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14. TERTIARY DINOFLAGELLATE BIOSTRATIGRAPHY OF SITES 907, 908, AND 909 IN THE NORWEGIAN-GREENLAND SEA[1]

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ABSTRACT

Oligocene and Miocene cores from Ocean Drilling Program Leg 151 Holes 907A, 908A, 909C, and 913B in the Norwegian-Greenland Sea were studied palynologically, using a total of 300 samples. Dinoflagellate cysts are present in all samples, allowing age interpretations for all holes.

At Site 907 on the Iceland Plateau, the deepest sediments show a Langhian–Serravallian assemblage and the highest section studied (Cores 151-907A-16X to 9H) has an undifferentiated Tortonian to Pliocene assemblage. Oceanic conditions warmer than the present day and poor nutrient conditions are deduced from the taxonomic composition.

Sites 908 and 909 in the Fram Strait are less than 50 km apart in very contrasting situations: Site 909 is in 2500 m water depth on the Greenland-Spitsbergen Sill and Site 908 is on the Hovgård Ridge, elevated to more than 1000 m above the surrounding seafloor. Organic residues from both sites are dominated by terrestrially derived palynomorphs and plant fragments (many >100 µm), and dinocyst/pollen ratios are relatively low. This indicates relatively nearshore depositional environments almost to the end of the Miocene. Palynology supports and supplements the plate tectonic model for the origin of the Hovgård Ridge as a micro-continental sliver from the Svalbard Platform.

At Site 909, dinoflagellates date a near complete Miocene succession with two possible stratigraphic breaks in the Langhian–Serravallian interval. Throughout the Langhian–Serravallian to Messinian–Zanclean? interval, warm-water species indicate temperate conditions.

At Site 908, 160 m of late Rupelian–early Chattian sediments are unconformably overlain by late Miocene sediments, leaving a hiatus of 15 to 18 m.y. A series of conspicuous acmes observed within three species at Site 909 could be used to date the truncated Miocene section at Site 908.

Cyst reworking in the sediments at Sites 908 and 909 is consistently of late Early Cretaceous and early Paleogene ages and shows a Late Cretaceous gap corresponding to the Albian–Paleogene hiatus observed in the late Mesozoic–Cenozoic formations on Spitsbergen.

INTRODUCTION

Ocean Drilling Program (ODP) Leg 151 was the third leg to sample sediments and basement rocks from the Norwegian-Greenland Sea to reveal its geological and paleoceanographic evolution. Extensive palynological studies were performed on the two previous legs: Leg 38 (Koreneva et al., 1976; Manum, 1976) and Leg 104 (Boulter and Manum, 1989; Manum et al., 1989; Mudie, 1989). Only shore-based palynological studies were conducted for Leg 38, whereas the Shipboard Scientific Parties included a palynologist on Legs 104 and 151 (Leg 104: Peta J. Mudie; Leg 151: John Firth).

Results of palynological studies of 300 samples from the pre-Pliocene sequences recovered from Sites 907, 908, and 909 are presented in this paper, with emphasis on dinoflagellate cyst stratigraphy. A core from the Miocene section of Site 913 is also included, while the Paleogene section from that site has been studied by Firth (this volume). Other shorebased palynological studies on the Leg 151 cores are on spores and pollen from Site 908 by Boulter and Manum (this volume) and Pliocene–Pleistocene marine palynomorphs from Site 911 by Mathiessen and Brenner (this volume), and Pliocene–Pleistocene spores and pollen from Site 910 and 911 by Willard (this volume).

The scientific objectives of Deep Sea Drilling Program (DSDP) and ODP Legs 38, 104, and 151 reflect the progress during the last three decades in the stratigraphic, structural, and geophysical knowledge and modeling of the Norwegian-Greenland Sea. Seventeen sites drilled in 1974 (Leg 38) were selected primarily to verify the model developed during the preceding decade for plate-tectonic evolution of the Norwegian-Greenland Sea. Dinocysts were the only consistent pre-Miocene microfossils present at most sites and provided useful correlations. In 1984 (Leg 104), a major aim was to verify the volcanic origin of the thick sequence of dipping reflectors underlying the sedimentary formations along the earliest rift zone. Leg 104 (1984) was the first to perform continuous coring in this region. Again, dinocyst biostratigraphy was shown to be the only dating tool for large sections, and cysts and pollen were used to date and identify a unique vegetation at the time of the extensive volcanic event at the Paleocene–Eocene transition.

Although Legs 38 and 104 had paleoceanography as a secondary objective, this was the primary objective of Leg 151 (1993), which aimed at revealing the history of the North Atlantic-Arctic Gateway. This oceanic connection plays an important role in the evolution of North Atlantic paleoceanography and therefore of global climates since Paleogene times. A comprehensive discussion of the scientific basis for selection of the Leg 151 sites was presented by Myhre and Thiede (1995).

Dinoflagellate cysts (dinocysts) have proved to be the most consistently represented microfossil group in Tertiary sediments of the Norwegian-Greenland Sea. In some early Miocene sections drilled

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on Leg 104 (Sites 642 and 643; Manum et al., 1989), abundances in the order of 150,000 to 200,000 specimens per gram of sediment were recorded. Palynological studies of the Norwegian-Greenland Sea cores have been aimed primarily at solving correlative and chronostratigraphic problems. Paleoenvironmental and paleobotanical problems have also been addressed, however, based on the terrestrial palynomorphs and palynodebris associated with the dinocysts, which sometimes dominate the organic assemblages of Leg 151.

Numerous undescribed dinocyst taxa, some of which having proven biostratigraphically useful, have been recorded from the Norwegian-Greenland Sea Tertiary. However, owing to the tight publication schedule for the ODP reports and proceedings, attention had to be directed toward stratigraphic recording of cysts from as many samples as feasible rather than to describing new taxa. Similarly, the emphasis of the present contribution is on dinocyst stratigraphy and correlation. Illustrations are limited to documentation of the stratigraphically most significant taxa.

Site 907 is located on the eastern part of the Iceland Plateau (Fig. 1). Here, pre-cruise studies had shown an undisturbed, flat-lying pelagic sediment sequence with the potential of yielding a detailed paleoenvironmental record of the past 10–12 m.y.

Sites 908 and 909 are situated in the central part of the Fram Strait, between 78° and 79°N latitude, where the Hovgård Ridge, a prominent northwest-southeast–striking structural high about 150 km long, rises abruptly more than 1000 m above the seafloor in the area (Figs. 1, 2). The ridge has significant influence on the present circulation in the Greenland Sea. In order to understand the paleoceanographic evolution of the northernmost Atlantic, knowledge of the geological history of this prominent feature is crucial. Unfortunately, the pre-Pliocene sequence at all of the sites yielded few marine fossils other than dinocysts, which has limited the potential for environmental interpretations. Also, from a dinocyst worker's point of view, the palynological assemblages from Sites 908 and 909 are less rewarding than assemblages from most previous sites in the Norwegian-Greenland Sea because of their dominantly terrestrial component. Nevertheless, useful biostratigraphic interpretations can still be made.

MATERIALS AND METHODS

Samples were processed at the University of Oslo and at the Geological Survey of Denmark and Greenland (GEUS). The processing in Oslo followed traditional methods, including HCl, HF, ultrasonic treatment, and sieving at 20 µm. No oxidation was applied. The samples prepared at GEUS were treated as described in Poulsen et al. (1990), and Desezar and Poulsen (1994). The samples prepared at GSC Atlantic, Geological Survey of Canada (GSC) were treated with HCl and HF, and then given a HCl wash. This was followed by a heavy liquid separation and mild oxidation, up to four minutes in dilute nitric acid, for some of the samples. The others were not oxidized. All samples were screened through a 180-µm mesh and a 20-µm mesh. The <20-µm fraction was then screened through a 10-µm mesh screen, and the <10-µm fraction was discarded. Samples were washed in a dilute solution of ammonium hydroxide before staining with bismuth.

Table 1 lists the samples used. In the range charts the samples are plotted against depths below the seafloor (mbsf). In the stratigraphic discussion we refer to the core and section number and give the depth in parentheses (). The exact position within each borehole can be obtained from Table 1. Figured specimens (Plates 1–3) labeled with a

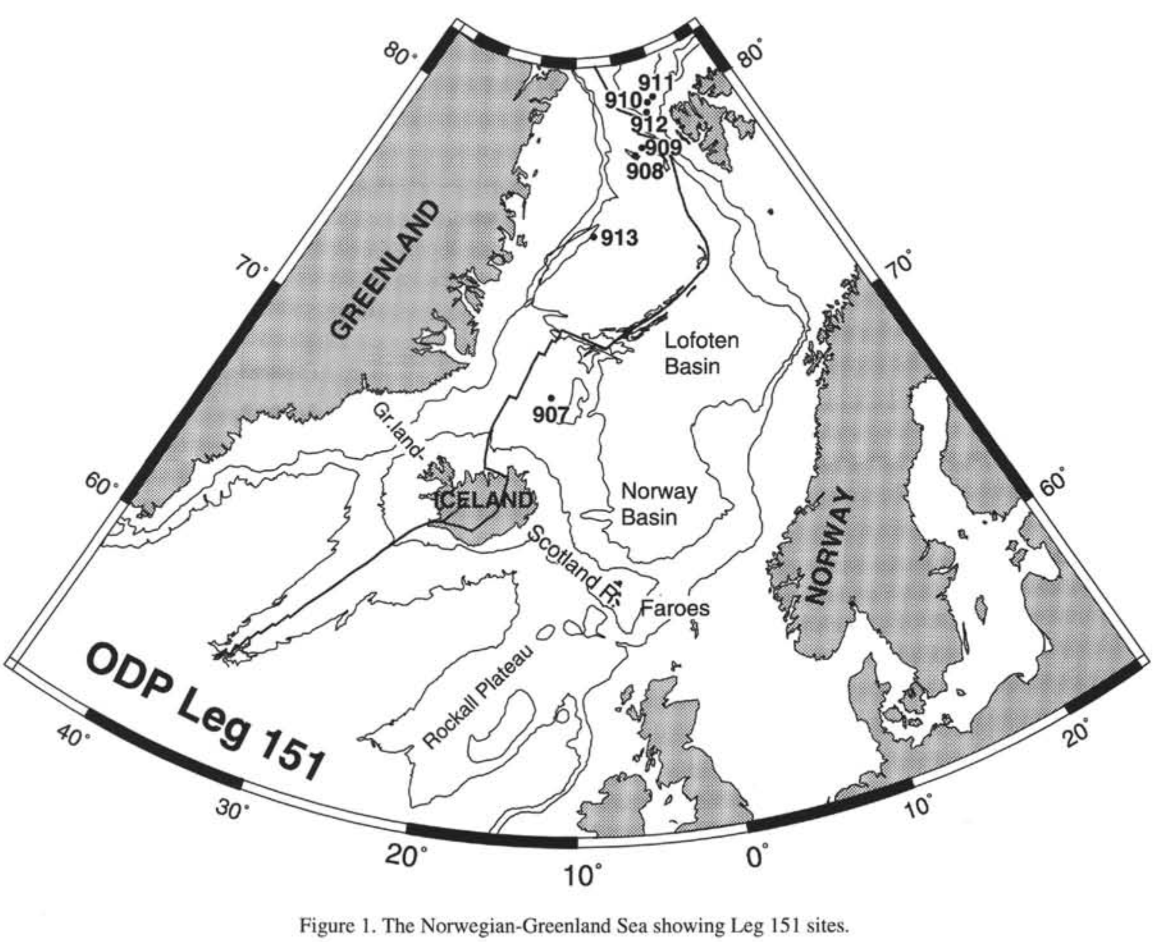

Figure 1. The Norwegian-Greenland Sea showing Leg 151 sites.

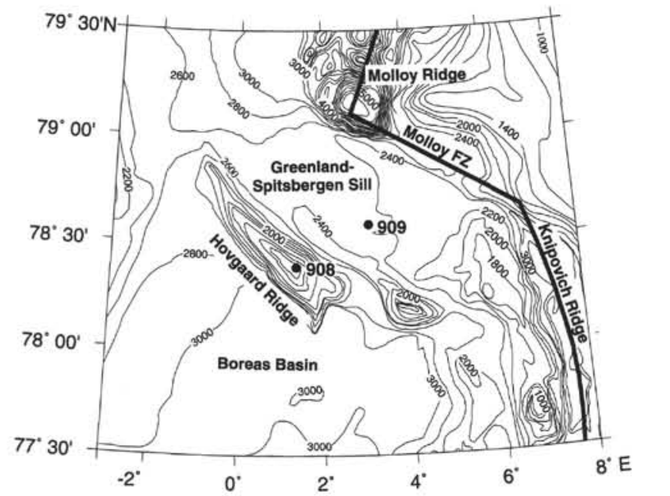

Figure 2. Bathymetry of the Fram Strait around the Hovgård Ridge and ODP Sites 908 and 909. Major plate tectonic structures are indicated (from Karlberg, 1995).

GEUS catalog number are stored at GEUS, figured specimens labeled with GSC are stored at GSC, and figured specimens labeled with UO are stored at the University of Oslo.

DINOCYST BIOSTRATIGRAPHY AND TOTAL ORGANIC ASSEMBLAGES

The dinoflagellate biostratigraphy used in this study is based on that of Brown and Downie (1985), Costa and Manum (1988), de Vernal and Mudie (1989a, b), de Vernal et al. (1992), Edwards (1984, 1988), Head et al. (1989a, b), Lund et al. (1993), Manum et al. (1989), Shipboard Scientific Party (1994), and Williams et al. (1993). Several zonation schemes, formal and also informal, which are relevant to the present study have been proposed (e.g., Piasecki, 1980; Costa and Manum, 1988; Head et al., 1989a; Manum et al., 1989; Powell, 1992).

No widely accepted zonation is, however, applicable in the region and time interval of our study. In higher latitudes in particular, paleoenvironmental events might be superimposed on more regional biostratigraphic events. Thus, after reviewing the medium to high latitude Miocene studies (e.g., Williams, 1975; Manum, 1976; Williams and Bujak, 1977; Costa and Downie, 1979; Bujak and Davies, 1983; Edwards, 1984; Manum et al., 1989; Piasecki, 1980; and others), Head et al. (1989a) concluded that there was no widely accepted zonal scheme for the Arctic region. Most of our samples are from the Miocene; for this interval, both taxonomy and stratigraphic documentation for ranges of significant taxa are in need of further improvement.

In this study we have applied an informal biostratigraphic subdivision into numbered zones; Oli1 to Oli5 for the Oligocene, Mio1 to Mio6 for the Miocene, and Pli1 to Pli3 for the Pliocene. Table 2 summarizes the first appearances (FADs) and last occurrences (LODs) of dinocysts used for the definition of these zones and for our biostratigraphic interpretations.

SITE 907

Site 907 was drilled on the eastern part of the Iceland Plateau in 1800 m water depth (Fig. 1). The hole reached terminal depth in basalt after coring 216 m of sediment. The site represents the western part of a paleoenvironmental transect across the Norwegian Sea; Leg 104 sites represent the eastern part of this transect.

Five sedimentary lithological units were recognized by the Shipboard Scientific Party (1995a, p. 61). This study is based on samples from the base of Unit V to the middle of Unit IIIA, where the Shipboard Scientific Party (1995a, p. 77) had placed the Miocene/Pliocene boundary in Core 151-907A-10H (84.8 mbsf). The lithologies are silty clay, with various amounts of biosilica alternating with thin nannofossil ooze beds.

The sampling density was approximately three to each core (49 samples from 141 m of cored sediments). The samples yielded only small amounts of organic matter (spores, pollen, dinocysts, wood, cuticles); spores, pollen, and dinocysts were the most abundant groups. Table 3 lists the recorded species alphabetically and gives their reference number in the range charts (Fig. 3).

Biostratigraphy

Miocene (Langhian or older): Sample 151-907A-23H-CC (216.40 mbsf)

The lowermost sample, 151-907A-23H-CC (216.40 mbsf), lacks index taxa, but the presence of *Batiacasphaera sphaerica* suggests that no pre-Miocene is present because this species appears to have its FAD in the Miocene (M.J. Head, pers. comm., 1991; Head et al., 1989a).

Langhian–Serravallian: Samples 151-907A-23H-4 to 20H-CC (211.50–187.90 mbsf)

Zone Mio3, equivalent to a Langhian–Serravallian age, is indicated by the deepest record of *Unipontidinium aquaeductum* in Sample 151-907A-23H-CC (211.50 mbsf) and the highest record of *Distatodinium paradoxum* in Sample 151-907A-22H-CC (206.85 mbsf). The deepest record of *Amiculosphaera umbracula* in Sample 151-907A-20H-CC (187.90 mbsf) is also referred to this zone.

Serravallian–Tortonian: Samples 151-907A-20H-4 to 16H-4 (182.92–144.94 mbsf)

This interval is referred to the *Zones Mio4–5* because of lack of index taxa that can differentiate them. The top of *Zone Mio5* is indicated by the highest record of *Palaeocystodinium golzowense* in Sample 151-907A-16H-4 (144.94 mbsf).

Tortonian–Messinian: Samples 151-907A-16H-2 to 9H-2 (141.94–75.55 mbsf)

Zone Pli1 or older, equivalent to the Zanclean or older, is indicated by the highest record of *Reticulatosphaera actinocoronata* in Core 151-907A-12H-CC (111.97 mbsf) and *Operculodinium piaseckii* in Core 151-907A-12H-2 (104.08 mbsf). The upper part of the interval, Samples 151-907A-11H-CC to 9H-2 (102.64–75.55 mbsf), is characterized by low dinocyst diversity, with fewer than three species in most samples, and by the absence of index taxa. Paleomagnetic data (Shipboard Scientific Party 1995a, p. 77) show that the Miocene/Pliocene boundary is near the top of Section 151-907A-10H-2 (84.75 mbsf). Therefore, only the interval below Section 151-907A-10H-2 (84.75 mbsf) is here referred to the Tortonian–Messinian, while the interval above is assigned a post-Miocene age.

Interpretations and Conclusions

The oceanic species *Nematosphaeropsis rigida* occurs in moderate to high numbers, whereas *Impagidinium pallidum,* which is also

Table 1. List of samples from Sites 907, 908, 909, and 913.

