7. CAMPANIAN DWARF CALCAREOUS NANNOFOSSILS FROM WODEJEBATO GUYOT¹

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ABSTRACT

Calcareous nannofossils occur in lagoonal sediments recovered from Sites 873, 874, and 877 drilled on Wodejebato Guyot in the central Pacific Ocean. Nannofloras are present only in a few layers, from which several smear slides were prepared. All the specimens were counted, and the relative abundance of taxa was computed as percentages. Assemblages are characterized by excellent preservation, very high diversity (= number of taxa), but extremely low abundance. Both diversity and abundance decrease from the inner perimeter ridge along the northern edge of the atoll (Sites 877 and 874) to the inner lagoon (Site 873), but the assemblage composition is very similar at the three sites. The dominant species are *Prediscosphaera* spp., *Cribrosphaerella ehrenbergii, Cretarhabdus* spp., *Biscutum constans*, and *Zygodiscus erectus*. *Watznaueria barnesae* is common but not dominant. Holococcoliths were observed at all sites. All taxa are represented by dwarf specimens.

At Site 877, the CC22 Zone of late Campanian age was determined; at Sites 873 and 874, nannofloral assemblages indicate a Campanian age. The Cenomanian-restricted species *Corollithion kennedyi* was found at Site 877, suggesting the presence of older sediments on Wodejebato Guyot. Evidence of reworking is also given by the occurrence of recrystallized, broken, and often phosphatized specimens of long-ranging taxa. Reworking is more abundant in the lagoon than at the inner ridge.

The investigation was extended to the upper Campanian interval recovered at Site 869, which was drilled during Leg 143 on the oceanic floor south of Wodejebato Guyot. Here, nannofloras are represented by normal-sized specimens, and the assemblage composition is typically oceanic, suggesting that the nannoplankton at Sites 873, 874, and 877 adjusted to restricted environmental conditions. Calcareous nannoplankton occur in extant lagoons, where coccoliths are found in the sediments and in the water samples. Lagoonal nannofloras are also preserved in the fossil record of various ages: Neogene, Oligocene, Paleocene, Early Cretaceous, and Middle to Late Jurassic. There are similarities and differences between the nannofloras from Wodejebato and assemblages from other ancient lagoons. The small size of the coccoliths seems to be a peculiarity of lagoonal assemblages and may be related to the unusual environmental conditions. The genus *Braarudosphaera*—inferred to be a low salinity form—is usually absent.

The relatively high abundance of fertility indicators *B. constans* and *Z. erectus* at Sites 873, 874, and 877 is possibly controlled by the proximity of Wodejebato Guyot to the paleoequatorial upwelling belt during the Campanian. In fact, similar nannofloras were previously reported from mid-Cretaceous sites at comparable paleolatitudes in the central-western Pacific. This interpretation is substantiated by the record of Site 869, where a few layers are relatively enriched in *Prediscosphaera* spp., *C. ehrenbergii, B. constans*, and *Z. erectus*, although nannofloral assemblages for the most part are affected by diagenesis and dominated by such dissolution-resistant taxa as *Watznaueria barnesae*, *Cretarhabdus* spp., and *Micula decussata*. The present study suggests that *C. ehrenbergii* and *Prediscosphaera* also possibly bloomed under relatively fertile surface-water conditions in the Late Cretaceous.

INTRODUCTION

During Ocean Drilling Program (ODP) Leg 144 in the western Pacific Ocean, five sites were drilled on Wodejebato Guyot (Marshall Islands) (see site map preceding title page). Site 873 is located in the central part of the guyot, Sites 874 and 877 are situated on the inner perimeter ridge, and Sites 875 and 876 are positioned on the outer perimeter ridge. A hole was also drilled south of Wodejebato Guyot (Site 869) during Leg 143 to recover pelagic sediments from the archipelagic apron (Fig. 1 and Table 1).

Wodejebato Atoll was formed during the Cretaceous as a volcanic edifice, and shallow-water limestones were deposited during the Late Cretaceous. Pelagic foraminifer and nannofossil oozes capped the guyot through the Tertiary and Quaternary (Premoli Silva, Haggerty, Rack, et al., 1993). Although the Cretaceous sedimentary sequences are represented by platform limestones, calcareous nannofossils were extensively hunted at all sites to obtain biostratigraphic ages based on calcareous plankton and to improve our knowledge of Cretaceous nannoplankton paleoecology. Calcareous nannofossils were not observed in the platform sequences recovered at Sites 875 and 876 on the outer ridge, whereas a few nannofossil-bearing layers were found at the base of the shallow-water limestones at Sites 873, 874, and 877. In this paper, we report the nannofloral assemblages recovered at these sites and discuss the possible paleoecologic/paleoceanographic implications of the findings.

Comparison with calcareous nannofloras recovered at Site 869 will allow us to separate the influence of lagoonal vs. oceanic conditions.

MATERIAL AND METHODS

At Sites 783, 874, and 877, calcareous nannofossils occur in the oldest marine sediments overlying the volcanic pedestal and preceding the deposition of shallow-water limestone (Fig. 2). The basal platform sediment at the three sites is represented by gray claystone and siltstone with abundant pyrite, which testify to marine conditions in a low-energy, lagoonal environment (Premoli Silva, Haggerty, Rack, et al., 1993). A very detailed sampling was performed to ascertain the presence even of sparse calcareous nannofloras: 16 samples were analyzed from Site 877, 6 samples from Site 874, and 3 samples from Site 873 (Table 2). Most layers were barren of calcareous nannofossils; therefore, this study was focused on the few nannofossil-bearing samples.

Smear slides were prepared using standard techniques: raw material was permanently mounted using the Norland Optical Adhesive. In addition, because of the extremely low abundance of coccoliths, sediments were ultrasonically cleaned and centrifuged to concentrate the

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Figure 1. Location of the sites studied. Sites 873, 874, and 877 were drilled during Leg 144 on Wodejebato Guyot, whereas Site 869 was drilled on the archipelagic apron south of Wodejebato Guyot during Leg 143. Modified after Sager, Winterer, Firth, et al. (1993). Contour intervals in hundreds of meters.

nannofossil specimens. However, assemblage abundance did not improve significantly, and we preferred to study raw material to retain the original sediment composition. Investigation of the nannofossilbearing samples was also performed with the scanning electron microscope (SEM) (Table 2), but the best results derive from the polarizing light microscope study.

A quantitative study of nannofossils was performed on all fossiliferous samples using smear slides of raw sediments with the polarizing light microscope at 1250× magnification. Because of the rarity of nannofossils, duplicate smear slides were prepared for the nannofossiliferous samples and all the specimens present were counted. The investigation of a single sample went on for several hours, scanning the entire surface of slides (area of 1 slide = 9 cm²). The relative abundance of taxa is reported in Tables 3–6, both as counts and percentages.

Calcareous nannofossils from Site 869 were studied in the interval coeval with the upper Campanian nannofossiliferous layers at Sites 873, 874, and 877. Qualitative and semiquantitative investigations were performed on smear slides of raw sediments with the polarizing light microscope at 1250× magnification. The samples yielding the most abundant nannofloras were also quantitatively studied, counting at least 300 specimens per slide (Table 7).

RESULTS FROM SITES 873, 874, AND 877

In the basal marine sediments recovered at Sites 873, 874, and 877, 17 samples out of 24 were barren of calcareous nannofossils. The 7 fossiliferous samples contain nicely preserved and highly diverse (= number of species) nannofloras, but abundances are extremely low. The most abundant assemblage was observed in Sample 144-877A-20R-1, 44–45 cm, where only 1418 (1383 autochthonous and 35 reworked) specimens were counted in 4 smear slides (= 36 cm²). At Site 873, the best assemblage is contained in Sample 144-873A-11R-2, 20 cm, with 294 specimens (284 autochthonous and 10 reworked) in 3 smear slides, and 287 specimens (279 autochthonous and 8 reworked) were detected in the most nannofossiliferous sample at Site 874 (Sample 144-874B-21R-1, 40–41 cm). The list of all nannofossil taxa observed at Sites 873, 874, and 877 is given in the Appendix.

