HABIB, D. and DRUGG, W., 1988. Reworked palynomorphs and their use in the determination of sedimentary cycles. *Geology*, 16:662-665.
- ESHET, Y., MOSHKOVITZ, S., HABIB, D., BENJAMINI, C. and MAGARITZ, M., 1992. Calcareous nannofossil and dinoflagellate stratigraphy across the Cretaceous-Tertiary boundary at Hor Hahar, Israel. *Marine Micropaleontology*, 18:199-228.
- FIRTH, J. V., 1987. Dinoflagellate biostratigraphy of the Maastrichtian to Danian interval in the U.S. Geological Survey Albany Core, Georgia, U.S.A. *Palynology*, 11:199-216.
- GARTNER, S. and KEANY, J., 1978. The terminal Cretaceous event: a geological problem with an oceanographic solution. *Geology*, 6:707-712.
- GOHN, G. S., 1988. Late Mesozoic and early Cenozoic geology of the Atlantic Coastal Plain, North Carolina to Florida. In: Sheridan, R. E. and Grow, J. A., The Geology of North America, the Atlantic continental margin. Geological Society of America, 1:107-130.
- GREGORY, W. A. and HART, G. F., 1992. Towards a predictive model for the palynologic response to sea-level changes. *Palaios*, 7:3-33.
- HABIB, D., ESHET, Y. and VAN PELT, R., in press. Palynology of sedimentary cycles, In: Traverse, A., Ed., Sedimentation of organic particles. Cambridge, England: Cambridge University Press.
- HABIB, D. and KNAPP, S. D., 1982. Stratigraphic utility of Cretaceous small acritarchs. *Micropaleontology*, 28:335-371.
- HABIB, D., KRAMER, C. and MILLER, J. A., 1990. Dinoflagellates and depositional organic facies in KT boundary sections of the southern United States. Geological Society of America. Abstracts with Programs, 22:A278.
- HABIB, D. and MILLER, J. A., 1989. Dinoflagellate species and organic facies evidence of marine transgression and regression in the Atlantic coastal plain. *Palaeogeography, Palaeoclimatology, Palaeoecology*, 74:23-47.
- HABIB, D. and MOSHKOVITZ, S., 1991. Dinoflagellate and calcareous nannofossil response to sea level change in KT boundary sections. Geological Society of America. Abstracts with Programs, 23:A184.

PLATE 5

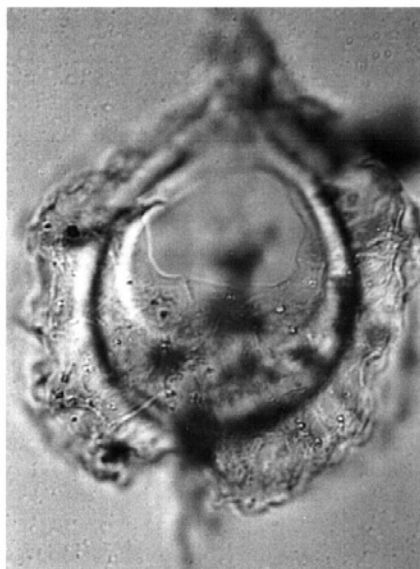
Dinoflagellates, approximately $\times 650$.

- 1-4 *Lanternosphaeridium reinhardtii*. 1a-c. Holotype. 1a, Internal view of dorsal surface. Pericystal archeopyle in focus. 1b, optical section, showing the prominent apical and antapical spikes. 1c, External view of ventral surface; focus on butterfly-shaped sheathed pericyst. Note the minor folds of the sheath which are radiating outwards. Sample 5.4. Braggs roadcut section. 2, Specimen with shorter polar spikes. Optical section. Sample 7.1. Braggs roadcut section. 3a, b. Closely sheathed specimen. Lateral view with opercular pieces of pericyst and endocyst

