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7. OLIGOCENE–EARLY MIOCENE DINOCYST STRATIGRAPHY OF HOLE 985A (NORWEGIAN SEA)[1]

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ABSTRACT

The rich and diverse dinocyst assemblages in Cores 162-985A-32X through 62X confirm the importance of these microfossils in unraveling the evolution of the Norwegian Sea. Cosmopolitan taxa, with well-documented stratigraphic ranges in northwest Europe, indicate the following ages: Sections 162-985A-62X-1 through 51X-2, Rupelian (early Oligocene); 50X-5, Oligocene, possibly Chattian; 48X-6, Aquitanian? (early Miocene); 48X-4 through 37X-5, Aquitanian (early Miocene); and 36X-5 through 32X-1, Burdigalian (early Miocene). This stratigraphic interpretation suggests that a major hiatus, which can be correlated with an apparently coeval hiatus at Site 643, occurs within the Chattian at Site 985. Several endemic dinocyst taxa with unusual morphology and restricted stratigraphic occurrences are present in Hole 985A and other Norwegian Sea sites, especially Site 643. By using Hole 985A data for control, the Oligocene–Miocene sediments can be correlated with some degree of confidence in the Norwegian Basin.

INTRODUCTION

Ocean Drilling Program (ODP) Leg 162 Site 985 is located in the central part of the Norwegian Sea in 2788 m water depth, on a gentle, east-facing slope of the Iceland Plateau (Figs. 1, 2). Two holes were drilled, Holes 985A and 985B. This report discusses the lower part of the deeper hole, Hole 985A, which reached a total depth of 587.9 meters below seafloor (mbsf) and from which was obtained 553.42 m of core.

Drilling at Site 985 had two main objectives (Shipboard Scientific Party, 1996, pp. 254–256). The primary objective was to provide additional data for a paleoenvironmental transect across the Norwegian Sea, including previous sites drilled on Legs 104 and 152. The aim of this transect was to study late Cenozoic development of water-mass circulation between the Arctic and the Atlantic Oceans. The secondary objective was to obtain Paleogene carbonate-bearing sediments that would yield material suitable for paleotemperature and paleoceanographic studies. Paleogene sediments have been recovered from only a few previous Deep Sea Drilling Project (DSDP)/ODP sites in the Norwegian-Greenland Sea, and poor recovery and diagenetic overprinting have precluded stable isotope studies. Scarcity or absence of calcareous and siliceous microfossils has also hampered biostratigraphic control in the Paleogene sections (Goll, 1989).

Site 985 was located on Anomaly 22 crust (~50 Ma) with an assumed normal subsidence history, so it was considered promising for attainment of the secondary objective. Contrary to expectations, both calcareous and siliceous microfossils were scarce. The Shipboard Scientific Party (1996, pp. 268–269) considered the uppermost nine cores to be Pliocene on the basis of the nannofossils. The sparse siliceous microfossils suggested that Cores 162-985A-24X through 31X could be middle Miocene. Below Core 31X, agglutinated benthic foraminifers indicated a late Oligocene–early Miocene age for Cores 162-985A-33X through 40X and an undifferentiated Oligocene age for Cores 41X through 62X.

In contrast to other microfossil groups, dinoflagellate cysts (dinocysts) occur consistently in the Paleogene section of Hole 985A, as is true elsewhere in the Norwegian-Greenland Sea where they have proved useful for age control (Manum, 1976; Manum et al., 1989; Firth, 1996; Poulsen et al., 1996). As shown in this report, dinocysts provide improved age control for the Oligocene and lowermost Miocene cores from Site 985.

In order to elucidate the geological history in the bottom part of Hole 985A, where none of the other microfossil groups provided age control, we studied dinocysts from Core 162-985A-62X (579.09 mbsf) up to and including Core 32X (290.49 mbsf; Fig. 3; Table 1). The lowest sample for which there was independent control was Core 162-985A-31X, which was considered to be of definite Miocene age by the shipboard stratigraphers. A total of 98 5-cm^3 samples were processed using standard palynological methods. Forty-eight samples (approximately every other sample) were processed in the palynology laboratory at the Geological Survey of Canada (Atlantic) in Dartmouth, Nova Scotia; the remainder, in the palynology laboratory in the Geology Department of the University of Oslo, Norway.

Lithostratigraphically, the studied section comprises Unit V and the lower part of Subunit IVC as defined by the Shipboard Scientific Party (1996, pp. 261–268). These units are composed of clay with varying minor occurrences of silt and are distinguished mainly on the basis of a sharp increase in magnetic susceptibility at their boundary in Section 162-985A-50X-2.

Site 985 was approximately conjugate to Site 643, with respect to the spreading axis, until Anomaly 7 time (Oligocene–early Miocene transition) when the axis shifted to west of the Iceland Plateau (Shipboard Scientific Party, 1996, p. 267). The evolution of the basin was presumably similar at both sites, which is confirmed by the correspondence in the succession of dinocyst events in the Oligocene and lower Miocene sections (Fig. 4).

BIOSTRATIGRAPHY

Basis for Age Determination

Many of the index species for the Oligocene–Miocene in northwestern Europe have not been recorded from the Norwegian Sea. This has been a handicap for palynological studies on cores from previous DSDP/ODP legs in the Norwegian-Greenland Sea since the first cruise to these waters in 1974 (DSDP Leg 38; Manum, 1976). Nevertheless, for the age determinations shown in Table 2 and Figure 3 for Hole 985A, we were able to use several dinocyst species with well-documented ranges and for which there is independent stratigraphic (usually nannofossil or planktonic foraminiferal) control out-