Table 1. Latitude, longitude, and water depth of Sites 873, 874, and 877 (Leg 144) and Site 869 (Leg 143).

Site	Latitude (N)	Longitude (E)	Water depth (m)	Setting
873	11°53,84'	164°55.20'	1334	Lagoon
874	12°00.76'	164°55.22'	1374	Inner ridge
877	12°01.14'	164°55.30'	1355	Inner ridge
869	11°00.09'	164°45.02'	4826.7	Archipelagic apror

Biostratigraphy

Calcareous nannofossils that were found at the base of the platform sequences at Sites 873, 874, and 877 allow us to constrain the age of the onset of marine sedimentation. At Site 877, the occurrence of the marker species *Quadrum trifidum, Eiffellithus eximius,* and *Reinhard-tites anthophorus* indicates the CC22 Zone (Sissingh, 1977) of late Campanian age. At Sites 873 and 874 nannofloral assemblages indicate a Campanian age, but marker species with a more restricted range were not observed. However, the volcanic substratum in all sites that were drilled on Wodejebato Guyot consists of reversely magnetized basalts, which are attributed to magnetic polarity Zone 33R of early Campanian age (Nakanishi et al., 1992). Therefore, the oldest marine sediments at Sites 873 and 874 are of late Campanian age.

The stratigraphy of the Cretaceous is currently under revision to improve the correlation between chronostratigraphy and biomagnetostratigraphy, based on recent findings of sections with ammonite control in which calcareous plankton biostratigraphy and/or magnetostratigraphy were established. This revision resulted in a new calibration of stage boundaries with respect to magnetic polarity chronozones and/or calcareous plankton biozones (Premoli Silva and Sliter, 1994; Erba et al., this volume). In particular, based on ammonite chronostratigraphy, the Campanian/Maastrichtian boundary is now placed at the base of magnetic Chronozone 31R (Lommerzheim and Hambach, 1992); it is dated to 71.3 Ma (Gradstein et al., 1994), and lies in the lower part of the Gansserina gansseri planktonic foraminifer Zone and close to the zonal boundary between CC23 and CC24 of the nannofossil zonation of Sissingh (1977). Consequently, the calcareous plankton biozones previously used to determine the early Maastrichtian are now attributed to the late Campanian (Fig. 3). This implies that the latest Campanian age that was originally attributed to Core 144-877A-20R (Premoli Silva, Haggerty, Rack, et al., 1993) is now revised to a middle late Campanian age.

The Cenomanian-restricted species *Corollithion kennedyi* was found at Site 877, suggesting the presence of older sediments on Wodejebato Guyot. Other species with a stratigraphic range older than the Campanian were also observed. They include *Axopodorhabdus albianus, Rhagodiscus asper,* and *Eprolithus floralis.* Evidence of reworking is also given by the occurrence of recrystallized, broken, and often phosphatized specimens of long-ranging taxa such as *Watznaueria barnesae, Cretarhabdus surirellus,* and *Zygodiscus erectus.* Reworking is more abundant in the lagoon (Site 873) than at the inner perimeter ridge (Sites 877 and 874). These findings are in agreement with previous records of Albian rudists that were dredged along the flanks of Wodejebato Guyot (Lincoln et al., 1993). The occurrence of mid-Cretaceous sediments on Wodejebato indicates that the Campanian basalts represent a second episode of volcanism that followed an Early Cretaceous pulse (Lincoln et al., 1993).

Assemblage Composition

The nicely preserved late Campanian nannofossil assemblages from Wodejebato Guyot show a decrease in both diversity and abundance from the inner ridge of the northern edge of the atoll (Site 877) to the lagoon (Site 873). A peculiarity of all the nannofloras is the very



Figure 2. Stratigraphic synthesis of Sites 873, 874, and 877 drilled on Wodejebato Guyot (modified after Premoli Silva, Haggerty, Rack, et al., 1993). The gray pattern indicates the position of intervals yielding late Campanian calcareous nannofossils that are discussed in this paper.

small size of nannofossils; taxa are represented by specimens that are much smaller than standard size but that retain all the other diagnostic characters (Plates 1 and 2). A morphometric study was conducted on late Campanian nannofossil specimens from Wodejebato Guyot and the archipelagic apron; size variations are reported in Table 8. It must be noticed that sizes of the lagoonal specimens are distinctively smaller than those of the holotypes and the oceanic specimens.

Assemblages are dominated by *Prediscosphaera* spp., *Cribro-sphaerella ehrenbergii, Cretarhabdus* spp., *Zygodiscus* spp. (mainly *Zygodiscus erectus*), and *Biscutum* spp. (mainly *Biscutum constans*) (Fig. 4). *Watznaueria barnesae* is common but not dominant; other typically oceanic taxa are also present, although never abundant. A few specimens of holococcoliths were observed in all the nannofossil-iferous samples. One single specimen of *Braarudosphaera regularis* was observed only in Sample 144-873A-11R-2, 20 cm.

Reworking is more abundant at Site 873 in the lagoon (3.40% and 5.73% of nannofloras) than at the inner ridge (Site 874: 2.79% of nannofloras; Site 877: 2.47% of nannofloras). Besides marker species with a stratigraphic range older than the Campanian, the reworked specimens are represented by long-ranging taxa that are typically recrystallized, broken, and often phosphatized (Fig. 4 and Tables 3–6).

To our knowledge, this is the first documentation of calcareous nannofossils from lagoonal or restricted environments in Cretaceous atolls from the Pacific Ocean. Our finding of very peculiar assemblages with specific composition and morphometric characters suggests nannoplankton adjustments to anomalous environmental conditions. Campanian nannofossil assemblages from Wodejebato will be compared with coeval nannofloras recovered at Site 869 drilled on the archipelagic apron south of Wodejebato Guyot as well as with extant and fossil nannoplankton from lagoonal environments.

Table 2. Summary of samples investigated for calcareous nannofossils at Sites 873, 874, and 877 on Wodejebato Guy

Core, section, interval (cm)	Light microscope	SEM	Abundance autochthonous (NS)	Diversity autochthonous (NT)	Reworking (% total nannoflora)
144-873A-					
11R-2, 15-16	1				
11R-2, 20	3	*	284	42	3.40
11R-2, 17-22	5	*	148	36	5.73
144-874B-					
21R-1, 0-1	1				
21R-1, 35-36	2		_		
21R-1, 40-41	5	*	279	45	2.79
21R-1, 44-45	2				
21R-1, 148-149	2				
21R-CC	ī				
144-877A-					
20R-1, 16-17	1	*	6	6	0
20R-1, 28-29	1				
20R-1, 42-44	1	*	38	19	0
20R-1, 44-45	4	*	1383	68	2.47
20R-1, 54-55	1		—		
20R-1, 70-71	1	*	3	3	0
20R-1, 81-82	1		-		
20R-1, 92-94	1		_		
20R-1, 101-102	1				
20R-1, 102-103	1				
20R-2, 0-1	1				
20R-2, 1-2	1		-		
20R-2, 15-16	1				
20R-2, 34-35	1				
20R-2, 61-62	1		_		
20R-2, 98-99	1				

Notes: Single asterisk (*) denotes that SEM investigation was performed. SEM = scanning electron microscope. NS = number of specimens. NT = number of taxa.

PREVIOUS RECORDS OF CALCAREOUS NANNOFLORAS FROM LAGOONAL ENVIRONMENTS

Extant calcareous nannoplankton were described from lagoons of the Great Barrier Reef (Marshall, 1933; Folk, 1972) and from the British Honduras (Scholle and Kling, 1972; Kling, 1975). The oldest documentation was given by Marshall (1933), who observed coccolithophorids as persistent components of the lagoonal phytoplankton of the Great Barrier Reef area. Coccoliths increased in abundance in passages to the outer ocean, and a seasonal decrease in abundance correlated with decreases in the salinity of surface waters below 35°. This finding was interpreted as the result of washing in of coccoliths from open-ocean waters. Subsequently, Folk (1972) confirmed the presence of calcareous nannofossils in those lagoons and noted that muds deposited behind the Great Barrier Reef consist of abundant coccoliths that are possibly an autochthonous component of lagoonal phytoplankton.

