

16. LOWER CRETACEOUS NANNOFOSSIL BIOSTRATIGRAPHY OFF NORTHWESTERN AUSTRALIA (LEG 123)¹

Jörg Mutterlose^{2,3}

ABSTRACT

Moderately to sparsely nannofossiliferous Neocomian siliciclastics and rich Aptian–Albian nannofossil chinks were cored at two Leg 123 sites on the abyssal plains off northwestern Australia. At Site 765, the basal 70 m of cored section yields questionable Tithonian and Berriasian to early Hauterivian assemblages of moderate diversity containing *Crucellipsis cuvillieri*, *Tegumentum striatum*, *Speetonia colligata*, and *Crucibiscutum salebrosum*. The overlying Hauterivian–lower Aptian is represented by 140 m of sediments barren of nannofossils. Above this, the remaining 80 m of the Lower Cretaceous section has been assigned to the *Rhagodiscus angustus* Zone (late Aptian–early Albian in age) and the *Prediscosphaera columnata* Zone (middle–late Albian in age). Common species include *Rhagodiscus angustus*, *Prediscosphaera columnata*, *Eprolithus floralis*, *Eprolithus* sp., *Chiastozygus litterarius*, *Rucinolithus irregularis*, and *Flabellites biforaminis*.

At Site 766, the Neocomian, represented by 200 m of sediment, yields *C. cuvillieri*, *T. striatum*, *S. colligata*, and *C. salebrosum*. Within the overlying Aptian–Albian sequence of 80 m, the *Rhagodiscus angustus*, and *P. columnata* zones were recognized.

The paleobiogeographic patterns and implications are discussed, with special emphasis paid to the bipolar high-latitude distribution pattern of *C. salebrosum* in the Valanginian–Hauterivian. Biostratigraphically important species are discussed and their occurrence in the Indian Ocean is compared with one from the Tethys and Boreal realms. Two new species, *Serbiscutum gaultensis* and *Eprolithus bettenstaedtii*, are described.

INTRODUCTION

During Legs 122 and 123, eight holes were drilled (Sites 759 through 766) off northwestern Australia across the Exmouth Plateau and the adjacent abyssal plains. These sites cover two complete transects from a continental margin to an old ocean basin (Fig. 1).

One of the principal goals of Leg 123 (Sites 765 and 766) was to decipher the early rifting history of the northwestern Australian margin and the initial opening of the Indian Ocean by drilling the oldest sediments and basement of the Indian Ocean in the Argo Abyssal Plain.

Drilling at Site 765, which is situated at the southern margin of the Argo Abyssal Plain, recovered a thick (330 m) sequence of Lower Cretaceous and possibly Uppermost Jurassic sediments, covered by 600 m of Upper Cretaceous and Tertiary sediments. The Lower Cretaceous sediments are dominated by siliciclastics, in particular, varicolored claystone (lithologic Units VII, VI, V, and Subunit IVD) in the lower part ([?]Tithonian, Berriasian–early Aptian) and nannofossil chinks (late Aptian–Albian) in the upper part (lithologic Subunits IVC through IVA; Fig. 2).

Site 766, farther south at the boundary between the Gascoyne and Cuvier abyssal plains, penetrated about 300 m of Lower Cretaceous sediments (Valanginian–Albian). These consist of sandstones and siltstones in the lower part (Valanginian–Barremian) and nannofossil chinks in the upper part (Aptian–Albian; Fig. 2). The Lower Cretaceous sediments are overlain by 160 m of nannofossil oozes of Late Cretaceous, Tertiary, and Quaternary age.

At both sites, scientists recovered thick and apparently complete Lower Cretaceous sequences. Only in the southern oceans (at Site 261) had a fairly consistent sequence of Neocomian sediments previously been drilled. Sediments of an Aptian–Albian age, however, have been recovered in several ODP/DSDP sites (Fig. 3). Thus, Sites 765 and 766 offer scientists an ideal opportunity to gain firsthand information about the Neocomian faunas and floras of the southern oceans. In reference to calcareous nannofossils, the following aspects are of particular interest:

1. Biostratigraphy of the Neocomian in the southern oceans.
2. The Aptian floral turnover, which has been observed elsewhere.
3. Paleobiogeography of Neocomian floras.
4. Comparison of Tethyan, Boreal, and Indo-Pacific floras.

METHODS

Simple smear-slide preparations were examined under the light microscope using a magnification of 1500x. The abundance of calcareous nannofossils in the Lower Cretaceous material is variable. Nannofossils may constitute anywhere from 0% to 70% of the rock. Abundances for each species were estimated by using the following criteria:

VA	= very abundant	(11–100 specimens/field)
A	= abundant	(2–10 specimens/field)
C	= common	(1 specimen/1–10 fields)
F	= few	(1 specimen/11–100 fields)
R	= rare	(1 specimen/more than 100 fields)

Preservation is indicated in the following way: E1 (slightly etched), E2 (moderately etched), and E3 (heavily etched). Although it occurs, overgrowth was not noted in the range charts. For examination under the scanning electron microscope, samples were prepared following the procedures outlined by Wise and Kelts (1972).

¹ Gradstein, F. M., Ludden, J. N., et al., 1992. *Proc. ODP, Sci. Results*, 123: College Station, TX (Ocean Drilling Program).

² Department of Geology, University of Nebraska, Lincoln, NE 68588, U.S.A.

³ Current address: Institut für Geologie und Paläontologie, Universität Hannover, Callinstrasse 30, 3000 Hannover 1, F.R.G.

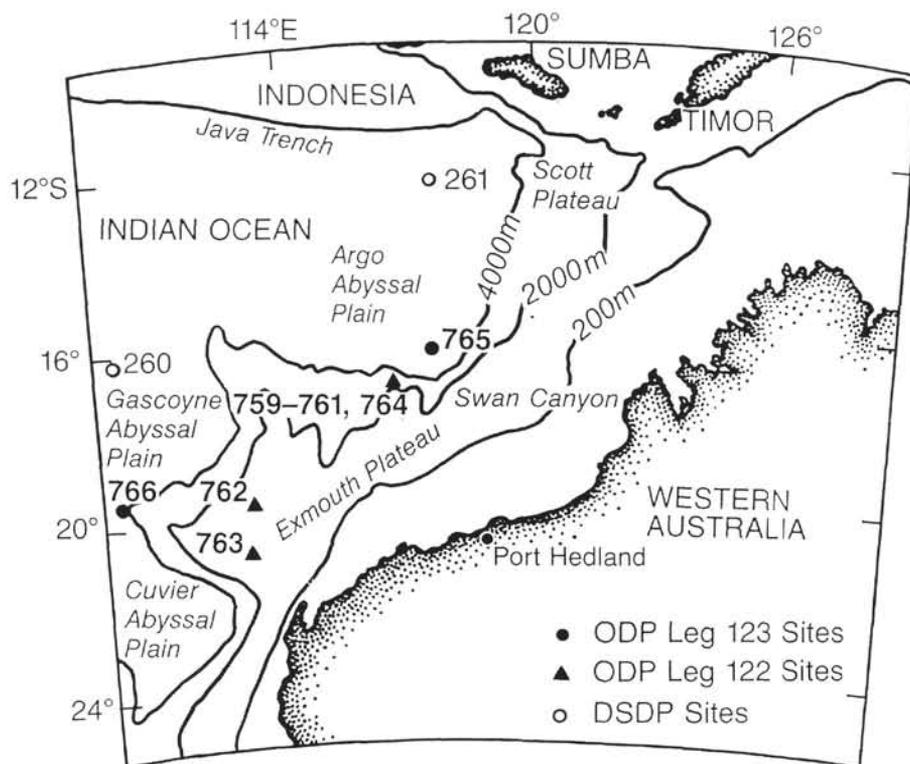


Figure 1. Location of Sites 765 and 766 in relation to DSDP Leg 27 and ODP Leg 123 sites.

Many of the Neocomian siliciclastics recovered from Sites 765 and 766 are barren of nanofossils. Although much of this material has been examined, barren samples only occasionally are reported in the range chart. Thus, not all samples considered here are listed in the range charts.

Taxa considered here are listed in the Appendix. Most bibliographic references for these taxa are given in Perch-Nielsen (1985); any not included therein are given in the references. All illustrations in the plates are scanning electron photomicrographs unless noted otherwise in the captions. In the captions, P, D, and L denote proximal, distal, and lateral views, respectively. Abbreviations LM, TL, POL, and PH denote light photomicrograph, plain transmitted light, cross-polarized light, and phase contrast light photomicrograph, respectively.

LOWER CRETACEOUS NANNOFOSSIL BIOSTRATIGRAPHY

All the Lower Cretaceous zonation schemes published so far are of limited value, because they refer to the Tethys (Sissingh, 1977; Thierstein, 1971, 1973; Roth, 1978; Covington and Wise, 1987; Bralower et al., 1989; Applegate et al., 1989) or the Boreal Realm (Jakubowski, 1987; Mutterlose, 1988; Crux, 1989; Mutterlose, 1991). A zonation based on material from the southern oceans has been published only for the Aptian-Albian (e.g., Wise, 1983). The zonation presented in this chapter, however, does use age determinations from a combination of the published schemes. A detailed discussion of the zonation scheme used here is presented later.

Site 765 (Table 1)

Hole 765C (15°54'1"S, 117°34.495'E; water depth, 5717 m) is located about 350 km northwest of the coast of western Australia in the southernmost part of the Argo Abyssal Plain, about 50 km north of the Exmouth Plateau (Fig. 1). About 931 m of sediment

was penetrated, of which about 330 m has been assigned an Early Cretaceous (Berriasian-Albian) and possibly Late Jurassic ([?]Tithonian) age for the basal few meters. Abundances and preservation of nanofossils are shown in Table 1.

Basaltic basement was encountered at a depth of 931.2 m in Section 123-765C-62R-4. The lowermost part of the overlying sedimentary sequence, Sections 123-765C-62-4 to 123-765C-58-2 (lithologic Subunits VIIB and VIIA), apart from a few samples, are barren of calcareous nanofossils. Samples taken directly above the basalt (123-765C-62R-4, 28 cm; -62R-4, 10 cm; -62R-3, 100 cm; -62R-3, 100 cm; -62R-3, 20 cm; -62R-2, 140; -62R-2, 28 cm) are barren. The first nanofossils were observed in Sample 123-765C-62R-1, 120 cm. Samples 123-765C-61R-4, 30 cm, and 123-765C-61R-3, 52 cm, yield similar, poorly preserved, low-abundance, low-diversity assemblages. These impoverished floras are dominated by *Cyclagelosphaera deflandrei* with less common *Microstaurus chiastius* and *Microstaurus quadratus*. These stratigraphically older specimens of *C. deflandrei* are large and oval, while younger forms in the overlying Neocomian section are circular. None of these species can be used to define the age of these samples exactly.

Based on sections from southern Europe and the southern North Atlantic (Bralower et al., 1989), *M. quadratus* has its first occurrence at the base of the Tithonian, whereas *M. chiastius* is not present until the middle Tithonian. Both species extend into the Hauterivian and Cenomanian, respectively. *C. deflandrei* has been used by Roth (1983) as an index fossil that ranges from the middle Callovian to the Valanginian.

Thus, none of the species observed in these lowermost nanofossil-bearing samples gives any decisive clue for the exact age of the sediments encountered above the basement. However, the exact age of these sediments is a crucial question, because a Kimmeridgian to Oxfordian age had been expected before drilling. One of the objectives of this site was to encounter the oldest

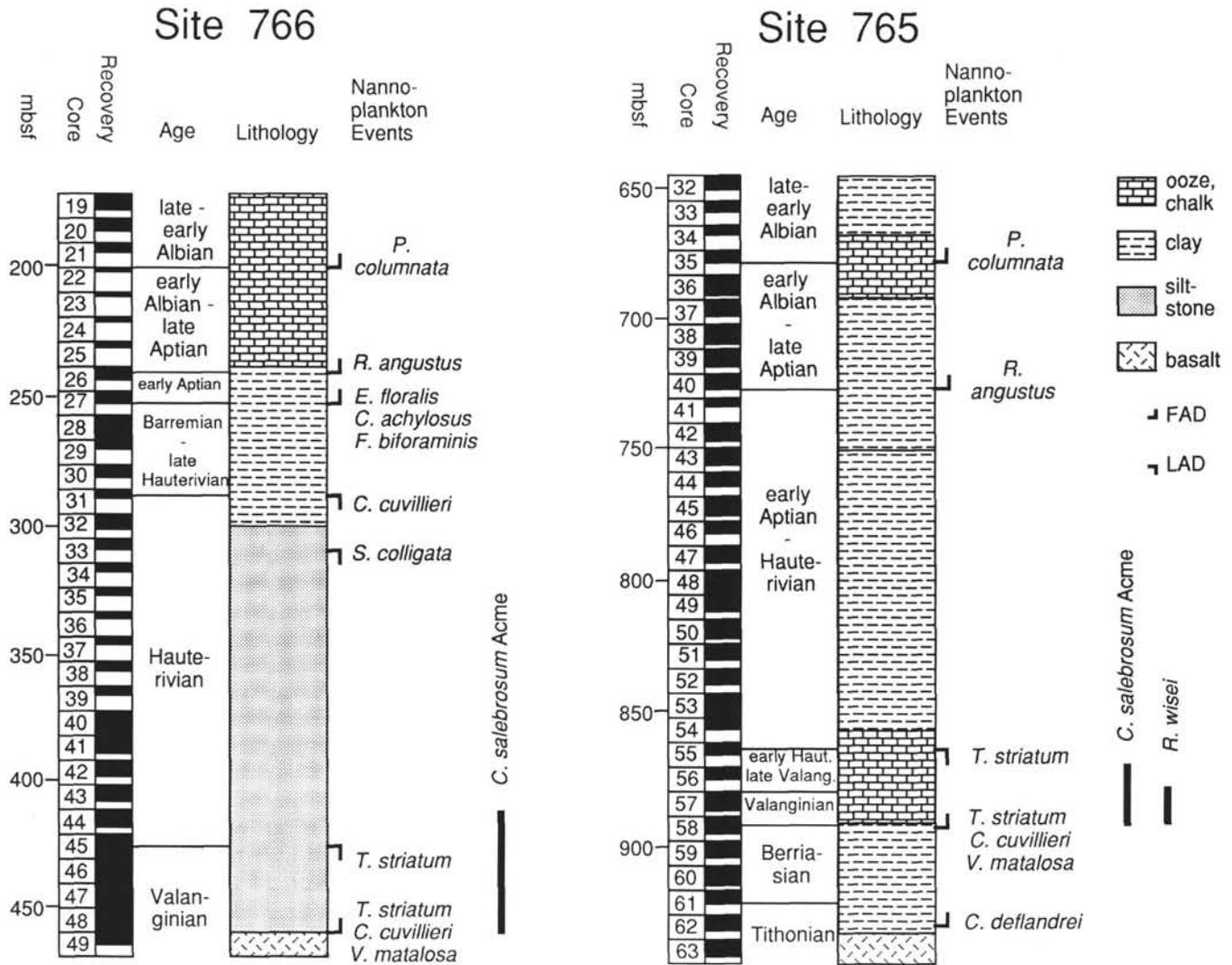


Figure 2. Lithologic and biostratigraphic summary of the Lower Cretaceous of Holes 765C and 766A.