Core, section	Depth (mbsf)
151-907A-	
9H-2	75.55
9H-4	78.55
9H-6	81.55
10H-2	84.88
10H-4	88.04
10H-6	91.27
10H-CC	93.01
11H-2	94.54
11H-4	97.54
11H-6	100.53
11H-CC	102.64
12H-2	104.08
12H-4	107.07
12H-6	109.99
12H-CC	111.97
13H-2	113.54
13H-4	116.54
13H-6	119.54
13H-CC	121.62
14H-2	122.94
14H-4	125.94
14H-CC	130.98
15H-2	132.44
15H-4	135.44
15H-CC	140.25
16H-2	141.94
16H-4	144.94
16H-CC	149.91
17H-2	151.44
17H-4	154.44
17H-CC	159.54
18H-2	160.94
18H-4	163.94
18H-CC	168.90
19H-2	170.44
19H-4	173.44
19H-6	176.44
20H-2	179.94
20H-4	182.92
20H-CC	187.90
21H-2	189.44
21H-4	192.44
21H-CC	197.38
22H-2	198.94
22H-4	201.94
22H-CC	206.85
23H-2	208.50
23H-4	211.50
23H-CC	216.40
151-908A-	
8H-1	63.39
8H-5	69.11
9H-2	74.13
9H-5	78.52
11H-2	93.12
12X-02	102.83
13X-02	112.62
14H-2	122.23
15X-2	131.93
16X-2	141.43
17X-2	150.93
18X-1	158.85
18X-2	160.34
18X-2	160.43
18X-3	161.85
18X-4	163.34
18X-5	164.86
18X-6	166.36
18X-7	167.39
19X-1	168.79
19X-2	170.03
19X-2	170.29
19X-3	171.79
19X-4	173.29

Core, section	Depth (mbsf)
19X-5	174.53
19X-5	174.79
19X-CC	175.30
20X-1	177.93
20X-2	179.63
20X-2	179.67
20X-2	179.95
20X-2	180.26
20X-3	180.55
20X-3	180.85
20X-3	181.13
20X-3	181.45
20X-3	181.77
20X-4	182.30
20X-4	182.35
20X-4	182.65
20X-4	183.06
20X-5	183.55
20X-5	183.85
20X-5	184.16
20X-5	184.44
20X-5	184.76
20X-6	185.05
20X-6	185.35
20X-6	185.58
20X-6	185.66
20X-CC	186.64
21X-1	188.24
21X-2	189.33
21X-2	189.87
21X-3	191.29
21X-4	192.94
21X-5	193.35
21X-6	194.93
21X-CC	196.56
22X-1	197.90
22X-2	199.53
22X-3	201.04
22X-4	202.41
22X-5	203.93
22X-CC	204.48
23X-1	207.18
23X-2	208.75
23X-3	210.23
23X-4	211.72
23X-5	213.21
23X-6	214.71
23X-CC	214.90
24X-1	216.41
24X-2	217.91
24X-3	219.70
24X-4	221.64
24X-5	223.12
24X-6	223.74
24X-7	225.21
24X-CC	225.41
25X-1	226.02
25X-2	227.51
25X-3	228.68
25X-4	230.18
25X-5	231.73
25X-6	233.25
25X-CC	233.37
26X-1	235.72
26X-2	236.87
26X-3	238.81
26X-4	240.08
26X-5	242.02
26X-6	243.23
27X-1	245.27
27X-2	246.67
27X-3	248.13
27X-4	249.61
27X-5	251.13
27X-CC	252.40
28X-1	254.84

Core, section	Depth (mbsf)
28X-2	256.40
28X-3	258.02
28X-4	260.23
28X-5	261.18
28X-6	262.61
28X-CC	263.24
29X-1	264.93
29X-2	266.54
29X-3	267.60
29X-4	269.61
29X-5	271.14
29X-6	272.69
29X-CC	273.73
30X-1	274.72
30X-2	276.32
30X-3	277.94
30X-4	278.67
30X-5	280.76
30X-6	281.90
30X-7	283.28
30X-CC	283.37
31X-1	283.92
31X-2	286.34
31X-3	287.87
31X-4	288.96
31X-5	290.64
31X-6	291.97
31X-7	292.73
31X-CC	292.98
32X-1	293.57
32X-2	295.21
32X-3	296.82
32X-4	298.50
32X-5	300.06
32X-6	301.86
32X-7	302.40
32X-CC	302.69
33X-1	303.72
33X-2	305.48
33X-3	307.15
33X-4	308.01
33X-5	309.75
33X-6	311.27
33X-CC	312.30
34X-1	313.27
34X-1	313.72
34X-2	314.52
34X-3	316.06
34X-4	317.53
34X-5	319.01
35X-2	321.99
35X-3	324.53
35X-4	326.03
35X-5	327.57
35X-6	327.99
36X-1	330.64
36X-2	332.28
36X-3	333.45
36X-4	335.26
36X-5	336.19
37X-1	340.74
37X-2	342.24
151-909C-	
27R-CC	341.70
28R-CC	351.23
29R-CC	362.65
30R-CC	364.60
31R-CC	382.64
32R-CC	391.24
33R-CC	402.10
34R-CC	411.25
35R-CC	422.07
36R-CC	431.10
37R-CC	431.97
38R-CC	445.76

Core, section	Depth (mbsf)
39R-CC	453.16
40R-CC	467.79
41R-CC	479.89
42R-CC	487.91
43R-CC	499.15
44R-CC	505.77
45R-CC	516.60
46R-CC	524.30
47R-CC	536.36
48R-CC	546.70
49R-CC	556.92
50R-CC	562.14
51R-CC	573.01
52R-CC	581.68
53R-CC	593.31
54R-CC	599.15
55R-CC	614.33
56R-01	615.16
57R-CC	632.13
58R-CC	636.07
59R-CC	652.04
60R-CC	662.23
61R-CC	670.02
62R-CC	682.40
63R-CC	687.36
64R-01	692.31
65R-01	701.79
66R-CC	713.88
67R-CC	730.49
68R-CC	735.59
69R-CC	749.00
70R-CC	757.82
71R-CC	768.30
72R-CC	778.00
73R-CC	787.05
74R-CC	795.74
75R-CC	807.72
76R-CC	817.17
77R-CC	823.66
78R-CC	831.50
80R-CC	855.75
81R-CC	861.78
82R-CC	867.88
83R-CC	880.40
84R-CC	891.11
85R-CC	896.77
86R-CC	907.64
87R-CC	916.23
88R-CC	926.37
89R-CC	935.90
91R-CC	954.00
92R-CC	963.00
93R-CC	973.00
95R-CC	992.00
97R-CC	1011.00
98R-CC	1020.00
99R-CC	1030.61
100R-01	1039.75
100R-02	1040.72
100R-CC	1040.86
101R-01	1048.82
101R-02	1050.32
102R-01	1052.94
102R-02	1055.44
102R-04	1057.71
102R-CC	1057.96
103R-01	1058.34
103R-02	1060.48
103R-CC	1062.13
151-913B-	
19W	376.54
19W	377.70
19W	379.19
19W	380.69
19W	381.66

an oceanic form, occurs inconsistently and in low numbers. The latter is a subpolar to polar form (Head et al., 1989a; B. Dale, unpubl. data 1995), and its low representation may indicate that the oceanic conditions were warmer than present-day subpolar conditions.

The assemblages in most of the samples show high proportions of small round forms such as *Batiacasphaera* spp., *Tectatodinium psilatum, Impagidinium strialatum,* or *Cymatiosphaera invaginata.* The abundance of these forms is probably of paleoenvironmental significance, but only for *I. strialatum* is there firm evidence regarding environmental distribution, indicating warm temperate oceanic conditions. *Batiacasphaera* spp., *T. psilatum,* and *C. invaginata* may also be indicative of similar conditions. They may also indicate nutrient-poor waters, because the assemblages show dominance of gonyaulacoids over peridinioids, which indicates poor nutrient conditions.

Table 2. Stratigraphic index species used in this study.

Age	Zone	First appearance datum (base of zone)	Last occurrence datum (top of zone)	Nannoplankton zones
Tiglian–Bavalian	Qty1		*Amiculosphaera umbracula* *Filisphaera filifera* *Impagidinium japonicum* *I. multiplexum I. velorum* *Tectatodinium pellitum*	NN 18-19
Piacenzian–Praetiglian	Pli3		*Invertocysta lacrymosa* *Lejeunecysta communis* *L.* cf. *fallax*	NN 16-18
Zanclean–Piacenzian?	Pli2		*Batiacasphaera micropapillata* *Hystrichosphaeropsis obscura*	NN 15-16
Zanclean	Pli1		*Operculodinium piaseckii* *Reticulatosphaera actinocoronata*	NN 12-14
Messinian–Zanclean	Mio6	*Impagidinium aculeatum* *Spiniferites splendidus*	*Dapsilidinium pastielsii* *Labyrinthodinium truncatum* *Unipontidinium aquaeductum*	NN 11
Tortonian	Mio5	Incertae sedis sp. 1 of Edwards (1984) *Operculodinium janduchenei.*	*Palaeocystodinium golzowense*	NN 8-10
Serravallian	Mio4	*Achomosphaera? andalousiensis*	*Systematophora placacantha*	NN 7-8
Langhian–Serravallian	Mio3	*Amiculosphaera umbracula* *Impagidinium patulum* *Selenopemphix dioneaecysta* *Unipontidinium aquaeductum*	*Apteodinium australiense* *Distatodinium paradoxum*	NN 5-6
Langhian	Mio2	*Invertocysta tabulata* *Labyrinthodinium truncatum*	*Apteodinium spiridoides* *Cribroperidinium tenuitabulatum*	NN 4
Aquitanian–Burdigalian	Mio1		*Cordosphaeridium cantharellum*	NN 1-4
Chattian	Oli5		*Batiacasphaera* cf. *B. baculata* *Chiropteridium* spp.	NP 25
	Oli4	*Batiacasphaera micropapillata*	*Areoligera semicirculata* *Deflandrea phosporitica* *Phthanoperidinium comatum* *Spiniferella cornuta* *Thalassiphora pansa*	NP24
Rupelian	Oli3	*Thalassiphora pansa*		NP23
	Oli2		*Phthanoperidinium amoenum*	NP22
	Oli1	*Areoligera semicirculata* *Chiropteridium galea* *Reticulatosphaera actinocoronata*		NP21

At Sites 642 and 643 outside the Vøring Plateau, small proximate cysts were common in the Miocene intervals (Manum et al., 1989), but they did not show the overwhelming frequencies as were seen at Site 907. Time-equivalent assemblages from Sites 908 and 909 in the Fram Strait show no corresponding abundance of small round cysts.

Sites 907, 908, and 909 have some distinctive suites of acmes. The acme suite at Site 907 includes a high abundance of *Impagidinium strialatum,* which is a warm-water species. At Site 908, an acme of *Nematosphaeropsis rigida* is followed upcore by acmes of *Evittosphaerula* sp. 2 of Manum et al. (1989) and of *Barssidinium* spp. A second acme of *N. rigida* coincides with the abundant to dominant occurrence of *Operculodinium israelianum,* which is also a warm-water species. An acme of *O. israelianum* at Site 909 occurs above the successive acmes of *Nematosphaeropsis* spp., *Evittosphaerula*? sp. 2 of Manum et al. (1989), and *Barssidinium* spp. (see below). The acme events at Site 907 do not appear correlative to any of the events recorded at Site 909.

Reworking

Jurassic to Paleogene dinocysts are present in low numbers in many analyzed samples. The taxa include *Gonyaulacysta jurassica, Sirmiodinium grossi,* and *Chlamydophorella, Cyclonephelium, Circulodinium, Achilleodinium, Isabelidinium, Wetzeliella,* and *Apectodinium* spp.

SITE 909

At Site 909, three holes (909A–C) were drilled; the following analysis deals with sediments from Hole 909C. The site is located centrally in the Fram Strait on the sill separating the Greenland Sea and the Arctic Ocean (Figs. 1–2, 4). The site is in 2518 m water depth and is immediately north of the Hovgård Ridge.

Terminal depth of the hole was 1061.80 mbsf, where, because of heavy hydrocarbons, drilling had to be stopped for safety reasons.

Table 3. Alphabetic list of recorded species and their reference number in the range charts (Figs. 3, 5, 6).

Name	Hole 909C		Hole 908A		Hole 907A	
	F	L	F	L	F	L
Achomosphaera ramulifera		82	37			
Achomosphaera sp. 1	33	23	71	27	67	34
Achomosphaera? *andalousiensis*	64	27	93	14		
Amiculosphaera umbracula	65	15	79	2	40	22
Apteodinium australiense	22	80	36	69		
Apteodinium spiridoides	13	104	32	75		
Apteodinium spp.	79	35			22	64
Areoligera semicirculata			9	66		
Areosphaeridium spp.			89	38		
Artemisiocysta cladodichotoma			26	76		
Artemisiocysta spp.			67	57		
Barssidinium graminosum	62	22	72	28	48	25
Batiacasphaera cf. *baculata* of Head et al. 1989	77	85				
Batiacasphaera gemmata	92	65	55	5		
Batiacasphaera hirsuta	28	43	65	43	50	4
Batiacasphaera micropapillata	61	36	51	6	12	1
Batiacasphaera minuta	95	57			16	49
Batiacasphaera sphaerica	29	37	63	4	7	17
Batiacasphaera spp.	31	32	60	22	51	52
Bitectatodinium tepikiense	105	2			57	40
Brigantedinium (al. *Protoperidinium*) spp.	96	58				
Brigantedinium simplex (al. *P. conicoides*)	107	1				
Caligodinium amiculum			31	62		
Chiropteridium galea "complex"			2	67		
Chiropteridium spp.	23	62				
Cordosphaeridium cantharellum			7	72		
Cordosphaeridium minimum	15	19	12	13	6	20
Cordosphaeridium spp.	94	33				
Cribroperidinium spp.	63	56				
Cribroperidinium tenuitabulatum			53	61		
Cristadinium cristatoserratum			85	54		
Cristadinium spp.	68	92				
Cymatiosphaera? *invaginata*			83	30	59	21
Dapsilidinium pastielsii	100	34	17	51	35	23
Dapsilidinium pseudocolligerum	81	84				
Dapsilidinium spp.	47	74	16	20	17	48
Deflandrea heterophlycta			34	85		
Deflandrea phosphoritica "complex"			14	65		
Deflandrea spp.	4	107				
Dinocyst 3 of Manum et al. 1989			58	81		
Dinopterygium cladoides			66	68		
Dinopterygium cladoides of Morgenroth 1966			30	71		
Diphyes spp.	42	99				
Distatodinium biffii			6	83		
Distatodinium craterum	53	97			37	60
Distatodinium paradoxum	44	95	35	82	28	62
Distatodinium spp.	35	16	16	91	8	18
Evittosphaerula spp.	86	75				
Evittosphaerula? sp. 2 of Manum et al. 1989	59	79	69	49	66	10
Filisphaera filifera	43	98			61	37
Glaphyrocysta microfenestrata	47	88				
Habibacysta tectata					60	39
Heteraulacacysta campanula			33	94		
Homotryblium spp.	80	39				
Homotryblium vallum	88	68				
Hystrichokolpoma denticulatum	41	100				
Hystrichokolpoma pacificum	25	50	95	1		
Hystrichokolpoma poculum	55	64				
Hystrichokolpoma rigaudiae	73	87	20	48		
Hystrichokolpoma sp. 2 of Manum et al. 1989	1	67				
Hystrichokolpoma spp.	49	59	3	19		
Hystrichokolpoma truncatum	89	69				
Hystrichosphaeropsis obscura	12	42	68	60	55	45
Hystrichosphaeropsis spp.	54	88				
Hystrichostrogylon coninckii	74	90			29	63
Impagidinium aculeatum	106	13				
Impagidinium japonicum	78	45	61	77	45	53
Impagidinium pallidum	51	41	91	36	52	19
Impagidinium paradoxum			66	93		
Impagidinium patulum			85	14	62	38
Impagidinium sp. 2 of Manum et al. 1989		20	101			
Impagidinium sp. 3 of Manum et al. 1989	16	102				
Impagidinium spp.	36	17	39	23	10	9
Impagidinium strialatum	24	53	90	39	31	8
Impletosphaeridium spp.	98	21			42	11
Incertae sedis sp. 1 of Edwards 1984					65	24
Invertocysta lacrymosa	34	24				
Invertocysta tabulata	32	29	80	3		
Labyrinthodinium truncatum	6	82	75	58	19	30
Lejeunecysta spp.	37	5	24	7	21	7
Lingulodinium brevispinosum	50	52			58	32
Lingulodinium machaerophorum (al. *L. polyedrum*)	26	46	13	8	25	28
Lophocysta sulcolimbata	87	76				
Melitasphaeridium choanophorum	18	18	73	16	63	25
Membranophoridium aspinatum			1	95		
Nematosphaeropsis labyrinthea	17	103				
Nematosphaeropsis lemniscata	38	6	50	41	38	59
Nematosphaeropsis rigida	52	28	84	11	13	2

Table 3 (continued).

Name	Hole 909C F	Hole 909C L	Hole 908A F	Hole 908A L	Hole 907A F	Hole 907A L
Nematosphaeropsis spp.	76	77				
Oligosphaeridium spp.	30	38			32	57
Operculodinium (al. *Protoceratium*) spp.	7	73	42	17	4	44
Operculodinium centrocarpum (al. *P. reticulatum*)	39	7	11	24	9	12
Operculodinium cf. *giganteum* of Manum et al. 1989					54	47
Operculodinium? eirikianum			57	56	56	46
Operculodinium israelianum (al. *P. reticulatum*)	57	40	87	29	39	27
Operculodinium janduchenei	90	70				
Operculodinium? cf. *longispinigerum*				88	46	
Operculodinium longispinigerum	103	30				
Operculodinium piaseckii	71	60	62	21	44	14
Operculodinium? echigoense	58	96				
Operculodinium? eirikianum	9	61				
Palaeocystodinium golzowense	8	71	10	32	3	50
Palaeocystodinium sp. 1			27	63	53	51
Palaeocystodinium spp.	27	47		33	48	
Palaeotetradinium spp.			23	65		
Pentadinium laticinctum	82	55	18	64	30	42
Pentadinium spp.	67	94				
Phelodinium spp.	40	8	86	25	46	54
Phthanoperidinium alectrolophorum			48	90		
Phthanoperidinium amoenum			43	87		
Phthanoperidinium comatum			44	78		
Phthanoperidinium geminatum			40	89		
Phthanoperidinium spp.			52	79		
Polykrikos schwartzii	72	91				
Polykrikos spp.			46	93		
Polysphaeridium congregatum					47	55
Polysphaeridium subtile	5	106				
Polysphaeridium zoharyi (al. *P. bahamense*)	70	78				
Protoperidinium spp.	83	44			41	13
Protoperidinium spp."round browns"	19	9	28	18	49	6
Quinquecuspis (al. *Protoperidinium*) spp.			64	52		
Reticulatosphaera actinocoronata	2	12	23	35	20	31
Reworked dinoflagellate cysts	108	108	96	96	67	67
Riculacysta perforata	75	81				
Selenopemphix (al. *Protoperidinium*) *subinerme*			78	55		
Selenopemphix brevispinosa			77	34		
Selenopemphix dioneaecysta			76	40		
Selenopemphix nephroides			49	53		
Selenopemphix spp.	10	20	15	12		
Spiniferella cornuta			8	73		
Spiniferites elongatus					14	3
Spiniferites membranaceus					56	84
Spiniferites mirabilis	101	31	41	80	34	41
Spiniferites ovatus	14	105				
Spiniferites pseudofurcatus "group"	97	54	21	45	18	43
Spiniferites ramosus "group"	11	10	4	9		
Spiniferites sp. B of Piasecki 1980	45	89	94	15		
Spiniferites spp.	21	25	5	10	11	5
Stelladinium spp.	91	4				
Svalbardella sp. 1					59	74
Svalbardella spp.	56	86				
Systematophora placacantha	46	83	37	70	2	66
Systematophora spp.	93	49	70	31		
Tectatodinium pellitum	60	51	38	26	24	33
Tectatodinium psilatum	84	63	26	29		
Tectatodinium spp.	104	26				
Thalassiphora pelagica					29	92
Thalassiphora? pansa					25	86
Trinovantedinium glorianum					74	44
Trinovantedinium papulum					81	33
Trinovantedinium spp.	3	11	54	50	64	36
Tuberculodinium vancampoae (al. *P. steinii*)	48	66	45	47	1	35
Unipontidinium aquaeductum					15	61
Votadinium (al. *Protoperidinium*) spp.	99	48	43	56		
Vozzhennikovia spp.					22	42

Note: F = range chart, sorted by first occurrences; L = range chart, sorted by last occurrences.