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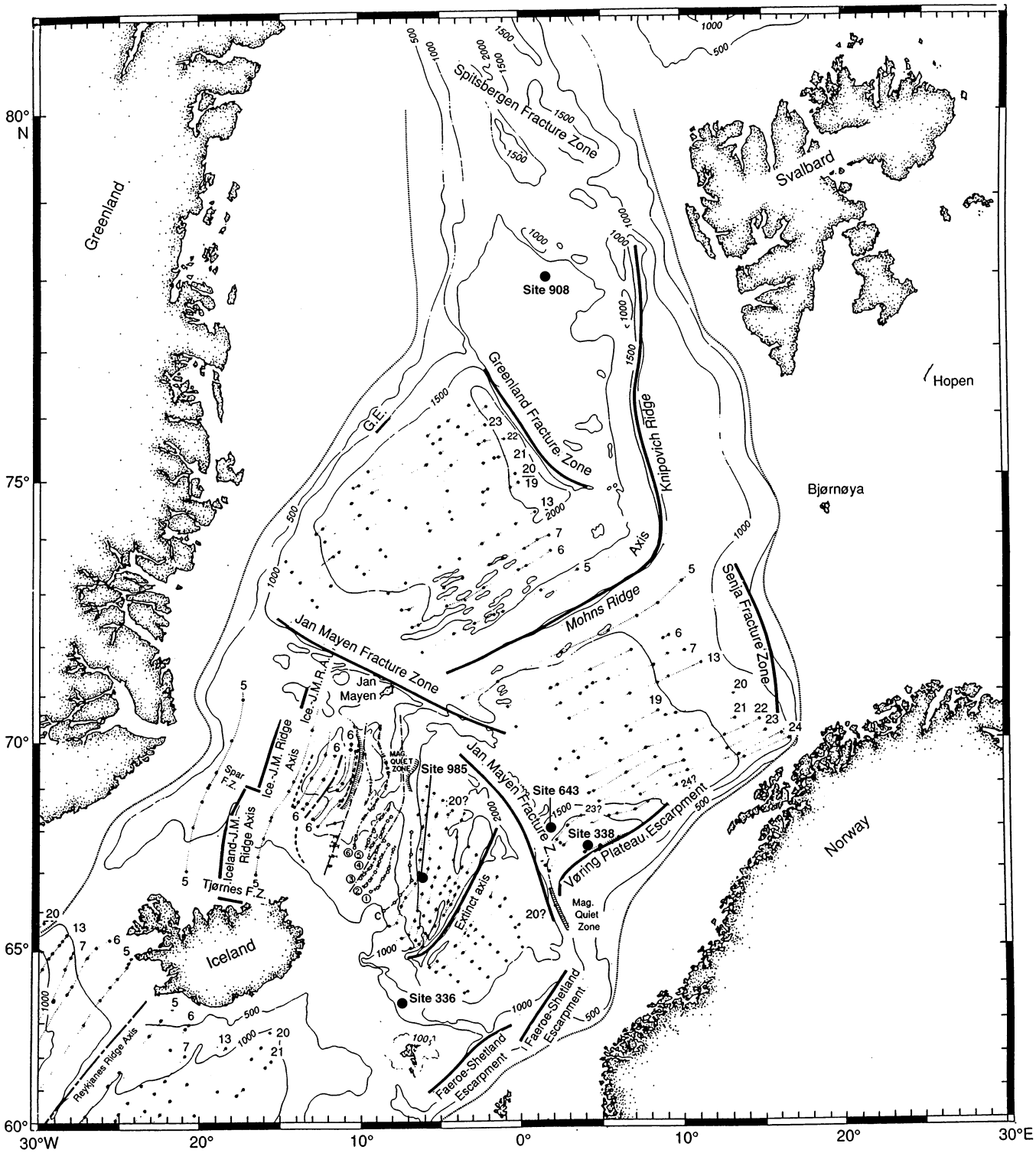

Figure 1. Location of DSDP/ODP sites discussed in this paper.

side the Norwegian Sea. The other dinocyst taxa used for age determination belong to formal and informal taxa that have restricted ranges in the Norwegian Sea, particularly in cores from Leg 104, Site 643 (Manum et al., 1989, and others), but have seldom been recorded outside the area. We found these taxa helpful in correlation with Site 985.

For correlation between Site 985 and Site 643, we have used the chronostratigraphic framework established for the Norwegian-Greenland Sea sites by Goll (1989) in his comprehensive biostratigraphic synthesis for Leg 104. This has recently been modified (R. M. Goll, unpubl. data), and we are using the new version for this study. In Figure 4 (center column), the ages assigned by Goll to the Miocene cores from Site 643 are shown using the time scale of Berggren et al. (1995). These ages are based on evidence from several microfossil groups, except for the earliest part of the Miocene (Cores 104-643A-42X through 31X) where dinocysts provide the only bio-

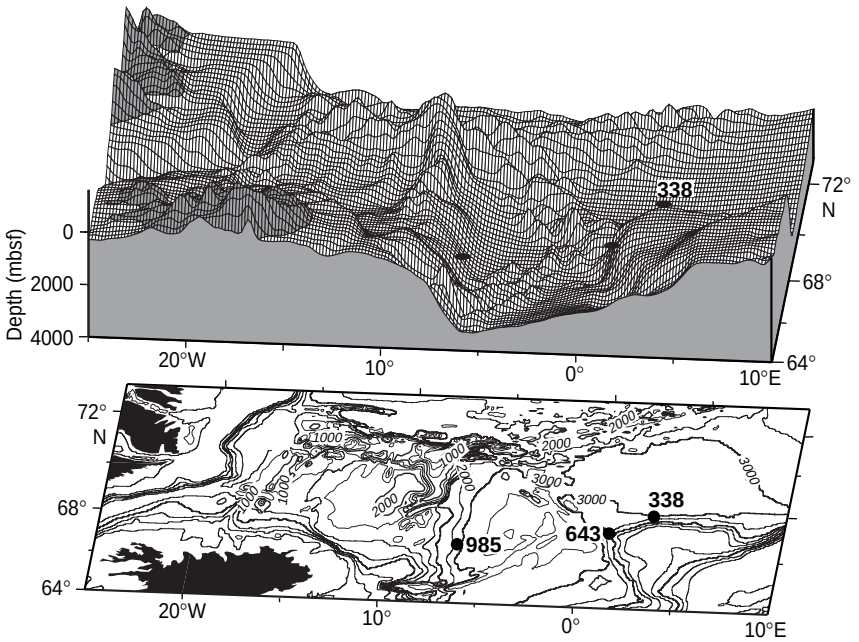

Figure 2. Bathymetry of the Norwegian Sea in the vicinity of Sites 338, 643, and 985 (from Shipboard Scientific Party, 1996).