Site	S. Atlantic					S. Ocean				Indian Ocean							
Stage	356	361	363	364	530	327	330	511	693	692	249	261	761	762	763	765	766
Albian	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
Aptian		■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
Barremian						■	■	■	■	■	■	■	■	■	■	■	■
Hauterivian											■	■	■	■	■	■	■
Valanginian												■	■	■	■	■	■
Berriasian												■	■	■	■	■	■
Tithonian												■	■	■	■	■	■
Kimmeridgian												■	■	■	■	■	■
Oxfordian												■	■	■	■	■	■
Callovian												■	■	■	■	■	■

Figure 3. Location and ranges of DSDP/ODP drill sites in the South Atlantic, Southern, and Indian oceans that penetrated Lower Cretaceous sediments.

oceanic crust in the Indian Ocean. A pre-drilling assumption of a Kimmeridgian–Oxfordian age for the oldest sediments overlying the basement was based on two observations:

1. Paleomagnetism indicated a Late Jurassic age for the basement (anomaly M26).
2. At Hole 261 (located about 320 km farther north and thus having a presumably younger basement), sediments of Oxfordian and Kimmeridgian age were encountered above the basement. This implied an even older age for the crust at Site 765 farther south.

According to these assumptions, the initial opening of the Indian Ocean should have happened during the Oxfordian or Callovian. Because no other index species to indicate a definite Tithonian or Berriasian age have been observed in Hole 765C, the age of the oldest sediments is questionable. Support for a Tithonian age of the sediments in Sections 123-765C-62R-1 through -61R-3 comes from correlation of the nannofossil assemblages consisting of *C. deflandrei*, *M. chiastius*, and *M. quadratus*, with a similar assemblage in DSDP Site 261, 320 km north of Site 765. In Site 261, this assemblage occurs above Kimmeridgian to lower

Table 1 (continued).

Age	Nanno-plankton zone	Preservation	Sample no.	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59	60	61	62	63	64	65	66	67	68	69	70	71	72	73	76	77	78				
				<i>Cretarhabdus conicus</i>	<i>Crucibiscutum</i> sp.	<i>Vekshinella stradneri</i> ssp. 1	<i>Zeugrhabdotus</i> sp.	<i>Speetonia colligata</i>	<i>Watznaeria biporta</i>	<i>Bidiscus rotatorius</i>	<i>Vekshinella quadricarcula</i>	<i>Eprolithus floralis</i>	<i>Eprolithus</i> sp.	<i>Flabellites biforaminis</i>	<i>Rhagodiscus angustus</i>	<i>Watznaeria supracretacea</i>	<i>Seribiscutum gaultensis</i>	<i>Chiastozygus litterarius</i>	<i>Grantarhabdus coronadventis</i>	<i>Zeugrhabdotus erectus</i> ssp. 2	<i>Tegumenium stradneri</i>	<i>Corolithion aclylosus</i>	<i>Cretarhabdus surirellus</i>	<i>?Acaenolithus</i> sp.	<i>Rhagodiscus swinnertonii</i>	<i>Cretarhabdus crenulatus</i>	<i>Rucinolithus irregularis</i>	<i>Zeugrhabdotus sisyphus</i>	<i>Vekshinella</i> cf. <i>quadricarcula</i>	<i>Nannoconus globulus</i>	<i>Parabolithus infinitus</i>	<i>Chiastozygus</i> sp.	<i>Crucicribrium striatum constansii</i>	<i>Prediscosphaera columnata</i>	<i>Corolithion geometricum</i>	<i>Zeugrhabdotus</i> cf. <i>elegans</i>	<i>Seribiscutum primitivum</i>	<i>Braarudosphaera hockwoldensis</i>				
early-late Albian	<i>P. columnata</i>	E2	31, CC	.	R	.	.	.	.	F	F	.	F	R	R	.	F	F	F	F	.	.	.	R	.	R	R	.	.	R	.	F					
		E2	32-1, 27	.	.	R	.	.	R	R	R	.	R	R	R	.	R	F	R	.	.	.	.	.	R	.	R	R	.	.	.	.	R	.	.	.	.	.
		E2	32-2, 53	R	.	.	R	R	R		
		E2	32-3, 53		
		E3	32, CC		
		E2	33-1, 61	.	.	R	.	.	.	R	.	R	R	R	R	.	.	.	.	.	R	.	.	.	.	.	R	.	.	.	.	.	.	.	.	R	.	.	.		
		E2	33-3, 30	.	.	.	R	R	R		
		E2	33, CC	R	R	.	.	R	R	
		E1	34-2, 70	R	F	R	R	R	R	R	R	R	F	R	F	R	R	R	R	R	R	R	R	R	R		
		E1	34-4, 15	.	.	R	.	.	.	R	R	.	R	R	R	R	F	.	R	R	R	R	R	R	R	R	.	.	R	.	.	
		E2	34, CC	.	.	R	.	.	.	R	F	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	
		E1	35-1, 50-51	R	R	F	R	R	R	R	R	F	R	R	R	R	R	R	R	.	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	
		E2	35-1, 105	.	.	R	R	F	F	F	.	R	R	R	R	R	
late Aptian-early Albian	<i>R. angustus</i>	E2	35-2, 47-48	R	R	.	.	.	R	R	.	.	.	R	R	R	.	R	R	R	R	R	.	.	.	R	R	.	R	.	.	.	.	R	.	.	.	.	.
		E2	35-4, 65-66	R	.	.	R	R	R	R	R	R	.	.	R	R	R	.	.	.	R	
		E3	35, CC	R	.	.	R	R	R	R	R	R	.	.	R	R	
		E2	36-1, 136	.	.	R	.	.	R	R	.	R	R	R	R	R	R	F	R	.	.	R	F		
		E2	36-5, 116	R	F	R	R	R	R	R	R	R	
		E2	36-6, 51-53	.	.	R	.	.	.	R	R	.	R	R	R	R	F	R	R	R	R	R	R	R	.	.	.	R	.	.	.	R	R	
		E2	37-2, 102	R	R	F	R	R	R	R	R	R	R	F	R	R	R	R	R	
		E1	37-4, 21-22	R	R	R	.	.	.	F	R	R	R	R	R	R	R	C	R	C	R	R	R	R	.	R	R	R	
		E2	38-1, 20	R	F	R	.	.	.	C	.	R	R	R	R	R	R	F	R	R	R	R	R	.	.	R	R	R	R	R	
		E2	38-2, 20	.	R	R	.	.	.	R	R	.	R	R	R	R	R	C	R	R	R	R	R
		E2	38-3, 135	.	R	R	.	.	.	R	F	R	R	R	R	R	R	F	R	R	R	R	R
		E2	38-6, 45	R	R	R	.	F	R	R	R	F	F	F	F	R	R	R	R	.	R
		E2	39-1, 140	.	.	R	.	.	.	F	R	.	R	R	R	R	F	R	F	R	R	R	R
		E1	39-2, 110	.	.	R	.	.	.	F	R	.	F	R	R	R	F	R	C	C	R	R	R	R	.	.	.	R	R
		E1	39-4, 30-31	.	.	R	.	.	.	F	R	R	R	R	R	R	F	R	C	C	R	R	R	R	.	R	R	R	R	R	
		E1	39-5, 4-5	.	.	C	.	.	.	C	R	R	.	.	.	C	C	C	R	R	R	R	R	R	.	R	R	
		E1	40-1, 20	.	.	R	.	.	.	R	R	F	C	C	R	R	R	R	R	R
E2	40-2, 106-107	R	R	R	.	.	.	R	R	.	R	F	R	R	R	.	R	R	R	R	R	R		
E2	40-3, 002	R	R	R	.	.	.	R	R	.	R	R	R	R	F	R	R	R	R	R	R	R		
E2	40-4, 30	R	R	R	R	R	R		
Hauterivian-Aptian		E2	40-4, 128		
		E2	40-5, 47-48	
		E3	41-1, 49-50
			42-1, 60-61
			42-2, 50	
		E2	42-3, 7-9
			42-4, 51-52
E2	42-5, 45-47		
	43-6, 69		
E2	44-1, 23-24	R		

Tithonian sediments and below Berriasian to Hauterivian sediments (Proto Decima, 1974). In view of this correlation and because of the absence of species typical for the Berriasian, I have assigned a Tithonian age to the lowermost nannofossil-bearing samples of Site 765 from Sections 123-765C-62R-2 to -61R-3.

The subsequent interval, including Samples 123-765C-61R-2, 30 cm, to -58R-2, 140 cm, is difficult to date using calcareous nannofossils, because definite index species are missing. A Tithonian(?) and/or Berriasian-Valanginian age is possible, based on samples from the underlying and overlying sections. A Berriasian age is constrained by dinoflagellate markers, which suggests a late Berriasian age (*Batioladinium reticulatum* Zone) for Samples 123-765C-59-5, 8-9 cm, and -59R-4, 105-112 cm (McMinn, this volume).

Sample 123-765C-58R-1, 131 cm, yields the first diverse nannofossil assemblage, which is dominated by *Watznaueri barnesae*.

Biostratigraphically important species include *Rucinolithus wisei*, *Crucibiscutum salebrosum*, *Crucellipsis cuvillieri*, *Lithraphides carniolensis*, and *Vagalapilla matalosa*.

The biostratigraphic information supplied by the most important marker, *R. wisei*, is biased by the different ranges given by Thierstein (1971; Berriasian-Valanginian) and Bralower et al. (1989; upper Berriasian-lower Valanginian). Based on more recent publication, a late Berriasian to late-early Valanginian age is assumed for *R. wisei*. The oldest occurrence of *C. salebrosum* has been reported from the *Peregrinoceras albidum* ammonite Zone (late Ryazanian) from Speeton, where this species is common (Crux, 1989). The Ryazanian corresponds to the upper part of the Berriasian (for detailed discussion of this problem, see Zeiss, 1983). However, because no older nannofossil-bearing strata were examined, *C. salebrosum* may extend into the lower Berriasian.

Thus, based on the co-occurrence of this species with *R. wisei*, a late Berriasian to late-early Valanginian age of this sample seems most likely. *C. cuvillieri* ranges from the latest Tithonian to the early-late Hauterivian (Bralower et al., 1989) in the Mediterranean area. The species is rare only in the Boreal Realm, where it ranges into the late-early Hauterivian. Abundances and preservation of nannofossils are shown in Table 2. A sequence of interlayered *C. cuvillieri* ranges from the latest Tithonian to the early-late Hauterivian (Bralower et al., 1989) in the Mediterranean area. This species is rare only in the Boreal Realm, where it ranges into the late-early Hauterivian. *L. carniolensis* has its first occurrence in the uppermost Tithonian, near the Tithonian/Berriasian boundary (Bralower et al., 1989). The presence of *V. matalosa* is of interest because this species has so far been recorded only from the latest Barremian onward.

Sample 123-765C-58R-1, 85 cm, yields an assemblage comparable to that of Sample 123-765C-58R-1, 131 cm. However, *Tegumentum striatum* (= *Eiffellithus striatum*) is of stratigraphic importance. For the Mediterranean area (Sites 603, 638), Applegate et al. (1989) reported the first occurrence of this species from the earliest Hauterivian. For the Boreal Realm, Mutterlose (1991) already described *T. striatum* from the early-late Valanginian; however, as a result of facies control, it is absent from the early Valanginian. Thus, this species may extend into the early Valanginian. In the Boreal Realm, *T. striatum* extends into the late Hauterivian; however, it becomes rare in the late Hauterivian. Based on the co-occurrence of *T. striatum* and *R. wisei*, this sample may have a late-early to early-late Valanginian age. Based on the highest occurrence of *R. wisei* in Sample 123-765C-57R-1, 135 cm, the interval from -58R-1 to -57R-1 has been assigned a Valanginian age. The calcareous intervals from which *R. wisei* has been recorded have been interpreted as classical turbidite sequences (Ludden, Gradstein, et al., 1990). Thus, the

co-occurrence of the two species may result from reworking as well.

Based on the highest occurrence of *R. wisei* in Sample 123-765C-55R-2, 109-110 cm, Sections 123-765C-56R-4 to -55R-2 (lithologic Unit VI) are early-late Hauterivian or older in age.

This is further constrained by the occurrence of *Speetonia colligata* in Sample 123-765C-56R-2, 60-61 cm. In other areas, *S. colligata* ranges from the base of the Berriasian to the early-late Hauterivian (Bralower et al., 1989; Mutterlose, 1991).

The acme of *C. salebrosum*, observed in Samples 123-765C-58R-1, 131 cm, to -55R-2, 109-110 cm, may possibly be another age indicator. In the Boreal Realm, *C. salebrosum* is most common in the late Valanginian and early Hauterivian, while it is rare only in the late Hauterivian and Barremian. These observations are supported by the highest occurrence of *T. striatum* in Sample 123-765C-55R-3, 50 cm.

Above this, Samples 123-765C-55R-1, 120 cm, to -40R-4, 128 cm (lithologic Units VI and V) contain only rare *W. barnesae* and a few other species. This interval was assigned a late Hauterivian to early Aptian age; this age determination is based, however, on data only from the underlying and overlying beds. This assumption is constrained by palynological data (McMinn, this volume). Samples 123-765C-54R-CC to -54R-4, 49-50 cm, contain dinoflagellates of a late Hauterivian to Barremian age. The highest occurrence of palynomorphs characterizing the late Barremian was observed in Sample 123-765C-50R-CC. The interval 123-765C-49R-CC to 40R-4 has been assigned an early Aptian age on the basis of palynomorphs.

A well-preserved nanoflora occurs in Sample 123-765C-40R-4, 30 cm. A fairly rich and diverse assemblage consisting of *Rhagodiscus angustus*, *Chiastozygus litterarius*, *Eprolithus floralis*, (= *Eprolithus apertior*) sp., and *Flabellites biforamini*s suggests a late Aptian to earliest Albian age. The first occurrence of *R. angustus* has been used widely to define the base of the *Rhagodiscus angustus* Zone (*sensu* Thierstein, 1971), which has a late-early to earliest Albian age (Perch-Nielsen, 1979, 1985; Jakubowski, 1987). The other species mentioned have their first occurrences in the early Aptian (Mutterlose, 1991). Thus, the *Chiastozygus litterarius* Zone (*sensu* Thierstein, 1973) *Rucinolithus irregularis* Zone, *sensu* Thierstein, 1977) of early Aptian age is represented by an underlying interval barren of nannofossils or is missing.

Sample 123-765C-35R-1, 105 cm, is characterized by the lowest occurrence of small-sized *Prediscosphaera columnata*, which first appear in the early Albian elsewhere.

Site 766 (Table 2)

Hole 766A (19°55.985'S, 110°27.243'E; water depth = 4008 m) was drilled at the boundary between the Cuvier and Gascoyne abyssal plains about 350 km off the coast of western Australia (Fig. 1). This site is located about 650 km southwest of Site 765.

About 460 m of sediment was encountered, of which about 300 m (Cores 123-766A-48R to -18R) has been assigned an Early Cretaceous age (latest Valanginian to Albian). Abundances and preservation of nannofossils are shown in Table 2. A sequence of interlayered, small basalt sills and sediments was encountered at a depth of 458 mbsf (Core 123-766A-48R). This has been replaced by a thick diabase intrusion at 467 m (Core 123-766A-49R).