Our palynological analysis runs downhole from Core 151-909C-27R-CC, within the upper half of lithologic Unit II, where shipboard analysis had suggested the Pliocene/Miocene boundary (Shipboard Scientific Party, 1995c, p. 172). Units II and III both consist mainly of clayey silt, the main difference being the more evident lamination and bedding in Unit III.

Eighty-one samples from Cores 151-909C-103R to 27R (1062.13–342.70 mbsf) were studied, giving an average sample density of one per core. Table 3 lists the recorded species alphabetically and gives their reference number in the range charts (Fig. 5).

Biostratigraphy

Aquitanian?–Langhian?: Samples 151-909C-103R-CC to 98R-CC (1060.48–1020.00 mbsf)

The deepest samples have low to very poor dinocyst productivity and zonal index species are lacking. Only *Reticulatosphaera actinocoronata* is consistently and sometimes frequently present. *Hystrichokolpoma* sp. 2 of Manum et al. (1989) occurs in the bottom sample; it was not recorded below the Miocene in Site 643 (Leg 104).

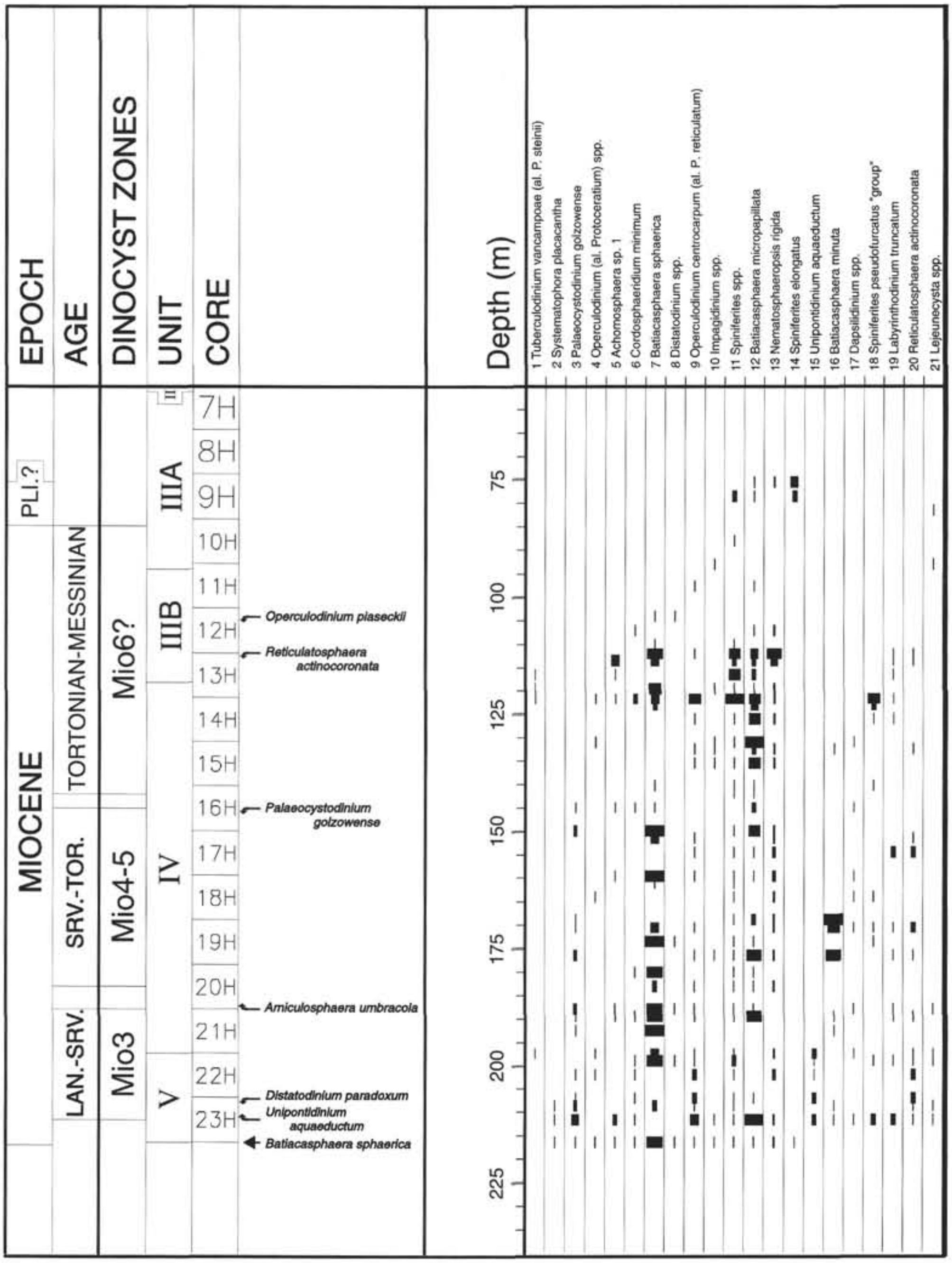

Figure 3. Dinocyst range chart for Hole 907A, sorted by (**A**) first occurrences and (**B**) last occurrences.

Trinovantedinium spp. also extend to the bottom; the genus appears not to have a pre-Miocene range.

Langhian: Samples 151-909C-98R-CC to 95R-CC (1020.00–992.00 mbsf)

The base of *Zone Mio2,* equivalent to a Langhian age is indicated by the deepest record of *Labyrinthodinium truncatum* in Sample 151-909C-98R-CC (1020.00 mbsf). The top of *Zone Mio2* is identified by the highest record of *Apteodinium spiridoides* in Sample 151-909C-95R-CC (992.00 mbsf).

Langhian–Serravallian: Samples 151-909C-93R-CC to 82R–CC (973.00–867.78 mbsf)

Zone Mio3, equivalent to a Langhian–Serravallian age, is indicated up to the highest records of *Apteodinium australiense* and *Distatodinium paradoxum* in Samples 151-909C-87R-CC (916.23 mbsf) and 81R-CC (861.78 mbsf), respectively. However, the deepest record of *Achomosphaera*? *andalousiensis,* the FAD index species for *Zone Mio4,* in Sample 82R-CC (867.88 mbsf) is 6 m deeper than the LOD of *D. paradoxum.* Therefore, we chose to use the FAD of *A*?

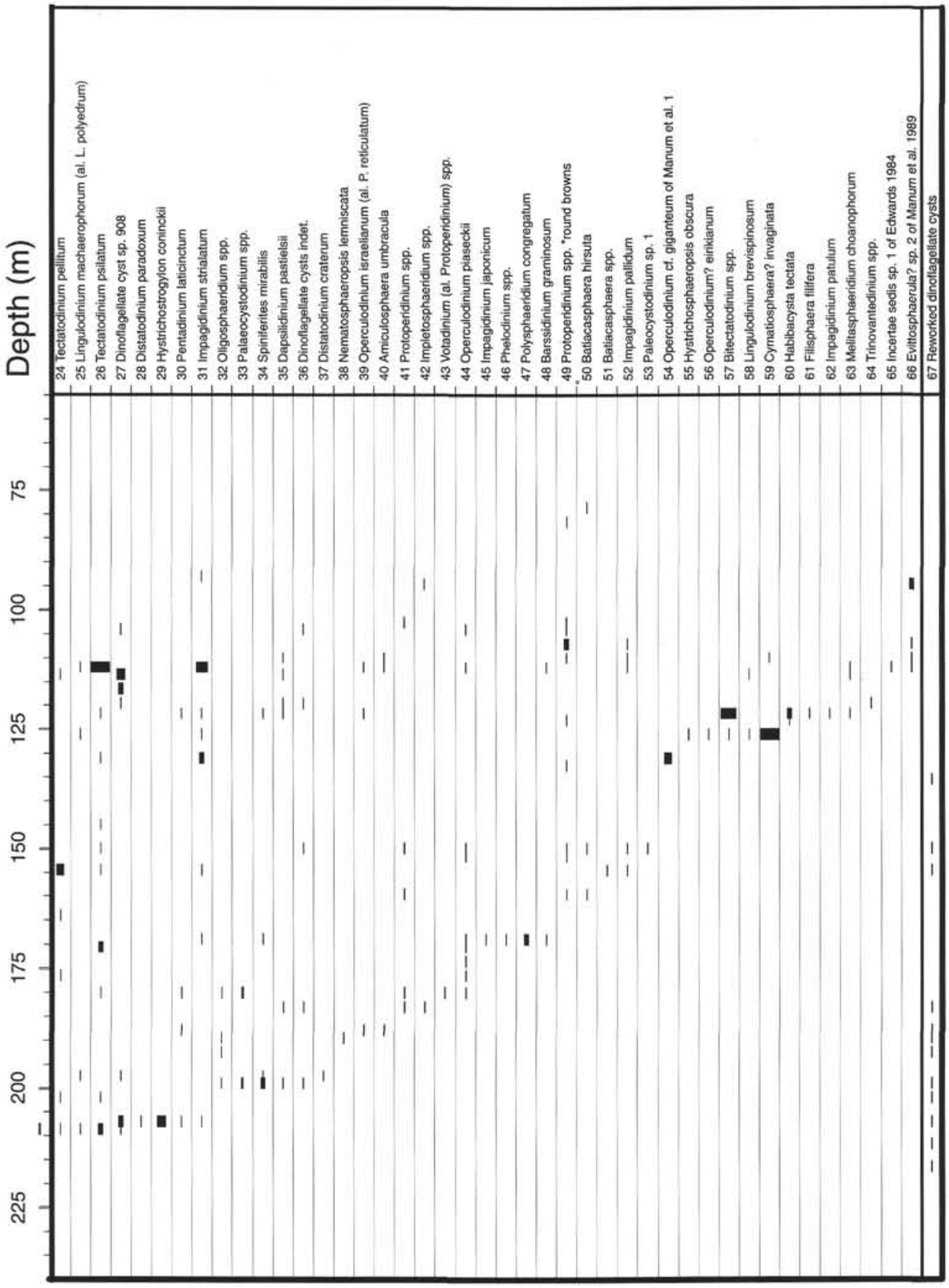

Figure 3A (continued).

andalousiensis as the zonal boundary criterion and placed the boundary in Sample 82R-CC (867.88 m).

Serravallian: Samples 151-909C-82R-CC to 70R-CC (867.88–757.82 mbsf)

The lower boundary for the *Zone Mio4* is indicated by the deepest record of *Achomosphaera*? *andalousiensis,* in Sample 151-909C-82R-CC (867.88 mbsf). The top of this zone is defined by the highest record of *Systematophora placacantha* in Sample 151-909C-70R-CC (757.82 mbsf). The zone is correlated to the middle to late Serravallian.

Tortonian: Samples 151-909C-69R-CC to 51R-CC (749.00–573.01 mbsf)

The top of *Zone Mio5* is defined by the highest record of *Palaeocystodinium golzowense*, which is found in Sample 151-909C-51R-CC (573.01 mbsf).

Messinian–Zanclean: Samples 151-909C-50R-CC to 27R-CC (562.14–341.70 mbsf)

Strata up to Sample 151-909C-27R-CC (341.70 mbsf) are no younger than Zone Pli1, based on the highest record of *Reticu-*

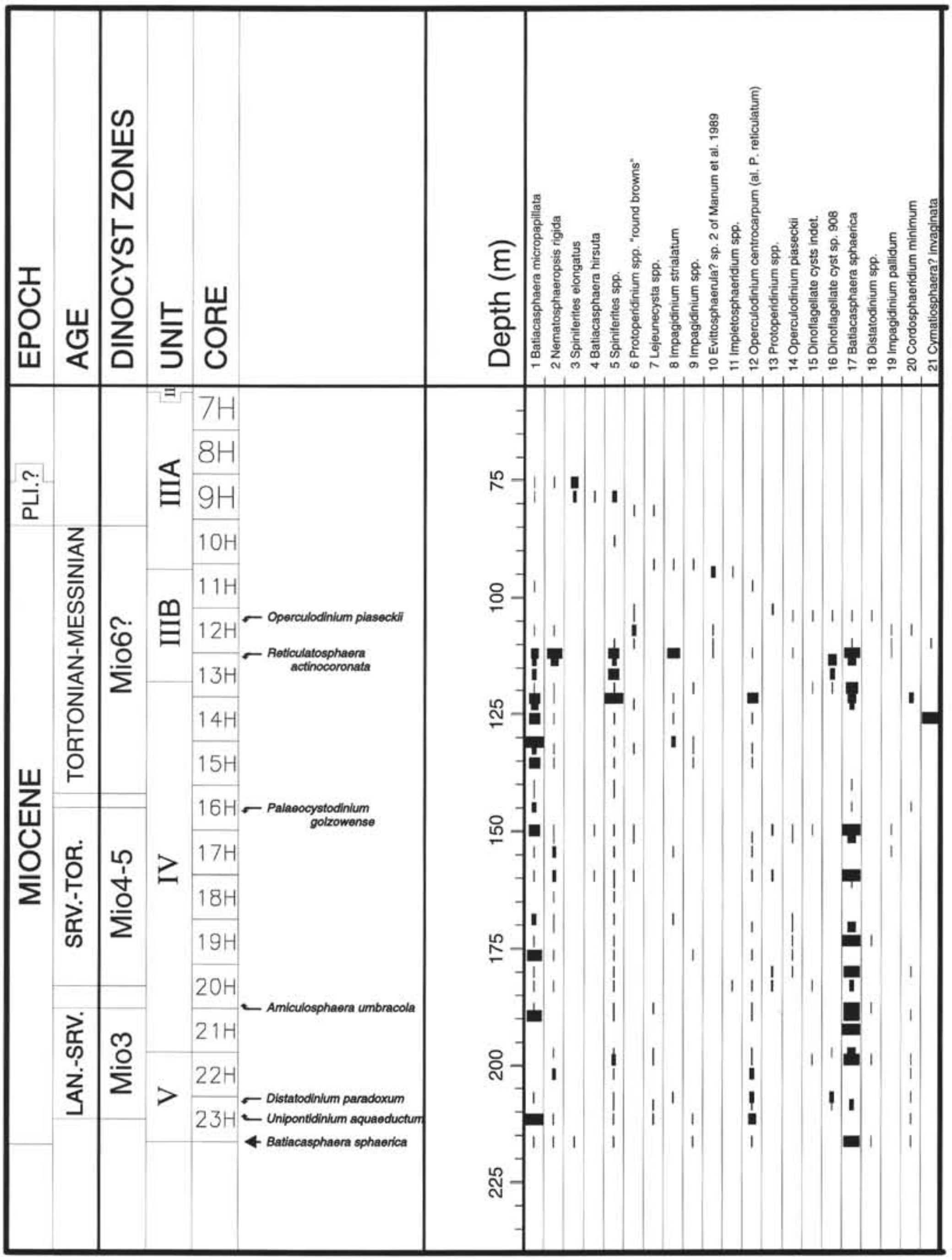

Figure 3B (continued).

latosphaera actinocoronata at this level. Accordingly, the interval is referred to *Zone Mio6* to *Zone Pli1*, corresponding to the Messinian to Zanclean.

Interpretation and Conclusions

The dinocyst assemblages are diverse and indicate normal surface productivity. A persistent to high representation of warm-water species, such as *Achomosphaera*? *andalousiensis*, *Operculodinium israelianum*, and *Polysphaeridium zoharyi*, in the Langhian–Serravallian to Messinian–Zanclean? interval indicates temperate rather than subpolar to polar conditions. The corresponding time interval at Site 907 also has a fairly high representation of warm-water species, such as *Impagidinium strialatum*, *Operculodinium israelianum*, *Polysphaeridium congregatum*, *Spiniferites mirabilis*, and *Tuberculodinium vancampoae*, indicating temperate rather than subpolar to polar water paleotemperatures. Species such as *Impagidinium patulum*, *Nematosphaeropsis rigida*, and the *Spiniferites ramosus* "group" are consistently present. They are basically outer neritic to oceanic forms and indicate that the basin was subject to oceanic influence.

Protoperidiniacean dinocysts are common to abundant throughout. They may indicate either cold or nutrient-rich surface conditions. However, they may also originate from nearshore habitats and be

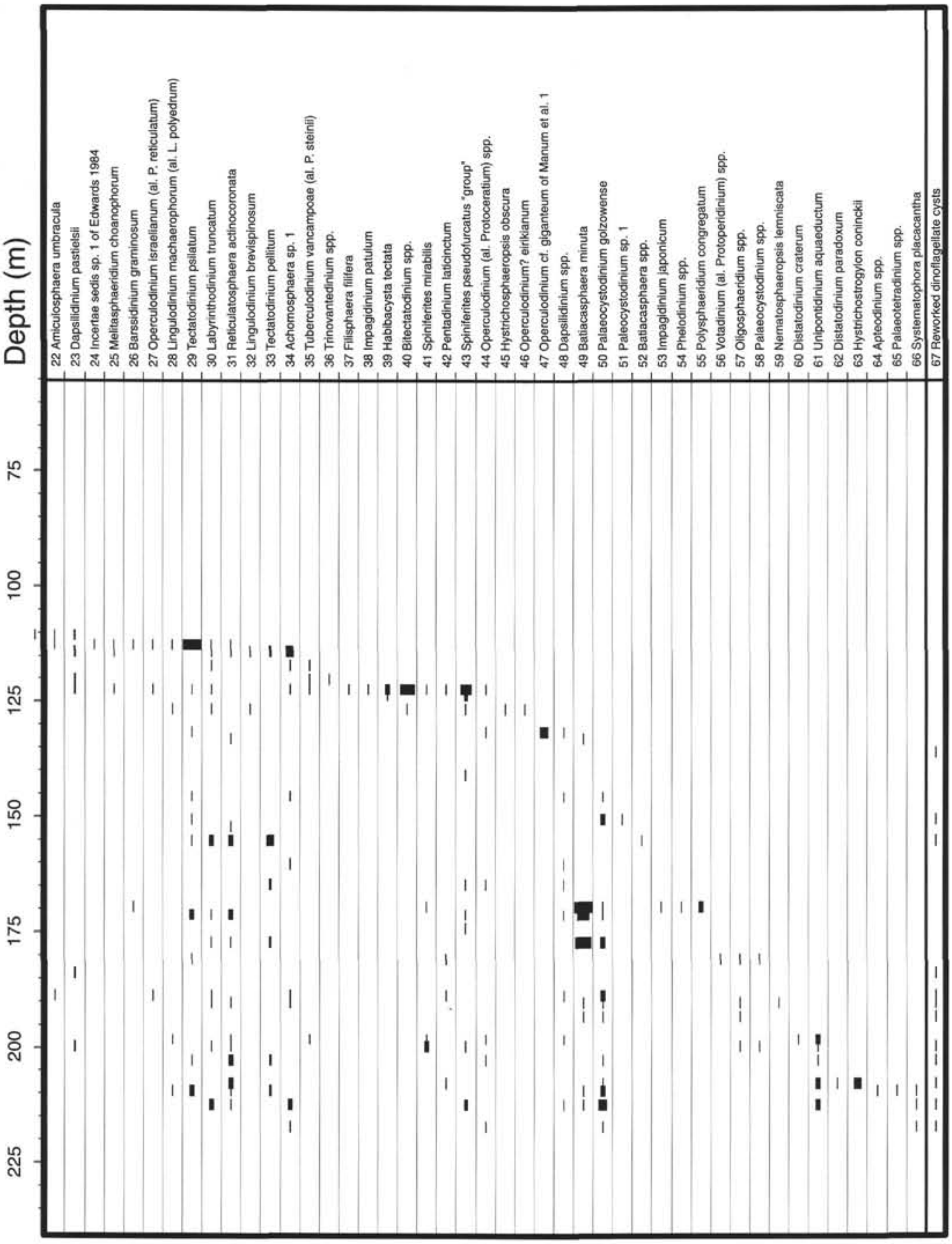

Figure 3B (continued).

brought in by downslope transport (Head et al., 1989a). At this site, however, the low representation of other neritic species suggests that downslope transport of shelf sediments was low.