The occurrence of coccolithophorids in the back-reef lagoons of southern Belize, British Honduras, was documented both in sediment and water samples (Scholle and Kling, 1972; Kling, 1975). The sampled area of the lagoon has normal oceanic salinity (34°) because openocean waters enter the lagoon through a deep southern entrance. The abundance of coccospheres was high and comparable with that reported for the nearby Caribbean Sea, suggesting that calcareous nannoplankton inhabited the lagoon and were not washed in from openmarine waters. Quantitative analysis of water samples showed that both abundance and diversity (= number of taxa) appeared to diminish as one moved away from the deep entrance at the southern end of the lagoon. Assemblages were dominated by very few species (Emiliania huxleyi, Gephyrocapsa oceanica, and Syracosphaera spp.), whereas all the other taxa were equally rare; holococcolithophorids were well represented. Although nannoplankton composition in the southern British Honduras resembled that of the Gulf of Mexico-Caribbean region, some forms common in tropical oceanic waters were extremely rare or absent. Kling (1975) noted that Braarudosphaera bigelowii was not present in the plankton samples and rare specimens were observed in only one sediment sample.

Cronin et al. (1991) described micropaleontological assemblages in Neogene lagoonal sediments drilled at Enewetak Atoll in the Marshall Islands. Calcareous nannofossils were found at various depths within the Miocene to Pleistocene sequence and provided useful biostratigraphic horizons. A more detailed description of calcareous nannofloras from the boreholes at Enewetak Atoll is given by Bybell and Poore (1991), but the study was focused on biostratigraphy and did not provide information on the specimens' size. Occurrence of nannofossils is limited to a few layers that contained rare to common assemblages. Preservation fluctuated from very poor to fair, whereas diversity (= number of taxa) was moderate.

Calcareous nannoplankton from lagoonal environments are also documented in the fossil record, as recently summarized by Noël et al. (1993b). Nannofossils from Oligocene lagoonal deposits of Limagne, France, were originally reported by Dangeard (1931) and later described by Busson and Noël (1972) and Noël et al. (1993a). The finely laminated sediments contain almost monospecific and nicely preserved coccoliths and coccospheres, which show taxonomic changes from one light lamina to the next one. Similar findings were also documented for other Oligocene deposits in France (Doebl et al., 1976; Noël et al., 1993a). All the assemblages are characterized by excellent preservation and are dominated by very few taxa, which seem to be represented by small coccoliths. Holococcoliths were found in a few samples, whereas *Braarudosphaera bigelowii* was observed only in one sample from the Valence basin (France) and one sample from the Bremmelbach area (France).

Noël et al. (1992) illustrated calcareous nannoliths from Danian lagoonal or lacustrine deposits from the Petites Pyrénées (France); however, the strong diagenesis of the lithographic limestones studied prevented the identification of any taxa. The attribution of these nannoliths to coccoliths was based on the similarity of the ultrastructure to that of some Mesozoic lithographic and coccolith-bearing limestones of lagoonal environment.

The occurrence of coccoliths in Mesozoic lagoonal deposits is not very clear because of strong diagenetic modifications of the nannofacies. However, detailed investigations of Cretaceous and Jurassic deposits in Spain and France suggest that coccoliths possibly inhabited lagoons, at least temporarily (see Noël et al. [1993b] for a synthe-

	Slide A	Slide E	Slide D	Slide B	Total	Total nannoflora (%)	Autochthonou: nannoflora (%)
Ahmuellerella octoradiata	1	11	5	7	24	1.69	1.74
Arkhangelskiella specillata				3	3	0.21	0.22
Biscutum constans	14	13		71	109	0.35	7.88
Biscutum sp. Rukrvaster havi			1	4	1	0.33	0.07
Calculites obscurus				4	4	0.28	0.29
Chiastozygus amphipons	13	22	11	17	63	4.44	4.56
Chiastozygus litterarius	2	4	5	8	19	1.34	1.37
Corollithion achylosum				2	2	0.14	0.14
Corollithion asymmetricus		1				0.07	0.07
Corollithion exiguum	1	1	2	9	11	0.78	0.80
Cretarnabaus angustijoratus	1	5	2	22	20	0.40	0.51
Cretarhabdus crenulatus		34		4	34	2 40	2.46
Cretarhabdus striatus				5	5	0.35	0.36
Cretarhabdus surirellus	31	3	21	25	80	5.64	5.78
Cribrosphaerella ehrenbergii	26	38	24	53	141	9.94	10.20
Crucibiscutum salebrosum	3				3	0.21	0.22
Cylindralithus crassus	1	100417	2		3	0.21	0.22
Cylindralithus serratus		4		~	4	0.28	0.29
Cylindralithus sp.		2	2	3	3	0.21	0.22
Discornadaus rotatorius Eiffallithus asimine	- ÷	2	3	10	10	0.21	0.22
Fiffellithus aorkae	4		L.	23	8	0.56	0.58
Eiffellithus parallelus	.4	2	1	a	3	0.21	0.22
Eiffellithus turriseiffelii	10	8	3	3	24	1.69	1.74
Lithastrinus grillii		34761		3	3	0.21	0.22
Lithraphidites carniolensis	5	20	4	6	35	2.47	2.53
Lithraphidites sp.				16	16	1.13	1.16
Manivitella pemmatoidea	4	4	2	5	15	1.06	1.08
Microrhabdulus attenuatus	2				2	0.14	0.14
Microrhabdulus belgicus	9	5	9	5	28	1.97	2.02
Microrhabdulus decoratus	3	1	0	2	14	0.99	0.22
Micula concava Micula decussata	37	1	<u>1</u>	1	5	0.21	0.36
Nannoconus sp. (wide canal)	1			4	3	0.33	0.22
Octoevelus sp. (wide canar)				1	1	0.07	0.07
Orastrum campanensis		2			2	0.14	0.14
Orastrum sp.	3	3	4	14	24	1.69	1.74
Ottavianus sp.		3			3	0.21	0.22
Placozygus sigmoides		2			2	0.14	0.14
Prediscosphaera bukryi			22	14	36	2.54	2.60
Prediscosphaera cretacea	10	29	12	45	96	6.77	6.94
Prediscosphaera honjoi	21	28	26	64	139	9.80	10.05
Prediscosphaera intercisa		1		27	27	0.49	0.51
Prediscosphaera sp.		15		21	15	1.90	1.95
Oradrum sissinahii	2	3	1		6	0.42	0.43
Quadrum sosthicum	~	1		2	3	0.21	0.22
Quadrum trifidum	4	9	4	2	19	1.34	1.37
Reinhardtites anthophorus				9	9	0.63	0.65
Reinhardtites cf. R. anthophorus		1			1	0.07	0.07
Rhagodiscus angustus	2	2	1	3	8	0.56	0.58
Rhagodiscus splendens	2	2		1.21	4	0.28	0.29
Rotelapillus laffittei				2	2	0.14	0.14
Rucinolithus terebrodentarius		2		0	2	0.14	0.14
Serioiscutum primitivum	2			8	2	0.56	0.58
Tranolithus phacelosus	4	4			4	0.28	0.14
Vagalanilla stradneri	2	- 14		1	3	0.20	0.22
Watznaueria barnesae	â	4	7	10	30	2.12	2.17
Zygodiscus diplogrammus	2	5	2	2	11	0.78	0.80
Źygodiscus erectus	19	30	19	71	139	9.80	10.05
Zygodiscus spiralis				2	2	0.14	0.14
Coccosphaera		1			1	0.07	0.07
Holococcolith (2.5 µm)				2	2	0.14	0.14
Sp. C				2	2	0.14	0.14
Sp. E		10			10	0.71	0.72
Sp. r Indeterminate species	26	1	15	16	26	2.54	2.60
Aronodorhabdus albianus		4	15	10	30	0.14	2.00
(reworked)			1	- 1	4	0.14	
Corollithion kennedyi (reworked)		1		3	4	0.28	
Cretarhabdus surirellus (reworked)		1		6	7	0.49	
Eprolithus floralis (reworked)				2	2	0.14	
Rhagodiscus asper (reworked)				3	3	0.21	
Watznaueria barnesae (reworked)		04		5	5	0.35	
Zygodiscus erectus (reworked)		1		11	12	0.85	
Total					1418		
Total autochthonous					1383		
Reworked					35	2.47	
4.5.6 T. 17 I. I. S. M. M.					2721		

Table 3. Abundance of nannofossil taxa in Sample 144-877A-20R-1, 44-45 cm.