The lowermost nannofossil-bearing Sample 123-766A-50R-1, 5 cm, yields a fairly rich and diverse assemblage dominated by *W. barnesae*. Biostratigraphically important species include *C. cuvillieri*, *C. salebrosum*, and *Tegumentum*. The presence of the latter species and the absence of *R. wisei*, observed in Hole 765C, indicates a late Valanginian age. While *C. cuvillieri* and *C. salebrosum* have their first occurrences in the Berriasian (for discussion, compare with Site 765), *T. striatum* is known from the early

to late Valanginian onward. On the basis of the last occurrence of *T. striatum* in Sample 123-766A-45R-5, 97–99 cm, interval 123-766A-50R-1 to -45R-5 was assigned a late Valanginian to early Hauterivian age.

Based on the highest occurrence of *C. cuvillieri* in Sample 123-766A-31R-3, 29–31 cm, Sections 123-766A-49R-3 to -31R-3 are early–late Hauterivian or older in age. *C. cuvillieri* has an earliest to late Hauterivian extinction elsewhere.

Samples 123-766A-31R-1, 39–41 cm, to 123-766A-27R-3, 18–19 cm, have been assigned a latest Hauterivian and Barremian age. However, this age assignment is based only on the presence of *C. cuvillieri* in the underlying sections and of typical Aptian species in the overlying sections. The base of the Aptian is defined by the lowest occurrence of *Corollithion achylosus*, *Flabellites biforaminiis*, *Rotelapillus crenulatus* and in *E. floralis* in Sample 123-766A-27R-1, 108–109 cm. Interval 123-766A-27-1 to -26-2 is of early Aptian age. The lowest occurrence of *R. angustus* (indicating a late–early to early–late Aptian age) is found in Sample 123-766A-26R-1, 10 cm. The *R. angustus* Zone (late Aptian–earliest Albian) is represented by the interval 123-766A-26R-1 to -22-CC. The nominate species for the overlying *P. columnata* Zone (early–late Albian) first occurs in Sample 123-766A-21R-CC.

Regional Correlation

Because drilling at Sites 765 and 766 recovered a fairly complete Lower Cretaceous sequence moderately rich in calcareous nannofossils, a biostratigraphic correlation between both sites (based on calcareous nannofossils) is possible (Fig. 2). Because of the restricted environment, most of the Neocomian sediments consist of siliciclastics that were deposited rapidly. Nannofossils were common only in less than one-half the samples examined. However, the assemblages of both sites compare well.

In both sites, the Valanginian and Hauterivian are characterized by the same index fossils, including *C. cuvillieri*. In addition to these species, *C. salebrosum* is common throughout the Valanginian and lower Hauterivian sequences of both sites. A correlation of the presumably lower Hauterivian and Barremian sections of both sites is not possible because these strata are barren of nannofossils. In addition, the lower Aptian of Site 765 is also barren. In Site 765, the nannofossil-bearing interval starts in the *R. angustus* Zone of the late Aptian. However, late Aptian and Albian index fossils (*R. angustus* and *P. columnata*) are common to both sites, allowing for a correlation of these beds. In addition to these species, both sites share the same flora. These consist, apart from those species common throughout the Lower Cretaceous, of *B. irregularis*, *F. biforminis*, *E. varolii*, *E. apertior*, *C. litterarius*, and *C. achylosus*.

A fairly complete sequence was observed at DSDP Site 261 about 320 km north of Site 765. The nannofossils at this site, which were described by Proto Decima (1974) and more recently by Dumoulin and Bown (this volume), indicate an upper Oxfordian to Albian age. The Oxfordian age of the oldest sediments in Site 261 is based on *Stephanolithion bigotii*, a species that is restricted to the Callovian–Kimmeridgian (Bown et al., 1988). The overlying strata yield low-diversity assemblages that consist of *W. manivatae* (= *C. deflandrei*), *R. asper*, *Z. embergeri*, *W. barnesae*, *W. communis*, *C. margerelii*, and *W. britannica*. These have been assigned a Tithonian age (Proto Decima, 1974, p. 595; Dumoulin and Bown, this volume; Table 3). These assemblages are characterized by the absence of typical Lower Cretaceous species, including *L. carniolensis* and *Cretarhabdus* spp. It seems likely that these Tithonian assemblages, which lack any definite marker species of either a Late Jurassic or Early Cretaceous age, correspond to the low-diversity and low-abundance assemblages of Site 765 Cores 123-765C-62R-4, -61R-4, and -61R-3 (compare

previous discussion). These show similar impoverished floras that consist of *C. deflandrei*, *M. chiastius*, and *M. quadratus* only. The Berriasian–Hauterivian interval of Site 261 yielded *C. cuvillieri* and *C. salebrosum*. The presence of these species allows for a correlation of Sections 27-261-31R-2 to -28R-2, 123-765C-58R-1 to -55R-2, and 123-766A-50R-1 to -31R-3.

PALEOENVIRONMENT AND PALEOBIOGEOGRAPHY

Lower Cretaceous nannofossils show provincialism similar to that exhibited by macrofaunas (ammonites, belemnites, bivalves, brachiopods, and foraminifers). Major faunal and floral changes across the Barremian/Aptian boundary caused a reorganization of the paleogeographic distribution patterns separating the Berriasian to Barremian (= Neocomian) from the Aptian to Albian (= Gault). These changes, referred to as the worldwide Aptian turnover, revitalize the outdated terms “Neocomian” and “Gault” used here. For the Berriasian to Barremian interval, it is possible to differentiate two realms as follows:

1. **A northern, moderate temperate Boreal Realm** (northwestern Europe, Russia, Greenland, northern America): Characterized by cosmopolitan, Boreal, endemic, and scattered incursions of Tethyan floras. Endemic species are those forms that evolve from originally Tethyan species, but become restricted to the Boreal Realm (e.g., *Nannoconus abundans*, *Nannoconus borealis*). The scattered incursions of Tethyan floras mark highstands of sea level and warming periods.

2. **A southern, tropical-to-subtropical Tethyan Realm** (southern and central Europe, the Mediterranean area, Mexico): Dominated by cosmopolitan and Tethyan floras, while Boreal floras are absent.

Data available from Neocomian macrofaunas of the Indo-Pacific area suggest that this area is a province of the Tethyan Realm (Mutterlose, this volume). The calcareous nannofossils show a similar pattern. The overall composition of the floras of Sites 765 and 766 suggests moderate-to-weak Tethyan influences for the Neocomian. Thus, the Tethyan Realm can be subdivided into a Mediterranean Province and an Indo-Pacific Province.

Until Leg 123, little was known about the Neocomian nannofossils of the Indo-Pacific area. The nannofloras of the two holes drilled during Leg 123 are discussed in relation to their paleobiogeography.

Berriasian–Barremian (Neocomian)

Most samples from Holes 765C and 766A yield assemblages dominated by *W. barnesae*. Other species found consistently throughout most of the samples include *E. fossacincta*, *W. britannica*, *B. constans*, *B. rotatorius*, *Zeughrabdodus embergeri*, *T. striatum*, and *L. carniolensis*. These species also have consistent occurrences in both the Tethyan and Boreal realms throughout the Lower Cretaceous. Thus, these species represent a eurytropic flora. A second group of nannofossils present in the two holes may be labeled as Tethyan; however, these only occasionally made their way into the Indo-Pacific area. These species include *C. cuvillieri*, *S. colligata*, *C. rothii*, *Nannoconus* spp., and *Micrantholithus*. All these species are rare at both sites, but indicate the same distribution pattern for northwestern Europe, where they also are rare (Mutterlose, 1991).

A third possible group of species developed independently in the Indo-Pacific area. Apart from *V. matalosa*, no other Neocomian species could be referred to in this way. In the Boreal Realm, *V. matalosa* has been observed from the latest Barremian–early Aptian onward; records for the Tethys are not clear. However, this species may be identical to *V. compacta*, which has

Table 2 (continued).

Hauterivian	<i>C. cuvillieri</i>	E2	39R-3, 84-85	. . . . R	. R R R .	R F R . .	F . R . C	. . R . .	. R R R .	. . . . .	. . R R R	. . . . .	. . R R R	
		E2	40R-1, 120	. . . . .	. R R F R	. . . . .	R R . . C	. . . . .	. . . . .	. . . . .	. . . . .	. . . . .	. . . . .	. . R R R
		E2	40R-2, 106	. . . R .	. R R . R	. . . . .	R R . . C	R R . . R	. . . . .	. . . . .	. . . . .	. . . . .	. . . . .	. . R R R
		E1	40R-3, 13	R . . R .	. . . F R	. . . . .	R R R R C	R R . . R	. . . . .	. . . . .	. . . . .	. . . . .	. . . . .	. . R R R
		E2	40R-4, 50	. . . R .	. R R R R	. . . . .	R R . . C	R R . . R	. . . . .	. . . . .	. . . . .	. . . . .	. . . . .	. . R R R
		E2	40R-5, 76-77	. . . . .	. R . . .	. . . . .	R . . . C	R . . . R	. . . . .	. . . . .	. . . . .	. . . . .	. . . . .	. . R R R
		E2	40R-7, 16-17	. . . R R	. . . R R	. . . . .	R R R R C	R R . . R	. . . . .	. . . . .	. . . . .	. . . . .	. . . . .	. . R R R
		E2	41R-2, 29	. . . R R	. . . R R	. . . . .	R R R R C	R R . . R	. . . . .	. . . . .	. . . . .	. . . . .	. . . . .	. . R R R
		E3	41R-4, 40-41	. . . . .	. R . . .	. . . . .	. . . . .	. . . . .	. . . . .	. . . . .	. . . . .	. . . . .	. . . . .	. . R R R
		E3	41R-6, 21-22	. . . . .	. . . F .	. . . . .	R . . . C	R . . . R	. . . . .	. . . . .	. . . . .	. . . . .	. . . . .	. . R R R
		E2	42R-2, 57-59	. . . . .	. R R . .	. . . . .	R R . . C	R . . . R	. . . . .	. . . . .	. . . . .	. . . . .	. . . . .	. . R R R
		E2	42R-5, 34-36	R . . R R	. . . R F	. . . . .	R . . . C	R . . . R	. . . . .	. . . . .	. . . . .	. . . . .	. . . . .	. . R R R
		E2	43R-2, 82-84	R . . R R	. . . . .	. . . . .	R . . . C	R . . . R	. . . . .	. . . . .	. . . . .	. . . . .	. . . . .	. . R R R
		E2	43R-5, 78-80	R . . R R	. . . R R	. . . . .	R R . . C	R . . . R	. . . . .	. . . . .	. . . . .	. . . . .	. . . . .	. . R R R
		E2	44R-1, 129-130	R R . . F	. . . R R	. . . . .	R R . . C	R . . . R	. . . . .	. . . . .	. . . . .	. . . . .	. . . . .	. . R R R
		E2	44R-3, 118-119	. . . . .	. . . R .	. . . . .	R . . . C	R . . . R	. . . . .	. . . . .	. . . . .	. . . . .	. . . . .	. . R R R
		E2	44R-5, 96-97	. . . . .	. F R . .	. . . F R	. . . . .	F R R R C	R R . . R	. . . . .	. . . . .	. . . . .	. . . . .	. . R R R
		E2	45R-1, 106-108	. . . . .	. R R . .	. . . F R	. . . . .	R R R R C	R . . . R	. . . . .	. . . . .	. . . . .	. . . . .	. . R R R
		E2	45R-3, 148-149	R . . R F	. . . R F	. . . . .	R . . . C	R . . . R	. . . . .	. . . . .	. . . . .	. . . . .	. . . . .	. . R R R
late Valanginian-early Hauterivian	<i>T. striatum</i>	E2	45R-5, 97-99	. . . R .	. . R F .	R R . . R	F . R R C	. . . . .	. . . . .	. . . . .	. . . . .	. . . . .	. . R R R	
		E2	46R-1, 141-142	. R . F .	. . . R .	R R . . R	F R R R C	R . . . R	. . . . .	. . . . .	. . . . .	. . . . .	. . R R R	
		E2	46R-3, 145-146	. . . R R	. . R F R	R R R R R	F R F R A	. . . . .	. . . . .	. . . . .	. . . . .	. . . . .	. . R R R	
		E2	46R-5, 138-140	. . . . .	. . R C R	R R R R R	F . F . A	R . . . R	. . . . .	. . . . .	. . . . .	. . . . .	. . R R R	
		E2	47R-1, 80-81	. . . R F	. . R F R	R R . . R	F . R R C	. . . . .	. . . . .	. . . . .	. . . . .	. . . . .	. . R R R	
		E2	47R-3, 51-52	. . . . .	. . R F R	R R . . F	F . R . C	. . . . .	. . . . .	. . . . .	. . . . .	. . . . .	. . R R R	
		E2	47R-5, 50-51	. . . . .	. . R R R	. . . . .	C . R . C	. . . . .	. . . . .	. . . . .	. . . . .	. . . . .	. . R R R	
		E2	47R-7, 29-30	. . . R F	. . R R R	. . F R R	F . R . C	. . . . .	. . . . .	. . . . .	. . . . .	. . . . .	. . R R R	
		E2	48R-2, 110	. . R . F	. R R C R	. . R R R	F . R . A	. R . . .	. . . . .	. . . . .	. . . . .	. . . . .	. . R R R	
		E1	48R-3, 10	. . . R R	. R R C R	. . R R R	R R R . C	. . . . .	. . . . .	. . . . .	. . . . .	. . . . .	. . R R R	
		E2	48R-4, 140	F . . C .	. R C R R	. . F R R	F R R . A	. . . . .	. . . . .	. . . . .	. . . . .	. . . . .	. . R R R	
		E2	48R-5, 65-66	F . . C R	. R C F .	. . R . .	C . R . A	R R . . .	. . . . .	. . . . .	. . . . .	. . . . .	. . R R R	
		E1	48R-6, 10	R . . R R	. R R C R	. . R R R	R . . R C	R R . . R	R R R . .	. . . . .	. . . . .	. . . . .	. . . . .	. . R R R
		E2	49R-1, 140	R . . R .	. R C R .	. . . . .	R . . . C	R . . . R	R R . . .	. . . . .	. . . . .	. . . . .	. . . . .	. . R R R
		E2	49R-2, 120	R R . R R	. R C F .	. . R . .	. . R . C	. . . . .	. . . . .	. . . . .	. . . . .	. . . . .	. . . . .	. . R R R
		E2	49R-3, 102-108	. . . . .	. . F R .	. . . . .	R . . . F	. . . . .	. . . . .	. . . . .	. . . . .	. . . . .	. . . . .	. . R R R
E2	49R-4, 58	. R . . .	. . C R .	. . . . .	R . . . C	. . . . .	. . . . .	. . . . .	. . . . .	. . . . .	. . . . .	. . R R R		
E2	50R-1, 5	R R R F R	. R R C R	. . F R R	F R R R A	R R . . .	. . . . .	. . . . .	. . . . .	. . . . .	. . . . .	. . R R R		

Abundances are characterized by VA (very abundant) = 11-100 specimens/field, A (abundant) = 2-10 specimens/field, C (common) = 1 specimen/1-10 fields, F (few) = 1 specimen/11-100 fields, R (rare) = 1 specimen/more than 100 fields. Preservation: E1 = slightly etched, E2 = moderately etched, E3 = heavily etched.

Table 3. Localities where *C. salebrosum* has been reported (see Fig. 4).