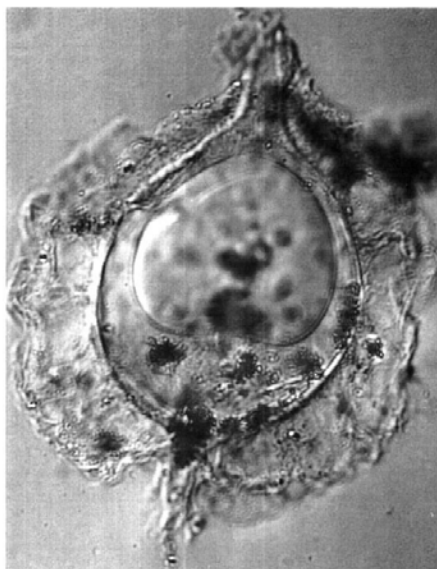
free but adherent at the archeopyle. 3a, Focus on pericystal opercular piece. 3b, Postcingular and precingular cyst tabulation evident. Small radial folds of the pericyst present at the junctures of cyst plates. Sample 9.1 Braggs roadcut section. 4a, b. Closely sheathed specimen. 4a, Focus on apical spike. 4b, Focus on margins of pericystal and endocystal archeopyles. Sample 8.1, Braggs roadcut section.

- 5 *Deflandrea* sp. A. Sample 3.2, Braggs roadcut sections.

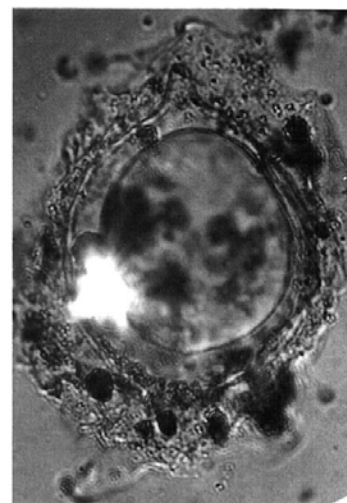
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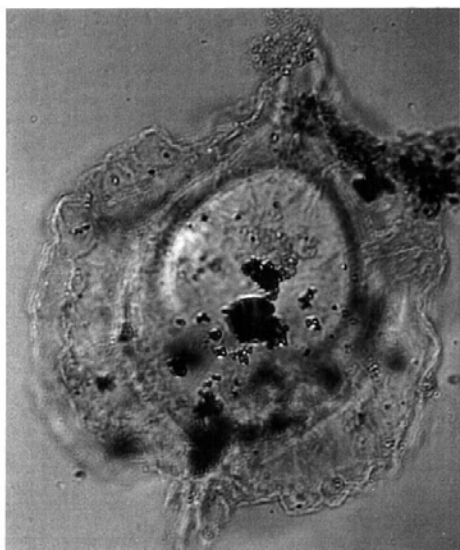
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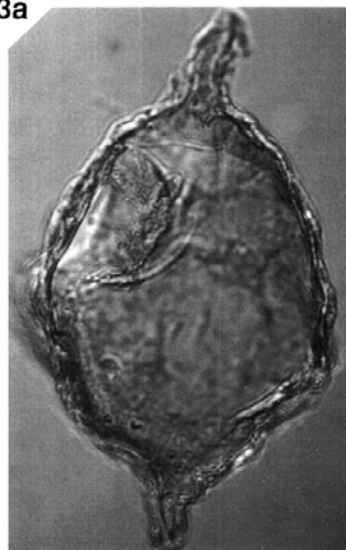
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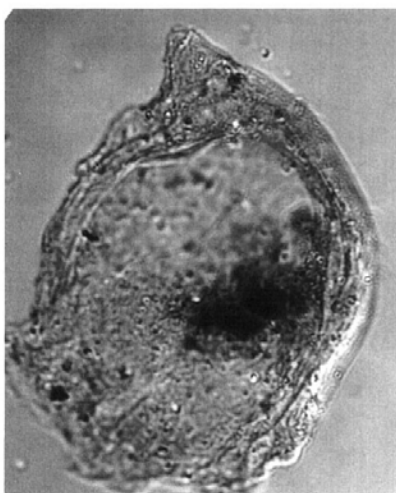
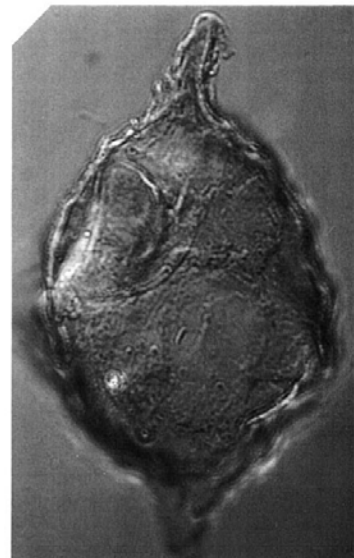
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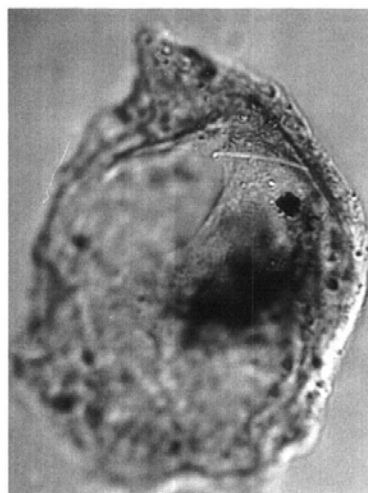
3a