The range chart shows reworking of many taxa at two levels: in Core 151-909C-89R (940 mbsf), and at the transition between lithologic Units IIIA and IIIB at the base of Core 151-909C-87R (923.40 mbsf), respectively. Possible stratigraphic breaks may occur at these levels.

SITE 908

Site 908 was drilled on the crest of the Hovgård Ridge in 1273 m water depth (Figs 1, 2). This study deals with Hole 908A, which penetrated 344.6 m of sediment (314 m cored) before drilling had to be stopped in a hard formation (sedimentary) that caused the destruction of the drill bit. A second much shallower hole (Hole 908B) was drilled for high-resolution sampling of the youngest sediments.

The present position of the Hovgård Ridge in the center of the Fram Strait prevents it from receiving sediments from the surrounding margins. In Oligocene times, however, the Svalbard platform is considered to have been a sediment source. A plate-tectonic model for the evolution of the western Svalbard margin (Fig. 4) proposes an origin for the ridge by rifting from the Svalbard platform, after Anomaly 13 time (33 Ma or Eocene/Oligocene boundary; for more details and references see Myhre and Thiede, 1995; Karlberg, 1995).

Two lithologic units separated by a major unconformity were recognized by the Shipboard Scientific Party (1995b, p. 117). Unit II

A

B

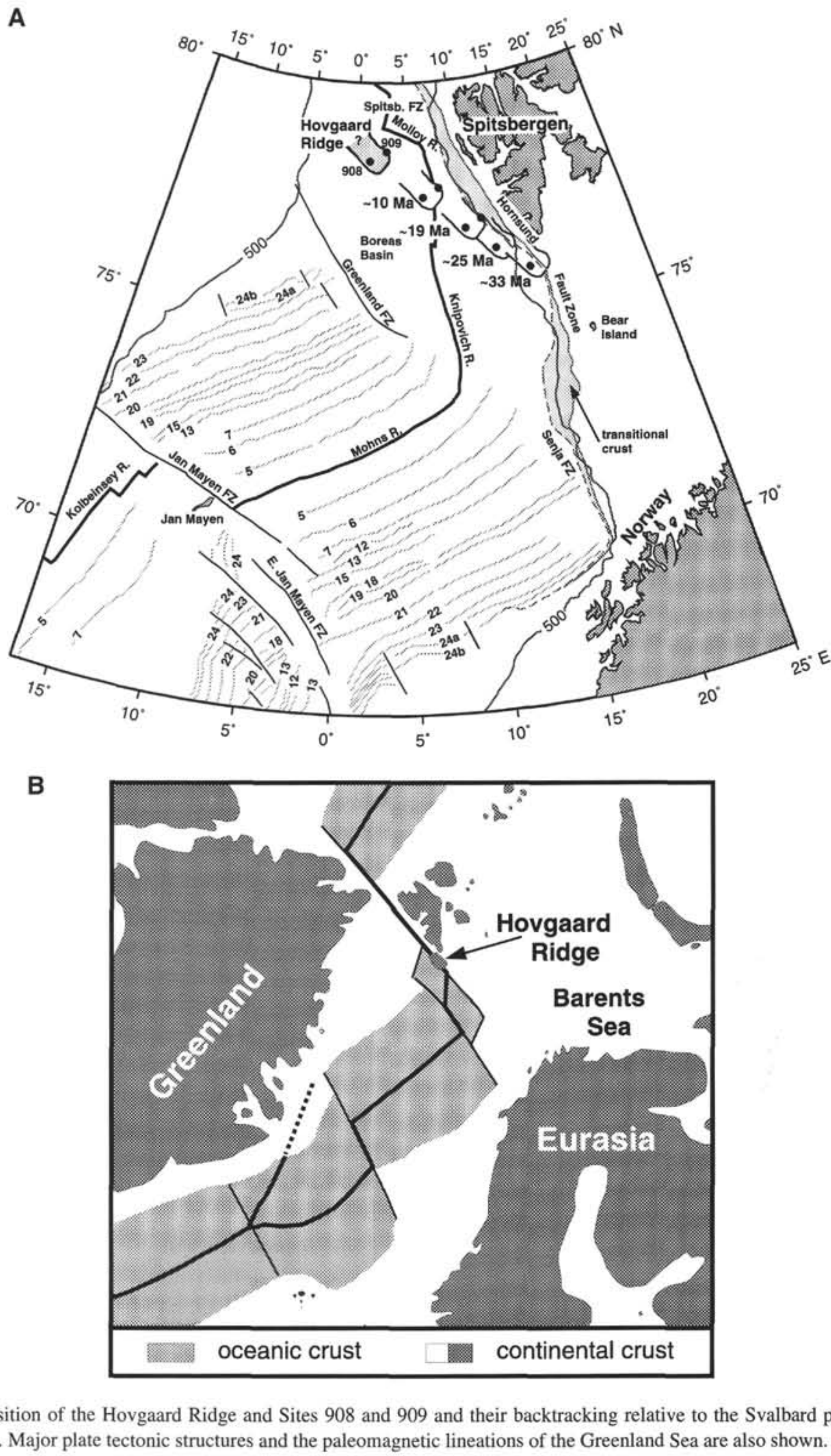

Figure 4. **A.** Present day position of the Hovgaard Ridge and Sites 908 and 909 and their backtracking relative to the Svalbard platform through time to the Eocene-Oligocene transition. Major plate tectonic structures and the paleomagnetic lineations of the Greenland Sea are also shown. (T. Karlberg, 1995). **B.** Diagrammatical plate tectonic reconstruction.

(Cores 151-908A-37X through 20X-6 [344.60–185.00 mbsf]), consists mainly of silty clay and clay, with generally large amounts of biosilica with diatoms as the dominant component. This unit was interpreted as being hemipelagic by the Shipboard Scientific Party (1995b, p. 121), based on the fine-grained character and high biosilica content. Unit I differs from Unit II in lacking biosilica and being less lithified. Subunits IA to IB frequently contain dropstones, while Subunit IC consists mainly of silty clay. For this study, samples downhole from Core 151-908A-8H in the upper part of Unit IB were examined. Sampling density is one sample per core (9.5 m) in Cores 151-908A-8H to 17X and approximately one sample per section (1.5 m) from Section 151-908A-18X-1 and down to the bottom. Critical intervals in Sections 151-908A-18X-1 to 18X-7 and 20X-1 to 21X-CC were sampled at about 30-cm intervals (see Table 1).

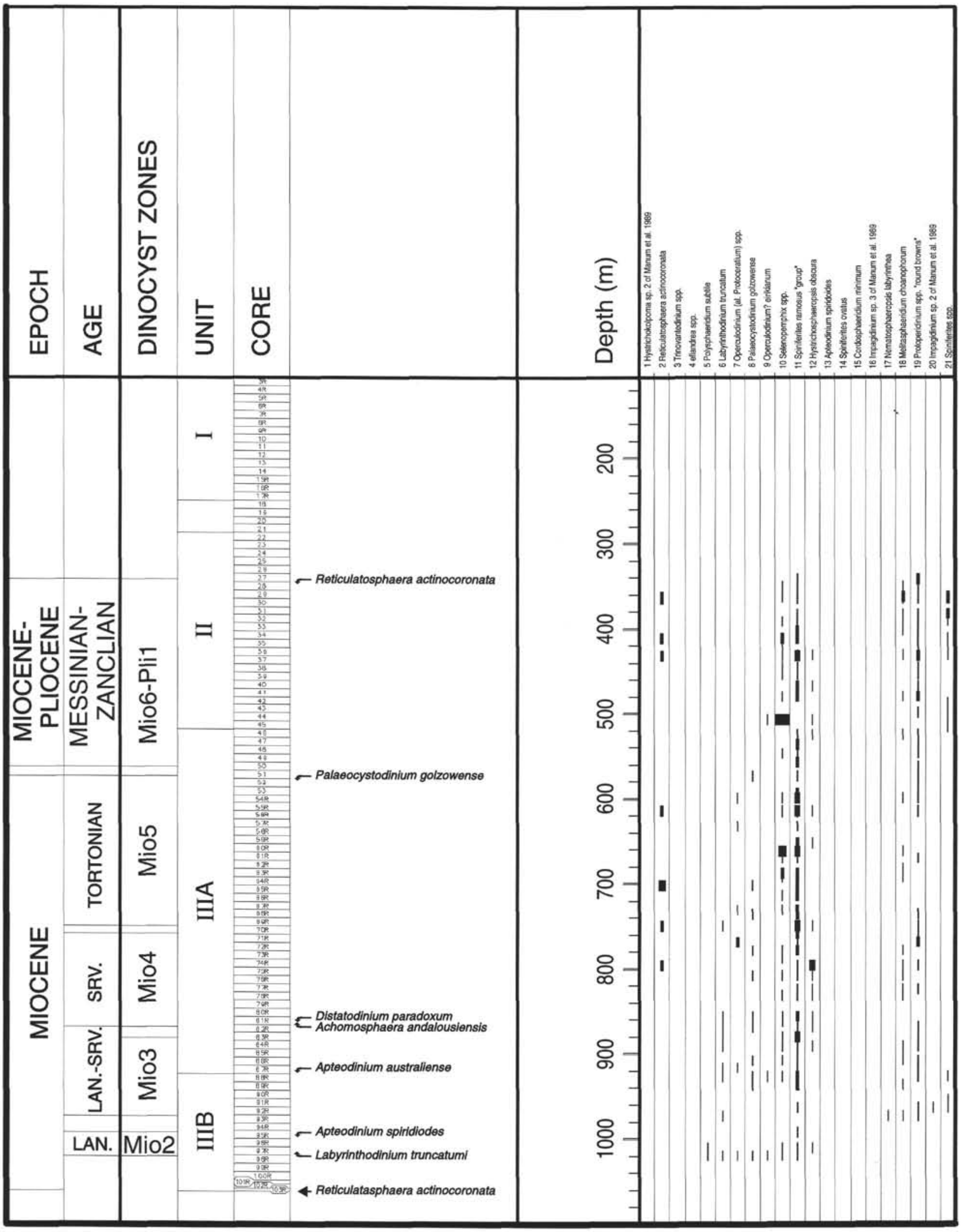

Figure 5. Dinocyst range chart for Hole 909C, sorted by (**A**) first occurrences and (**B**) last occurrences.

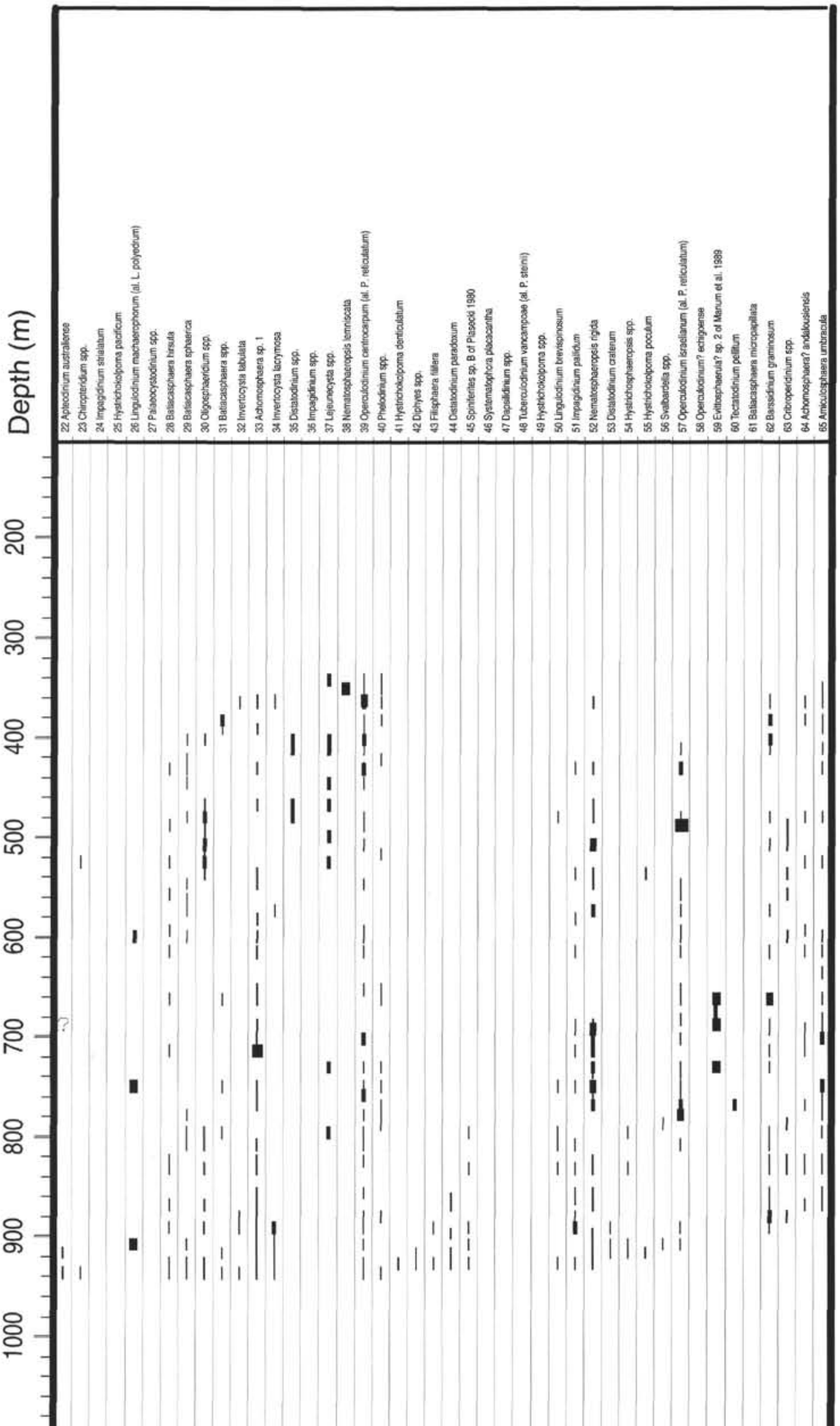

Figure 5A (continued).

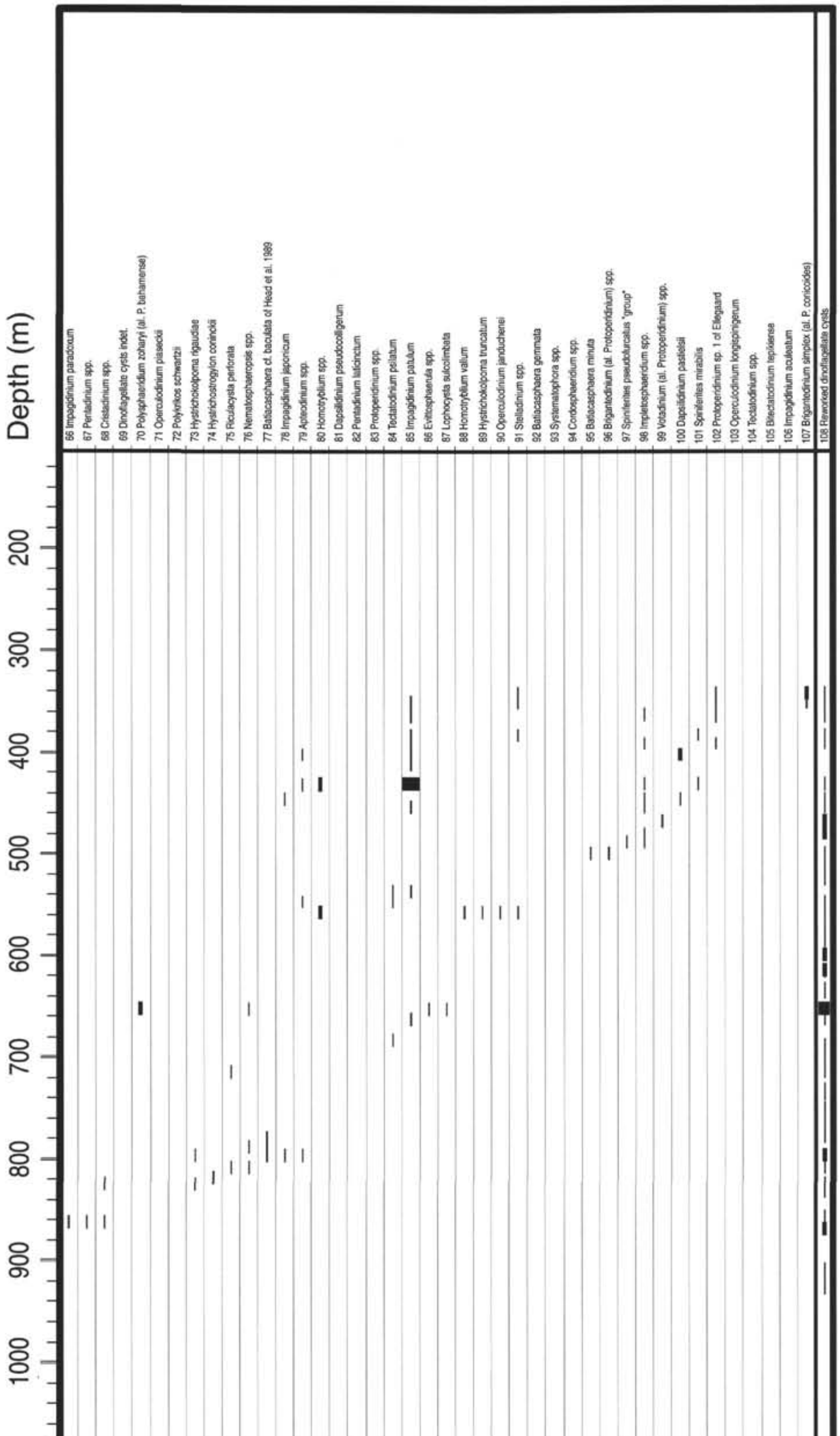

Figure 5A (continued).