Locality	Abundance	Time interval	Reference
1. Sklinnabanken, Norway	Very abundant	Ryazanian	Crux (1989)
2. Moray Firth, Scotland	Abundant	Ryazanian– Barremian	Jakubowski (1987)
3. Speeton, England	Common	Ryazanian– Barremian	Crux (1989)
4. Northwestern Germany	Rare	Valanginian– Aptian	Mutterlose (1991)
5. DSDP Site 511	Abundant	(?)Barremian	Wise (1983)
6. Site 692	0.6%–28%	Valanginian	Mutterlose and Wise (1990)
7. Site 766	Present	Valanginian	This volume
8. Site 763	Common	Albian	Haq, von Rad, O'Connell, et al. (1990)
9. Site 762	Common	Valanginian	Haq, von Rad, O'Connell, et al. (1990)
10. Site 761	Common	Valanginian	Haq, von Rad, O'Connell, et al. (1990)
11. Site 765	Common	Valanginian	This volume
12. DSDP Site 261	Present	Berriasian– Albian	Proto Decima (1974)

been mentioned from the Berriasian in Mediterranean sections (Bralower et al., 1989). So far, *V. matalosa* is the only species that evolved in the Indo-Pacific area. This observation is of importance because it suggests the origin of southern ocean marine floras. Clarke and Crame (1989) recently discussed the origin of southern ocean marine faunas.

Boreal floras (*T. septentrionalis*, *Kokia* spp.) and endemic species (*Micrantolithus speetonensis*) were not observed. The presence of common *C. salebrosum* throughout the Valanginian and early Hauterivian at both sites is striking (compare Tables 1 and 2). This species is not present in the late Hauterivian and Barremian, but reappears in the Aptian. So far, this species has not been described from nanofossil-rich Tethyan sections (e.g., Thierstein, 1971, 1973; Applegate et al., 1989; Bralower et al., 1989), but is common in the late Berriasian, Valanginian, and late Hauterivian of the Boreal Realm (Mutterlose, 1988, 1991; Crux, 1989). Figure 4 shows the bipolar distribution of *C. salebrosum* for the Valanginian and early Hauterivian. Sites that contain these species are numbered on the map and listed in Table 3, along with abundances, stratigraphic interval, and references. Based on the paleogeographic reconstructions by Barron et al. (1981), the localities mentioned here (Sites 261, 511, 765, and 766) had a paleolatitude of 50° to 55°S. However, more recent data by Ogg et al. (this volume) suggest a paleolatitude of 35° to 37°S for Sites 261, 765, and 766 through the Early Cretaceous. Other sites in the southern oceans (DSDP Site 258, ODP Site 693) had a position of at least 60°S. The northwestern European sites that yield *C. salebrosum* had a paleolatitude of 40° to 45°N (Barron et al., 1981).

In Holes 765C and 766A, *C. salebrosum* is common throughout the Valanginian and early Hauterivian interval and declines in the middle Hauterivian. Its absence in the early Hauterivian and Barremian of Hole 765C probably was caused by dissolution. It appears again in the Aptian. In the Boreal Realm, *C. salebrosum* is most common in the early Berriasian and Valanginian and declines during the early Hauterivian. The species has rarely been observed in late Hauterivian and Barremian sequences.

Interestingly, in northwestern Europe, this species is most common in the late Ryazanian, but declines in the Valanginian. In addition (based on two sites only), an apparent increase in abundance occurs toward higher-latitude sites. Abundances in the Sklinnabanken Section, which is located off northern Norway, are much higher than those in the Speeton Section (northeastern

England). The Speeton Section is located about 1400 km southwest of the Norwegian Section.

This bipolar distribution pattern suggests that *C. salebrosum* is a stenotrophic species characterizing latitudes between 40° and 45°N and 35° to 40°S. Its absence in low latitudes might be explained by temperature control; thus, *C. salebrosum* may be a species of moderate-to-cooler waters. The absence of *C. salebrosum* in low latitudes may be explained by the following possibilities:

1. The species is actually a cool-water morphotype of a tropical species.
2. The species is present, although extremely rare.
3. The species was able to migrate between its two major areas of distribution, the high latitudes, during short periods of cooling.
4. The low-latitude forms are represented by an uncalcified, thus un preservable, generation.

Even if *C. salebrosum* is described from low-latitudes in the future, it is still more common in high latitudes than in low latitudes. This distribution is remarkable because no high-latitude bipolar distributions have been described so far from the Neocomian. The absence of *Corollithion silvaradion* in Holes 765C and 766A, a species that has been observed both on the Falkland Plateau in DSDP Site 511 (Wise, 1983) and in the Boreal Realm (Crux, 1989), may be explained by the overall poor preservation of the material studied.

Aptian–Albian (Gault)

The pattern described above changes in the Aptian. A floral turnover, linked to a change to open-oceanic conditions, characterizes the early Aptian. This change from a juvenile to a mature ocean stage is reflected by the sediments as well (von Rad et al., 1989). A similar turnover was observed in the Boreal Realm (Mutterlose, 1991). This turnover also is characterizing the macrofaunas of both realms.

Cosmopolitan Neocomian floral components become more common in the Gault. In addition, several species have their first occurrence in the early Aptian. These include *Rucinolithus irregularis*, *Chiastozygus litterarius*, *Flabellites biforaminis*, *Eprolithus floralis*, *Eprolithus* sp., and *Seribiscutum gaultensis*. Apart from *S. gaultensis*, all of these species are known from both the Tethys and Boreal realms. Thus, this Aptian turnover marks the break-

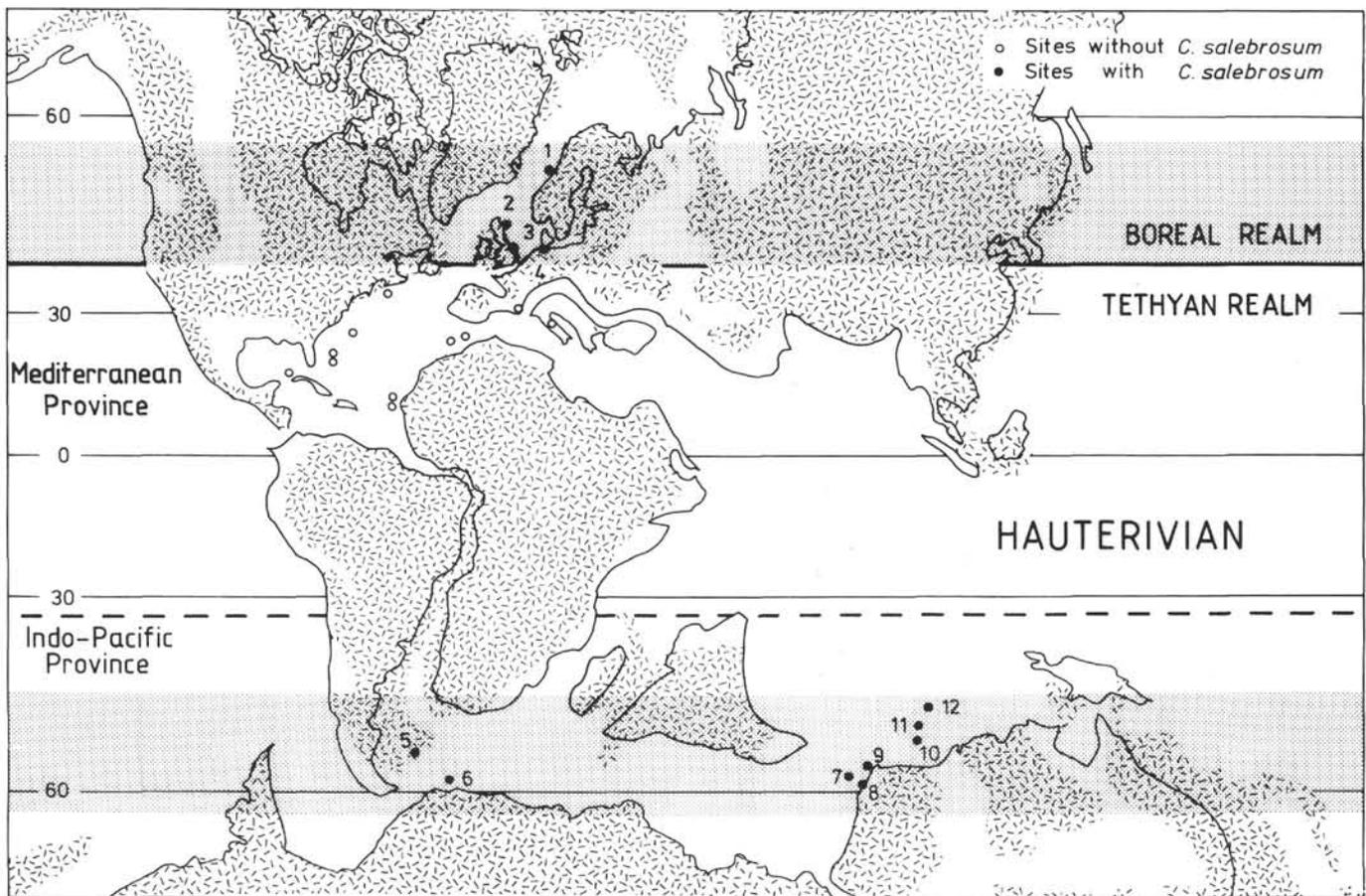


Figure 4. Bipolar distribution of *C. salebrosum* during the Valanginian and Hauterivian; areas where this taxon is most likely to be found indicated by a stippled pattern. Sites that contain *C. salebrosum* are numbered on the map and are listed in Table 3, along with abundances (where known), stratigraphic interval, and references. Paleogeographic reconstruction after Barron et al. (1981).

down of Tethyan and Boreal provincialism. The homogenization of floras may be related to a paleogeographical change, caused by the breakup of Gondwana and a rise in sea level during the Aptian. However, this idea of a more or less homogeneous flora for the Aptian–Albian interval is modified by two facts:

1. Typical Tethyan genera, such as *Nannoconus*, *Micrantholithus*, *Conusphaera*, which are common in the Aptian–Albian of the Mediterranean area, are extremely rare in Sites 765 and 766.

2. Both ODP sites yield *S. primitivum*, which occurs throughout the Albian and the Cenomanian. The distribution of this latter species (Fig. 5) has been recently discussed (Roth and Bowdler, 1981; Roth and Krumbach, 1986; Wise, 1988; Mutterlose and Wise, 1990). The species is restricted to high-latitude sites in both the Northern and Southern hemispheres and occurs in two belts between 35° to 50°N and 35° to 50°S. So far this species has not been described from low latitudes (compare Fig. 5). This bipolar distribution pattern, comparable to the one shown by *C. salebrosum* in the Valanginian and lower Hauterivian intervals, also may be explained by temperature control. Thus, *S. primitivum* would be indicative of a cool surface-water regime, characterizing high-latitude assemblages.

E. floralis (= *E. apertior*) is another species that has been described as a species more common in high-latitudes (Roth and Krumbach, 1986). Not enough data are available for *S. gaultensis*; this fairly small and inconspicuous species may well have been

overlooked in recent studies. However, a bipolar pattern similar to the one observed for *S. primitivum* seems another possibility.

LOWER CRETACEOUS NANNOFOSSIL ZONATION

As has already been pointed out, none of the existing nannofossil zonations is directly applicable to the Neocomian of the Indo-Pacific area, because all these are based on material from the Mediterranean area (Thierstein, 1971, 1973; Bralower et al., 1989; Applegate et al., 1989) or on material from the Boreal Realm (Crux, 1989; Mutterlose, 1988, 1991). Based on the data gained from Sites 765 and 766, a possible correlation for the Indo-Pacific area, the Mediterranean area, and the Boreal Realm by using calcareous nannofossil events is discussed.

Indo-Pacific Nannofloral Events

The nannofossil markers used here to date the Early Cretaceous are based on observations from Sites 765 and 766 (Fig. 6). The only other data available for the Neocomian of the Indo-Pacific are those from Site 261, which are not detailed enough to be integrated. However, additional observations are available for the Aptian–Albian interval (e.g., from the Falkland Plateau [Wise, 1983]). Figure 3 shows the locations where Lower Cretaceous rocks were penetrated in the southern ocean. The resolution of the subdivision suggested is limited by the poor preservation within parts of the siliciclastic sequence, in particular, those of late Hauterivian and Barremian age. The following data for the Indo-Pacific area have been compiled from Dumoulin and Bown (this

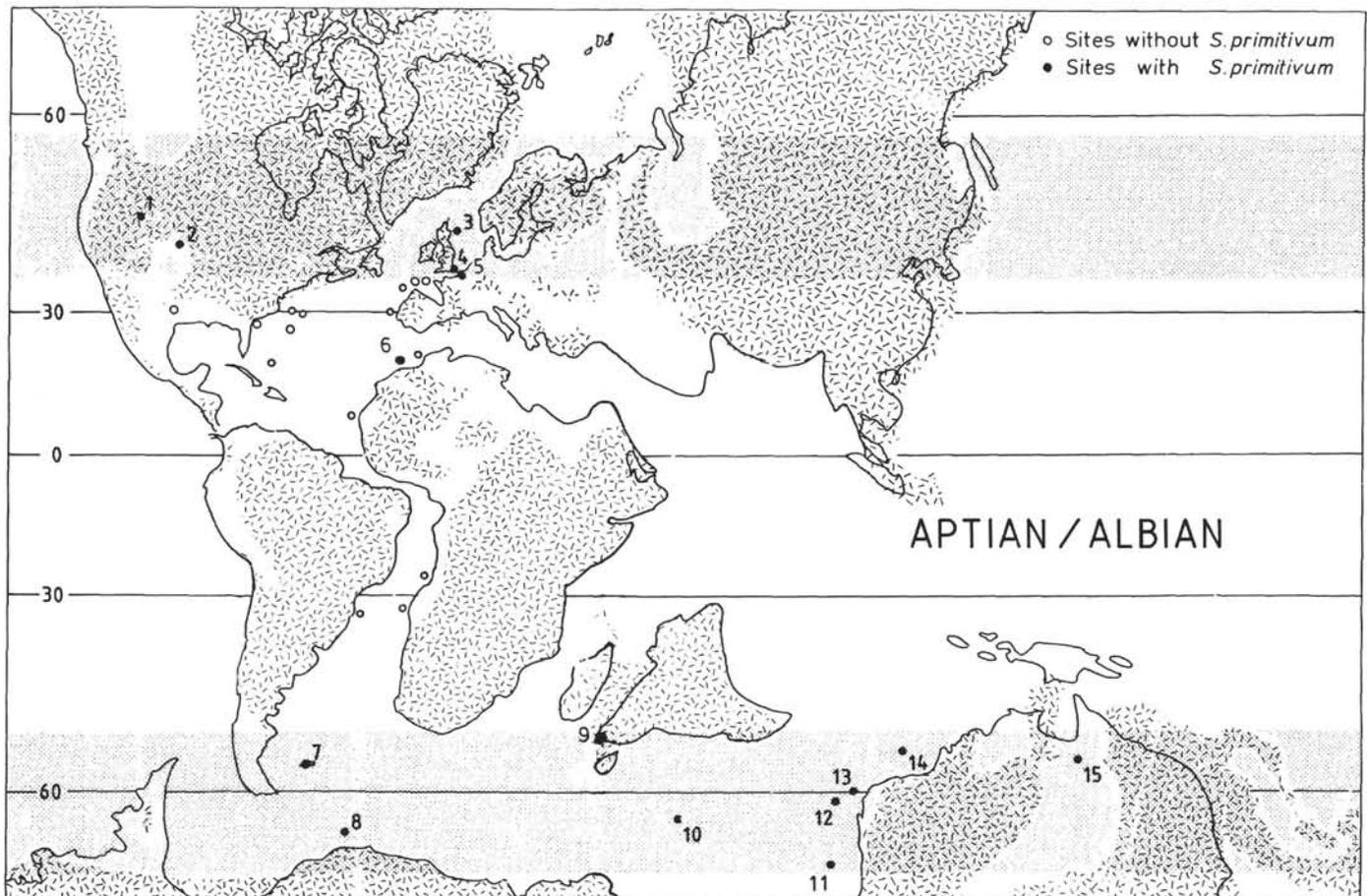


Figure 5. Bipolar distribution of *S. primitivum* during the Aptian to Cenomanian; areas where this taxon is most likely to be found indicated by stippled pattern (from Mutterlose and Wise, 1990). Sites that contain *S. primitivum* are numbered on the map and are listed in Table 4, along with abundances (where known), stratigraphic interval, and references. Paleogeographic reconstruction after Barron et al. (1981).