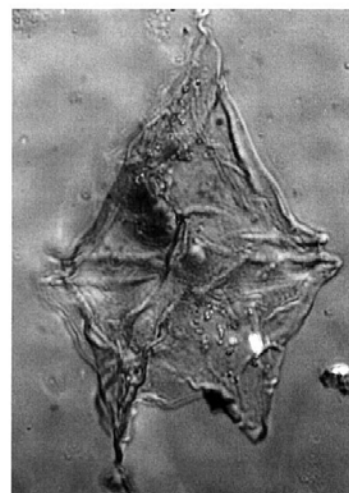
3b



4a



4b



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- HABIB, D., MOSHKOVITZ, S. and KRAMER, C., 1992. Dinoflagellate and calcareous nannofossil response to sea-level change in Cretaceous-Tertiary boundary sections. *Geology*, 20:165-168.
- HANSEN, J. M., 1977. Dinoflagellate stratigraphy and echinoid distribution in Upper Maastrichtian and Danian deposits from Denmark. *Bulletin of the Geological Society of Denmark*, 26:1-26.
- , 1979. A new dinoflagellate zone at the Maastrichtian-Danian boundary in Denmark. *Dan. Geol. Unders. Arbog*, 1978. pp. 131-140.
- HAQ, B. U., HARDENBOL, J. and VAIL, P. R., 1988. Mesozoic and Cenozoic chronostratigraphy and cycles of sea-level change. In: Wilgus, C. K., et al., Eds., *Sea-level changes: an integrated approach*. Society of Economic Paleontologists and Mineralogists, Special Publication No. 42:71-108.
- HAY, W. W. and MOHLER, H. P., 1967. Calcareous nannofossils from Early Tertiary rocks at Pont Labau, France and Paleocene-Early Eocene correlations. *Journal of Paleontology*, 41:1505-1541.
- HAY, W. W., MOHLER, H. P., ROTH, P. H., SCHMIDT, R. R. and BOUDREAUX, J. E., 1967. Calcareous nannoplankton zonation of the Cenozoic of the Gulf Coast and Caribbean-Antillean area and transoceanic correlation. *Transactions of the Gulf Coast Association of Geological Societies*, 17:428-480.
- HULTBERG, S. U., 1986. Danian dinoflagellate zonation, the C-T boundary and the stratigraphical position of the fish clay in southern Scandinavia. *Journal of Micropaleontology*, 5:37-47.
- JARZEN, D. M., 1978. The terrestrial palynoflora from the Cretaceous-Tertiary transition, Alabama, U.S.A. *Pollen et Spores*, 20:535-553.
- JIANG, M. J. and GARTNER, S., 1986. Calcareous nannofossil succession across the Cretaceous-Tertiary boundary in east-central Texas. *Micropaleontology*, 32:232-255.
- JONES, D. S., MUELLER, P. A., BRYAN, J. R., DOBSON, J. P., CHANNELL, J. E. T., ZACHOS, J. C. and ARTHUR, M. A., 1987. Biotic geochemical and paleomagnetic changes across the Cretaceous-Tertiary boundary at Bragg, Alabama. *Geology*, 15:311-315.
- KOCH, R. C. and OLSSON, R. K., 1977. Dinoflagellate and planktonic foraminiferal biostratigraphy of the uppermost Cretaceous of New Jersey. *Journal of Paleontology*, 51:480-491.
- MAGARITZ, M., MOSHKOVITZ, S., BENJAMINI, C., HANSEN, H. J., HAKANSSON, E. and RASMUSSEN, R., 1985. Carbon isotope, bio- and magnetostratigraphy across the Cretaceous-Tertiary boundary in the Zin Valley, Negev, Israel. *Newsletter on Stratigraphy*, 15:100-113.
- MANCINI, E. A., TEW, B. H. and SMITH, C. C., 1989. Cretaceous-Tertiary contact, Mississippi and Alabama. *Journal of Foraminiferal Research*, 19:93-104.
- MANIVIT, H. and FEINBERG, H., 1984. Correlation of magnetostratigraphy and nannofossil biostratigraphy in Upper Cretaceous and Lower Paleocene sediments in the Walvis Ridge area. In: Moore, T. C., Rabinowitz, P. D., et al., *Initial Reports of the Deep Sea Drilling Project, Volume 74:469-474*. Washington, D.C.: U.S. Government Printing Office.
- MANUM, S. B., BOULTER, M. C., GUNNARSDOTTIR, H., RANGNES, K. and SCHOLZE, A., 1989. Eocene to Miocene palynology of the Norwegian Sea (ODP Leg 104). In: Eldholm, O., et al., Eds., *Proceedings of the Ocean Drilling Program, Scientific Results, Volume 104:611-662*. College Station, Texas: Ocean Drilling Program.
- MARTINI, E., 1970. Standard Paleogene calcareous nannoplankton zonation. *Nature*, 226:560-561.