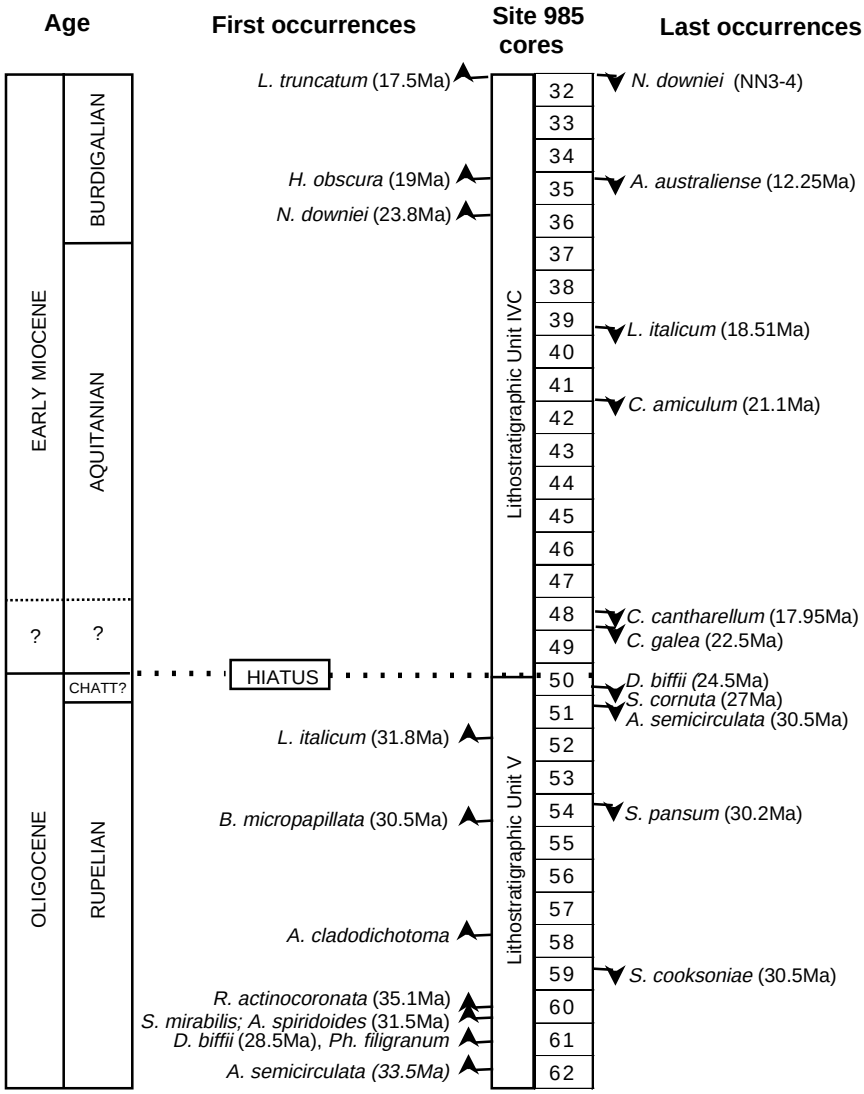

Figure 3. First and last occurrences of dinocyst taxa used for age determinations in Site 985 cores. References for quoted ages are given in Table 2.

Table 1. List of samples from Hole 985A analyzed in this study.

Core, section	Depth (mbsf)
162-985A-	
32X-1	290.49
32X-2	291.99
32X-4	294.99
32X-6	297.99
33X-1	300.09
33X-5	306.09
33X-6	307.59
34X-2	311.19
34X-5	315.69
35X-1	319.39
35X-2	320.89
35X-5	325.39
35X-6	326.89
36X-2	330.49
36X-5	334.99
36X-6	336.49
37X-2	340.09
37X-5	344.59
37X-6	346.09
38X-2	349.69
38X-5	354.19
39X-2	359.29
39X-5	363.79
39X-6	365.29
40X-2	368.89
40X-5	373.39
41X-2	378.09
41X-5	382.59
41X-6	384.09
42X-2	387.89
42X-5	392.39
43X-2	397.69
43X-5	402.19
43X-6	403.69
44X-2	407.39
44X-5	411.89
45X-2	417.09
45X-6	423.09
46X-1	425.29
46X-3	428.29
46X-4	429.79
46X-6	432.79
47X-3	437.89
47X-4	439.39
47X-6	442.41
48X-1	444.49
48X-3	447.49
48X-4	448.99
48X-6	451.99
49X-3	457.09
49X-4	458.59
49X-6	461.59
50X-1	463.59
50X-2	465.09
50X-4	468.09
50X-5	469.59
51X-2	474.69
51X-4	477.69
51X-5	479.19
52X-1	482.79
52X-2	484.24
52X-4	487.29
52X-5	488.79
53X-2	493.89
53X-4	496.89
53X-5	498.39
54X-1	501.99
54X-2	503.49
54X-3	504.99
54X-5	507.99
54X-6	509.49
55X-1	511.59
55X-2	513.09
55X-4	516.09
55X-5	517.59
55X-6	519.09
56X-1	521.29
56X-2	522.79
56X-3	524.29
56X-5	527.29
56X-6	528.79
57X-1	530.89
57X-2	532.39
57X-3	533.89
58X-1	540.49
58X-2	541.99
59X-1	550.09
59X-2	551.59
60X-1	559.79
60X-2	561.29
60X-3	562.79
60X-4	564.29
60X-5	565.79
61X-2	570.19
61X-3	571.57
61X-4	573.07
62X-1	579.09

stratigraphic control (Manum et al., 1989). Core 104-643A-43X has a NP25 nannofossil marker (*Discolithina enormis*) and is referred to by Goll as the late Oligocene. The age of Core 42X is in dispute: the dinocysts indicated an early Miocene age, whereas Goll considered it Oligocene. Independent stratigraphic control is also lacking for the Oligocene interval below Core 104-643A-43X, and the early Oligocene age indicated for Cores 47X through 50X is also contentious. The dinocyst range chart for Site 643 (Manum et al., 1989) shows a clear break between Cores 104-643A-46X and 47X, which supports Goll's interpretation of a major hiatus.

Age Determinations

First and last occurrences of stratigraphically useful species are shown in Table 2. Many of the taxa listed are informal, being known from previous dinocyst studies on Norwegian Sea cores; four informal taxa (*Lophocysta* sp. 1 and sp. 2, *Eatonicysta* sp. 1, Gen. et sp. indet.; see below under "Informal Taxa with Restricted Stratigraphic Ranges") are introduced in this study. For the taxonomy of formal species, we follow Lentin and Williams (1993).

Samples from Hole 985A, Cores 62X through 58X (which we regard as Oligocene), contain several taxa that first occur in the Oligocene of northwestern Europe. These are *Areoligera semicirculata, Artemisiocysta cladodichotoma, Phthanoperidinium filigranum, Reticulatosphaera actinocoronata,* and *Spiniferites mirabilis. Apteodinium spiridoides,* which occurs in Section 162-985A-60X-5, has never been recorded from pre-Rupelian sediments. The oldest known occurrence is 31.50 Ma (within the Rupelian), according to Stover and Hardenbol (1993). The presence of *Svalbardella cooksoniae* in Section 162-985A-59X-2 also supports a Rupelian age for the lowermost part of the hole. The last occurrence of *Areoligera semicirculata* in Section 162-985A-51X-2 upholds our interpretation of a Rupelian age for the interval from Core 162-985A-62X through Section 51X-2 because this species is restricted to the Rupelian (Williams et al., in press). Accordingly, the sample from Section 60X-5 is taken as no older than Rupelian. Section 50X-5 is tentatively included in the Chattian, on the basis of the last occurrence of *Spiniferella cornuta*, which, from Benedek (1972), has its youngest known occurrence at 27 Ma. This may represent the top of the Oligocene. Section 162-985A-48X-6, which contains *Chiropteridium galea,* is questionably included in the Aquitanian. The last occurrence of *C. galea* was taken to mark the top Oligocene at Sites 643 and 908. However, in the eastern United States, de Verteuil and Norris (1996) recorded this taxon in the earliest Miocene. Following these authors, we have questionably included Section 162-985A-48X-6 in the early Miocene. Our age determination implies that there is a major hiatus within the Chattian, which agrees with the boundary between lithostratigraphic Units V and IV in Section 162-985A-50X-2, which is considered the Oligocene/Miocene boundary. Section 162-985A-48X-4 is interpreted as early Miocene on the basis of the presence of *Leptodinium* sp. III of Manum (1976), which is known only from the Miocene.