Table 4. Localities where *S. primitivum* has been reported (see Fig. 5).

Locality	Abundance	Time interval	Reference
1. Utah, Wyoming, U.S.A	Present	Cenomanian	Roth and Krumbach (1985)
2. Kansas, U.S.A.	Rare	Santonian	Covington (1985)
3. Moray Firth, Scotland	Abundant	middle Albian	Jakubowski (1987)
4. Southern England	0.7%–0.3%	early Albian– late Albian	Roth and Krumbach (1986)
5. Normandy Coast	Present	Cenomanian	Amedro et al. (1978)
Paris Basin	Present	Albian	Manivit (1979)
6. DSDP Site 369	0.2%	early Albian	Roth and Krumbach (1986)
7. DSDP Site 327	3.8%	early Albian	Roth and Krumbach (1986)
	24.5%	late Albian	
DSDP Site 330	1.6%	early Albian	Roth and Krumbach (1986)
DSDP Site 511	Common	early Albian– Campanian	Wise (1983)
8. Site 693	9.9%	late Aptian	Mutterlose and Wind (1990)
9. Cauverey Basin	Common	middle Albian	Kale and Phansalkar (1989)
10. Kerguelen Plateau	Present	Cenomanian– Turonian	Thierstein (1977)
11. DSDP Site 258	30.0%	early Albian	Roth and Krumbach (1986)
	15.0%	late Albian	
12. DSDP Site 259	2.6%	early Albian	Roth and Krumbach (1986)
13. Site 766	Rare	late Albian	This volume
14. Site 765	Rare	late Albian	This volume
15. Queensland, Australia	Abundant	early Albian	Shafik (1985)

	BOREAL	TETHYS	INDIAN OCEAN	
ALBIAN	FAD <i>E. turriseiffelii</i>	FAD <i>E. turriseiffelii</i>	FAD <i>E. turriseiffelii</i>	ALBIAN
	FAD <i>P. columnata</i>	FAD <i>P. columnata</i>	FAD <i>P. columnata</i>	
APTIAN	FAD <i>F. biforamini</i>	FAD <i>E. floralis</i>	FAD <i>R. angustus</i>	APTIAN
	FAD <i>C. litterarius</i>	FAD <i>R. irregularis</i>	FAD <i>F. biforamini</i>	
BARREMIAN	FAD <i>V. matalosa</i>	LAD <i>C. oblongata</i>	FAD <i>R. irregularis</i>	BARREMIAN
	FAD <i>N. abundans</i>	LAD <i>S. colligata</i>		
	LAD <i>T. striatum</i>		LAD <i>C. cuvillieri</i>	
HAUTERIVIAN	LAD <i>E. antiquus</i>	FAD <i>L. bollii</i>	LAD <i>T. striatum</i>	HAUTERIVIAN
	FAD <i>E. antiquus</i>	LAD <i>E. windii</i>	LAD <i>T. striatum</i>	
VALANGINIAN	FAD <i>C. rothii</i>		AC <i>C. salebrosum</i>	VALANGINIAN
	FAD <i>T. striatum</i>	FAD <i>E. windii</i>	FAD <i>T. striatum</i>	
BERRIASIAN	FAD <i>M. speetonensis</i>	FAD <i>C. oblongata</i>		BERRIASIAN
		FAD <i>C. angustiforatus</i>	FAD <i>C. cuvillieri</i>	

Figure 6. Comparison of different nannofossil zonations for the Boreal Realm, the Tethys, and the Indo-Pacific area. For the Boreal Realm, the zonation is based on Mutterlose (1991), for the Tethys, on Applegate and Bergen (1988), and for the Indian Ocean on this study. FAD = first appearance datum; LAD = last appearance datum; AC = acme.

volume) and from this study. The abbreviations used in Figure 6 are FAD (= first appearance datum), LAD (= last appearance datum), and AC (= acme).

1. *Crucellipsis cuvillieri*
FAD: early Berriasian (Site 261)
LAD: late Hauterivian (Site 766)
Distribution: A cosmopolitan species most common in the Tethys and also present in both the Boreal Realm and the Indo-Pacific area.
2. *Tegumentum striatum*
FAD: late Valanginian (Site 765)
LAD: early Hauterivian (Site 766)
Distribution: This cosmopolitan species is present in the Boreal and Tethys realms and the Indo-Pacific area and represents an international marker. However, discrepancies occur in the FAD of this species (early Hauterivian in the Tethys [Applegate et al., 1989] and early-late Valanginian in the Boreal Realm [Mutterlose, 1991]).

3. *Crucibiscutum salebrosum*
FAD: Berriasian (Site 261)
AC: late Valanginian to early Hauterivian (Sites 765, 766)
Distribution: *C. salebrosum* shows a bipolar distribution and is common in the Boreal Realm and the Indo-Pacific area.
4. *Rucinolithus irregularis*
FAD: early Aptian (Site 766)
Distribution: A cosmopolitan species, possibly useful for defining the Barremian/Aptian boundary worldwide. Rare, however, in the early Aptian of the Boreal Realm.
5. *Flabellites biforamini*
FAD: early Aptian (Site 766)
Distribution: Another cosmopolitan species, possibly useful for defining the Barremian/Aptian boundary worldwide.
6. *Eprolithus floralis*
FAD: early Aptian (Site 766)
Distribution: A cosmopolitan species common in all three areas.
7. *Rhagodiscus angustus*
FAD: middle Aptian (Sites 765, 766)
Distribution: A cosmopolitan species, used worldwide.
8. *Prediscosphaera columnata*
FAD: early Albian (Site 765, 766)
Distribution: A species common worldwide.

Comparison with Other Areas

As has already been discussed, various zonation schemes have been suggested by several scientists for different parts of the world. Two different zonations of the Tethyan Realm have been suggested recently. Based on material from Sites 603 and 638, Applegate and Bergen (1988) and Applegate et al. (1989) devised 12 zones/subzones for the Berriasian–Albian interval (Fig. 6), defined by 11 nannofossil events. This zonation is based on the FADs and LADs of 11 index species. The following datums are used in Fig. 6: *Cretarhabdus angustiforatus* (FAD late early Berriasian), *Calcicalathina oblongata* (FAD Berriasian/Valanginian), *Eiffellithus windii* (FAD late early Valanginian), *T. striatum* (FAD early Hauterivian), *Lithraphidites bollii* (FAD early-late Hauterivian), *S. colligata* (FAD early late Hauterivian), *C. oblongata* (LAD middle Barremian), *R. irregularis* (FAD early Aptian), *E. floralis* (FAD early late Aptian), and *E. turriseiffelii* (FAD early Albian). Most of these markers are cosmopolitan species that have been observed both in the Boreal Realm and in the Indian Ocean; only *L. bollii* and *C. oblongata* are Tethyan species.

A zonation based on nannofossils has been proposed for the Boreal Realm recently by Mutterlose (1991). The resolution of this zonation is much higher than the one for the Tethys (compare Fig. 6). However, this zonation is based on Boreal, Tethyan, Boreal endemic, and cosmopolitan species, as well as on mass influxes of Tethyan species. In particular, the Valanginian–Barremian interval (Neocomian) is characterized by no cosmopolitan markers, while from the Aptian onward, a more homogeneous pattern can be observed. The following datums have been recognized: *Micrantholithus speetonensis* (LAD late-early Valanginian), *T. striatum* (FAD early-late Valanginian), *C. rothii* (FAD early Hauterivian), *E. antiquus* (FAD early Hauterivian), *T. septentrionalis* (FAD late Hauterivian), *N. abundans* (FAD early Barremian), *V. matalosa* (FAD late Barremian), *C. litterarius* (FAD early Aptian), *E. biforamini* (FAD early Aptian), *P. columnata* (FAD early Albian), and *E. turriseiffelii* (FAD late Albian).

In Figure 6, I try to correlate the zonations of the Boreal Realm, the Tethys, and the Indo-Pacific area. The FADs and LADs are similar to the ones described in the text, and the abbreviations

used correspond to the initials of the species mentioned. From Figure 6, it becomes obvious that a two-fold zonation exists. While major differences become apparent for the Berriasian–Barremian interval, the Aptian–Albian is characterized by a more or less homogeneous zonation based on cosmopolitan species. Thus, regional zonations have to be used for the Neocomian. However, a few cosmopolitan marker species are common in all three areas, including *C. angustiforatus*, *T. striatum*, and *C. cuvillieri*. *S. colligata* is too rare to be considered. On the other hand, a global scheme can be applied for the Aptian–Albian.

SYSTEMATIC PALEONTOLOGY

Genus *SERIBISCUTUM* Filewicz et al. in Wise and Wind, 1977
Seribiscutum gaultensis n. sp.
(Pl. 1, Figs. 1–6; Pl. 6, Fig. 4)

Derivatio nominis. The name is derived from the occurrence of this species in the Aptian–Albian interval (= Gault).

Holotype. Plate 1, Figure 5.

Type locality. Site 766: Gascoyne Abyssal Plain.

Typical stratum. Site 766: Sample 123-766A-21R-2, 32–34 cm; 192.82–192.84 mbsf; middle to lower upper Albian, *Prediscosphaera columnata* Zone.

Size. Maximum length = 5 µm; maximum width = 3.5 µm.

Material. Consistent occurrence at Site 765, Samples 123-765C-40R-3, 32–34 cm, to -31R-CC. Consistent occurrence at Site 766, Samples 123-766A-26R-1, 10 cm, to 20R-1, 67–68 cm.

Diagnosis. A small species of *Seribiscutum* with a central area filled by at least four horizontal elements.

Description. Small elliptical placolith constructed of about 20 to 26 nonimbricate, petaloidal outer elements in the distal shield. The maximum length varies between 4 and 5 µm; maximum width is about 3.5 µm. A second inner distal cycle forms a collar around the central area and is composed of about 20 vertically, nonimbricate inclined elements. The central area is nearly filled by at least four platelike elements that are interrupted in the center by a pore. The central elements are discernible under the light microscope and form a distinctive extinction pattern.

Differential diagnosis. *S. gaultensis* differs from *B. coronum* by its smaller size, its distaloid central elements, and its different stratigraphic occurrence. *S. gaultensis* differs from *S. primitivum* and *S. bijugum*, both of which have plates covering the central area, by its smaller size and the arrangement of its central elements. This species may represent an overgrown *Biscutum constans*, but it is always discernible from under the light microscope. In addition, the central area of *S. gaultensis* is wider than that of *B. constans*.

Range. *S. gaultensis* has been observed from the lower Aptian to the middle Albian from Sites 765 and 766.

Geographic distribution. So far, this species has been observed only from the Indian and Pacific oceans (Sites 765, 766).

Crucibiscutum salebrosum (Black, 1971) Jakubowski, 1986
(Pl. 6, Figs. 1 and 2)

1971 *Cruciplacolithus salebrosus* Black, p.397, pl.30, fig. 4.

1986 *Crucibiscutum salebrosum* (Black, 1971) Jakubowski, p.38, pl. 1, figs. 16 and 17.

Remarks. *C. salebrosum* has one small central area that is nearly completely covered by a massive axial cross constructed of simple solid elements.

Known range. Upper Berriasian/Valanginian to Albian.

Geographic distribution. Bipolar in high-latitudes.

Genus *EPROLITHUS* Stover, 1966
Eprolithus bettenstaedti n. sp.
(Pl. 5, Fig. 2; Pl. 6, Fig. 19)

Derivatio nominis. Named in honor of the late F. Bettenstaedt for his contributions to studies of Early Cretaceous foraminifers.

Holotype. See Plate 5, Figure 2.

Type locality. Site 766, Gascoyne Abyssal Plain.

Typical stratum. Site 766, Sample 123-766A-20R-2, 102–104 cm; 183.92–183.94 mbsf.

Size. Width = 5.5 µm.

Material. Rare in Site 766, Samples 123-766A-20R-2, 102–104 cm, and -20R-3, 95–96 cm.

Diagnosis. A species of *Erolithus* characterized by 11 regularly shaped wall elements.

Description. *Eprolithus bettenstaedti* is round and consists of 11 slightly imbricate vertical wall elements that surround a wide central area. The width of the wall makes up about one-third of the diameter of the whole specimen. The diameter is 5.5 µm. The construction of the central area is not clear because of poor preservation.

Differential diagnosis. *E. bettenstaedti* differs from contemporaneous species of the genus *Eprolithus* (*E. apertior*, *E. varolii*) by its 11 wall elements. *E. antiquus* has about 12 wall elements and is restricted to the early Hauterivian of the Boreal Realm.

Range. *E. bettenstaedti* has been observed only from the Albian of Site 766.

Geographic distribution. So far, this species has been observed only from the Indian Ocean.

Vagalapilla matalosa (Stover, 1966) Thierstein, 1973
(Pl. 6, Figs. 5–8)

1966 *Coccolithus matalosa* Stover, p. 139, pl. 2, figs. 1, 2.

1973 *Vagalapilla matalosa* (Stover, 1966) Thierstein, p. 37, pl. 3, figs. 15–18.

Remarks. *V. matalosa* differs from other species by a cycle of elements inside of the proximal rim. Bars (bridging the central opening in the form of a cross) have typically expanded ends. This species has previously been observed only in the upper Barremian–Campanian. At Site 765C, it has its lowest occurrence in the Berriasian–early Valanginian; at Site 766A, it is consistently present from the early Valanginian to the middle Albian. In the Tethyan and Boreal realms, this species occurs from the late Barremian/Aptian onward; thus, its presence in the Neocomian of the Indian Ocean may indicate an origin of this species in the southern oceans.

Known range. Lower Valanginian to Campanian.

Geographic distribution. Worldwide.

ACKNOWLEDGMENTS

I am grateful to J. Bergen (Tulsa, OK), D. K. Watkins (Lincoln, NE), and an unknown referee for critical reviews and useful suggestions. Sondra Stewart provided helpful editorial comments.