	Slide	Slide	Slide	Slide	Slide		Total	Autochthonous
	A	B	C	D	E	Total	(%)	(%)
Ahmuellerella octoradiata	1	_				1	0.35	0.36
Arkhangelskiella specillata	10				1	1	0.35	0.36
Biscutum constans	3		2	2	12	19	6.62	6.81
Biscutum sp.					1	1	0.35	0.36
Bukryaster hayi					1	1	0.35	0.36
Chiastozygus litterarius					2	2	0.70	0.72
Cretarhabdus angustiforatus	2			1	3	6	2.09	2.15
Cretarhabdus conicus	1		1	1	2	5	1.74	1.79
Cretarhabdus crenulatus	1					1	0.35	0.36
Cretarhabdus surirellus	8	3	2	1	4	18	6.27	6.45
Cribrosphaerella ehrenbergii	9	8	9	4	14	44	15.33	15.77
Cylindralithus crassus			1			1	0.35	0.36
Cylindralithus serratus			1			1	0.35	0.36
Discorhabdus rotatorius			1	2	2	5	1.74	1.79
Eiffellithus eximius	1	1				2	0.70	0.72
Eiffellithus gorkae					2	2	0.70	0.72
Eiffellithus turriseiffelii	2	1			1	4	1.39	1.43
Eiffellithus sp.				1		1	0.35	0.36
Lithastrinus grillii				2		2	0.70	0.72
Lithraphidites sp.					1	1	0.35	0.36
Lithraphidites carniolensis	5				3	8	2.79	2.87
Lithraphidites cf. L. praequadratus				1		1	0.35	0.36
Microrhabdulus belgicus		1	1		1	3	1.05	1.08
Microrhabdulus decoratus	5	3	3		5	16	5.57	5.73
Nannoconus multicadus	1					1	0.35	0.36
Parhabdolithus embergeri			1			1	0.35	0.36
Placozygus sigmoides			1			1	0.35	0.36
Prediscosphaera bukryi		2	1	1	1	5	1.74	1.79
Prediscosphaera columnata		1	1			2	0.70	0.72
Prediscosphaera cretacea	8			2	8	18	6.27	6.45
Prediscosphaera honjoi	15	2	5	5	16	43	14.98	15.41
Prediscosphaera sp.				2	2	4	1.39	1.43
Quadrum gartneri					1	1	0.35	0.36
Quadrum gothicum	1					1	0.35	0.36
Quadrum sp.				1		1	0.35	0.36
Reinhardtites anthophorus					4	4	1.39	1.43
Rhagodiscus angustus		1				1	0.35	0.36
Rucinolithus terebrodentarius				1	1	2	0.70	0.72
Seribiscutum primitivum					1	1	0.35	0.36
Thoracosphaera sp.			1		1	2	0.70	0.72
Vagalapilla matalosa					1	1	0.35	0.36
Zygodiscus diplogrammus		1		1		2	0.70	0.72
Zygodiscus erectus	9	1	4	4	1	19	6.62	6.81
Watznaueria barnesae	5	3	3	1	2	14	4.88	5.02
Sp. C					1	1	0.35	0.36
Indeterminate species	2			4	2	8	2.79	2.87
Cretarhabdus surirellus (reworked)					2	2	0.70	
Eprolithus floralis (reworked)				- 1		1	0.35	
Rhagodiscus asper (reworked)					1	1	0.35	
Watznaueria barnesae (reworked)					2	2	0.70	
Zygodiscus erectus (reworked)					2	2	0.70	
Tatal						207		
Total autochthonore						201		
Paworkad						2/9	2 70	
INCHOINEU						0	2.19	

|--|

sis). Busson et al. (1992b) described the nannofacies of Berriasian-Valanginian lagoonal limestones from the Catalonian Pyrénées, Spain, and interpreted common, morphologically homogeneous nannoliths as coccoliths. Taxonomic identification was hampered by the strong diagenesis of the limestones.

Coccoliths and nannoliths were also illustrated in Upper Jurassic lithographic limestones of lagoonal environment in Bavaria, Germany (Keupp, 1976; Busson et al., 1992a), and in the Jura region, France (Busson et al., 1992a). Keupp (1976) described a nicely preserved and diverse nannofossil assemblage in the upper Tithonian Solnhofen limestones, and therefore documented the occurrence of calcareous nannofossils in lagoonal deposits. Busson et al. (1992a) described nannoliths from three different Upper Jurassic lagoonal deposits; certain coccoliths, however, were illustrated only from Solnhofen, Bavaria. In other basins, strongly diagenized nannoliths could not be attributed to any nannofossil taxa.

Busson et al. (1993) investigated the nannofacies of sublithographic limestones that were deposited in Bathonian, middle Oxfordian, and Kimmeridgian lagoons in France. SEM analyses of numerous samples revealed that diagenetic modifications strongly altered the original characters of these fine-grained limestones. Minute-sized nannoliths with central holes were interpreted as the central wall linking the distal and proximal shields of coccoliths, but no taxa could be identified. If this interpretation is correct, then the nannofossil assemblages are oligospecific and represented almost exclusively by small-sized specimens.

Similarities and differences can be pointed out between the Campanian nannofossil assemblages recovered on Wodejebato Guyot and nannofloras that were described from extant and fossil lagoons. Analogies comprise the nice preservation, the occurrence of holococcoliths, and the general small size of specimens. *Braarudosphaera* is generally absent, with the only exception of single layers from extant sediments in the British Honduras lagoon (Kling, 1975) and Oligocene deposits in France (Noël et al., 1993a). This genus is characteristic of lowsalinity water masses, but seems to be rare in lagoons. Both in the Wodejebato lagoon and in the extant British Honduras lagoon, typical oceanic taxa are extremely rare and the abundance of calcareous nannofloras decreases from the reef frame toward the inner lagoon. Both characters suggest that connections with open-marine waters diminish away from the edge.

Diversity is high in the Wodejebato assemblages as well as in the extant nannoplankton from the British Honduras (Kling, 1975) and the Late Jurassic lagoonal nannofloras from Germany (Keupp, 1976), but almost monospecific assemblages are described for the Oligocene