We consider the interval from Section 162-985A-48X-4 to our uppermost sample in Section 162-985A-32X-1 to be early Miocene in age. The Aquitanian/Burdigalian boundary is placed between Sections 162-985A-37X-5 and 36X-5. Section 162-985A-37X-5 contains *Evittosphaerula paratabulata*, which at Site 643 first appears in Section 162-985A-34X-2, dated as 21 Ma by R.M. Goll (unpubl. data; Fig. 3). *Lophocysta sulcolimbata* first appears at Site 643 in Section 162-985A-32X-1, which is taken to be 20.5 Ma. Because the Aquitanian/Burdigalian boundary is 20.52 Ma, this indicates that Section 37X-5 is Aquitanian and Section 36X-5 is Burdigalian.

We consider Section 162-985A-32X-1, our uppermost sample, to be no younger than the Burdigalian because it contains *Nematosphaeropsis downiei.* Brown (1986) recorded this species from the early Miocene of Hole 548A in the Bay of Biscay. Powell (1986b) recorded it as *Nematosphaeropsis*? sp. A, from the lower Miocene of Italy.

Comparison of Dinocyst Events between Sites 985 and 643

The conjugate position of Sites 985 and 643, with respect to the spreading axis, makes it reasonable to assume that the evolution of the basin was similar at both sites. This is confirmed by the correspondence between the succession of dinocyst events shown for the Oligocene and lower Miocene sections of both sites (Fig. 4).

In Figure 4, we show the first and last occurrences of dinocysts that appear to be of stratigraphic significance at Site 985 and correlation with the same events at Site 643. The sequence of events in the two core holes is similar, particularly for taxa that appear to be endemic to the Norwegian Sea. The few taxa that do not fit are mostly species that also occur outside the Norwegian Sea. These taxa may well have distributions that are at variance with the endemic ones; they may be warmer water species showing erratic occurrences because of periodic migration into the higher latitudes. Another factor that may have influenced migration of lower latitude taxa is the Iceland-Faeroe Ridge, which was an obstacle to water-mass circulation and migration between the Norwegian Sea and the North Atlantic until well into Miocene times. The last occurrence of *Cordosphaeridium cantharellum* at the two sites does not follow the general pattern, being stratigraphically lower in Hole 985A. Its last occurrence at Site 643 may be reworked; its last consistent occurrence in that hole is in Section 162-643A-28X-7, which is in agreement with its last occur-

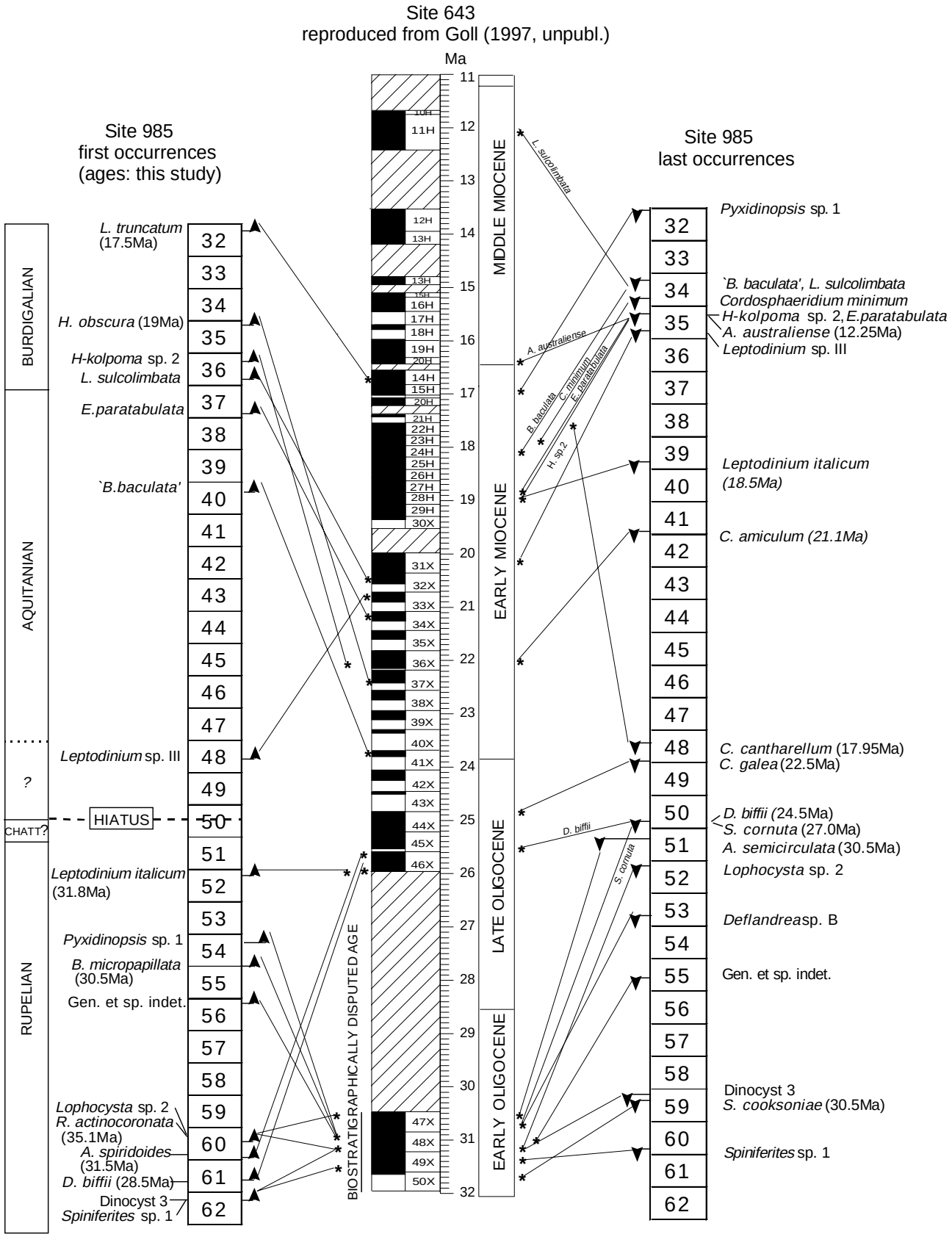

Figure 4. Dinocyst first and last occurrences in Site 985 cores compared to corresponding events in Site 643 (Leg 104). The center column shows Site 643 cores (recovery in black) and interpreted hiatuses (hatched) vs. the absolute time scale (reproduced from R.M. Goll, unpubl. data).

Table 2. First and last occurrences of stratigraphic marker taxa recorded from Site 985.