REFERENCES

- Amedro, F., Damotte, R., Manivit, H., Robaszynski, F., and Somay, J., 1978. Echelles biostratigraphiques dans le Cénomaniens du Boulonnais (Macro-micro-nannofossiles). *Geol. Mediterr.*, 5:5–18.
- Applegate, J. L., and Bergen, J. A., 1988. Cretaceous calcareous nannofossil biostratigraphy of sediments recovered from the Galicia Margin, ODP Leg 103. In Boillot, G., Winterer, E. L., et al., *Proc. ODP, Sci. Results*, 103: College Station, TX (Ocean Drilling Program), 293–348.
- Applegate, J. L., Bergen, J. A., Covington, J. M., and Wise, S. S., 1989. Lower Cretaceous calcareous nannofossils from continental margin drill sites off North Carolina (DSDP Leg 93) and Portugal (ODP Leg 103): a comparison. In Crux, J. A., and Van Heck, S. E. (Eds.), *Nannofossils and their Applications*: Chichester (Ellis Horwood), 212–222.
- Barron, E. J., Harrison, C.G.A., Sloan, J. L., and Hay, W. W., 1981. Paleogeography, 180 million years ago to the present. *Eclogae Geol. Helv.*, 74:443–470.
- Black, M., 1971. Coccoliths of the Speeton Clay and Sutterby Marl. *Proc. Yorks. Geol. Soc.*, 38:381–424.
- , 1973. British Lower Cretaceous coccoliths. I. Gault Clay. 2. *Monogr. Palaeontogr. Soc. London*, 127:49–112.
- Black, M., and Barnes, B., 1959. The structure of coccoliths from the English Chalk. *Geol. Mag.*, 96:321–328.
- Bown, P. R., Cooper, M.K.E., and Lord, A. R., 1988. A calcareous nannofossil biozonation scheme for the early to mid Mesozoic. *Newsl. Stratigr.*, 20:91–114.
- Bralower, T. J., 1987. Valanginian to Aptian calcareous nannofossil stratigraphy and correlation with the upper M-sequence magnetic anomalies. *Mar. Micropaleontol.*, 11:293–310.

- Bralower, T. J., Monechi, S., and Thierstein, H. R., 1989. Calcareous nannofossil zonation of the Jurassic-Cretaceous boundary interval and correlation with the geomagnetic polarity time scale. *Mar. Micropaleontol.*, 14:153-235.
- Clarke, A., and Crame, J. A., 1989. The origin of the Southern Ocean marine fauna. In Crame, J. A. (Ed.), *Origins and Evolution of the Antarctic Biota*. Geol. Soc. Spec. Publ. London, 47:253-268.
- Covington, J. M., 1985. New morphologic information on Cretaceous nannofossils from the Niobrara Formation (Upper Cretaceous) of Kansas. *Geology*, 13:683-686.
- Covington, J. M., and Wise, S. W., Jr., 1987. Calcareous nannofossil biostratigraphy of a Lower Cretaceous deep-sea fan: Deep Sea Drilling Project Leg 93 Site 603, lower continental rise off Cape Hatteras. In van Hinte, J. E., Wise, S. W., Jr., et al., *Init. Repts. DSDP*, 93: Washington (U.S. Govt. Printing Office), 617-660.
- Crux, J. A., 1989. Biostratigraphy and palaeogeographical applications of Lower Cretaceous nannofossils from north western Europe. In Crux, J. A., and van Heck, S. E. (Eds.), *Nannofossils and Their Applications*: Chichester (Ellis Horwood), 143-211.
- Haq, B. U., von Rad, U., O'Connell, S., et al., 1990. *Proc. ODP, Init. Repts.*, 122: College Station, TX (Ocean Drilling Program).
- Jakubowski, M., 1986. New calcareous nannofossil taxa from the Lower Cretaceous of the North Sea. *INA Newsl.*, 8:38-42.
- _____, 1987. A proposed Lower Cretaceous calcareous nannofossil zonation scheme for the Moray Firth Area of the North Sea. *Abh. Geol. Bund. (Austria)*, 39:99-119.
- Kale, A. S., and Phansalkar, V. G., 1989. Black Shale facies from Albian of Cretaceous of South India. *Abstr., 28th Int. Geol. Congr.*, 2:149-150.
- Ludden, J. N., Gradstein, F. M., et al., 1990. *Proc. ODP, Init. Repts.*, 123: College Station, TX (Ocean Drilling Program).
- Manivit, H., 1979. Le nannoplancton du stratotype de l'Albien: biozonation, systématique, nannofaciès, paléocologie. In Rat, P. (Ed.), *L'Albien de l'Aube, Les Stratotypes Français*. C.N.R.S., 307-340.
- Manivit, H., Perch-Nielsen, K., Prins, B., and Verbeek, J. W., 1977. Mid Cretaceous calcareous nannofossil biostratigraphy. *Proc. K. Ned. Akad. Wet., Ser. B: Palaeontol., Geol., Phys., Chem.*, B80:169-181.
- Mutterlose, J., 1988. Das kalkige Nannoplankton des nw-deutschen Valangin und seine paläozeanographische Deutung. *Berl. Geowiss. Abh. Reihe A*, 94:175-209.
- _____, 1991. Das Verteilungs- und Migrationsmuster des kalkigen Nannoplanktons in der borealen Unterkreide (Valangin.-Apt.) NW-Deutschlands. *Palaeontographica B*, 221:27-152.
- Mutterlose, J., and Wise, S. W., Jr., 1990. Lower Cretaceous nannofossil biostratigraphy of ODP Leg 113 Holes 692B and 693A, continental slope off East Antarctica, Weddell Sea. In Barker, P. F., Kennett, J. P., et al., *Proc. ODP, Sci. Results*, 113: College Station, TX (Ocean Drilling Program), 325-351.
- Perch-Nielsen, K., 1979. Calcareous nannofossils from the Cretaceous between the North Sea and the Mediterranean. In Wiedmann, J. (Ed.), *Aspekte der Kreide Europas*. IUGS Ser. A, 6:223-272.
- _____, 1985. Mesozoic calcareous nannofossils. In Bolli, H. M., Saunders, J. B., and Perch-Nielsen, K. (Eds.), *Plankton Stratigraphy*: Cambridge (Cambridge Univ. Press), 329-426.
- Proto Decima, F., 1974. Leg 27 calcareous nannoplankton. In Veevers, J. J., Heirtzler, J. R., et al., *Init. Repts. DSDP*, 27: Washington (U.S. Govt. Printing Office), 589-621.
- Roth, P. H., 1978. Jurassic and Lower Cretaceous nannoplankton biostratigraphy and oceanography of the northwestern Atlantic Ocean. In Benson, W. E., Sheridan, R. E., et al., *Init. Repts. DSDP*, 44: Washington (U.S. Govt. Printing Office), 731-759.
- _____, 1983. Jurassic and Lower Cretaceous calcareous nannofossils in the western North Atlantic (Site 534): biostratigraphy, preservation and some observations on biogeography and paleoceanography. In Sheridan, R. E., Gradstein, F. M., et al., *Init. Repts. DSDP*, 76: Washington (U.S. Govt. Printing Office), 587-621.
- Roth, P. H., and Bowdler, J., 1981. Middle Cretaceous calcareous nannoplankton biogeography and oceanography of the Atlantic Ocean. In Warme, J. E., Douglas, R. G., and Winterer, E. L. (Eds.), *The Deep Sea Drilling Project: a Decade of Progress*. Spec. Publ.—Soc. Econ. Paleontol. Mineral., 32:517-546.
- Roth, P. H., and Krumbach, K. R., 1986. Middle Cretaceous calcareous nannofossil biogeography and preservation in the Atlantic and Indian oceans: implications for paleoceanography. *Mar. Micropaleontol.*, 10:235-266.
- Shafik, S., 1985. Calcareous nannofossils from the Toolebuc Formation, Eromanga Basin Australia. *BMR J. Aust. Geol. Geophys.*, 9:171-181.
- Sissingh, W., 1977. Biostratigraphy of Cretaceous calcareous nannoplankton. *Geol. Mijnbouw*, 56:37-65.
- Stover, L. E., 1966. Cretaceous coccoliths and associated nannofossils from France and the Netherlands. *Micropaleontology*, 12:133-167.
- Thierstein, H. R., 1971. Tentative Lower Cretaceous calcareous nannoplankton zonation. *Eclogae Geol. Helv.*, 64:459-488.
- _____, 1973. Lower Cretaceous calcareous nannoplankton biostratigraphy. *Abh. Geol. Bundesanst. (Austria)*, 29:1-52.
- _____, 1977. Mesozoic calcareous nannofossils from the Indian Ocean, DSDP Legs 22 to 27. In Heirtzler, J. R., Bolli, H. M., Davies, T. A., Saunders, J. B., and Sclater, J. G. (Eds.), *Indian Ocean Geology and Biostratigraphy*. Am. Geophys. Union, 339-351.
- von Rad, U., Thurov, J., Haq, B. U., Gradstein, F., Ludden, J., and ODP Leg 122/123 Shipboard Scientific Parties, 1989. Triassic to Cenozoic evolution of the NW Australian continental margin and the birth of the Indian Ocean (preliminary results of ODP Legs 122 and 123). *Geol. Rundsch.*, 78:1189-1210.
- Wise, S. W., Jr., 1983. Mesozoic and Cenozoic calcareous nannofossils recovered by Deep Sea Drilling Project Leg 71 in the Falkland Plateau region, Southwest Atlantic Ocean. In Ludwig, W. J., Krasheninnikov, V. A., et al., *Init. Repts. DSDP*, 71 (Pt. 2): Washington (U.S. Govt. Printing Office), 481-550.
- _____, 1988. Mesozoic-Cenozoic history of calcareous nannofossils in the region of the southern ocean. *Palaeogeogr., Palaeoclimatol., Palaeoecol.*, 67:157-179.
- Wise, S. W., Jr., and Kelts, K. R., 1972. Inferred diagenetic history of a weakly silicified deep sea chalk. *Trans. Gulf Coast Assoc. Geol. Soc.*, 22:177-203.
- Wise, S. W., Jr., and Wind, F. H., 1977. Mesozoic and Cenozoic calcareous nannofossils recovered by DSDP Leg 36 drilling on the Falkland Plateau, Southwest Atlantic sector of the Southern Ocean. In Barker, P., Dalziel, I.W.D., et al., *Init. Repts. DSDP*, 36: Washington (U.S. Govt. Printing Office), 269-492.
- Zeiss, A., 1983. Zur Frage der Äquivalenz der Stufen Tithon/Berrias/Wolga/Portland in Eurasien und Amerika. Ein Beitrag zur Klärung der weltweiten Korrelation der Jura-/ Kreide-Grenzsichten im marinen Bereich. *Zitteliana*, 10:427-438.

Date of initial receipt: 24 May 1990

Date of acceptance: 16 May 1991

Ms 123B-124

APPENDIX

List of species mentioned in the text, arranged in alphabetical order by generic epithets.

- Assipetra infracretacea* (Thierstein, 1973) Roth, 1973
Axopodorhabdus dietzmannii (Reinhardt, 1965) Wind and Wise, 1977
Bidiscus rotatorius Bukry, 1969
Biscutum coronum Wind and Wise in Wise and Wind, 1977
Broinsonia signata Noel, 1969
Braarudosphaera hockwoldensis Black, 1973
Calccalathina oblongata (Worley, 1971) Thierstein, 1971
Chiastozygus litterarius (Gorka, 1957) Manivit, 1971
Chiastozygus striatum Black, 1971
Chiastozygus tenuis Black, 1971
Conusphaera rothii (Thierstein, 1971) Jakubowski, 1986
Corollithion achylosus (Stover, 1966) Thierstein, 1971
Corollithion geometricum (Gorka, 1957) Manivit, 1971
Corollithion silvaradion Filewicz et al. in Wise and Wind, 1977
Cretarhabdus angustifloratus (Black, 1971) Bukry, 1973
Cretarhabdus crenulatus Bramlette and Martini, 1964
Cretarhabdus schizobrachiatus (Gartner, 1963) Mutterlose, 1991
Cretarhabdus surirellus (Deflandre in Deflandre and Fert, 1954) Thierstein, 1971
Cretarhabdus striatus (Stradner, 1963) Black, 1973
Crucibiscutum hayi (Black, 1973) Jakubowski, 1986
Crucibiscutum salebrosum (Black, 1971) Jakubowski, 1986
Crucicribrum striatum constansii Wise and Parker in Wise, 1983
Crucicribrum striatum constansii Wise and Parker in Wise, 1983
Crucicribrum striatum constansii Wise and Parker in Wise, 1983
Crucicribrum striatum constansii Wise and Parker in Wise, 1983
Crucicribrum striatum constansii Wise and Parker in Wise, 1983
Cyclagelosphaera deflandrei (Manivit, 1966) Perch-Nielsen, 1985

- Cyclagelosphaera margerelii* Noel, 1965
Diadorhombus rectus Worsley, 1971
Eiffelithus turriseiffelii (Deflandre, 1954) Reinhardt, 1965
Eiffelithus windii Applegate and Bergen, 1988
Ellipsagelosphaera britannica (Stradner, 1963) Perch-Nielsen, 1968
Ellipsagelosphaera fossacincta Black, 1971
Ellipsagelosphaera keftalrempti Grün in Grün and Allemann, 1975
Eprolithus antiquus Perch-Nielsen, 1979
Eprolithus bettenstaedtii Mutterlose n. sp.
Eprolithus floralis (Stradner, 1962) Stover, 1966
Eprolithus varolii Jakubowski, 1986
Etmorhabdus hauterivianus (Black, 1971) Applegate et al. in Covington and Wise, 1987
Flabellites biforamini Thierstein, 1973
Flabellites oblonga (Bukry, 1969) Crux, 1982
Glaukolithus compactus (Bukry, 1969) Perch-Nielsen, 1984
Glaukolithus diplogrammus Deflandre in Deflandre and Fert, 1954
Grantarhabdus coronadventis (Reinhardt, 1966) Grün in Grün and Allemann, 1975
Grantarhabdus meddii Black, 1971
Haqius circumradiatus (Stover, 1966) Roth, 1978
Hemipodorhabdus gorkae (Reinhardt, 1969) Grün in Grün and Allemann, 1975
Kokia Perch-Nielsen, 1988
Lithraphidites bollii (Thierstein, 1971) Thierstein, 1973
Lithraphidites carniolensis Deflandre, 1963
Lithraphidites moray-firthensis Jakubowski, 1986
Manivitella pemmatoidea (Deflandre in Manivit, 1965) Thierstein, 1971
Micrantholithus Deflandre in Deflandre and Fert, 1954
Micrantholithus hoschulzii (Reinhardt, 1966) Thierstein, 1971
Micrantholithus obtusus Stradner, 1963
Micrantholithus speetonensis Perch-Nielsen, 1979
Microstaurus chiastius (Worsley, 1971) Grün in Grün and Allemann, 1975
Microstaurus quadratus Black, 1971
Nannoconus Kamptner, 1931
Nannoconus abundans Stradner and Grün, 1973
Nannoconus globulus Brönnimann, 1955
Nannoconus steinmannii Kamptner, 1931
Parabololithus infinitus (Worsley, 1971) Thierstein in Roth and Thierstein, 1972
Prediscosphaera columnata (Stover, 1966) Perch-Nielsen, 1984
Reinhardtites fenestratus (Worsley, 1971) Thierstein, 1972
Rhagodiscus angustus (Stradner, 1963) Reinhardt, 1971
Rhagodiscus asper (Stradner, 1963) Reinhardt, 1971
Rhagodiscus swinnertonii (Black, 1971) Applegate et al. in Covington and Wise, 1987
Rotelapillus laffitei (Noel, 1957) Noel, 1973
Rotelapillus crenulatus (Stover, 1966) Perch-Nielsen, 1984
Rucinolithus irregularis Thierstein in Roth and Thierstein, 1972
Rucinolithus wisei Thierstein, 1971
Scampanella cornuta Forchheimer and Stradner, 1973
Seribiscutum bijugm Filewicz et al. in Wise and Wind, 1977
Seribiscutum gaultensis Mutterlose n. sp.
Seribiscutum primitivum (Thierstein, 1974) Filewicz et al. in Wise and Wind, 1977
Sollasites horticus (Stradner et al. in Stradner and Adamiker, 1966) Cepek and Hay, 1969
Speetonia colligata Black, 1971
Stephanolithion bigotii Deflandre, 1939
Tegumentum octiformis (Köthe, 1981) Crux, 1989
Tegumentum stradneri Thierstein in Roth and Thierstein, 1972
Tegumentum striatum (Black, 1971) Taylor, 1978
Tegumentum tripes (Köthe, 1981) Mutterlose, 1988
Tranolithus gabalus Stover, 1966
Tubodiscus jurapelagicus (Worsley, 1971) Roth, 1973
Tubodiscus verena Thierstein, 1973
Vagalapilla compacta Bukry, 1969
Vagalapilla matalosa (Stover, 1966) Thierstein, 1973
Vekshinella quadriarculla (Noel, 1965) Rood et al., 1971
Vekshinella stradneri ssp. 1 Rood et al., 1971
Vekshinella stradneri ssp. 2
Watznaueria barnesae (Black in Black and Barnes, 1959) Perch-Nielsen, 1968
Watznaueria biporta Bukry, 1969
Watznaueria britannica (Stradner, 1963) Reinhardt, 1964
Watznaueria communis Reinhardt, 1964
Watznaueria maniviteae (Forchheimer, 1972) Proto Decima, 1974
Watznaueria ovata Bukry, 1969
Watznaueria supracretacea (Reinhardt, 1965) Wind and Wise, 1976
Zeugrhabdotus embergeri (Noel, 1959) Perch-Nielsen, 1984
Zeugrhabdotus elegans Gartner, 1968
Zeugrhabdotus erectus ssp. 2
Zeugrhabdotus erectus ssp. 1
Zeugrhabdotus sisyphus (Gartner, 1968) Crux, 1989