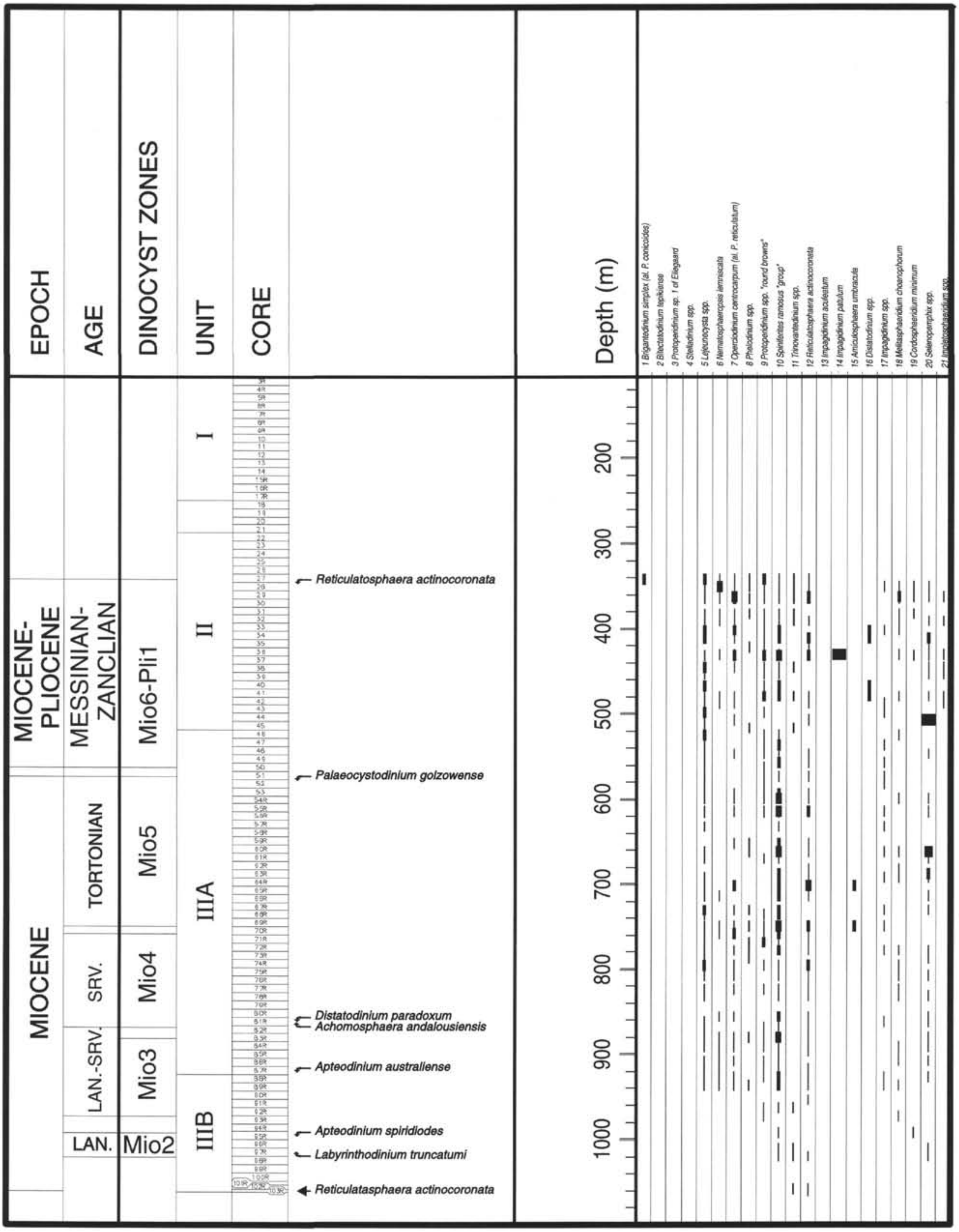

Figure 5B (continued).

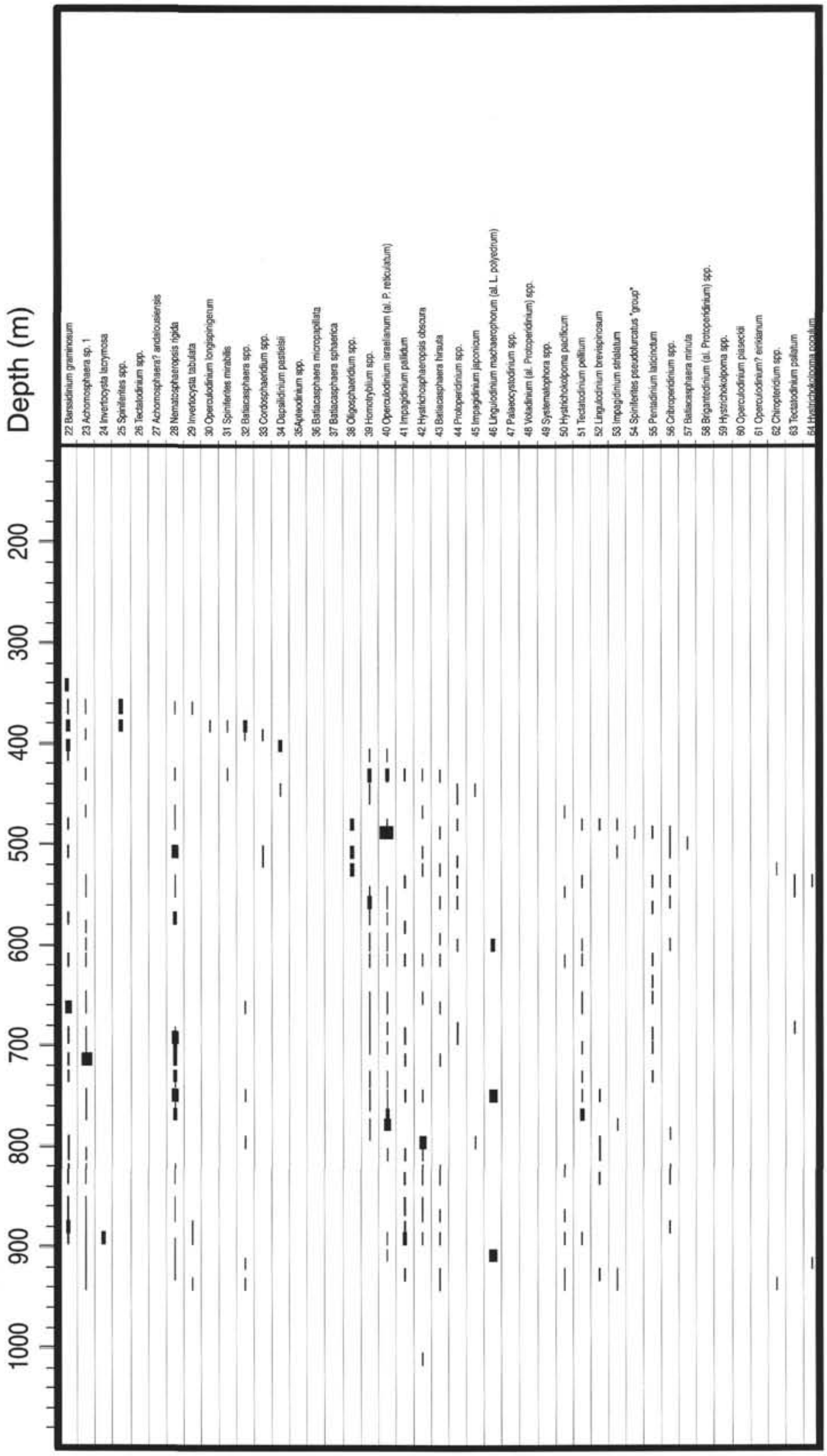

Figure 5B (continued).

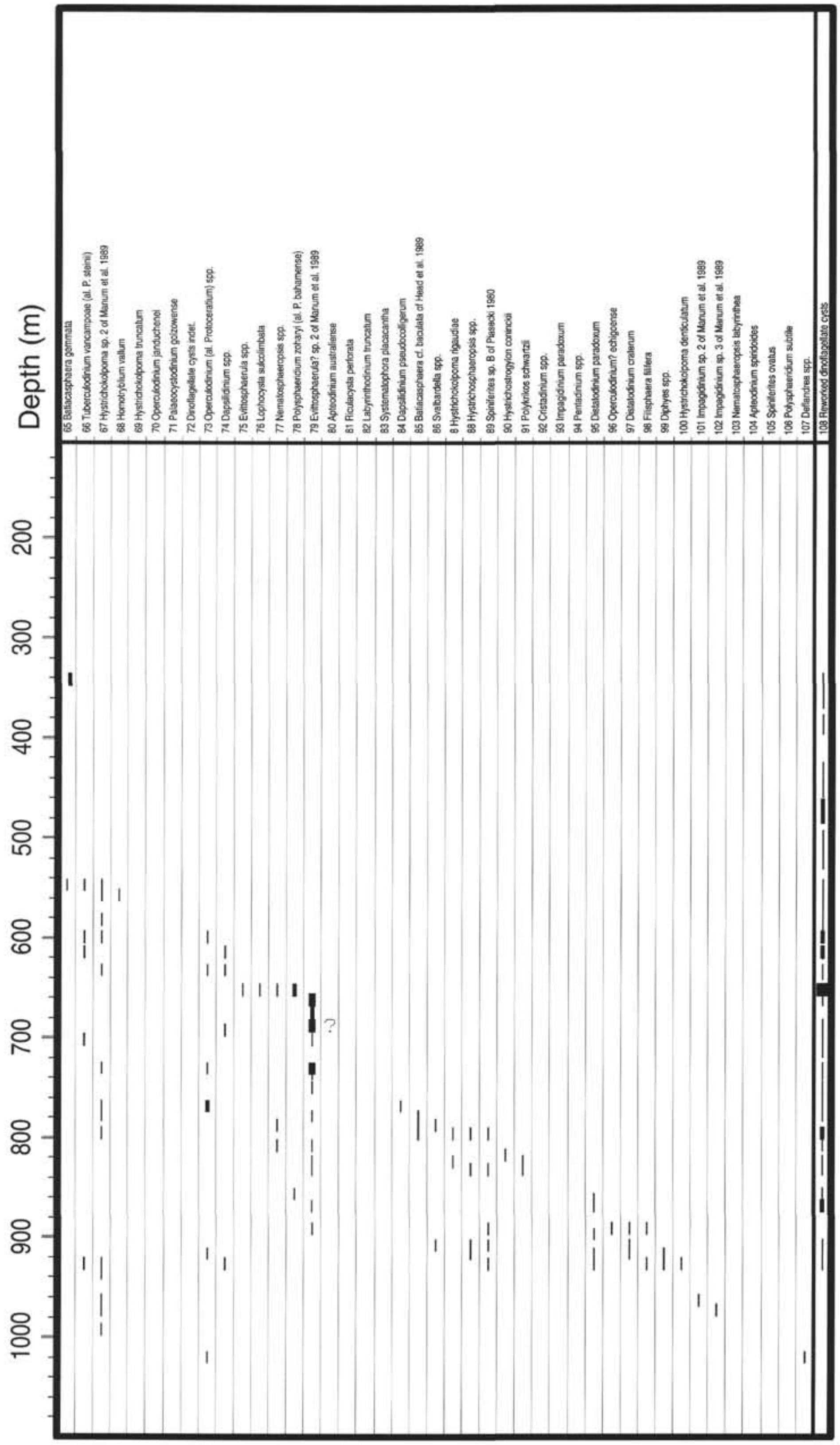

Figure 5B (continued).

Palynodebris dominate over palynomorphs throughout the studied section, and pollen dominates over dinocysts. The debris is composed of tissue fragments of land plants (woody and cuticles), many larger than 100 µm, and a dominating "cloud" of finely dispersed organic particles (removed through sieving). Table 3 lists the recorded species alphabetically and gives their reference number in the range charts (Fig. 6).

Biostratigraphy

Late Rupelian: Samples 151-908A-37X-2 to 27X-4 (342.24–249.61 mbsf)

Zone Oli3 or late Rupelian is indicated by the consistent occurrence of *Thalassiphora*? *pansa* from Sample 151-908A-35X-5 (327.99 mbsf). Three species that have well-documented FADs in the Rupelian (*Areoligera semicirculata, Chiropteridium galea,* and *Reticulatosphaera actinocoronata*) are recorded consistently from near the bottom of the hole, from Samples 151-908A-37X-2, 37X-1 and 36X-2 (342.24 mbsf, 340.74 mbsf and 332.28 mbsf), respectively, indicating that there are no pre-Oligocene sediments in the hole. The two cores below the deepest record of *Thalassiphora*? *pansa* (Sample 151-908A-35X-6) are probably no older than the late Rupelian (J. Backman, unpubl. data).

Early Chattian: Samples 151-908A-27X-4 to 20X-5 (249.61–184.76 mbsf)

The base of *Zone Oli4* is defined by the deepest record of *Batiacasphaera micropapillata,* found in Sample 151-908A-27X-4 (249.61 mbsf). The Rupelian/Chattian boundary must therefore be placed just below this level. The highest sample from this interval has three species with LOD in *Zone Oli4: Areoligera semicirculata, Chiropteridium galea,* and the *Deflandrea phosphoritica* "complex." *Thalassiphora*? *pansa,* which also has its LOD in *Oli4,* is recorded up to Sample 151-908A-24X-2 (217.91 mbsf).

Several species of *Phthanoperidinium* occur sporadically from Samples 151-908A-30X-CC up to 21X-2 and particularly in Samples 151-908A-24X-CC to 23X-1. The genus has its stratigraphic top in the early Chattian so its occurrences almost up to the unconformity are consistent with an early Chattian age for this part of the section. The occurrence of *Phthanoperidinium amoenum* in Samples 151-908A-24X-3 and 26X-2 are problematic, since its LOD, according to Powell (1992), approximates the FAD of *Thalassiphora*? *pansa.* However, there is only a single occurrence below Core 151-908A-30X-CC. This suggests that the specimens of *P. amoenum* in the higher cores may be reworked.

Unconformity: Late Chattian–Serravallian, in Section 151-908A-20X-5, between 106 cm and 137 cm (184.76–184.44 mbsf)

The Shipboard Scientific Party (1995b, p. 117) placed an unconformity between Cores 151-908A-20X-6 and 20X-5 (185 mbsf), where the boundary between lithologic Units II and I was drawn. Samples at about 30-cm intervals were studied above and below this boundary to define biostratigraphically the position and extent of the hiatus.

In the samples up to Sample 151-908A-20X-5, 137–138 cm, species with well-documented LODs at the top of NP24 or lower Chattian (*Deflandrea phosphoritica, Areoligera semicirculata*) are present, while Miocene markers are absent. The sample from 31 cm above, from Sample 151-908A-20X-5, 105–106 cm, has, in contrast, a good Miocene assemblage with *Evittosphaerula*? sp. 2 and *Barssidinium graminosum* and lacks species with Oligocene LODs. Based on palynology, therefore, the unconformity is placed between 137 cm and 106 cm in Section 151-908A-20X-5.

Above the unconformity, direct dating using known ranges is difficult because the number of index fossils is low. *Evittosphaerula*? sp. 2 and *Barssidinium graminosum* occur consistently. *Amiculosphaera umbracula* and *Invertocysta tabulata* occur from Sample 151-908A-20X-3 to our highest sample, 151-908A-8H-1. The documented FAD of both is in the Serravallian (Williams et al., 1993). *Selenopemphix dionaeacysta,* which has its lowest occurrence in Sample 151-908A-20X-4, has a documented FAD in NN6 strata (Shipboard Scientific Party, 1994). *Labyrinthodinium truncatum,* which occurs in Sample 151-908A-20X-4, has a Langhian to Tortonian–Messinian range. These taxa therefore indicate that the oldest sediments above the unconformity are not older than the Serravallian. However, their maximum age is further constrained to the Tortonian by correlation with Site 909 (see Site 908 "Interpretation and Conclusions" section, this chapter). The unconformity, therefore, spans the late Chattian plus early and middle Miocene.

Tortonian: Samples 151-908A-20X-5 to 15X-2 (184.44–131.93 mbsf)

Zone Mio5, equivalent to a Tortonian age, is indicated for this interval by correlation with Site 909 (see Site 908 "Interpretation and Conclusions" section, this chapter). The highest record of *Palaeocystodinium golzowense* in Sample 151-908A-15X-2 (131.93 mbsf) defines the top of *Zone Mio5.*

Messinian–Zanclean: Samples 151-908A-15X-2 to 8H-1 (131.93–63.39 mbsf)

Zones Mio6–Pli1 (undifferentiated) is indicated for this interval. The highest record of *Operculodinium piaseckii* in Sample 151-908A-12X-2 (102.83 mbsf) indicates *Zone Pli1* or older strata, equivalent to a Zanclean or older age below this level. The consistent record of *Batiacasphaera micropapillata* up to our highest sample, 151-908A-8H-1 (63.39 mbsf), indicates that no younger strata than *Zone Pli2* are present up to this level. The Miocene/Pliocene boundary could not be defined by using cysts.

Interpretation and Conclusions

Dating of the Unit II samples from Site 908 is difficult because of the reworked cysts, some of which apparently are not much older than those in situ. There is also some uncertainty over the ranges of some of the in situ taxa, particularly because of the few unambiguous references in the literature to Chattian dinocysts.

Dating of the Miocene section is also not easy, especially since it is truncated at the base and has a poor representation of index taxa just above the unconformity. However, a comparison with Site 909, which has an almost complete Miocene succession, is helpful. A number of conspicuous acmes recorded at both sites appear to represent correlative bioevents. At Site 908, acmes of *Nematosphaeropsis* spp., *Evittosphaerula*? sp. 2, and *Barssidinium* spp. are recorded in Samples 151-908A-20X-4 to 18X-6 (182–180 mbsf, 181–175 mbsf and 171–166 mbsf) respectively. A corresponding succession of acmes is recorded at Site 909, where an acme of *Nematosphaeropsis* spp. occurs in Samples 151-909C-71R-CC to 64R-1 (768–692 mbsf), while there are two acmes of *Evittosphaerula*? sp. 2, in Samples 151-909C-67R-CC (730 mbsf) and 151-909C-63R-CC to 60R-CC (687–662 mbsf) respectively. This succession of acmes is ended by that of *Barssidinium* spp. in Core 151-909C-60R-CC (662 mbsf).