	Slide A	Slide B	Slide C	Slide D	Slide E	Total	Total nannoflora (%)	Autochthonous nannoflora (%)
Ahmuellerella octoradiata				1	Virtually	1	0.64	0.68
Arkhangelskiella specillata			2	1	barren	3	1.91	2.03
Biscutum constans	1			8		9	5.73	6.08
Biscutum sp.				2	Only	2	1.27	1.35
Calculites obscurus				ĩ	fragments	1	0.64	0.68
Chiastozygus amphipons		1	1	- i -	of	3	1.91	2.03
Chiastozygus litterarius				1	Prediscosphaera	Ĩ	0.64	0.68
Corollithion exiguum				- i -	rreuseosphaera	- i -	0.64	0.68
Cretarhabdus angustiforatus			- F	3		4	2.55	2.70
Cretarhabdus conicus			î	2		3	1.91	2.03
Cretarhabdus crenulatus			i	÷.		ă.	0.64	0.68
Cretarhabdus surirellus				2		2	1.27	1 35
Cribrosphaerella ehrenbergii	2	3	6	12		23	14.65	15 54
Cylindralithus sp	**		0	1		1	0.64	0.68
Fiffellithus parallelus				1		1	0.64	0.68
Fiffellithus oorkaa			1	4		5	3.18	3 38
Lithastrinus arillii			1	1		ī	0.64	0.68
Microrhabdulus attonuatus				- S -		- 2	0.64	0.68
Microrhabdulus decovatur		1	2.4	1.0		5	2.19	3 38
Micromabadius accordius			-+	- 1		1	0.64	0.68
Orgetrum common anele						- 1	0.64	0.68
Otasirum cumpanensis			1			1	0.64	0.68
Parhabdolithur ambaraoni			1	- i i		4	0.64	0.08
Parhabaoninus embergeri			10 E	-		1	5.10	5.41
Prediscosphaera cretacea	2		2	16		20	12.74	12.51
Prediscosphaera nonjoi	- 4		4	10		20	12.74	13.31
Quadrum garineri				1			0.64	0.00
Quaarum sissinghii				1		-	0.04	0.00
Reinnarantes anthophorus				2		2	1.2/	1.55
Rhagoaiscus angustus			6	1		1	0.64	0.08
Rhagodiscus spiendens			1	24		4	0.64	0.08
Vandanilla an						1	0.64	0.08
Wagalapilla Sp.			1			10	6.27	6.76
warznaueria barnesae	1		5	4		10	0.37	0.70
Zygoaiscus aipiogrammus	1		2			4	2.55	2.70
Lygoalscus erectus	1		2			14	8.92	9.40
Sp. C				1		1	0.04	0.08
Indeterminate species				10		10	0.37	0.70
Cretarnabdus surirellus (reworked)				2		2	1.27	
Rhagodiscus asper (reworked)				1		1	0.64	
Watznaueria barnesae (reworked)				4		4	2.55	
Zygodiscus erectus (reworked)				2		2	1.27	
Total						157		
Total autochthonous						148		
Reworked						9	5.73	

Table 5. Abundance of nannofossil taxa in Sample 144-873A-11R-2, 17-22 cm.

laminated lagoonal deposits from France (Noël et al., 1993a). The very low diversity of the Danian and Mesozoic lagoonal sediments (Busson et al., 1992a, 1992b, 1993; Noël et al., 1992) were interpreted as oligospecific assemblages that bloomed under restricted conditions. However, the strong diagenesis that was documented for the Mesozoic lagoonal limestones might have considerably altered the original assemblage composition.

LATE CAMPANIAN NANNOFLORAS FROM SITE 869, SOUTH OF WODEJEBATO GUYOT

Calcareous nannofossils are common in the Upper Cretaceous sediments recovered at Site 869, where an almost complete sequence of the biozones proposed by Sissingh (1977) were identified (Fig. 3) (Sager, Winterer, Firth, et al., 1993). The upper Campanian interval attributed to Zones CC23–CC21 contains rare to very abundant nannofloras with moderate to poor preservation and limited diversity (= number of taxa). Fragmentation and evidence of dissolution were noticed in all samples, which yield assemblages dominated by the dissolution-resistant taxa *Watznaueria barnesae*, *Cretarhabdus* spp., and *Micula decussata* (Fig. 4 and Table 7). Holococcoliths were not observed. This assemblage composition reflects both oceanic conditions and dissolution at a water depth close to the CCD (Table 1).

Calcareous nannofloras at Site 869 are, therefore, very different from the coeval assemblages recorded on Wodejebato Guyot. Nannofossils at Site 869 are represented by normal-sized specimens (Table 8) and assemblages are typically oceanic, suggesting that nannofloras documented at Sites 873, 874, and 877 were influenced by peculiar environmental conditions.

PALEOECOLOGIC AND PALEOCEANOGRAPHIC INTERPRETATIONS

The nannofloras recovered in the upper Campanian sediments deposited in the lagoon and at the inner ridge of Wodejebato Guyot are characterized by dwarf specimens and a specific assemblage composition. Both abundance and diversity decrease as one passes from the atoll frame (Sites 874 and 877) to the middle part of the lagoon (Site 873), possibly indicating a better connection of the edge of the atoll with the open ocean. We think that nannoplankton were endemic to the restricted environment and not washed repeatedly into the Wodejebato lagoon from the open ocean during storm events. In fact, coeval nannofossils at Site 869, which is located in the open ocean south of Wodejebato, are represented by normal-sized specimens and assemblages are typically oceanic. Comparison with calcareous nannoplankton in extant and fossil lagoons suggests that the small size of coccoliths may represent the response to the distinctive environment. The absence/scarcity of Braarudosphaera indicates that surface waters in the lagoons studied were not necessarily hyposaline, probably because of efficient connections with the open-marine environment.

At Sites 873, 874, and 877, nannofloral composition resembles assemblages that are interpreted as characteristic of relatively highfertility conditions. Paleoecological/paleoceanographic studies of mid-Cretaceous nannofossils resulted in the identification of a few index species (Roth, 1981, 1989; Roth and Bowdler, 1981; Erba, 1986, 1987, 1992a, 1992b; Roth and Krumbach, 1986; Watkins, 1986, 1989; Mutterlose, 1989, 1991; Premoli Silva et al., 1989). In particular, *Zygodiscus erectus* and *Biscutum constans* were inferred to be indicators of relatively high fertility of surface waters in various

		0111	-		Total	Autochthonous
	Slide	Slide	Slide		nannotiora	nannoflora
	A	В	C	Total	(%)	(%)
Ahmuellerella octoradiata	1		4	5	1.70	1.76
Arkhangelskiella specillata		1		1	0.34	0.35
Biscutum sp.	2	2			0.68	0.70
Biscutum cf. B. coronum		2	2	4	1.36	1.41
Biscutum constans	4	5	9		3.06	3.17
Braarudosphaera regularis		1		1	0.34	0.35
Calculites obscurus	1			1	0.34	0.35
Chiastozygus amphipons	3	6	2	11	3.74	3.87
Chiastozygus litterarius		2	2	4	1.36	1.41
Corollithion exiguum	2			2	0.68	0.70
Corollithion signum	2			2	0.68	0.70
Cretarhabdus conicus	2	4		6	2.04	2.11
Cretarhabdus sp.			7	7	2.38	2.46
Cretarhabdus striatus			1	1	0.34	0.35
Cretarhabdus surirellus	3	8	2	13	4.42	4.58
Cribrosphaerella ehrenbergii	13	20	5	38	12.93	13.38
Crucibiscutum salebrosum			1	1	0.34	0.35
Cylindralithus servatus			î	î	0.34	0.35
Discorhabdus rotatorius		2		ż	0.68	0.70
Fiffellithus gorkae	E	ī		2	0.68	0.70
Lithraphidites carniolensis		÷.	3	ã	1.02	1.06
Microrhabdulus decoratus	5	5	3	13	4 42	4 58
Microrhabdulus helsicus	Ĩ	1	5	2	0.68	0.70
Orastrum sp	î.	2	2	5	1.70	1.76
Ottavianus sp.	6	2	2	10	3.40	3.52
Parhabdolithus emberaeri	ĭ	ĩ	ĩ	3	1.02	1.06
Placozyoux fibuliformis		2		2	0.68	0.70
Placozygus sigmoides		2	3	5	1.70	1.76
Prediscosnhaera hukrvi	6	2	2	11	3 74	3.87
Prediscosphaera columnata	2		ĩ	3	1.02	1.06
Prediscosphaera cretacea	4	4	0	17	5 78	5 00
Prediscosphaera honioi	7	12	2	21	7.14	7 30
Prediscosphaera intervisa	2	14	4	21	0.69	0.70
Ovadmm acthicum	4	1	1	ź	0.08	0.70
Phagodisous moustus		1	1	1	0.34	0.25
WalashingDo standardi		2	1	-	0.54	0.35
Water avania hamaaaa	0	27		10	6.46	6.60
waizhaueria barnesae	0	2	-4	19	6.46	6.69
Zygoaiscus aipiogrammus	2	10	11	19	7.40	0.09
Zygodiscus erectus	1	12	3	22	1.40	1.15
Zygoaiscus spiraiis			4	4	1.50	1.41
Indeterminate species	2.42		1	- t-	0.54	0.55
Sp. A	1			1	0.54	0.55
sp. c		2		3	1.02	1.06
Cretarhabdus surirellus (reworked)	2	125	1	3	1.02	
Watznaueria barnesae (reworked)	3	1	1	2	1.70	
Zygodiscus erectus (reworked)	2			2	0.68	
Total				294		
Total autochthonus				284		
Reworked				10	3.40	
2#57#37470257					15.75.76%	