- MONTECHI, S., BLEIL, U. and BACKMAN, J., 1985. Magnetobiochronology of Late Cretaceous-Paleogene and Late Cenozoic pelagic sedimentary sequence from the northwest Pacific (DSDP, Leg 86, Site 577). In: Heath, G. R., Burckle, L. H. et al., *Initial Reports of the Deep Sea Drilling Project, Volume 86:787-797*. Washington, D.C.: U.S. Government Printing Office.
- MOSHKOVITZ, S. and EHRLICH, A., 1976. Distribution of Middle and Upper Jurassic calcareous nannofossils in the northeastern Negev, Israel and in Gebel Maghara, northern Sinai. *Israel Geological Survey Bulletin*, 69:1-49.
- OLSSON, R. K. and LIU, C., 1991. On the occurrence of Cretaceous planktonic foraminifera in basal Paleocene strata in the Gulf coastal plain. *Geological Society of America, Abstracts with Programs*, 23:A184.
- , 1993. Controversies on the placement of Cretaceous-Paleogene boundary and the K/P mass extinction of planktonic foraminifera. *Palaios*, 8:127-139.
- OWENS, J. P. and GOHN, G. S., 1985. Depositional history of the Cretaceous Series in the U.S. Atlantic coastal plain; stratigraphy, paleoenvironments and tectonic controls of sedimentation. In: Poag, C. W., Ed., *Geologic evolution of the U.S. Atlantic margin*. New York: Van Nostrand Reinhold, pp. 25-86.
- PARTRIDGE, A. D., 1976. The geological expression of eustasy in the Early Tertiary of the Gipsland basin. *APEA Journal*, pp. 73-79.
- PERCH-NIELSEN, K., 1969. Die Coccolithen einiger Danischer Maastrichtien und Danienlokalitäten. *Meddelelser fra Dansk Geologisk Forening*, 19:51-69.
- , 1981a. New Maastrichtian and Paleocene nannofossils from Africa, Denmark, the U.S.A. and the Atlantic and some Paleocene lineages. *Eclogae Geologicae Helveticae*, 74:831-863.
- , 1981b. Les coccolithes du Paleocene pres de El-Kef, Tunisie et leurs ancetres. *Cahiers Micropaleontologies*, 3:7-23.
- , 1983. Recognition of Cretaceous stage boundaries by means of calcareous nannofossils. In: Birkelund, T., et al., Eds., *Symposium on Cretaceous Stage Boundaries*. Copenhagen. Abstracts, pp. 152-6.
- , 1985. Mesozoic calcareous nannofossils. In: Bolli, H. H., Saunders, J. B. and Perch-Nielsen, K., Eds., *Plankton stratigraphy*. Cambridge, England: Cambridge University Press, pp. 329-426.
- PERCIVAL, S. F. and FISCHER, A. G., 1977. Changes in calcareous nannoplankton in the Cretaceous-Tertiary biotic crisis at Zumaya, Spain. *Evolutionary Theory*, 2:1-35.
- POORE, R. Z., TAUXE, L., PERCIVAL, S. F., JR., LABRECQUE, J. L., WRIGHT, R., PETERSON, N. P., SMITH, C. C., TUCKER, P. and HSU, K. J., 1984. Late Cretaceous-Cenozoic magnetostratigraphic and biostratigraphic correlations for the South Atlantic Ocean, DSDP Leg 73. In: Hsu, K. J., Labrecque, J. L. et al., *Initial Reports of the Deep Sea Drilling Project, Volume 73:645-656*. Washington, D.C.: U.S. Government Printing Office.
- ROCCHIA, R., BOCLET, D., BONTE, P., JEHANNO, C., CHEN, Y., COURTILOT, V., MARY, C. and WEZEL, F., 1990. The Cretaceous-Tertiary boundary at Gubbio revisited: vertical extent of the Ir anomaly. *Earth and Planetary Science Letters*, 99:206-219.
- ROMEIN, A. J. T., 1977. Calcareous nannofossils from the Cretaceous-Tertiary boundary interval in the Barraco del Gredero (Caravaca, Province Murcia, S.E. Spain). *Koninklijke Nederlandse Akademie van Wetenschappen Amsterdam, Proceedings, series B*, 80:256-279.
- SMITH, C. C. and PESSAGNO, E. A., 1973. Planktonic foraminifera and stratigraphy of the Corsicana Fm. (Maastrichtian) north-central Texas.