Core, section	Depth (mbsf)	First occurrence	Last occurrence	Age determination
162-985A-				
32X-1	290.49		*Nematosphaeropsis downiei* (Brown, 1986: early Miocene/NN3-4) *Pyxidinopsis* sp. 1 Manum et al. (1989) (104-643A-15H-6 = 17 Ma)	
32X-2	291.99	*Labyrinthodinium truncatum* (Williams et al., in press: 17.5 Ma; 104-643A-14H-5 = 16.8 Ma)		
34X-2	311.19		*Batiacasphaera baculata* sensu Manum et al. (1989) (= "*Kallosphaeridium biornatum*" group of Heilmann-Clausen and Costa, 1990) (104-643A-24X-5 = 18 Ma) *Lophocysta sulcolimbata* (104-643A-11H-5 = 12 Ma)	
34X-5	315.69		*Cordosphaeridium minimum* = Dinocyst II, Manum (1976) and Manum et al. (1989) (104-643A-23X-5 = 18 Ma)	early Miocene, Burdigalian
35X-1	319.39	*Hystrichosphaeropsis obscura* (Williams et al., in press: 19 Ma; 104-643A-37X-3 = 22.5 Ma)	*Hystrichokolpoma* sp. 2 Manum et al. (1989) (Zevenboom, 1995: 17.3 Ma; 104-643A-28X-7 = 19 Ma), *Evittosphaerula paratabulata* (104-643A-27X-5 = 19 Ma	
35X-2	320.89		*Apteodinium australiense* (Williams et al., in press: 12.25 Ma; 104-643A-19X-6 = 16 Ma)	
35X-6	326.89		*Leptodinium* sp. III Manum (1976) and Manum et al. (1989) (104-643A-31X-2 = 20 Ma	
36X-2	330.49	*Nematosphaeropsis downiei* (Powell, 1986a as *Nematosphaeropsis*? sp. A: 23.8 Ma) *Hystrichokolpoma* sp. 2 Manum et al. (1989) (Zevenboom, 1995: 17.3 Ma; 104-643A-36X-5 = 22 Ma)		
36X-5	334.99	*Lophocysta sulcolimbata* (104-643A-32X-1 = 20.5 Ma)		
37X-5	344.59	*Evittosphaerula paratabulata* (104-643A-34X-2 = 21 Ma)		
39X-5	363.79		*Leptodinium italicum* (= *Leptodinium* sp. II Manum, 1976; *Impagidinium* sp. 1 Manum et al., 1989) (Williams et al., in press: 18.51 Ma; 104-643A-28X-7 = 19 Ma; 38-338-14-2 = 20 Ma)	
40X-2	368.89	*Batiacasphaera baculata* sensu Manum et al. (1989) (= "*Kallosphaeridium biornatum* group" of Heilmann-Clausen and Costa, 1990) (104-643A-41X-1 = 24 Ma)		early Miocene Aquitanian
41X-6	384.09		*Caligodinium amiculum* (Williams et al., in press: 21.1 Ma; 104-643A-36X-5 = 22 Ma)	
48X-3	447.49		*Cordosphaeridium cantharellum* (Williams et al., in press: 17.95 Ma; 104-643A-22X-5 = 18 Ma)	
48X-4	448.99	*Leptodinium* III Manum (1976) and Manum et al. (1989) (104-643A-33X-1 = 21 Ma)		
48X-6	451.99		*Chiropteridium galea* (Williams et al., in press: 22.5 Ma; 104-643A-44X-1 = 25 Ma)	?early Miocene

rence at ~18 Ma in northwestern Europe. *Apteodinium australiense* is another example of a species with a different range. *Apteodinium australiense* has its last occurrence in the Norwegian Sea in sediments older than in northwestern Europe, where it has been recorded from the middle Miocene (Serravalian). An endemic taxon that does not fit the pattern is *Leptodinium* sp. III. Its base may not have been noted in the core at Site 643 because it is rare and probably inconsistently identified.

A comparison of early Miocene events shows particularly good agreement between the intervals from Sections 40X-2 to 35X-1 of Site 985 and from Sections 41X-1 through 31X-2 of Site 643. The correlation of these intervals has implications for the interpretation of the early Miocene at these sites. A section equivalent to Cores 48X–41X at Site 985 appears to be missing at Site 643 because there is independent evidence for the NP25 zone in Core 104-643A-43X (but not 42X). Also, Core 162-985A-48X is considered by us to be early Miocene because of the presence of *Leptodinium* sp. III Manum, 1976. The occurrence of *Leptodinium* sp. III in Core 33X at Site 643 indicates a more complete lower Miocene section at that site.

Goll's (1989; R.M. Goll, unpubl. data) interpretation of an Oligocene hiatus is supported by our correlation of events. At Site 985, the hiatus comprises most of the Chattian, and the correlation between events in the sections below the hiatus at both sites indicates a similar time span for the hiatus at Site 643. The correlation also indi-

Table 2 (continued).

Core, section	Depth (mbsf)	First occurrence	Last occurrence	Age determination
50X-5	469.59		*Spiniferella cornuta* (Benedek, 1972: 27 Ma; 104-643A-47X-4) *Distatodinium biffii* (Williams et al., in press: 24.5 Ma; 104-643A-45X-6: 25.5 Ma)	Oligocene, possibly Chattian
51X-2	474.69		*Areoligera semicirculata* (= *Glaphyrocysta intricata* in Manum et al. (1989) (Williams et al., in press: 30.5 Ma; 104-643A-47X-1)	
52X-1	482.79	*Leptodinium italicum* (= *Leptodinium* sp. II Manum, 1976; *Impagidinium* sp. 1 Manum et al., 1989) (Williams et al., in press: 31.82 Ma; 38-338-24-2 = 27 Ma; 104-643A-46X-5)	*Lophocysta* sp. 2 (104-643A: in 48X-6 only)	
53X-4	496.89		*Deflandrea* sp. B of Powell (1986b) sensu Manum et al. (1989) (104-643A-47X-4)	
54X-2	503.49	*Pyxidinopsis* sp. 1 Manum et al. (1989) (104-643A-48X-1)	*Saturnodinium pansum* (Williams et al., in press: 30.24 Ma; 151-908A-24X)	
54X-6	509.49	*Batiacasphaera micropapillata* (Williams et al., in press: 30.5 Ma; 104-643A-48X-1)		
55X-4	516.09		Gen. et sp. indet. (104-643A: in 48X-1 only)	
56X-1	521.29	Gen. et sp. indet. (104-643A: in 48X-1 only)		
59X-1	550.09		Dinocyst 3 Manum et al. (1989) (104-643A-48X-6)	
59X-2	551.59		*Svalbardella cooksoniae* (Johnsen, 1983: 336-21-1 = 30.5 Ma; Costa and Manum, 1988: approximately 30.5 Ma; 104-643A-50X-1)	Rupelian
60X-3	562.79	*Reticulatosphaera actinocoronata* (Williams et al., in press: 35.1 Ma; 104-643A-47X-1) *Lophocysta* sp. 2 (104-643A: in 48X-6 only)		
60X-5	565.79	*Apteodinium spiridoides* (Williams et al., in press: 31.5 Ma; 104-643A-46X-1)	*Spiniferites* sp. 1 Manum et al. (1989) (104-643A-49X-3)	
61X-3	571.57	*Distatodinium biffii* (Williams et al., in press: 28.5 Ma; 104-643A-46X-3)		
62X-1	579.09	Dinocyst 3 Manum et al. (1989) (104-643A-48X-6) *Deflandrea* sp. B of Powell (1986b) sensu Manum et al. (1989) (104-643A-53X-3) *Areoligera semicirculata* (Williams et al., in press: 33.5 Ma) *Spiniferites* sp. 1 Manum et al. (1989) (104-643A-49X-4)		

Notes: First and last occurrences from published sources are quoted above (Leg 104, Site 643 data: Manum et al. [1989]; Leg 151, Site 908 data: Poulsen et al. [1997]; Leg 38, Site 338 data: Manum [1976]. Absolute ages quoted for cores from Sites 643 and 338 are according to R.M. Goll [unpubl. data]).

cates a much thicker Rupelian section at Site 985, which is reasonable considering that it was much closer to a continental sediment source in the Oligocene.