Table 6. Abundance of nannofossil taxa in Sample 144-873A-11R-2, 20 cm.

oceans and marginal seas. In the Pacific Ocean, Roth (1981) and Erba (1992b) documented a marked increase in abundance of these taxa close to the paleoequator. More precisely, Zygodiscus erectus and Biscutum constans were very abundant in a belt between 15°S and 5°S that bordered the paleoequatorial upwelling zone with dominance of biogenic silica. Paleolatitude data from Wodejebato (Premoli Silva, Haggerty, Rack, et al., 1993; ODP Leg 144 Shipboard Scientific Party, 1993; Nakanishi et al., 1992; Larson et al., this volume; Nakanishi and Gee, this volume) indicate that Wodejebato Guyot was at approximately 10°S during the Campanian (Fig. 5). Therefore, the nannofossil assemblage composition at Sites 873, 874, and 877 may reflect the paleolatitude of the guyot with respect to the paleoproductivity belt of the Cretaceous Pacific basin (Fig. 6). If Wodejebato nannofloras were controlled by the paleolatitude, we should find similar assemblages in the late Campanian nannofossil record at Site 869, which was at a comparable location with respect to the paleoequatorial upwelling belt (Fig. 6). Undoubtedly, the calcareous nannofloral composition at Site 869 is affected by diagenetic modifications caused by the great water depth (4826.7 mbsf), although it probably retains some primary signals. Even though the assemblages are enriched in the dissolution-resistant taxa Watznaueria barnesae, Cretarhabdus spp., and Micula decussata that can make up to 93% of the nannofloras (Fig. 4 and Table 7), in a few samples the remaining assemblages resemble the composition observed at Sites 873, 874, and 877. Specifically, Prediscosphaera spp., Cribrosphaerella ehrenbergii,

Zygodiscus erectus, and Biscutum constans are relatively abundant. Moreover, the upper Campanian to Maastrichtian interval at Site 869 displays a progressive enrichment in radiolarians, which seems to be characteristic of high-fertility conditions in the Mesozoic Pacific Ocean. In fact, Ogg et al. (1992) documented a major increase in biogenic silica in all Mesozoic sites close to the paleoequator and reconstructed a radiolarian-rich belt between 5°S and 5°N paleolatitude. A marked increase in the abundance of radiolarians was also described by Erba (1992b) in the core of the paleo-upwelling belt where nannofossils decrease in abundance and are affected by dissolution.

We infer that the relatively high fertility of the surface-water masses at the edge of the paleo-upwelling belt affected the nannofloras during the late Campanian. Although the nannofossil record of the Wodejebato Guyot is pristine as a result of deposition at shallow depths in a protected environment, the oceanic record at Site 869 is strongly modified by dissolution caused by the great water depth; however, it still retains some primary characters such as nannofloral composition and radiolarian distribution.

The most abundant nannofossils in the Wodejebato Campanian sediments are *Prediscosphaera* spp. and *Cribrosphaerella ehrenbergii*, whose paleoecological affinities are not defined. Although these taxa were reported from mid-Cretaceous sediments that were deposited just south of the paleoequator, they were not dominant under more fertile oceanic surface-water conditions (Roth, 1981; Erba, 1992b). It must be pointed out, however, that both *C. ehrenbergii* and

Nannofossil Zone Counts Total Abundance Preservation	CC 23 A P	CC 8-9 CC 8-9 CC 23 A P	A P CC, 13-14 CC A P	CC 23 MP	58, 1-301-8698-108-1, 85 CC 23 F	CC YES A P	6 '2-801-8698-10R-2' 6 F M	W A X 20 55 50 143-869B-10R-2, 63-64	ЧООО 143-869B-11R-1, 32 25	М О А О 143-869В-11R-1, 107-108 55 С М	M Y X X C X X X X X X X X X X X X X X X X	M N C R9869B-11R-3, 26-27	Wb X5 20 143-869B-11R-4, 71-72 X5 25	M W C 143-869B-11R-5, 9-10	d V D 143-869B-11R-5, 20	d v X X O 143-869B-11R-CC, 7-9
Ahmuellerella octoradiata			:0	5		0.2%				0.2%			,	ः		1 5
Arkhangelskiella specillata	¥		14	2	10	0.2%	-	0.3%	R	0.2%	0.2%		0.3%	R	R	0.2%
Biscutum constans						64		21		0.2%	3%	R	e g	1		÷
Ceratolithoides aculeus				- E		0.3%		1%	R				0.3%	R	R	0.2%
Chiastozygus litterarius	2)	S2	(<u>)</u>	- 25	<u>.</u>	- N	R	20	R	0.2%	64	20	2		S2	
Corollithion exiguum						0.2%		•0				•				• :
Cretarhabdus spp.	А	A	A	A	F	43%	С	36%	С	33%	23.4%	R	35%	A	A	18%
Cribrosphaerella ehrenbergii				R	F	2%	F	6%		0.2%	15%	R	2%	R	R	0.2%
Crucibiscutum salebrosum		63 24	10	20 20		14	201	80160	10	MERCORNER M	0.2%		0.02	1000	0.00	1000 A 1000
Cylindralithus sp.	ŝ		62	R		0.2%		0.6%	R	0.2%	0.2%	R	0.3%	R	R	0.2%
Discorhabdus rotatorius	8	22			<u></u>		1				0.2%	1.5	0.2%			012.62
Fiffellithus eximius	* 0	38 10	2.2 9.5	50 52	13 12	10		•3 53	R	0.2%	0.2%					*0 37
Fiffellithus turriseiffelii	•			•	•			•	R	0.2%	0.2%	-	0.00		R	
Lithraphidites carniolensis				55 10	20 20	3	18	53. Alt		0.2%	01270		0.2%		<u></u>	110
Manivitella permatoidea				•		0.2%	P	0.30%		0.2%	0.2%		• S 22	P	P	0.2%
Mierorhabdulus decoratus	* :	12	1	5.	P	0.2%	D	0.30%	2.	0.270	0.2%	<u>10</u>	0.30%	P	P	0.2 10
Micronabaulus accoraius		A		ċ	K	50%	K	Q.5 10	E	A.07.	0.270	, P	70%	C	C	400%
Parkabdalithua ambanaani	A	A	A	C		J-70	P	070	г	470	0.20	K	0.20%	C	D	40%
Parnabaolitnus embergeri	<i>8</i> 2	8		'n		0.00	K	201		201	0.2%	'n	0.5%	P	R	
Preatscosphaera cretacea				K	r	0.2%	F	370	r D	3%	4%	K	170	R	R	
Preaiscosphaera nonjoi	2	87	<u>12</u>	<i>t</i> 0	C	0.2%	P	1%	ĸ	2%	0.5%	'n	0.2%	ĸ	ĸ	0 ECI
Qradrum sissingnu	×			80		0.2%	÷	1%	6	0.2%	3¥	K	1%			0.5%
Quadrum gothicum	8		8	1		0.2%	R	0.3%	<u>.</u>	0.2%		7	3%		**	2%
Quadrum trifidum	. *	>3	•	F		3%	28	0.4%	F			÷	0.3%	•	1	
Reinhardtites anthophorus	2	14	22	10		0.3%	64	1	R	0.2%	0.2%	20	0.3%	S1	R	0.3%
Rhagodiscus asper			87	5 2	*	rew	8	*	*	2	2.2		2 2			26.55
Rhagodiscus splendens		34	34	48			34	971	20 A	3	32	R	-	3K		43
Rucinolithus irregularis			12	3		rew		2.5				2	T			
Tranolithus phacelosus	*		34	*				0.3%	÷					18		ĸ
Vagalapilla stradneri			ā	8			5	8	8	2	0.2%	1		24	3	2
Watznaueria barnesae	A	A	A	A	C	44%	C	41%	C	54.3%	48.4%	R	48%	A	A	38%
Zygodiscus diplogrammus	4	5	5	12	11	0.3%	F		F	0.3%	0.2%	10	0.3%	12	14	2
Zygodiscus erectus				*:				0.5%		0.6%	3%		* :			0.2%
Zygodiscus spiralis			a.				R	1		19 19	34				59.	20 20
Coccosphaera					2		R				0.3%	12	22	2	12	15

Table 7. Distribution of calcareous nannofossils in the upper Campanian interval recovered at Site 869.