We interpret the acmes recorded at Site 908 in the Cores 151-908A-20X-4 to 18X-6 (182–166 mbsf) as correlative to those at Site 909 in the interval from approximately Cores 151-909C-64R-CC to 60R-CC (700 to 662 mbsf), while the interval with the deeper acme of *Evittosphaerula*? sp. 2 at Site 909, in Core 151-909C-67R-CC (730 mbsf), is apparently missing at Site 908. This correlation leads

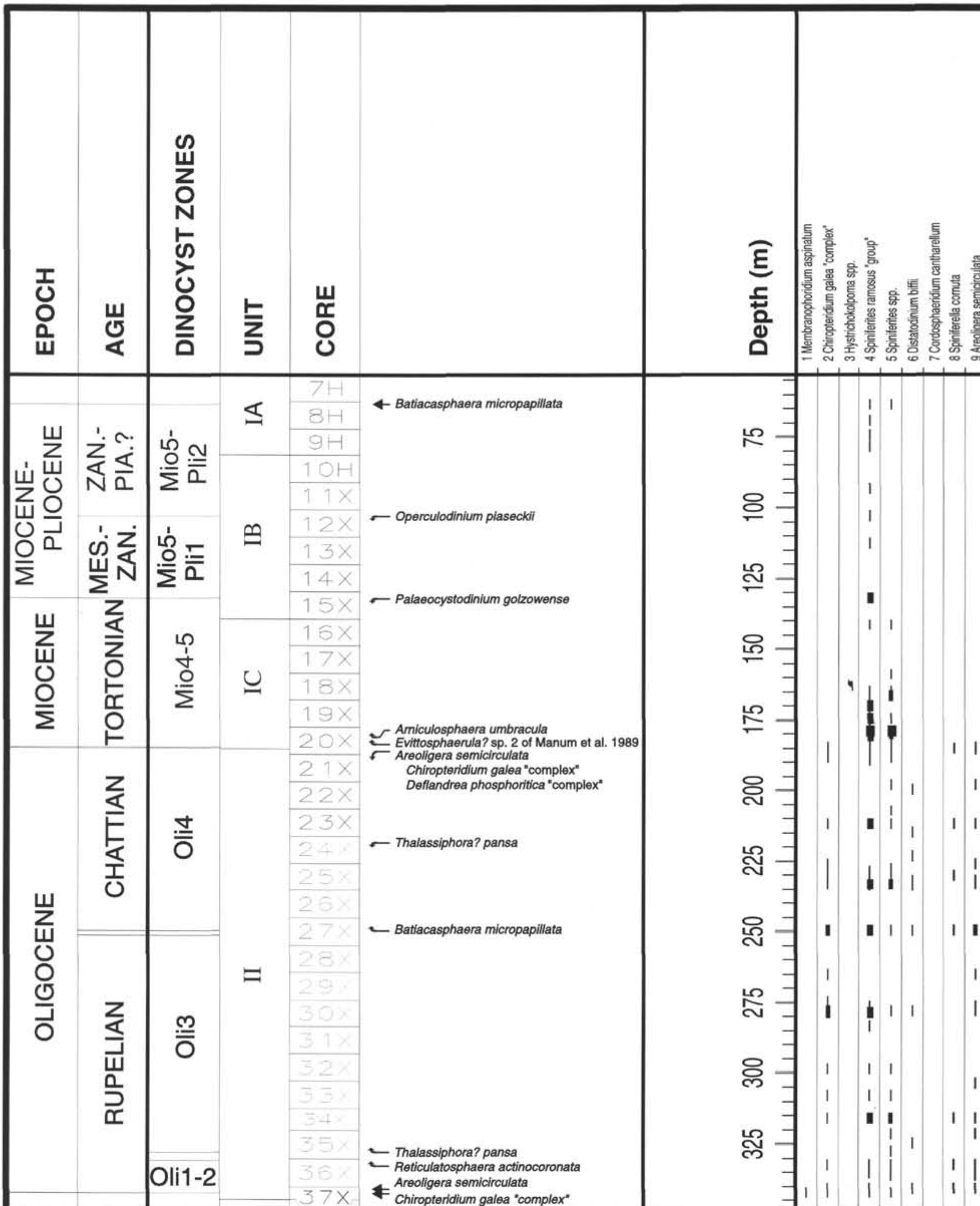

Figure 6. Dinocyst range chart for Hole 908A, sorted by (**A**) first occurrences and (**B**) last occurrences.

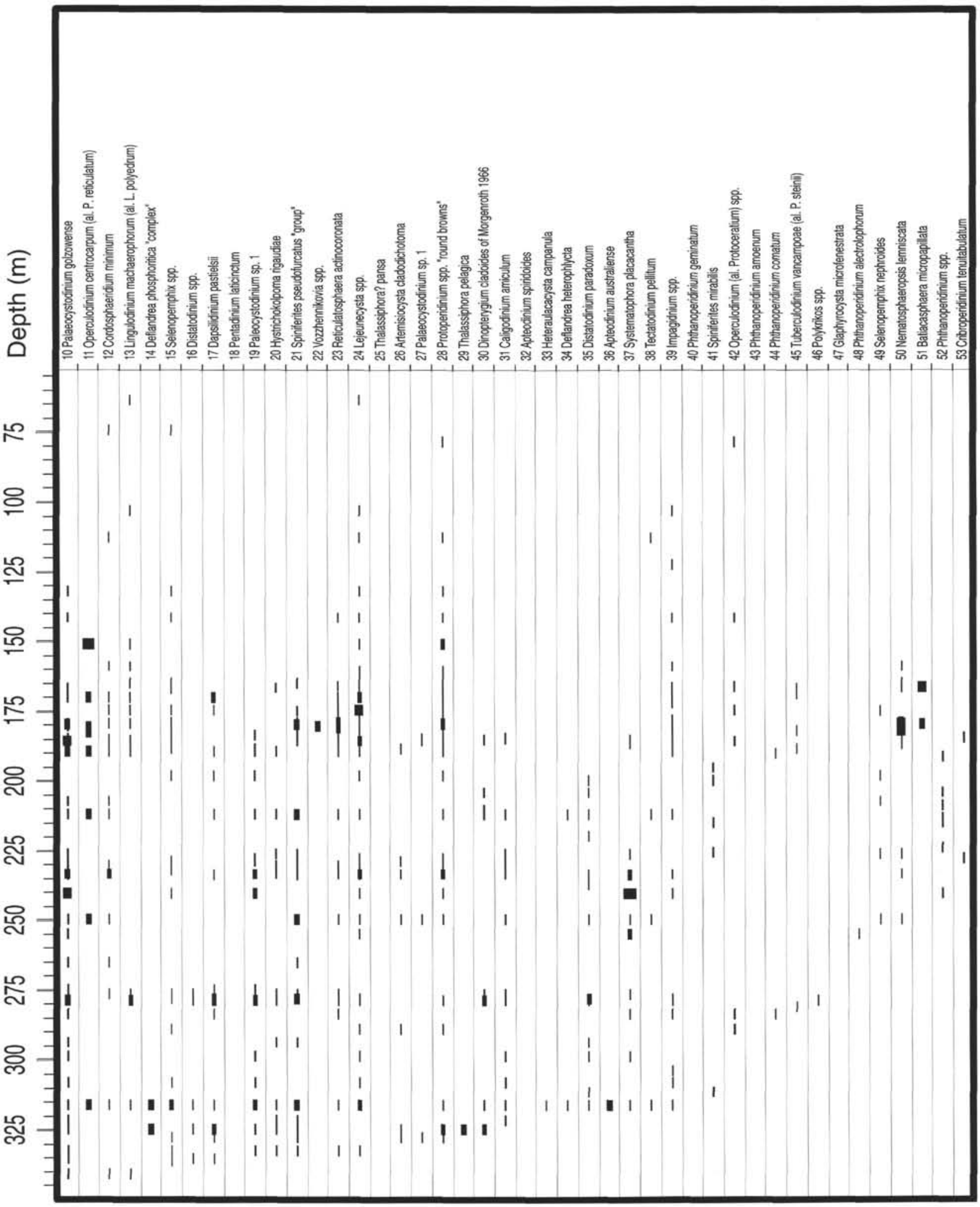

Figure 6A (continued).

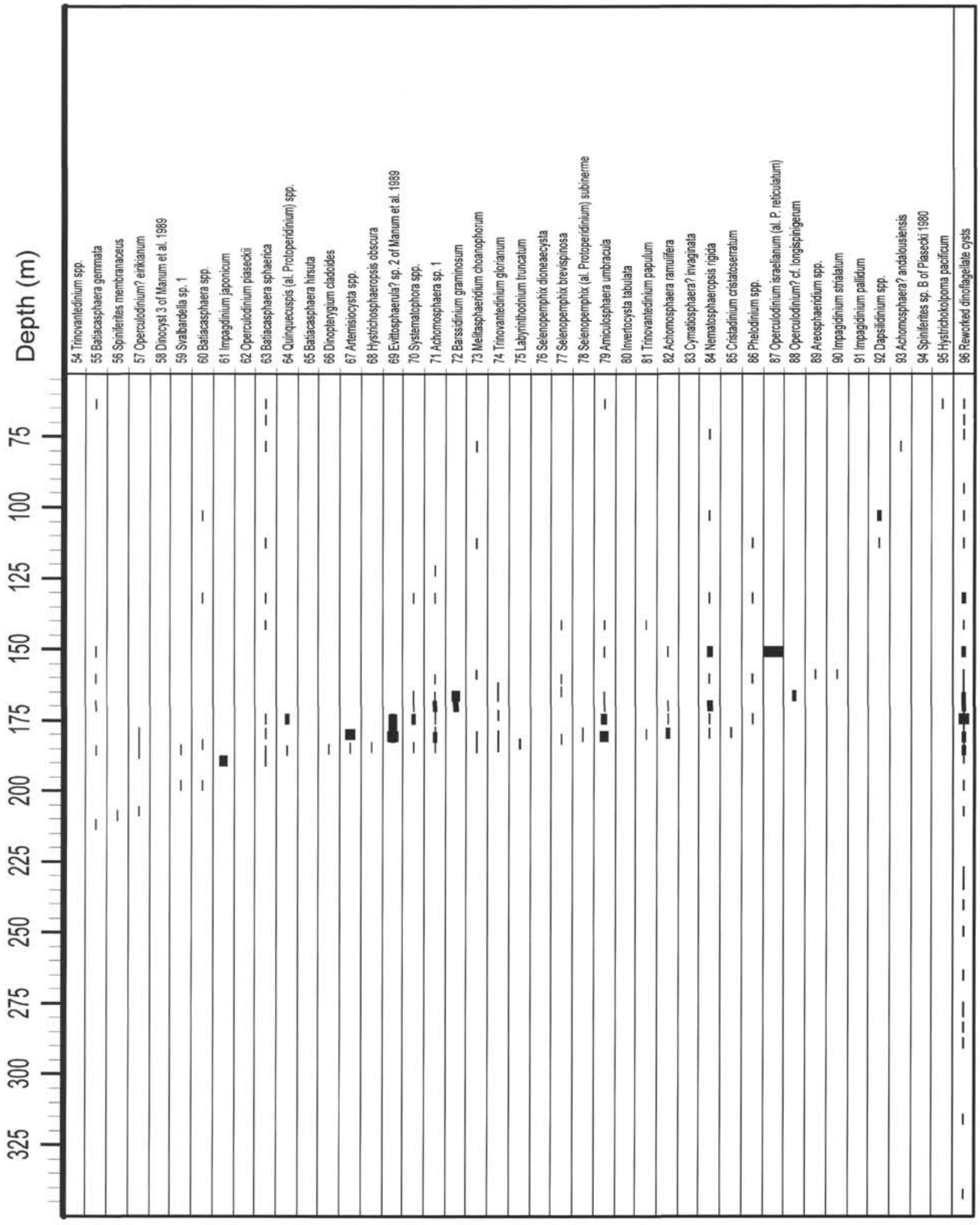

Figure 6A (continued).

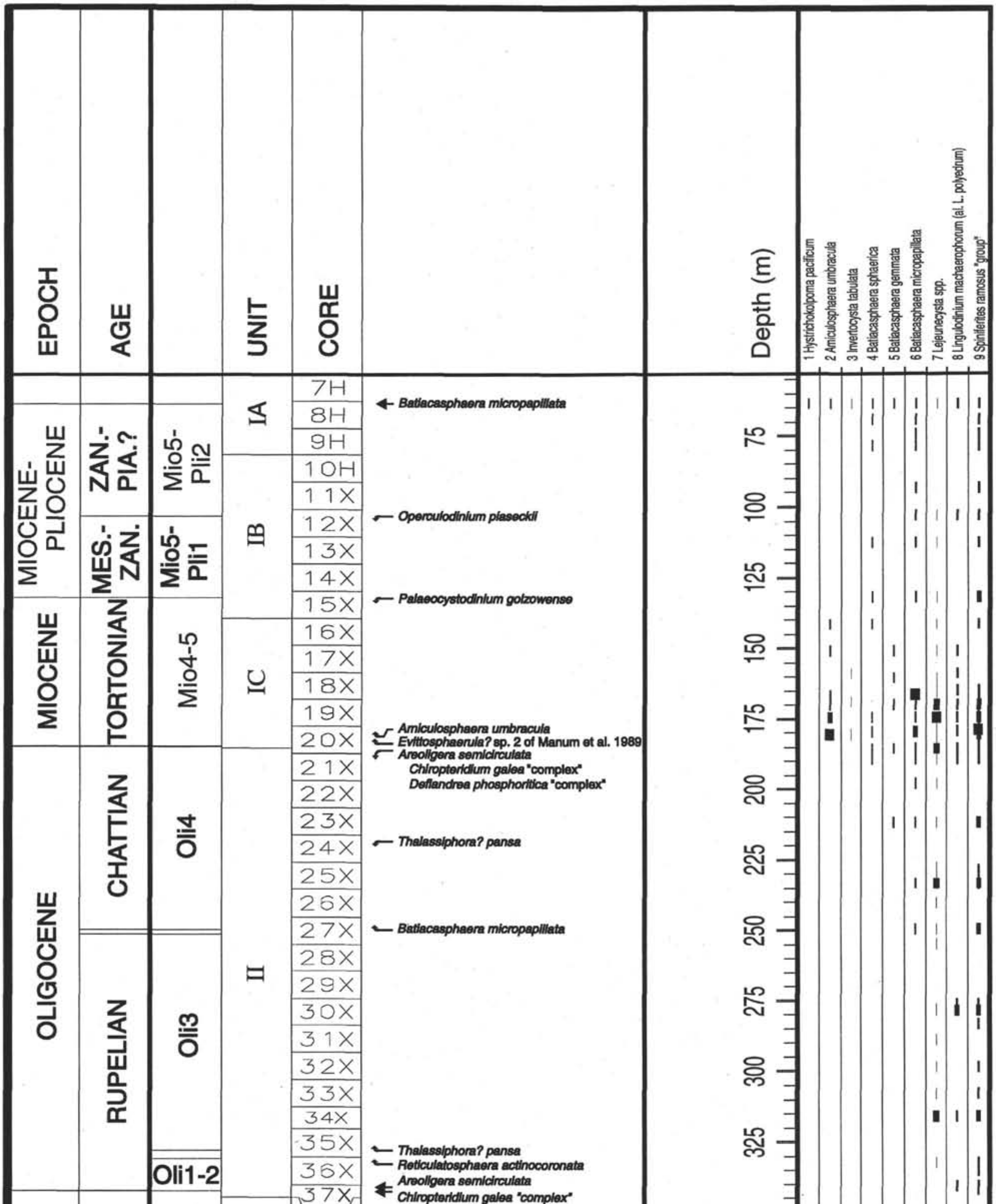

Figure 6B (continued).

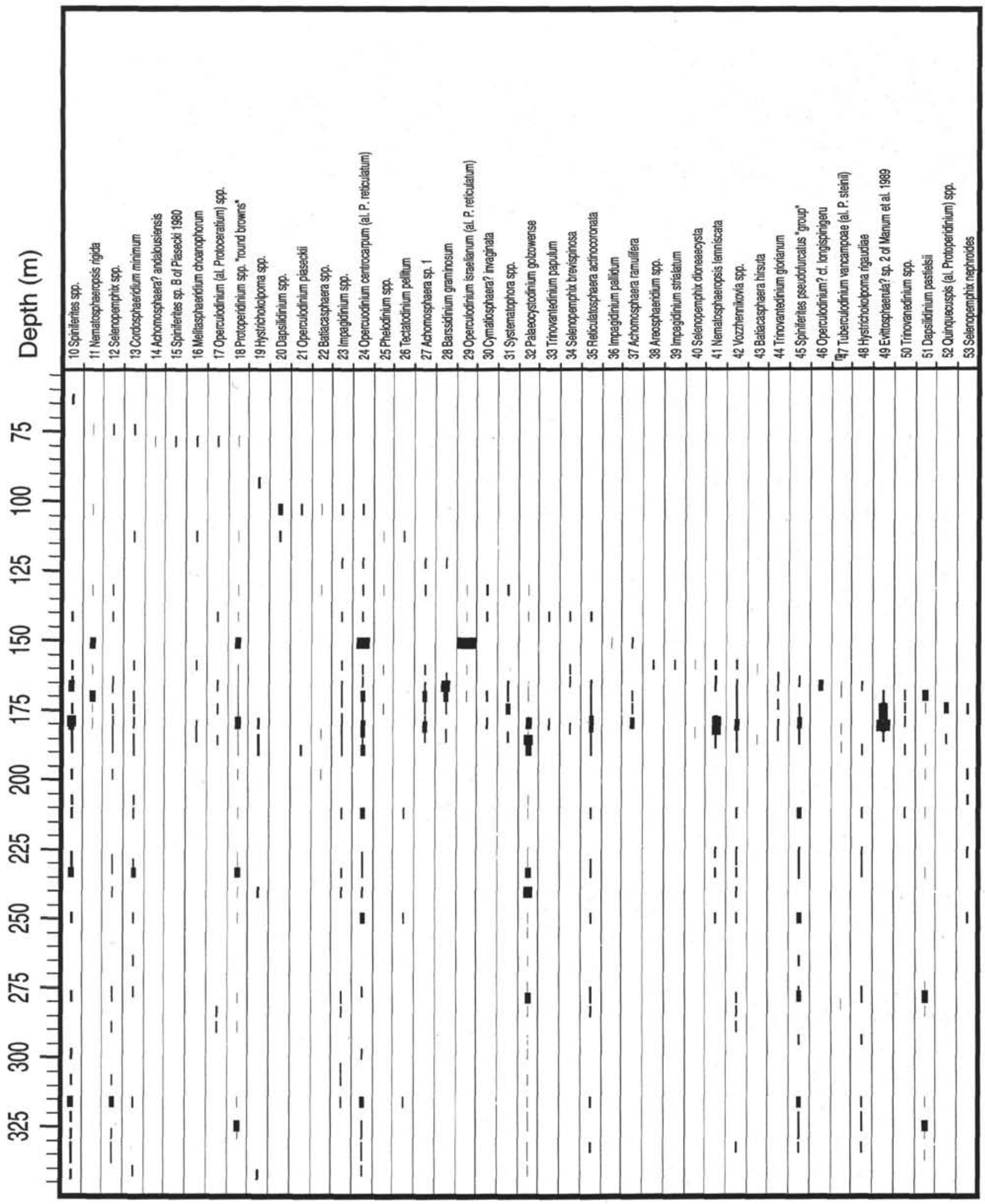

Figure 6B (continued).