- Cushman Foundation for Foraminiferal Research, Special Publication, 12:5-68.
- SOHL, N. F. and KOCH, C., 1986. Molluscan biostratigraphy and biofacies of the *Haustator bifida* assemblage zone (Maastrichtian) of the east Gulf coastal plain. In: Reinhardt, J., Ed., *Stratigraphy and sedimentology of continental, nearshore and marine Cretaceous sediments of the eastern Gulf coastal plain*, Field Trip No. 3 Society of Economic Paleontologists and Mineralogists, Annual Meeting, pp. 45-56.
- THIERSTEIN, H. R., 1981. Late Cretaceous nannoplankton and the change at the Cretaceous-Tertiary boundary. In: Warme, J., et al., eds. *The Deep Sea Drilling Project: A Decade of Progress*. Society of Economic Paleontologists and Mineralogists, Special Publication, 32: 355-394.
- WHITNEY, B. L., 1984. Dinoflagellate biostratigraphy of the Maestrichtian-Danian section in southern Maryland. In: Frederiksen, N. O. and Krafft, K. eds. *Cretaceous and Tertiary Stratigraphy, Paleontology and Structure, Southwestern Maryland and Northeastern Virginia*. American Association of Stratigraphic Palynologists Field Trip Volume and Guidebook, pp. 123-136.
- WORSLEY, T. R., 1974. The Cretaceous-Tertiary boundary event in the ocean. In: *Studies in paleoceanography*. Society of Economic Paleontologists and Mineralogists, Special Publication, 20:94-125.
- ZACHOS, J. C., ARTHUR, M. A. and DEAN, W. E., 1989. Geochemical and paleoenvironmental variations across the Cretaceous-Tertiary boundary at Braggs, Alabama. *Palaeogeography, Palaeoclimatology, Palaeoecology*, 69:245-266.
- ZAITZEFF, J. B. and CROSS, A. T., 1971. The use of dinoflagellates and acritarchs for zonation and correlation of the Navarro Group (Maestrichtian) of Texas. *Geological Society of America, Special Paper*, 127:341-377.

Manuscript received September 9, 1992

Manuscript accepted March 3, 1993