Notes: Estimates of the total nannofossil abundance are as follows: A (abundant):=>10% of all particles, C (common)= 1%-10% of all particles, F (few)= 0.1%-1% of all particles, and R (rare)=<0.1% of all particles. Estimates of the preservation are as follows: M (moderate)= most specimens display moderate overgrowth/dissolution, and species identification is usually not impaired; and P (poor)= most specimens display significant amounts of overgrowth/dissolution, and species identification is sometimes impaired. Estimates of the relative abundance of nannofossil species are as follows: A (abundant)= 10–30 specimens/field of view, C (common)= 1–10 specimens/field of view, F (few): 1 specimen/2–10 fields of view.



Figure 3. Late Cretaceous calcareous nannofossil biostratigraphy of Sites 873, 874, and 877 from Wodejebato Guyot and Site 869. Time scale after Gradstein et al. (1994); calcareous plankton biostratigraphy and chronostratigraphy are discussed by Erba et al. (this volume).

Prediscosphaera appeared in the mid-Cretaceous, and it is plausible that their abundance was relatively low because they were at the beginning of their evolution. Notwithstanding, both Roth's (1981) and Erba's (1992b) data sets document that *C. ehrenbergii* and *Pre-discosphaera* clearly increased in abundance close to the paleoequator even if they were outnumbered by *B. constans* and *Z. erectus*. The present study suggests that in the Late Cretaceous, *C. ehrenbergii* and *Prediscosphaera* possibly bloomed under relatively fertile surfacewater conditions.

CONCLUSIONS

Extensive, detailed investigation of calcareous nannofossils in shallow-water sequences drilled on Wodejebato Guyot resulted in the first documentation of nannoplankton from lagoonal or restricted environments in Cretaceous atolls from the Pacific Ocean. Although nannofloral assemblages are nicely preserved and highly diverse at Sites 873, 874, and 877, they are extremely rare and confined to a few layers within the oldest marine sediments above the basalts.

The late Campanian CC22 Zone of Sissingh (1977) was identified at Site 877, but the presence of older sediments on Wodejebato Guyot is evidenced by the occurrence of the Cenomanian-restricted species *Corollithion kennedyi*. These findings are in agreement with previous records of mid-Cretaceous sediments that were dredged along the flanks of Wodejebato Guyot (Lincoln et al., 1993). The Campanian basalts represent a second episode of volcanism that followed an Early Cretaceous pulse.

Decreases in abundance and diversity of nannofossils from the inner ridge that constituted the atoll's frame toward the middle part of the lagoon are interpreted as the result of decreasing connections with the open ocean. All taxa are represented by dwarf coccoliths that are markedly smaller than standard sizes, whereas normal-sized specimens were observed in coeval pelagic sediments recovered at Site 869, which is located on the basin floor south of Wodejebato Guyot. The small size seems to be peculiar to lagoonal nannoplankton because this character was noted in other assemblages recorded from extant and fossil lagoons.

At Wodejebato, assemblages are dominated by Cribrosphaerella ehrenbergii, Prediscosphaera spp., Cretarhabdus spp., Biscutum constans, and Zygodiscus erectus. Watznaueria barnesae is common but not dominant. Rare holococcoliths were observed at all sites. The relatively high abundance of the fertility indicators B. constans and Z. erectus at Sites 873, 874, and 877 was possibly controlled by the proximity of Wodejebato Guyot to the paleoequatorial upwelling belt during the Campanian. In fact, similar nannofloras were previously reported from mid-Cretaceous sites at similar paleolatitudes in the central-western Pacific. The present study suggests that in the Late Cretaceous, C. ehrenbergii and Prediscosphaera possibly bloomed under relatively fertile surface-water conditions. This paleoecological/ paleoceanographic interpretation is partially supported by the upper

Table 8. Size variations of the most abundant nannofossil species in late Campanian lagoonal sediments at Wodejebato (Sites 873, 874, and 877) compared with sizes of the oceanic specimens at Site 869 and the holotypes.

Species	Holotype	Site 869	Measured specimens (N)	Sites 873, 874, and 877	Measured specimens (N)
B. constans	L = 5 µm W = 4.5 µm	$L = 5 \mu m$ $W = 4.5 \mu m$	30	$L = 2.5 - 3.5 \ \mu m$ $W = 2 - 2.8 \ \mu m$	30
C. surirellus	$L = 4.8-6 \mu m$ W = 3.8-4.6 μm	L = 5.5 - 8.5 mm W = 4.5 - 6 um	30	$L = 3.5-4.5 \ \mu m$ W = 2.8-3.5 um	30
C. ehrenbergii	Not given L = 7 μ m, W = 5.5 μ m* L = 6.2 μ m, W = 4.8 μ m ⁺	$L = 6.5-7 \ \mu m$ $W = 5-6 \ \mu m$	30	$L = 4.4-5.6 \ \mu m$ W = 3.6-4.5 \ \ \ m	30
P. cretacea	Not given $L = 5.5-10 \ \mu m, W = 4-8 \ \mu m^*$ $L = 8.3 \ \mu m, W = 6.4 \ \mu m^{\dagger}$	$L = 6.5-8 \ \mu m$ $W = 5-6.6 \ \mu m$	30	L = 4–5.5 μm W = 3.5–4.7 μm	30
O. trifidum	$L = 9.9 \ \mu m^{++}$	$L = 9.5 - 12.5 \text{ um}^{**}$	15	$L = 5 - 7.6 \text{ um}^{**}$	15
W. barnesae	$L = 5.5 \ \mu m$ W = 4.8 \ \ \ m	$L = 6-9 \ \mu m$ W = 5-7 \ \ \ m	30	$L = 3.5-4.4 \ \mu m$ $W = 2.7-3.6 \ \mu m$	30
Z. erectus	$L = 4.9 \ \mu m$ W = 3.3 \ \ \ m	$L = 4-5 \ \mu m$ W = 3-3.5 \ \ \ m	30	$L = 2.5-3 \mu m$ $W = 2-2.5 \mu m$	30

Notes: N = number. L = length, and W = width. * = From Perch-Nielsen (1985). † = From Thierstein (1976). ** = Distance between two apexes.



Figure 4. Assemblage composition of late Campanian nannofloras at Sites 873, 874, and 877 on Wodejebato Guyot and Site 869. The geologic map of Wodejebato Guyot is simplified after Bergersen (1993). On Wodejebato Guyot, nannofossil abundance and diversity (= number of species) decrease from the inner ridge toward the middle part of the lagoon, whereas reworking decreases toward the frame of the guyot. At Site 869, assemblages are abundant and moderately to poorly preserved; oceanic and dissolution-resistant taxa are dominant.

Sites 873-877 (WODEJEBATO) Stratigraphy, Subsidence and Paleolatitude



(Nakanishi and Gee, this volume)

Measured paleolatitude (Ito and Nogi, this volume)

Figure 5. Location of Wodejebato Guyot at approximately 10°S during the Campanian as reconstructed by Nakanishi et al. (1992) and Larson et al. (this volume). The proximity to the paleoequatorial fertility belt probably controlled the nannofossil assemblage composition observed at Sites 873, 874, 877, and 869.



Figure 6. Synthesis of calcareous nannofossil biogeography for the Cretaceous (slightly modified after Roth [1989] and Erba [1992b]).

Campanian nannofossil record at Site 869, although diagenetic modifications affected the assemblage composition.

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^{*} Abbreviations for names of organizations and publications in ODP reference lists follow the style given in *Chemical Abstracts Service Source Index* (published by American Chemical Society).