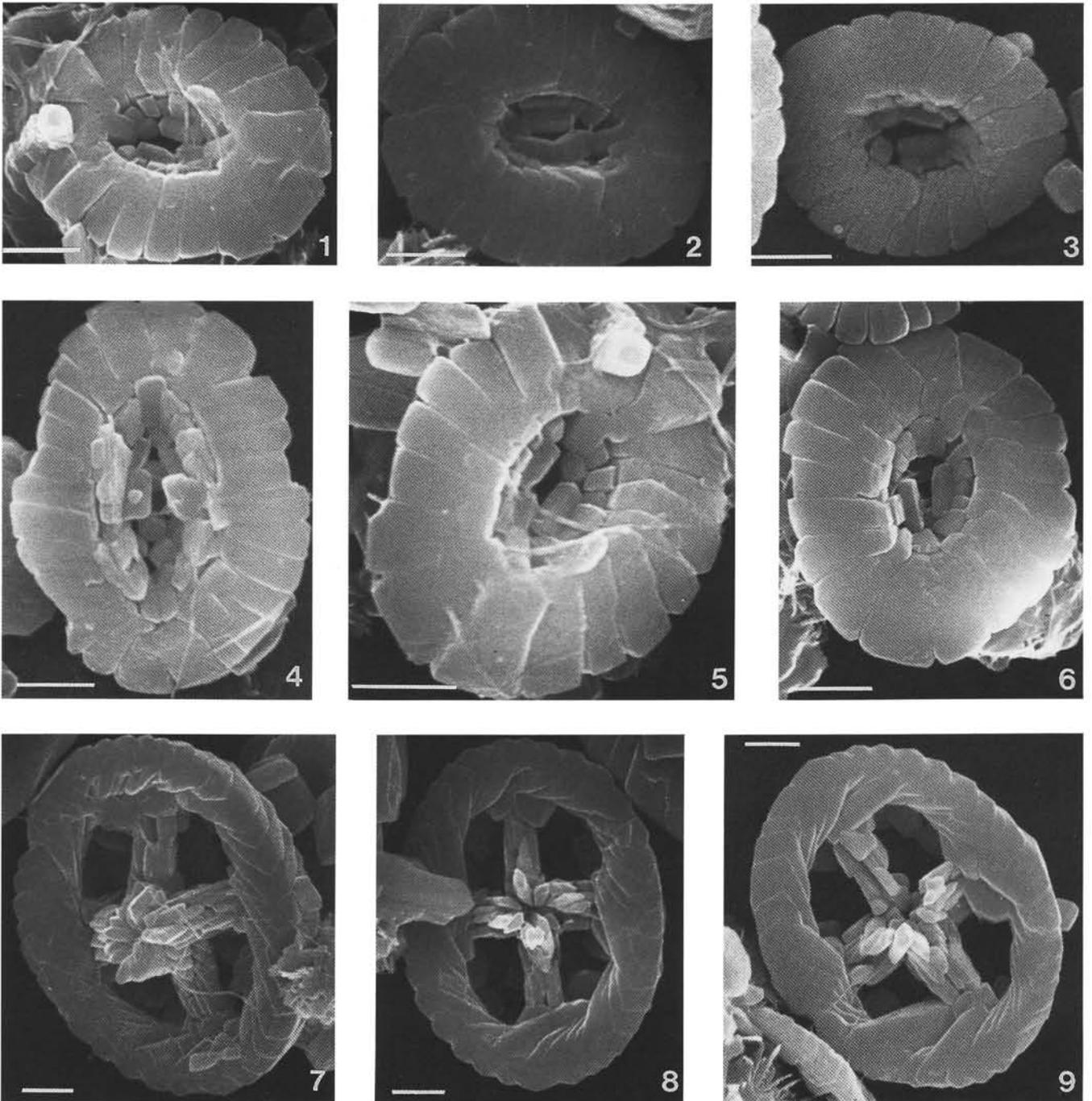


Plate 1. Biscutaceae and Ahmuellerellaceae from Hole 766A. All specimens from Sample 123-766A-21R-2, 32-34 cm. Scale of the bars of the photomicrographs = 1 μ m. 1-6. *Seribiscutum gaultensis* n. sp. 7-9. *Vekshinella stradneri* Rood et al., D.

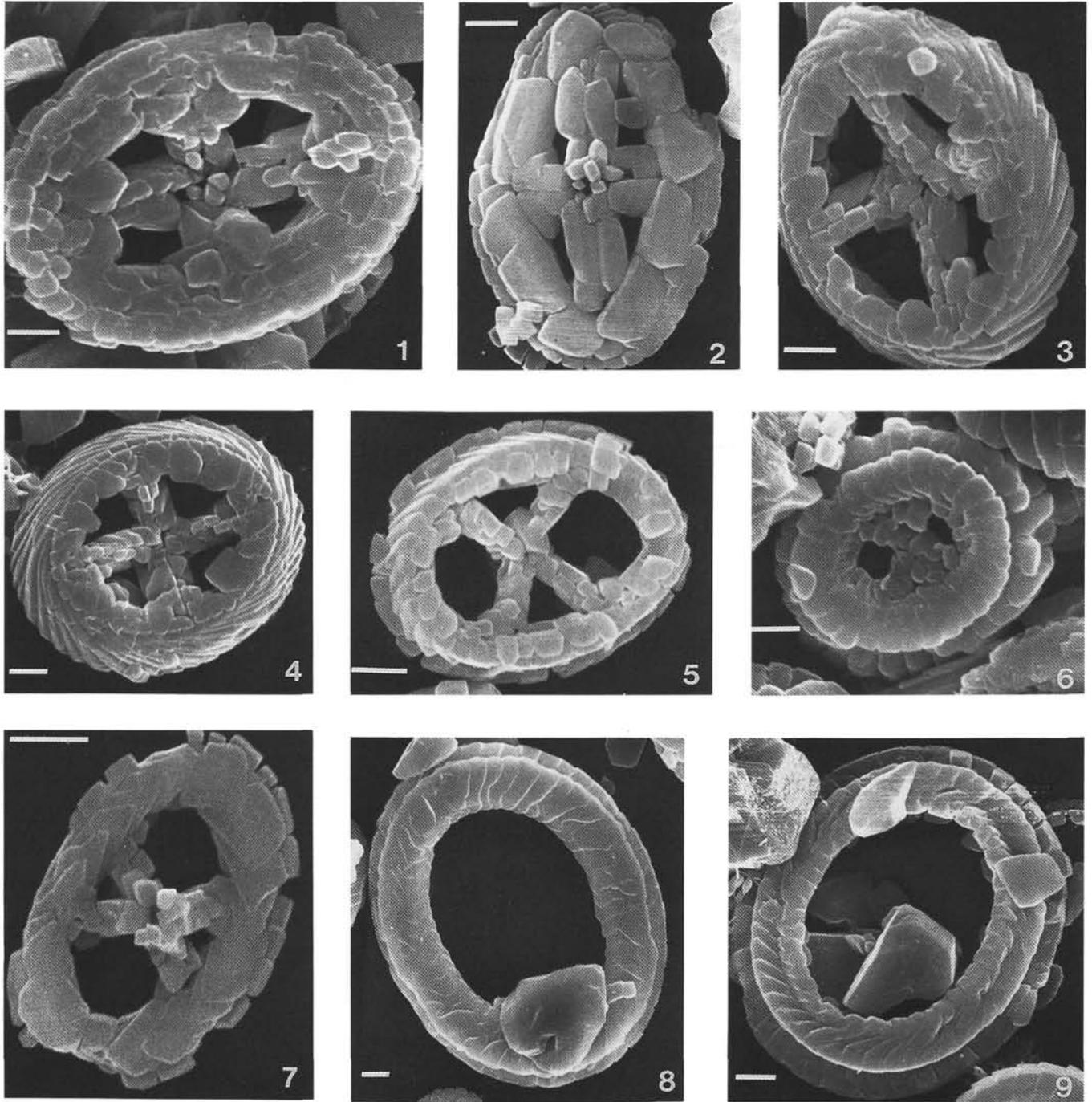


Plate 2. Ahmuellerellaceae, Chiastozygaceae, Ellipsagelosphaeraceae, and Podorhabdaceae from Hole 766A. Figure 6 is from Sample 123-766A-20R-2, 103–104 cm; all other figures from Sample 123-766A-21R-2, 32–34 cm. Scale of bars = 1 μ m. **1, 2.** *Broinsonia signata* (Noel); (1) P, (2) D. **3, 4.** *Vekshinella stradneri* Rood et al.; P. **5, 7.** *Chiastozygus* cf. *litterarius* (Gorka); (5) P, (7) D. **6.** *Flabellites biforamini* Thierstein; P. **8, 9.** *Manivitella pemmatoidea* (Deflandre in Manivit); P.

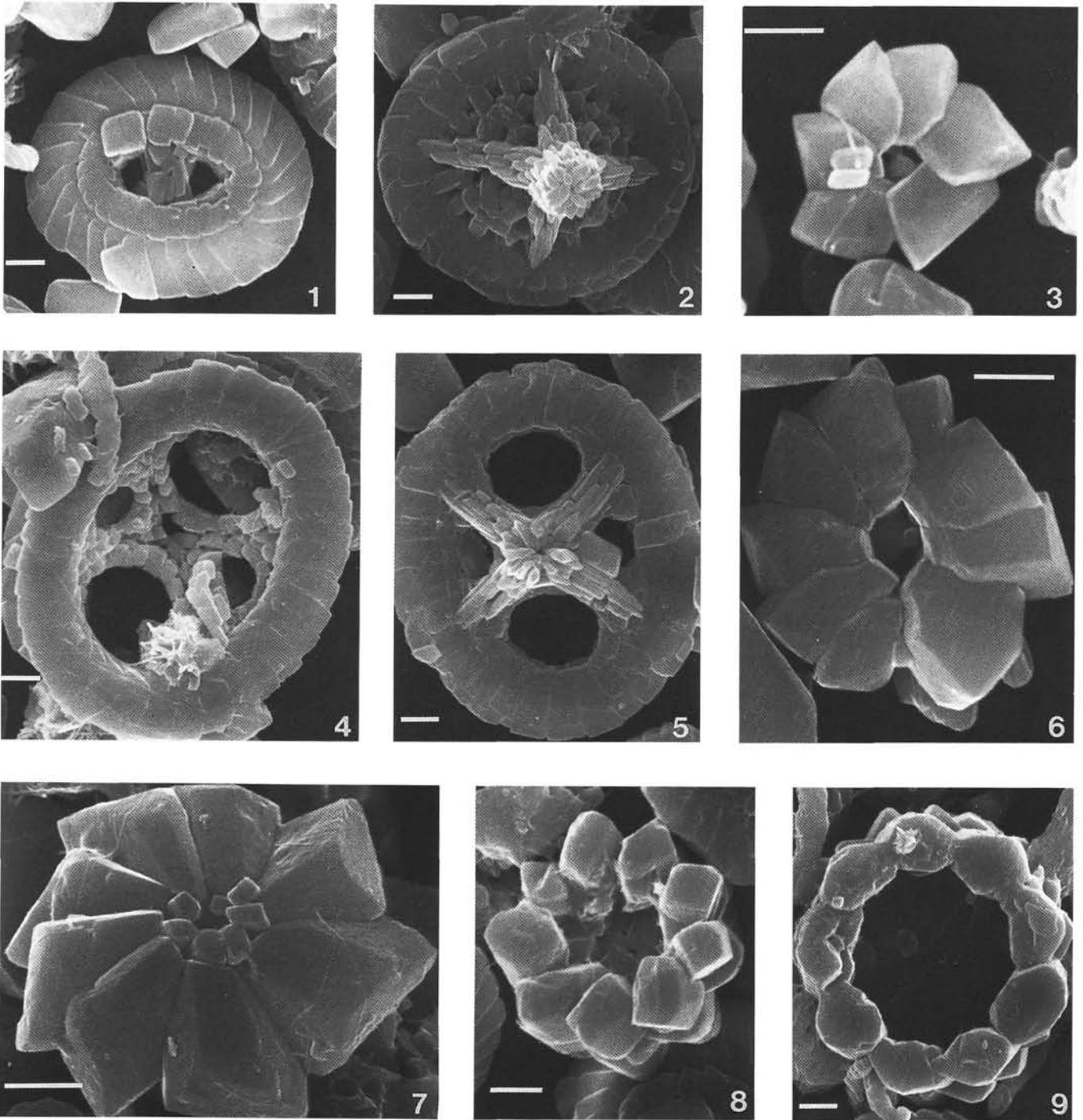


Plate 3. Ellipsagelosphaeraceae, Podorhabdaceae, and Polycyclolithaceae from Hole 766A. Figures 1 through 7 from Sample 123-766A-21R-2, 32–43 cm; Figures 8 and 9 from Sample 123-766A-20R-2, 102–104 cm. Scale bar = 1 μ m. 1. *Watznaueria britannica* (Stradner); D. 2. *Cretarhabdus conicus* Bramlette and Martini; D. 3, 6, 7. *Rucinolithus irregularis* (Thierstein in Roth and Thierstein). 4, 5. *Grantarhabdus coronoadventis* (Reinhardt); (4) P, (5) D. 8. *Eprolithus* sp. 9. *Eprolithus floralis* (Stradner).