Informal Taxa with Restricted Stratigraphic Ranges

The palynological study of the first DSDP leg to the Norwegian Sea (Leg 38; Manum, 1976) revealed many new and distinctive dinocyst taxa with restricted ranges. Time constraints did not allow description of these taxa; thus, they were only illustrated and informally named. A few of these taxa have since been described (i.e., *Evittosphaerula paratabulata* and *Lophocysta sulcolimbata* in Manum, 1979, and *Unipontidinium* [as *Nematosphaeropsis*] *aquaeductum* in Piasecki, 1980), but most still remain informal. The same nomenclature was applied in the dinocyst study of Leg 104 cores (Manum et al., 1989). Because the Leg 104 holes were continuously cored in contrast to the spot coring practiced during Leg 38, the stratigraphic ranges of many of these informal taxa were determined more precisely. New taxa with restricted ranges were also recorded, illustrated, and reported under open taxonomy. In the present study, many of these informal taxa have proved useful in correlating Site 985 with Site 643 and dating the Oligocene–lower Miocene section. In addition to the taxa in Table 2, we recorded a few others with restricted ranges. They all have distinctive morphologies, so that good illustrations suffice for identification. Given their restricted ranges in the Norwegian Sea, we are convinced that these taxa will be useful for future stratigraphic studies in the northernmost Atlantic. To facilitate identification, we present brief comments on taxa and include illustrations.

Batiacasphaera baculata sensu Manum et al., 1989
(pl. 1, fig. 9; not pl. 1, fig. 8); Plate 2, figure 8
= cf. *Batiacasphaera baculata* Manum, 1976 (pl. 2, fig. 25)
= "Kallosphaeridium biornatum group" of Heilmann-Clausen and Costa, 1990 (pl. 19, figs. 1, 5, 6)

This is a peridinioid cyst that, according to Damassa (1997), has a 3A3I archeopyle (also see illustration in Manum, 1976). It is therefore not related to *Batiacasphaera*. The thin autophragm has scattered rods on the surface. The form shown in Manum et al. (1989, pl. 1, fig. 8) is morphologically related, but the ornamentation is rounded warts rather than rods. The base is in Section 162-985A-40X-2 (104-643A-41X-1); the top is in Section 162-985A-34X-2 (104-643A-24X-5).

Deflandrea sp. B Powell 1986b sensu Manum et al., 1989
(pl. 9, fig. 7); Plate 2, figure 7

This form is characterized by its overall corroded appearance. The periphragm is often only partially preserved or missing. The endophragm is coarsely granular to spongy and has an appearance of being in various states of dissolution. *Deflandrea* sp. B has a consistent occurrence and is typically common to frequent in relative abundance. It seems to be closely related to *Deflandrea leptodermata*, which was originally recorded from the upper Eocene (Cookson and Eisenack, 1965). The base is in Section 162-985A-62X-2 (104-643A-53X-3); the top is in Section 162-985A-53X-4 (104-643A-47X-4)

Eatonicysta sp. 1; Plate 2, figures 4, 5

This taxon has an ectophragmal network that is intermediate between *Eatonicysta ursulae* and *Eatonicysta sequestra*. The cysts are smaller than those of the other species. The tabulation has not been determined. This taxon is consistently present from Sections 162-985A-60X-2 through 51X-4, with some high relative frequencies. It is sporadic above, and probably reworked specimens occur in Section 162-985A-47X-4 and higher.

Hystrichokolpoma sp. 2 Manum et al., 1989
(pl. 13, figs. 1, 2); Plate 2, figure 3
(= *Hystrichokolpoma reductum* nom. nud. of Zevenboom, 1995)

This species of *Hystrichokolpoma* resembles *Hystrichokolpoma rigaudiae* but is devoid of cingular processes. The base is in Section 162-985A-36X-2 (104-643A-36X-5); the top is in Section 162-985A-35X-1 (104-643A-28H-7).

Leptodinium sp. III Manum, 1976
(pl. 1, fig. 15); Plate 2, figure 6; Manum et al., 1989
(pl. 12, figs. 14, 15)

This taxon probably belongs to *Impagidinium.* Its distinctive features are rudimentary development of sutural ridges and short gonal processes. The base is in Section 162-985A-48X-4 (104-643A-33X-1); the top is in Section 162-985A-35X-6 (104-643A-31X-2).

Lophocysta sp. 1; Plate 1, figures 1–5

This differs from *Lophocysta sulcolimbata* in that the sulcal periphragm has perforations of greatly varying size, forming an irregular network and having some gonal processes up to 15 µm long. The base is in Section 162-985A-46X-4; the top is in Section 162-985A-41X-6.

Lophocysta sp. 2; Plate 1, figures 6–10

The endocyst is ovoidal, with a ventrally expanded and fenestrate periphragm attached to the endocyst laterally(?) by ribbonlike connections. The endocyst is ~30 µm × 45 µm, periphragm expansion two to three times the endocyst diameter. The archeopyle appears to be precingular. Ventral holes in the periphragm and holes in the ribbons are suggestive of plates, but sutures are lacking. *Piccoladinium fenestratum* Versteegh and Zevenboom (1995) resembles *Lophocysta* sp. 2 in its fenestrate periphragm but has parasutural features, and the sulcal fenestration appears different. This appears to be an extreme form of *Lophocysta.* The base is in Section 162-985A-62X-3; the top is in Section 162-985A-52X-1 (only in Section 104-643A-48X-6 of Hole; S.B. Manum, unpubl. data).

Pyxidinopsis sp. 1 Manum et al., 1989
(pl. 3, fig. 7); Plate 2, figures 9A, 9B

The proximate cysts have a spherical shape, a diameter ~42 µm, and a large 3P archeopyle. The autophragm is only with a distinct reticulation, lumina are 1–2 µm across, and muri are ~1 µm high. The base is in Section 162-985A-54X-2 (104-643A-48X-1); the top is in Section 162-985A-32X-1 (104-643A-15X-6).

Spiniferites sp. 1 Manum et al., 1989
(pl. 17, fig. 5); Plate 2, figure 10

The cyst body is 60–70 µm in diameter with rigid processes ~30 µm long and trifurcations up to 10 µm long. The cyst body is thick walled, rigid, and usually of dark brown color, with rugulate ornamentation forming an imperfect reticulum. The base is in Section 162-985A-62X-2 (104-643A-49X-4); the top is in Section 162-985A-60X-5 (104-643A-49X-3).