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APPENDIX

Species of calcareous nannofossils recognized in this study are listed in alphabetical order. Reported for each taxon are the author(s) who defined the species as well as possible subsequent author(s) who emended the species.

Ahmuellerella octoradiata (Gorka, 1957) Reinhardt, 1964

Arkhangelskiella specillata Vekshina, 1959

Axopodorhabdus albianus (Black, 1967) Wind and Wise in Wise and Wind, 1976

Biscutum cf. B. coronum Wind and Wise in Wise and Wind, 1976

Biscutum constans (Gorka, 1957) Black, 1967

Biscutum sp.

Braarudosphaera regularis Black, 1973

Bukryaster hayi (Bukry, 1969) Prins and Sissingh in Sissingh, 1977

Calculites obscurus (Deflandre, 1959) Prins and Sissingh in Sissingh, 1977 Chiastozygus amphipons (Bramlette and Martini, 1964) Gartner, 1968

Chiastozygus litterarius (Gorka, 1957) Manivit, 1971

Corollithion achylosum Stover, 1966

Corollithion asymmetricus Bukry, 1969

Corollithion exiguum Stradner, 1961

Corollithion kennedyi Crux, 1981

Corollithion signum Stradner, 1963

Cretarhabdus angustiforatus (Black, 1971) Bukry, 1973

Cretarhabdus conicus Bramlette and Martini, 1964

Cretarhabdus crenulatus Bramlette and Martini, 1964

Cretarhabdus striatus (Stradner, 1963) Black, 1973

- Cretarhabdus surirellus (Deflandre in Deflandre and Fert, 1954) Reinhardt, 1970
- Cribrosphaerella ehrenbergii (Arkhangelsky, 1912) Deflandre in Piveteau, 1952

Crucibiscutum salebrosum (Black, 1971) Jakubowski, 1986

Cylindralithus crassus Stover, 1966

Cylindralithus serratus Bramlette and Martini, 1964

Cylindralithus sp.

Discorhabdus rotatorius (Bukry, 1969) Thierstein, 1973

Eiffellithus eximius (Stover, 1966) Perch-Nielsen, 1968

Eiffellithus gorkae Reinhardt, 1965

Eiffellithus parallelus Perch-Nielsen, 1973

Eiffellithus turriseiffelii (Deflandre in Deflandre and Fert, 1954) Reinhardt, 1965

Eiffellithus sp.

Eprolithus floralis (Stradner, 1962) Stover, 1966

Lithastrinus grillii Stradner, 1962

Lithraphidites carniolensis Deflandre, 1963

Lithraphidites cf. L. praequadratus Roth, 1978 Lithraphidites sp.

Manivitella pemmatoidea (Deflandre in Manivit, 1965) Thierstein, 1971

Microrhabdulus attenuatus (Deflandre, 1959) Deflandre, 1963

Microrhabdulus belgicus Hay and Towe, 1963

Microrhabdulus decoratus Deflandre, 1959

Micula concava (Stradner in Martini and Stradner, 1960) Bukry, 1969

Micula decussata Vekshina, 1959 Nannoconus multicadus Deflandre and Deflandre, 1959

Nannoconus sp. (wide canal)

Octocyclus sp. (w

Orastrum campanensis (Cepek, 1970) Wind and Wise in Wise and Wind, 1976 Orastrum sp.

Ottavianus sp.

Parhabdolithus embergeri (Noël, 1958) Stradner, 1963

Placozygus fibuliformis (Reinhardt, 1964) Hoffman, 1970

Placozygus sigmoides (Bramlette and Sullivan, 1961) Romein, 1979

Prediscosphaera bukryi Perch-Nielsen, 1973

Prediscosphaera columnata (Stover, 1966) Manivit, 1971

Prediscosphaera cretacea (Arkhangelsky, 1912) Gartner, 1968

Prediscosphaera honjoi Bukry, 1969

Prediscosphaera intercisa (Deflandre in Deflandre and Fert, 1954) Shumenko, 1976

Prediscosphaera stoveri (Perch-Nielsen, 1968) Shafik and Stradner, 1971 Prediscosphaera sp.

Quadrum sissinghii Perch-Nielsen, 1986

Quadrum gartneri Prins and Perch-Nielsen in Manivit et al., 1977

Quadrum gothicum (Deflandre, 1959) Prins and Perch-Nielsen in Manivit et al., 1977

Quadrum trifidum (Stradner, 1961) Prins and Perch-Nielsen in Manivit et al., 1977

Quadrum sp.

Reinhardtites anthophorus (Deflandre, 1959) Perch-Nielsen, 1968

Rhagodiscus angustus (Stradner, 1963) Reinhardt, 1971

Rhagodiscus asper (Stradner, 1963) Reinhardt, 1967

Rhagodiscus splendens (Deflandre, 1953) Verbeek, 1977

Rotelapillus laffittei (Noël, 1957) Noël, 1973

Rucinolithus terebrodentarius Applegate, Bralower, Covington and Wise in Covington and Wise, 1987

Seribiscutum primitivum (Thierstein, 1974) Filewicz et al. in Wise and Wind, 1976

Stoverius biarcus (Bukry, 1969) Perch-Nielsen, 1984

Thoracosphaera sp.

Tranolithus phacelosus Stover, 1966

Vagalapilla stradneri (Rood, Hay and Barnard, 1971) Thierstein, 1973 Vagalapilla sp.

Watznaueria barnesae (Black in Black and Barnes, 1959) Perch-Nielsen, 1968 Zygodiscus diplogrammus (Deflandre in Deflandre and Fert, 1954) Gartner, 1968 Zygodiscus erectus (Deflandre in Deflandre and Fert, 1954) Bukry and Bramlette, 1969

Zygodiscus spiralis Bramlette and Martini, 1964

Holococcoliths

Sp. A

Sp. C

Sp. E

Sp. F

CAMPANIAN DWARF CALCAREOUS NANNOFOSSILS



Plate 1. Light microscope photomicrographs of Campanian calcareous nannofossils from Sites 873, 874, and 877 (Wodejebato Guyot) and Site 869 (archipelagic apron south of Wodejebato Guyot). All photographs 2500×. **1–3.** *Quadrum trifidum*, Sample 144-877A-20R-1, 44–45 cm. **4.** *Biscutum constans*, Sample 144-877A-20R-1, 44–45 cm. **5.** *Quadrum trifidum*, Sample 143-869B-10R-1, 93 cm. **6.** *Quadrum trifidum*, Sample 143-869B-10R-2, 63–64 cm. **7,8.** *Biscutum constans*, Sample 144-874B-21R-1, 40–41 cm. **9, 10.** *Cribrosphaerella ehrenbergii*, Sample 144-877A-20R-1, 44–45 cm. **11.** *Cribrosphaerella ehrenbergii*, Sample 143-869B-11R-2, 61–62 cm. **15.** *Cribrosphaerella ehrenbergii*, Sample 143-869B-10R-2, 63–64 cm. **16.** *Cribrosphaerella ehrenbergii*, Sample 143-869B-10R-1, 93 cm.

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Plate 2. Light microscope photomicrographs of Campanian calcareous nannofossils from Sites 873, 874, and 877 (Wodejebato Guyot) and Site 869 (archipelagic apron south of Wodejebato Guyot). All photographs 2500×. **1**, **2**. *Watznaueria barnesae*, Sample 144-877A-20R-1, 44-45 cm. **3**. *Watznaueria barnesae*, Sample 144-873A-11R-2, 20 cm. **4**. *Zygodiscus erectus*, Sample 144-877A-20R-1, 44-45 cm. **5**, **6**. *Watznaueria barnesae*, Sample 143-869B-11R-2, 61–62 cm. **8**. *Prediscosphaera cretacea*, Sample 144-873A-11R-2, 20 cm. **11**. *Watznaueria barnesae*, Sample 143-869B-11R-2, 61–62 cm. **12**. *Cribrosphaerella ehrenbergii*, *Prediscosphaera cretacea*, and *Watznaueria barnesae*, Sample 143-869B-10R-2, 63–64 cm.