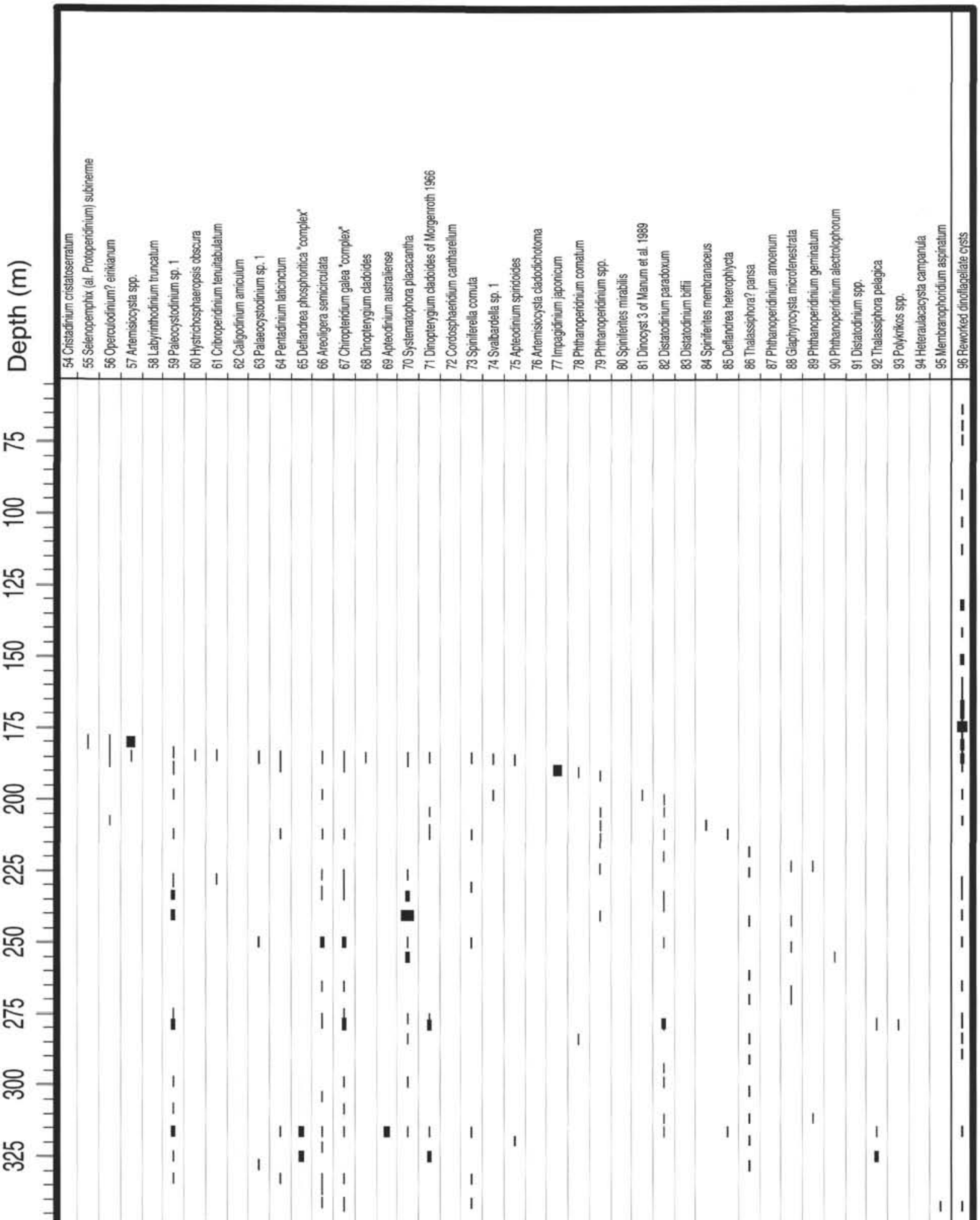

Figure 6B (continued).

to the assignment of a Tortonian–Messinian age to the Cores 151-908A-20X-4 to 18X-6 (182–166 mbsf) at Site 908.

The Shipboard Scientific Party (1995b, pp. 121, 135) interpreted the section below the unconformity as hemipelagic, based on its fine-grained character and high biosilica component (dominantly diatoms), and the type of organic matter as a mixture of terrigenous and marine, but dominantly of marine origin. However, our observations from the palynological residues conflict with these interpretations. The large quantity of terrestrially derived organic matter (>20 µm) has a fresh-looking, unaltered appearance indicating first-cycle deposition. Pollen and spores dominate the palynomorph assemblages, with dinocysts usually making up less than 20% (Fig. 7). Both the debris and the low cyst/pollen ratio indicate an adjacent vegetated land source.

The Shipboard Scientific Party's (1995b, p. 135) interpretation of the type of organic matter as dominantly marine was based on the ratios of organic carbon to nitrogen (C/N). Marine zoo- and phytoplankton empirically show C/N ratios averaging 5 to 8, contrasting with 20 to 200 for higher land plants. For Unit II, C/N ratios were found ranging from 7.3 to around 17 (one exceptional sample, showing also the maximum TOC value, had C/N = 42.9). However, the finely dispersed organic particles in the palynological residues appear more like minutely disseminated terrestrial debris than amorphous marine organic matter. The particles do not fluoresce under UV illumination as would be expected if they were of marine origin. The dinocysts present in the residues, on the other hand, show bright yellow fluorescence. It must be noted here that for Site 909, C/N ratios similar to those for Site 908 were obtained. There, however, the "marine" interpretation was not supported by hydrogen index (HI) values from Rock-Eval analysis, which indicated a high proportion of terrigenous material (Shipboard Scientific Party, 1995c, p. 193). No Rock-Eval analysis was done on Site 908 samples. Our interpretation of the organic assemblages ("kerogen") from Unit II is, therefore, that they are dominantly terrigenous, unlike the interpretation suggested by the relatively low C/N ratios. This also applies to the section that we studied above the unconformity.

Fluctuations in cyst/pollen ratios are normally interpreted as signals of shoreline displacements in a marginal marine environment. Trends in these ratios in Unit II sediments (Fig. 7) appear to signal cycles of displacements. Similar trends might be reflected in the amount of biosilica in the sediments, which is dominated by diatoms. Covariation between these two phytoplankton groups may reflect a common environmental control of the trends, most likely resulting from vertical movements of the Hovgård Ridge. Cyst/pollen ratios are generally higher in Unit I than in Unit II, but are still well below 50% (except for 75% cysts in one sample, dominated by *Operculodinium israelianum*). Above the hiatus there is first an increasing trend in cyst ratios through Subunit IC, followed by a slightly decreasing trend in higher cores.

The above observations add some new aspects to the evolution of the Hovgård Ridge that are in accord with the plate tectonic model, showing it as a sliver of the Svalbard Platform (Fig. 4). Deposition of Unit II sediments started in the late early Oligocene, some 3–4 m.y. after initiation of rifting between Greenland and Svalbard, which for a long time took place along a shear margin. This tectonic setting subjected the proto-Hovgård Ridge to a combination of transtentional and transform forces creating a basin into which rivers draining the forested coastland of the Svalbard Platform carried abundant terrestrial organic matter (Boulter and Manum, this volume). During deposition of Unit II, the distance to the shore and hence water depth at Site 908 appears to have had three to four major fluctuations. These probably reflect tectonically induced vertical movements of the Svalbard Platform sliver, superimposed on global sea-level changes. At some time between the latest Oligocene and late Miocene a late synrift uplift caused emergence of the ridge, resulting in nondeposition and erosion, observed as a hiatus representing some 15 to 18 m.y.

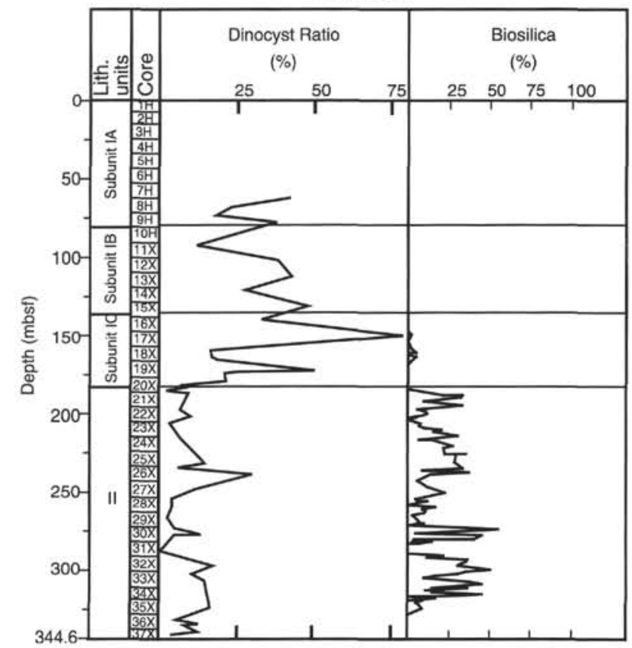

Figure 7. Percent dinocysts of total palynomorph sums (data from Cores 151-908A-37X to 18X from Boulter and Manum, this volume) and biosilica content of the sediments for Site 908 (from Shipboard Scientific Party, 1995b, p. 118, fig. 3).

The high biosilica content of Unit II sediments was regarded as evidence for hemipelagic conditions by shipboard scientists. Based on the character and quantity of the terrestrial organic input we rather consider the conditions to have been relatively nearshore and probably not very deep. An analog for relatively nearshore diatomitic deposition is found in the Fur Formation in Denmark (late Paleocene), which was deposited a short distance from vegetation-covered land (Pedersen and Surlyk, 1983).

The palynological assemblages recovered from Subunit IC are not very different from Unit II. Dinocyst ratios are somewhat higher, indicating more offshore conditions after the hiatus, and some samples show more terrestrial debris relative to pollen and more common fusinitic particles and reworked palynomorphs. However, the overall fresh-looking, first cycle character of the palynological assemblages is similar to Unit II, suggesting that Subunit IC sediments were also deposited in proximity of vegetated land.

Geophysical evidence suggests that a continent/continent transform boundary existed locally between the Hovgård Ridge and the Svalbard Platform even in the late Miocene (10 Ma; Fig. 4; J. Skogseid, pers. comm., 1995). However, marine basins must have developed along this boundary since early Miocene times, because dinocysts from Hole 909C, on the eastern flank of the ridge, indicate outer neritic conditions from the early Miocene. The source of the terrestrially derived organic matter in Subunit IC sediments is therefore less likely to have been the Svalbard Platform, but rather an elevated northern part of the Miocene Hovgård Ridge itself. To the northwest of Site 908 a seismic line (UB24-81; Shipboard Scientific Party, 1995b, p. 114, fig. 1) shows progressive onlap of younger sediments against the unconformity that forms a distinctive regional reflector.

Two glauconite layers near the base of Subunit IC were interpreted as possibly altered volcanic ash by the Shipboard Scientific Party (1995b, p. 121). Their Tortonian age, as indicated by the cysts, fits the age of plateau basalts on northern Spitsbergen, dated to between 9 and 12 Ma (Vågnes and Amundsen, 1993).

Reworking

Middle Cretaceous (Barremian–Albian) dinocysts were recorded in most Oligocene to Miocene samples, and Cretaceous trilete spores are relatively common in some samples. A minor element of early Paleogene cysts is also present, while unquestionable Late Cretaceous reworking was not observed. Reworking from pre-Cretaceous formations is rare.

The Late Cretaceous stratigraphic gap in the age of reworked fossils is interesting since nowhere in the Svalbard archipelago are Upper Cretaceous formations found. When Tertiary formations are preserved, they are resting on Albian or older formations. The question whether there was ever an extensive deposition of Late Cretaceous formations that were subsequently eroded remains unsettled. Our observations of reworking indicate that there were no Upper Cretaceous formations present in early Oligocene times, at least not in the western part of the Svalbard platform that drained toward the Hovgård Ridge microcontinent.

SITE 913

Core samples have been analyzed for dinoflagellate cysts. Range data for some studied sections are given in the range chart (Table 4). Site 913 was drilled in the deep Greenland Basin (3318 m water depth) and went to total depth of 770 mbsf. Miocene to Pleistocene sediments in the upper 432 m of the hole yielded poor recovery, but Paleogene sediments below were satisfactorily cored. The dinocyst stratigraphy of the Paleogene section is discussed by Firth (this volume). We have only studied five samples from Core 151-913B-19W (from 381.66 to 376.54 mbsf), which was assigned an unspecified Miocene age by the Shipboard Scientific Party (1995d).

The two lowermost samples in Core 151-913B-19W (381.66 and 380.69 mbsf) yielded rich and diverse assemblages. The two succeeding samples in Core 151-913B-19W (379.19 mbsf and 380.69 mbsf) were almost without organic material and no dinocysts were recorded. The uppermost sample Core 151-913B-19W (376.59 mbsf) yielded a few dinocysts.

The two lowermost samples contain abundant *Palaeocystodinium golzowense. Systematophora placacantha* was not recorded. In the upper of the two (Core 151-913B-19W [380.69 mbsf]), a single specimen of *Operculodinium janduchenei* was recorded. This refers the lowermost sample to *Zone Mio5,* equivalent to a Tortonian age.

In the uppermost sample in Core 151-913B-19W (376.59 mbsf) *Impagidinium aculeatum* occurs indicating *Zone Mio6* or younger zones, equivalent to a Messinian or younger age.

SUMMARY AND CONCLUSIONS

Dinocysts were recorded in sufficient numbers and diversity to be useful in most of the cores, allowing stratigraphic interpretations to be made for the Holes 907A, 908A, and 909C. Exceptions to this were sections around the Miocene–Pliocene transition of all three holes, where sparse dinocysts were of limited stratigraphic value. Many of the recorded taxa are yet undescribed, which was also the case in earlier palynological studies of Norwegian-Greenland Sea DSDP/ODP cores. However, it has not been within the scope of the present study to formally describe new taxa.

A marked difference between Site 907 and Sites 908 and 909 is evident in the quantities of palynological residues obtained and their composition. Approximately 2 cm³ samples of sediments from Hole 907, interpreted as pelagic, yielded small quantities of residues to make only one or two thin microscope preparations from each sample, with dinocysts as the dominant component. Holes 908 and 909, on the other hand, yielded material to make many preparations in which the dinocysts are overshadowed by terrestrial plant tissue fragments and spores and pollen, indicating proximity to a vegetated continental source.

The biostratigraphic controls for the index taxa used in our age assignments are based on published records from Europe, North America, and DSDP/ODP holes in the North Atlantic and the Labrador Shelf. During the last two decades, dinocysts have been extensively used in biostratigraphic interpretations of DSDP/ODP holes in the Norwegian-Greenland Sea. However, no regionally applicable suite of index fossils has yet been established for this region. One explanation for this may be that independent stratigraphic controls for the recorded dinocyst ranges are still wanting in precision. Paleomagnetic data are most likely to yield the best stratigraphic control, but such data are sparse or inconclusive for large parts of the studied holes. Dinocyst zonations and correlations are also hampered by the want of detailed systematic and morphologic studies of numerous new forms recognized in this region.

We identified Paleogene sediments only from 908, where a middle Oligocene sequence is unconformably overlain by sediments of late Miocene age. Dinocysts place this break within the interval from

Table 4. Dinocyst distribution for Hole 913B.

Dinocysts	381.66 (mbsf)	380.69 (mbsf)	379.19 (mbsf)	377.70 (mbsf)	376.54 (mbsf)
Achomosphaera spp.	Present	Present			
Amiculosphaera umbracula		Present			
Barssidinium spp.		Present			
Batiacasphaera spp.	Present	Present			Present
Dapsilidinium spp.		Present			
Filisphaera filifera		Common			
Impagidinium spp.	Present				Present
I. aculeatum					Present
Invertocysta spp.		Present			
Lejeunecysta spp.	Present				Present
Lingulodinium machaerophorum		Present	Barren	Barren	
Melitasphaeridium choanophorum	Present		of	of	
Nematosphaeropsis rigida	Present		dinocysts	dinocysts	
Operculodinium centrocarpum	Common	Common			
O. janduchenei		Present			
O. piaseckii	Present	Present			
Palaeocystodinium golzowense	Abundant	Abundant			
Phelodinium spp.					
Polysphaeridium spp.	Present				
Protoperidinium spp.					
Reticulatosphaera actinocoronata	Present	Common			
Spiniferites spp.		Common			
Tectatodinium spp.		Common			

Section 151-908A-20X-5 (184.44 and 184.76 mbsf). The formations studied at Site 909 comprise the lower?–middle Miocene to the upper Miocene and possibly the lower Pliocene. At Site 907, a fairly complete middle to upper Miocene sequence is present. The Miocene/Pliocene boundary, which was identified by shipboard paleomagnetic data in Section 151-907A-10H-1 (84.75 mbsf), could not be precisely identified by dinocysts. At Site 908 this boundary also could be only vaguely indicated within the interval from Samples 151-908A-15X-2 to 8H-1 (131.93 to 63.39 mbsf).

The dominance of terrestrial palynomorphs and palynodebris in Hole 908 sediments confirms the continental origin of the Hovgård Ridge as interpreted by geophysical studies.

Paleoenvironmental interpretations are otherwise limited. The high frequencies of small round forms typical of the Miocene at Site 907 are thought to indicate temperate and deep nutrient-poor waters. A suite of acmes of three dinocyst groups at Sites 908 and 909 (*Nematosphaeropsis* spp., followed by *Evittosphaerula*? sp. 2, and terminated by *Barssidinium* spp.) is considered to represent significant bioevents that can be used for correlation between Sites 908 and 909. At Sites 908 and 909, protoperidinoid cysts are common, with blooms that are possibly related to abundance of organic matter in the water masses.

Diversity trends have not been examined in detail, but there appears to be a decreasing trend through time, especially after the middle late Miocene. A south to north diversity gradient from Site 907 to Sites 908 and 909 is not immediately evident. Any diversity trends along the east-west transect from the Iceland Plateau to the Vøring Plateau are difficult to document at present, partly because of the abundant undescribed dinocyst taxa, many of which are small and difficult to differentiate. Diverse small round dinocysts were also recorded by Manum (1976) and Manum et al. (1989). A potential clearly exists for further paleoenvironmental interpretations based on dinocysts along this transect.

Many deep-water species like *Nematosphaeropsis rigida* are recorded as frequent to abundant. Species suggesting warm temperate and/or oceanic conditions, like *Operculodinium israelianum* or *Impagidinium strialatum,* are recorded with high frequencies in several samples from Sites 908 and 909. They suggest oceanic influence and temperate surface conditions.

SYSTEMATIC NOTES

Most taxa encountered in this study are dinoflagellate cysts: Division Dinoflagellata (Bütschli 1885) Fensome et al. 1993. The generic allocation and authorship of dinoflagellate cyst taxa follow Lentin and Williams (1993), except where otherwise stated.