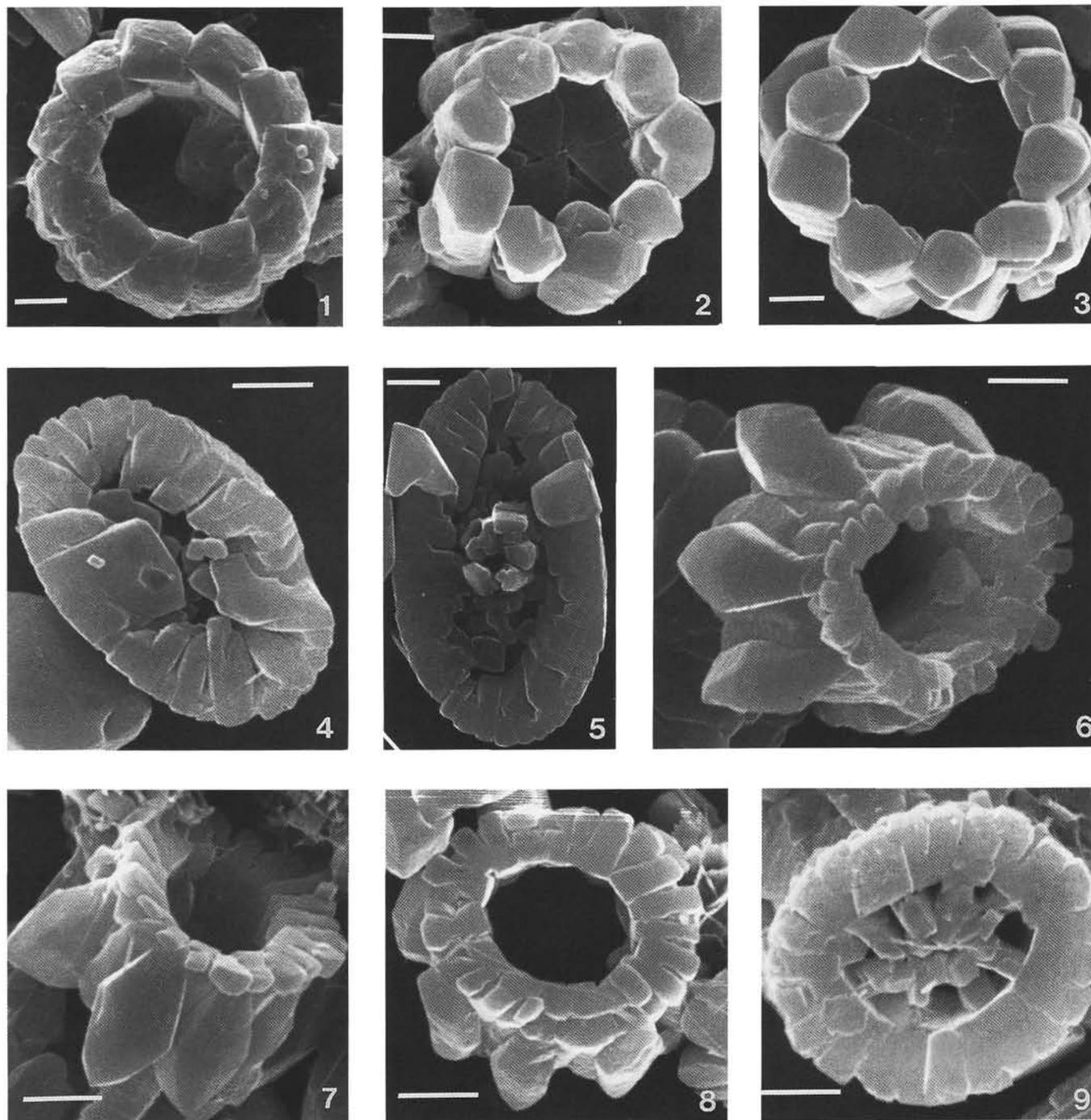


Plate 4. Polycyclolithaceae, Rhagodiscaceae, and Stephanolithiaceae from Hole 766A. Figure 1 from Sample 123-766A-20R-2, 102–104 cm; all other figures from Sample 123-766A-21R-2, 32–34 cm. Scale bar = 1 μ m. **1.** *Eprolithus bettenstaedtii* n. sp. **2, 3.** *Eprolithus floralis* (Stradner). **4, 5.** *Rhagodiscus angustus* (Stradner); (4) P; (5) D. **6–8.** *Rotelapillus crenulatus* (Stover); (6, 7) side views; (8) P. **9.** *Rotelapillus laffittei* (Noel); P.

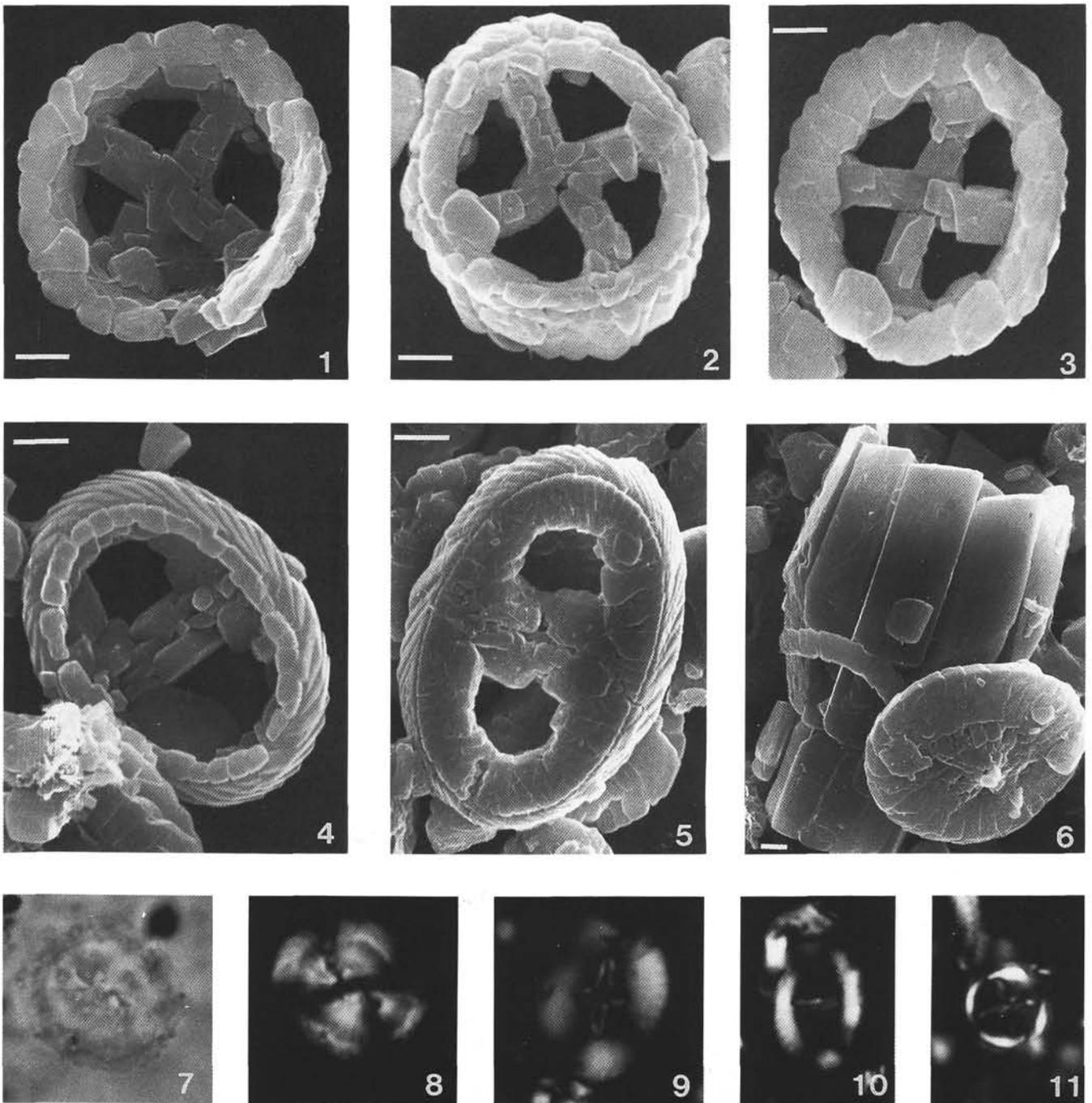


Plate 5. Stephanolithiaceae, Zygodiscaceae, and inc. sedis from Hole 766A and light photomicrographs. Figures 1 through 4, and 6 from Sample 123-766A-21R-1, 32–34 cm; Figure 5 from Sample 123-766A-20-2, 102–104 cm. Scale bar = 1 μ m. 1–3, *Corollithion achylosus* Stover; (1, 3) D; (2) P. 4, 5, *Glaukolithus diplogrammus* (Deflandre in Deflandre and Fert); (4) D; (5) P. 6, *Scampanella cf. cornuta* Forchheimer and Stradner (Figs. 7–11 2700 \times). 7, 8, *Cyclagelosphaera deflandrei* (Manivit); oval form; Sample 123-765C-62R-1, 120 cm; (7) TL; (8) POL. 9, *Crucellipsis cuvilliere* (Manivit); Sample 123-765C-56R-2, 60–61 cm; POL. 10, *Speetonia colligata* Black; Sample 123-765C-56R-2, 60-61; POL. 11, *Corollithion achylosus* (Stover); Sample 123-766A-20R-4, 35–36 cm; POL.

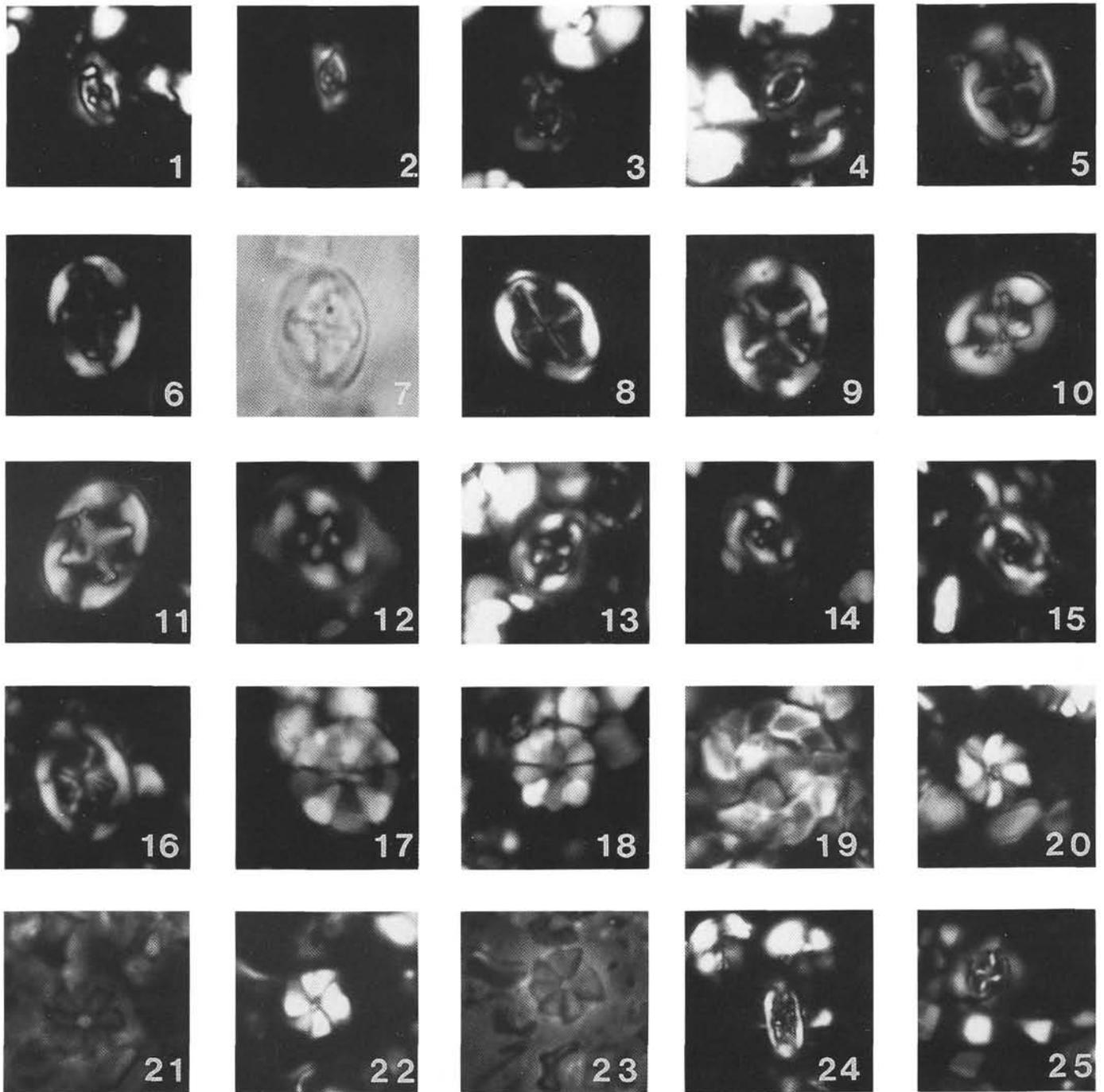


Plate 6. Photomicrographs from Holes 765C and 766A. Figure 24, 1800 \times , all other figures, 2700 \times . **1, 2.** *Crucibiscutum salebrosum* (Black); POL; (1 Sample 123-765C-56R-2, 102–104 cm; (2) Sample 123-766A-48R-4, 140 cm. **3.** *Seribiscutum primitivum* (Thierstein); POL; Sample 123-766A-20R-2, 103–104 cm. **4.** *Seribiscutum gaultensis* n. sp.; POL; Sample 123-766A-20R-1, 67–68 cm. **5–8.** *Vagalapilla matalosa* (Stover); (5) Sample 123-766A-48R-4, 140 cm; (6–8) Sample 123-766A-50R-1, 5 cm; (5, 6, 8) POL; (7) TL. **9–11.** *Tegumentum striatum* (Black); POL; (9) Sample 123-766A-50R-1, 5 cm; (10, 11) Sample 123-766A-48R-4, 140 cm. **12–15.** *Flabellites biforamini* Thierstein; POL; (12, 13) Sample 123-766A-20R-4, 35–36 cm; (14, 15) Sample 123-766A-20R-1, 67–68 cm. **16.** *Chiastozygus litterarius* (Gorka); POL; Sample 123-766A-20R-1, 67–68 cm. **17.** *Eprolithus floralis* (Stradner); POL; Sample 123-766A-20R-1, 67–68 cm; **18.** *Eprolithus* sp.; POL; Sample 123-766A-20R-1, 67–68 cm. **19.** *Eprolithus bettenstaedtii* n. sp.; POL; Sample 123-766A-20R-3, 95–96 cm. **20–23.** *Rucinolithus irregularis* Thierstein; (20, 22) POL; (21, 23) TL; (20, 21) Sample 123-766A-21R-CC. **24.** *Rhagodiscus angustus* (Stradner); POL; Sample 123-765C-39R-4, 30–31 cm. **25.** *Prediscosphaera spinosa* (Bramlette and Martini); POL; Sample 123-766A-20R-3, 95–96 cm.