Dinocyst 3 Manum et al., 1989
(pl. 8, figs. 3, 4); Plate 2, figures 1, 2

This form mimics an *Evittosphaerula* in having a periphragmal parasutural network. However, it has a dorsally attached endocyst and differs from *Evittosphaerula* in having only three apical plates and in not having the wide cingular plates. It is also quite small compared with *Evittosphaerula;* the overall diameter usually is <50 µm. Versteegh and Zevenboom (1995) included *Evittosphaerula* sp. 1 in synonymy with *Piccoladinium fenestratum.* However, there appear to be significant differences, such as the large anterior sulcal in Dinocyst 3. This would more closely link it to *Evittosphaerula,* which has the L-type ventral organization, than to *Piccoladinium,* which has the S-type ventral organization. The base is in Section 162-985A-62X-1 (104-643A-48X-6); the top is in Section 162-985A-59X-1 (104-643A-48X-5).

Gen. et sp. indet.; Plate 1, figures 11–15

The general shape of this taxon resembles a money belt. The subspherical endocyst (~20 µm × 35 µm) has a large periphragmal loop (diameter 65–75 µm) attached to it in lateral(?) positions. The loop or belt widens distally to ~15–20 µm and is U-shaped in cross section; it has a thickened marginal rim and adjoining thickenings suggestive of parasutures. The endocyst is delicate, making the archeopyle difficult to identify, but it appears to be precingular. The base is in Section 162-985A-56X-1; the top is in Section 162-985A-55X-4 (104-643A only in Section 48X-1; S.B. Manum, unpubl. data).

Reworking

Extensive reworking of Paleogene taxa has created a problem throughout the section studied. We have therefore aimed at basing our analysis on first occurrences. Also, several Cretaceous taxa have been recorded. The Cretaceous taxa include *Aptea polymorpha, Canningia colliveri, Chatangiella tripartita, Chichaouadinium vestitum, Circulodinium distinctum, Cribroperidinium orthoceras, Cymososphaeridium validum, Odontochitina costata, Palaeohystrichophora infusorioides, Pseudoceratium eisenackii, Pseudoceratium securigerum,* and *Subtilisphaera pellucid.* The reworked Cretaceous dinocysts and spores occur throughout the section.

CONCLUSIONS

On the basis of the dinocyst assemblages, the Paleogene section in Hole 985A extends from Core 62X through Section 50X-5 and is predominantly Rupelian. The Rupelian/Chattian boundary is tentatively placed between Sections 162-985A-51X-2 and 50X-5, as determined from the highest or last occurrence of *Areoligera semicirculata.* Thus, the Rupelian is ~105 m thick; the Chattian, if present, is represented only by Section 162-985A-50X-5. The Chattian/Miocene boundary is interpreted as occurring between Sections 162-985A-50X-5 and 48X-6. This shows close agreement with the lithologic boundary between lithologic Units IV and V in Section 50X-2 (Shipboard Scientific Party, 1996, p. 265).

There is a remarkable correlation between dinocyst events at Sites 985 and 643, the latter drilled during Leg 104. This suggests that the major hiatus occurs at both sites within the Chattian. Also, there appears to be a more complete Miocene section at Site 643. Our preliminary findings indicate that of all the microfossil groups, the dinocysts offer the most potential for detailed correlation of the Oligocene–Miocene sediments in the Norwegian-Greenland Sea. More studies are needed to confirm this, but the results are encouraging.

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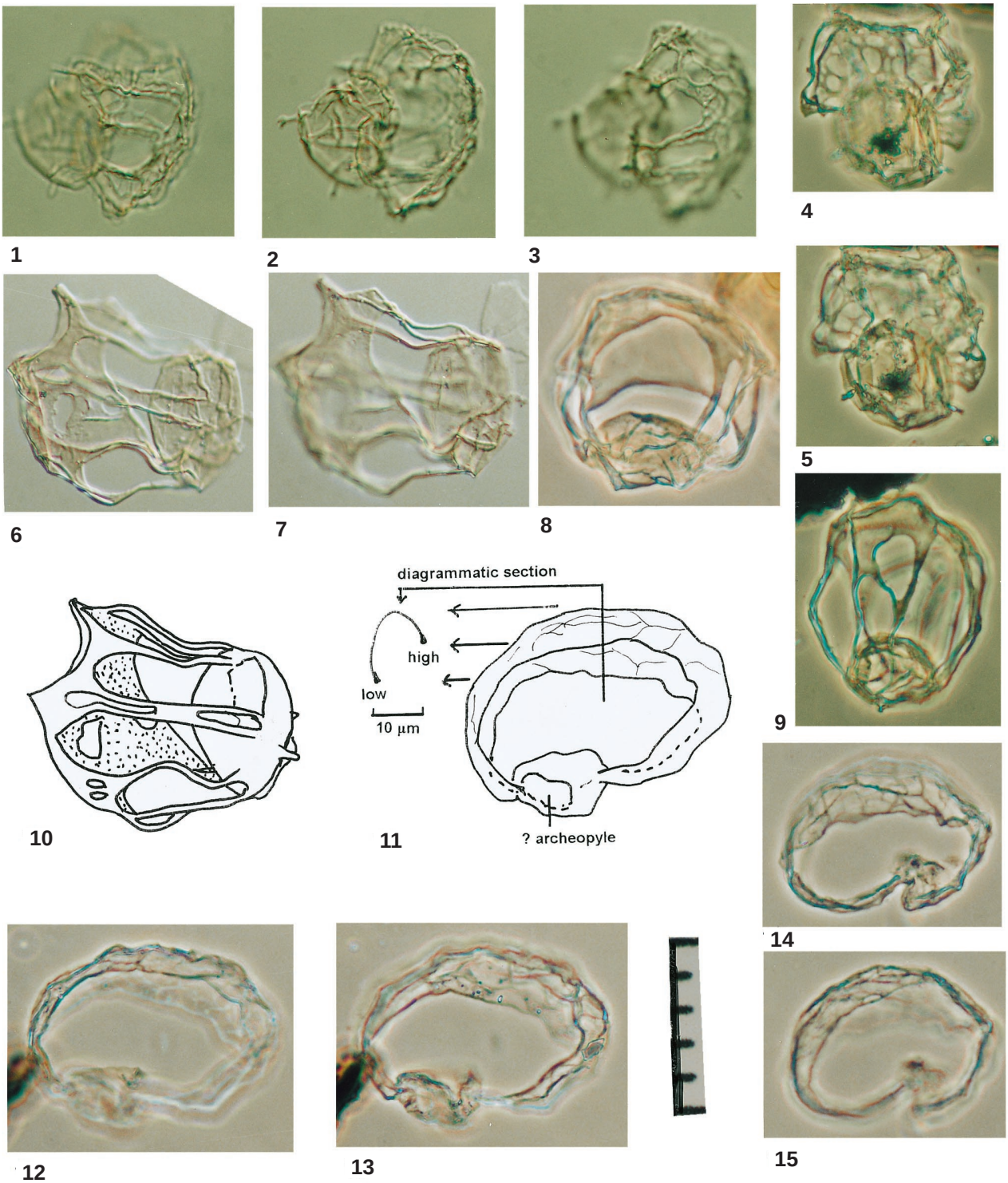