Notes on Selected Taxa

Achomosphaera sp. 1
Pl. 1, Figs. 7, 8

Remarks: A large and distinctive cyst form of *Spiniferites-Achomosphaera* morphology, overall width/length 120/130 µm, central body 65 × 50 µm, process length 30 to 40 µm. Processes bifurcate (except in sulcal area) midway up the stem before widely spreading trifurcations, which terminate with a few (mostly 2?) outward bending filaments, up to 2 µm long but variable. Phragms thin and unornamented, processes hollow. Periphragm creases at the widened process bases mimic sutures but proper sutures have not been observed. The distinctive processes are easily torn off and are recorded much more often than complete cysts.

Distribution: Consistently recorded from the deepest 20 m above the unconformity at Site 908 (Tortonian) and in the Langhian–Messinian (or Zanclean) intervals at Sites 907 and 909.

Artemisiocysta cladodichotoma
Pl. 2, Figs. 8, 11

Remarks: As with earlier records, we have not observed an archeopyle. Lacking proven dinoflagellate characters, Fensome et al. (1993) classified this cyst as an acritarch. However, many characters strongly suggest that it is a protoperidinoid cyst. The process type and the pentagonal outline of many specimens are reminiscent of the genus *Trinovantedinium,* and the grayish brown color of the phragm is also protoperidinoid.

Distribution: The species occurs consistently below the unconformity at Site 908. Above the unconformity, *Artemisiocysta* sp. is recorded as abundant in a single sample, but this is a different species having more and delicate processes.

Benedek and Müller (1974) showed *A. cladodichotoma* to be restricted to the Chattian when they established the nannoplankton control for the Tönisberg borehole, the type locality of the species. However, Benedek (1972) had in his original paper recorded the species also from Rupelian sediments, and the interval with its oldest record was actually retained in the Rupelian by Benedek and Müller (1974), who apparently missed it from the Rupelian in their range chart. Therefore, our Rupelian assignment of the section at Site 908 containing *A. cladodichotoma* is not in conflict with Benedek's (1972) record of it. No reliable last occurrence datum for the species is yet recorded.

Evittosphaerula? sp. 2 (Manum et al. 1989)

Thalassiphora? sp. A (Powell 1986a, b, c)
Gen. et sp. indet. 1 (Head et al. 1989b)
Evittosphaerula sp. (Engel 1991)

Remarks: Head et al. (1989b) gave a description of the morphology accompanied by good light and SEM photographs of this very distinctive form, which, however, remains to be formally described. It is clearly related neither to *Thalassiphora,* nor to *Evittosphaerula,* but is more like the latter because of its distinctive ribbon-like network resembling the network in *E. paratabulata.* However, the number of meshes is much lower (10) and they reflect no recognizable dinoflagellate tabulation. In some specimens, a thin-walled and wrinkled internal body is fixed to the network by three suspensors, but more often only remnants of the suspensors are preserved. Because of the lack of proven dinoflagellate morphology, the taxon must be classified as an acritarch.

Head et al. (1989b, p. 429) proposed that *Evittosphaerula* sp. 1 of Mudie (1989) is also conspecific, but the specimen illustrated by Mudie (1989, Pl. 2:3) is clearly different.

Distribution: *Evittosphaerula*? sp. 2 appears to be an important Miocene marker in the northernmost Atlantic. Within its recorded range it is consistently found and it shows distinctive acmes that we could use for correlation and dating between Sites 908 and 909. Similar events occur elsewhere (Sites 643 and 907) which stresses the potential significance in biostratigraphic and environmental interpretations.

Available evidence from elsewhere (Manum, in prep.) suggests that *Evittosphaerula*? sp. 2 has a range within the Tortonian, while our records from Site 909 suggest a somewhat earlier first appearance, in the late Serravallian.

A comparison with the last occurrence of *Labyrinthodinium truncatum* is of interest. At Sites 642/643 the range of *Labyrinthodinium truncatum* does not overlap with that of *Evittosphaerula*? sp. 2. At Sites 908 and 909, however, an overlap is recorded, likewise at Site 646.

Palaeocystodinium sp. 1
Pl. 3, Fig. 7

Remarks: A cyst form mimicking *Svalbardella cooksoniae* in its shape and size but lacking the periphragm ornamentation and evidence of tabulation that are distinctive of *Svalbardella.* Both horns possess a terminal nipple.

Distribution: Consistently present in the Oligocene section at Site 908, where it is often abundant in association with *Palaeocystodinium golzowense* and sporadically in the early to middle Miocene section at Site 909 that is not present at 908.

Svalbardella sp. 1
Pl. 3, Fig. 13

Remarks: This form differs from *Svalbardella cooksoniae* in being wider and having shorter horns. Benedek (1972) recorded a similar form as *Svalbardella* cf. *granulata* (but it is quite different from *S. granulata*) from strata assigned to NP24 by Benedek and Müller (1974). Similar forms were recorded by Damassa et al. (1990) as *Palaeocystodinium* sp. 1 and sp. 2, also from sediments of NP24 age. Illustrations in both of the papers mentioned show specimens with tabulation characters and periphragm ornamentation that we would regard as distinctive of *Svalbardella,* but they are different from *S. cooksoniae.*

Svalbardella sp. 1 and the other forms mentioned above seem to belong to a distinctive morphological group. More specimens need to be studied to separate them properly and establish formal taxa.

Distribution: This species has been recorded from the very top of the Oligocene section at Site 908. The records of similar forms mentioned above are so far restricted to NP24 equivalent strata, while *S. cooksoniae* has its LOD in the Rupelian.

Tuberculodinium vancampoae
Pl. 3, Fig. 12

Distribution: Single specimens of this species were recorded in Hole 908A below the unconformity recorded at the boundary between Unit I and Unit II (Core 151-908A-20X-6). Brinkhuis et al. (1992) indicated a FAD in NP25, which conflicts with our assignment of the youngest sediments below the unconformity to NP24. However, there are unsubstantiated records of *T. vancampoae* from the Rupelian (Damassa et al., 1990) and as early as the Eocene (Wrenn and Damassa, 1989). Edwards (1988) recorded *T. vancampoae* in Upper Oligocene sediments from South Carolina, where its range overlaps with that for *Chiropteridium* spp. The Shipboard Scientific Party (1994) recorded a similar overlap of *T. vancampoae* and *Chiropteridium* ranges at Site 902. Together with the present records this shows that *T. vancampoae* has an earlier FAD than hitherto recognized.

Vozzhennikovia spp.
Pl. 2, Figs. 14, 15

Remarks: Under this group name we include a number of biphragmal peridinoid cyst forms that are nearly round with poorly developed horns, periphragm smooth to vaguely ornamented, size 40 to 60 µm. Not all belong to *Vozzhennikovia,* but *V. spinula* and *V. ceariaichia* may be represented among them, both recently described as new species by Stover and Hardenbol (1993) from the Rupelian of the Boom Clay. Differentiation is difficult and requires a more thorough study than was possible for this paper.

Distribution: Recorded from the Oligocene and late Miocene at Site 908.

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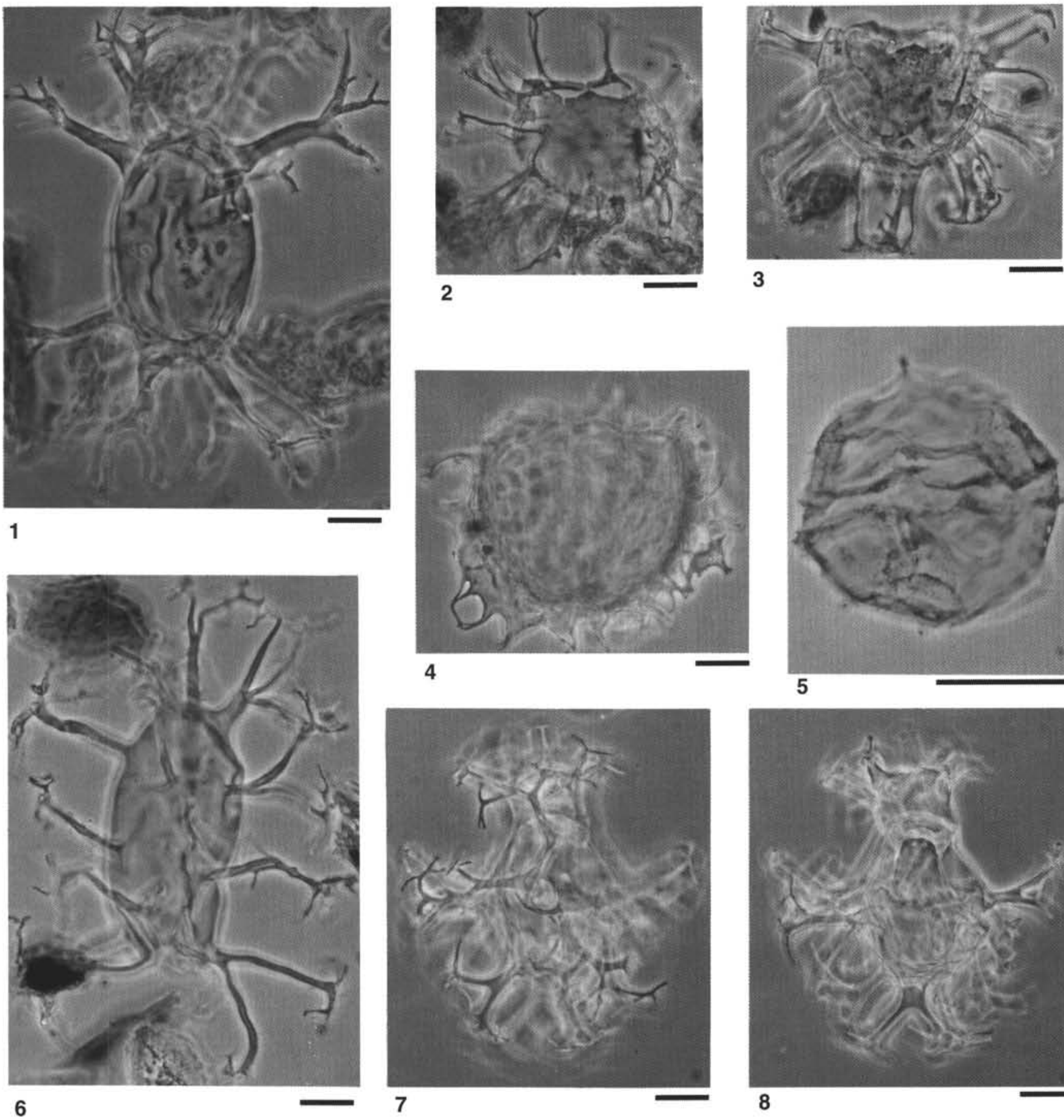

Plate 1. (Scale bars = 20 µm, Ph = phase contrast, B = bright field, EFC = England Finder coordinates). **1.** *Distatodinium biffii.* Sample 151-908A-25CC (UO-5161III; EFC JK32; Ph). **2–3.** *Areoligera? semicirculata.* 2. Sample 151-908A-36-2, 68–70 cm (UO-5217III; EFC D38; Ph). 3. Sample 151-908A-27-4, 21–23 cm (UO-5196VI; EFC M35/2; Ph). **4.** *Chiropteridium galea* "complex". Sample 151-908A-25-6, 15–17 cm (UO-5194III; EFC Q43–44/1–2; Ph). **5.** *Phthanoperidinium amoenum.* Sample 151-908A-26-2, 17–19 cm (GSC-P34567-01; EFC C35/3). **6.** *Distatodinium paradoxum.* Sample 151-908A-32-1, 37–39 cm (UO-5143III; EFC S36/2; Ph). **7–8.** *Achomosphaera* sp.1. Sample 151-908A-20-3; 105–106 cm (UO-5232II; EFC P37/1; Ph). 7. low; 8. high.

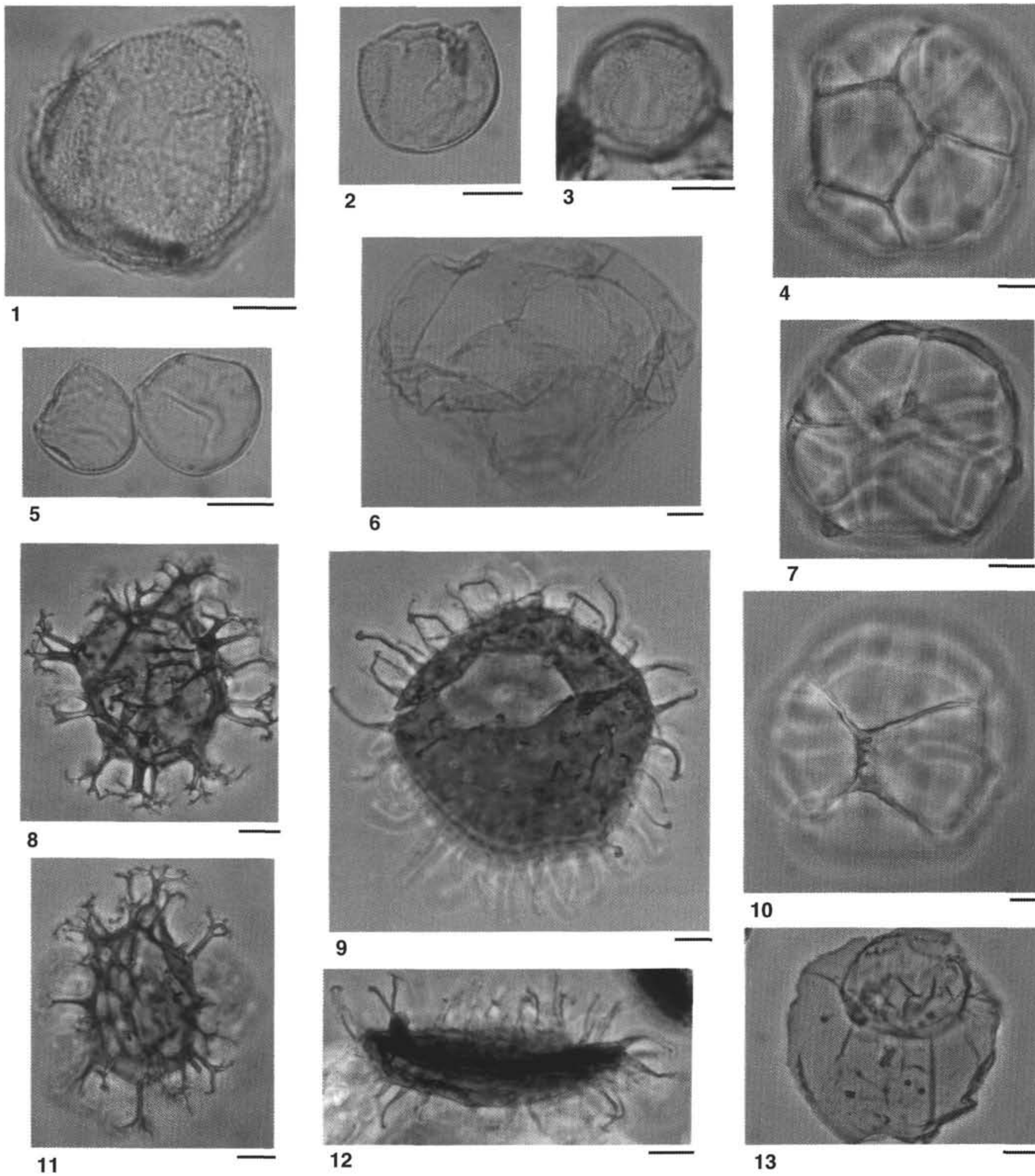

Plate 2. (Scale bars = 20 µm, Ph = phase contrast, B = bright field, EFC = England Finder coordinates). **1.** *Batiacasphaera hirsuta.* Sample 151-907A, 125.94 m (GEUS Catalogue no. NEP-1996-1). **2.** *B. micropapillata.* Sample 151-907A, 119.54 m (GEUS Catalogue no. NEP-1996-2). **3.** *Tectatodinium psilatum.* Sample 151-907A, 111.97 m (GEUS Catalogue no. NEP-1996-3). **4, 7, 10.** *Evittosphaerula* sp.2 of Manum et al. (1989). Sample 151-908A-19CC (UO-5155III, EFC E42/3-4; Ph). 4. low. 7. internal. 10. high. **5.** *Batiacasphaera sphaerica.* Sample 151-907A, 149.91 m (GEUS Catalogue no. NEP-1996-4). **6.** *Amiculosphaera umbracula.* Sample 151-909C, 362.65 m (GEUS Catalogue no. NEP-1996-5). **8, 11.** *Artemisiocysta cladodichotoma.* 8. Sample 151-908A-25-6, 15–17 cm (UO-5194II, EFC Q47; Ph). 11. Sample 151-908A-25-3, 8–10 cm (UO-5159III, EFC J44/2; Ph). **9, 12.** *Barssidinium graminosum.* 9. Sample 151-908A-18-6, 66–68 cm (UO-5182II, EFC S39; Ph). 12. Sample 151-908A-20-1, 53–55 cm (UO-5131IV, EFC D42; Ph). **13.** *Thalassiphora? pansa.* Sample 151-908A-24-5, 112–114 cm, GSC-P34564-01; EFC E38/1-2).

Plate 3. (Scale bars = 20 μm, Ph = phase contrast, B = bright field, EFC = England Finder coordinates) **1–2.** *Invertocysta tabulata*. 1. Sample 151-908A-18-1, 65–67 cm (UO-5129III, EFC RS39; Ph). 2. Sample 151-909C, 364.60 m. (GEUS Catalogue no. NEP-1996-6). **3.** *Nematosphaeropsis lemniscata*. Sample 151-909C, 382.64 m. (GEUS Catalogue no. NEP-1996–7; Ph). **4, 9, 11.** *Spiniferella cornuta*. 4, 9. Sample 151-908A-25-4, 8–10 cm (UO-5193II, EFC KL40/2–4; Ph) 4. low. 9. high. 11. Sample 151-908A-30-3, 104–106 cm (UO-5162IV, EFC BC37; Ph). **5.** *Cymatiosphaera invaginata*. Sample 151-907A, 125.94 m (GEUS Catalogue no. NEP-1996-8). **6.** *Labyrinthodinium truncatum*. Sample 151-909C-93CC (UO-5200II, EFC HJ44-45; Ph). **7.** *Polykrikos* sp. Sample 151-908A-18-66, 66–68 cm (UO-5182II, EFC OP45; Ph). **8.** *Palaeocystodinium* sp. 1. Sample 151-908A-27-4, 21–23 cm (UO-5196III, EFC D38; Ph). **10.** *Selenopemphix dioneaecysta*. Sample 151-908A-18-1, 65–67 cm (UO-5129III, EFC H44–45). **12.** *Tuberculodinium vancampoae*. Sample 151-909C, 362.65 m. (GEUS Catalogue no. NEP-1996-9). **13.** *Svalbardella* sp. 1. Sample 151-908A-20-6, 45–46 cm (UO-5243I, EFC L33-34). **14–15.** *Vozzhennikovia* spp. 14. Sample 151-908A-27-4, 21–23 cm (UO-5196II, EFC H42; Ph). 15. Sample 151-908A-25-6, 15–17 cm (UO-5194II, EFC J44/2; Ph).