Plate 1. (Scale = 50 µm for all figures except drawings; # = palynology slide number, Geology Department, University of Oslo, followed by England Finder coordinates; Ph = phase contrast; If = interference phase contrast.) **1–5.** *Lophocysta* sp. 1. (1–3) Lateral view: high, intermediate, and low focus, respectively. Sample 162-985A-46X-4, 89–90 cm (#5274^{I}, D36/4, If); (4, 5) antapical view (4) and apical view (5) by transparency showing archeopyle. Sample 162-985A-43X-6, 89–90 cm (#5265^{II}, K46/3, Ph). **6–10.** *Lophocysta* sp. 2. Sample 162-985A-53X-4, 89–90 cm. (6, 7) Lateral view, high and low focus respectively (#5281^{III}, N45/3, If); (8) semilateral view (#5281^{II}, L44/3-4, Ph); (9) antapical view (#5281^{I}, G36/4, Ph); (10) *camera lucida* drawing of specimen shown in (6, 7). **11–15.** Gen. et sp. indet., presumably apical/antapical views. Sample 162-985A-51X-1, 89–90 cm. (11) *Camera lucida* drawing with diagrammatic section of periphragmal loop of specimen shown in (12, 13); (12, 13) high and low focus, respectively (#5272^{V}, NO34, Ph); (14, 15) (#5272^{V}, K4/3–4, Ph).

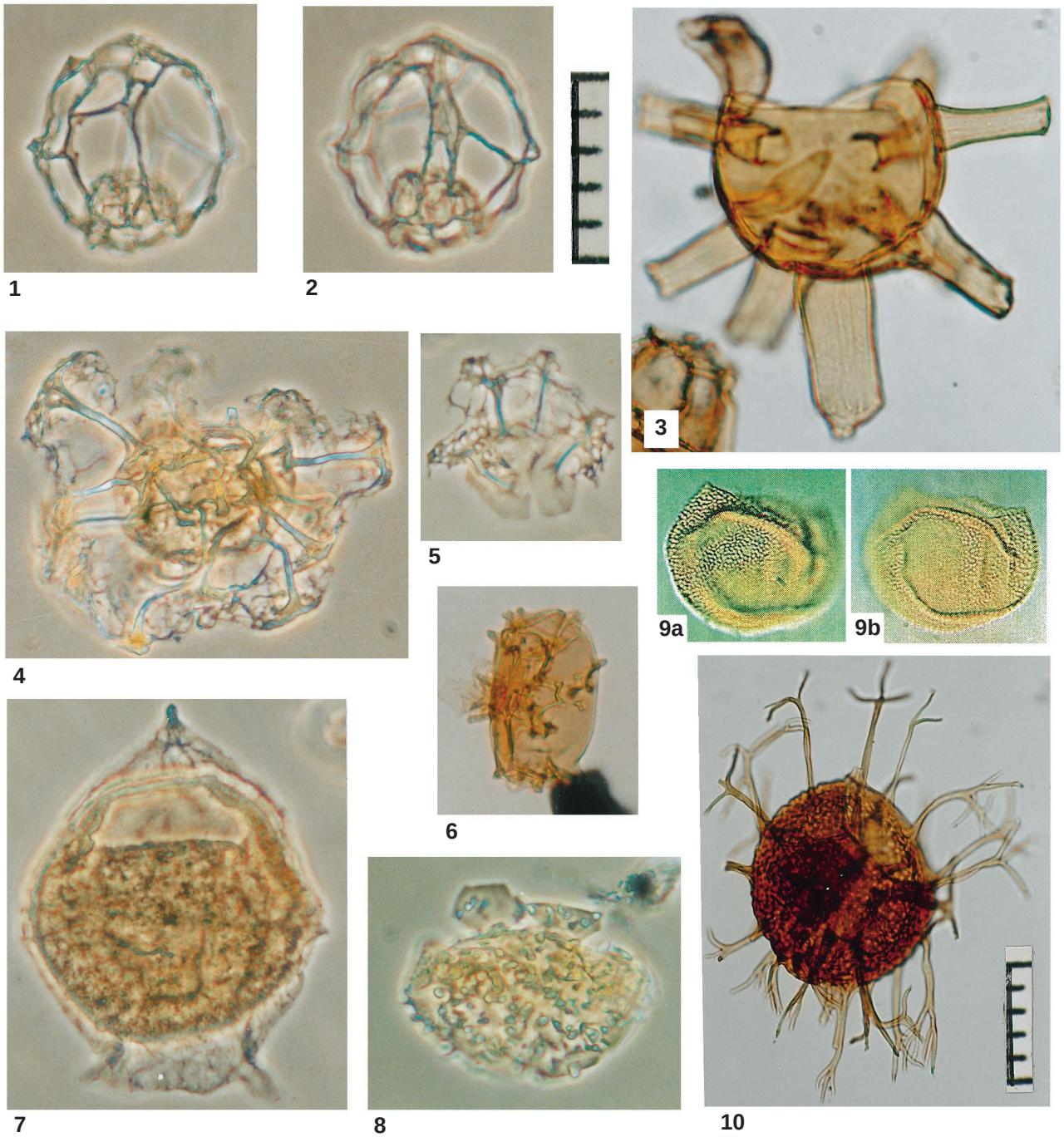

Plate 2. (Scale = 50 µm; scale below 3 applies to all figures except figure 9; # = palynology slide number, Geology Department, University of Oslo, followed by England Finder coordinates; Ph = phase contrast, If = interference phase contrast, Bf = bright field.) **1, 2.** Dinocyst 3 of Manum et al. (1989). Sample 162-985A-62X-1, 29–30 cm. (1) Antapical view; (2) apical view by transparency (#5255^{III}, =36/2, Ph). **3.** *Hystrichokolpoma* sp. 2 of Manum et al. (1989). Sample 162-985A-35X-6, 89–90 cm (#5260^{II}, K37/1–3, Bf). **4, 5.** *Eatonicysta* sp. 1. (4) Dorsoventral view. Sample 162-985A-57X-3, 89-90 cm (#5289^{II}, F39/2, Ph); (5) operculum. Sample 162-985A-58X-2, 89–90 cm (#5273^{IV}, N43/1–2, Ph). **6.** *Leptodinium* sp. III of Manum (1976). Sample 162-985A-46X-1, 89–90 cm (#5266^{II}, G38/4, Bf). **7.** *Deflandrea* sp. B of Powell (1986a) sensu Manum et al. (1989). Sample 162-985A-62X-1, 29–30 cm (#5255^{III}, E39/1-2, Ph). **8.** *Batiacasphaera baculata* sensu Manum et al. (1989). Sample 162-985A-39X-6, 89–91 cm (#5263^{III}, FG/37, Ph). **9A, 9B.** *Pyxidinopsis* sp. 1 of Manum et al. (1989). Sample 104-643A-44X-1, 19–21 cm (#4655^{I}, E38, IF). **10.** *Spiniferites* sp. 1 of Manum et al. (1989). Sample 162-985A-61X-2, 89–90 cm (#5253^{III}, O37/3, 0Bf).