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6. MIDDLE MIOCENE–UPPERMOST LOWER PLIOCENE DINOFLAGELLATE CYST BIOSTRATIGRAPHY, ODP LEG 186 HOLE 1151A, OFF SANRIKU COAST OF NORTHERN JAPAN, NORTHWESTERN PACIFIC[1]

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ABSTRACT

More than 70 dinoflagellate cyst taxa have been encountered in a palynological study of 34 samples from part of the Neogene section of Hole 1151A, Ocean Drilling Program (ODP) Leg 186 off the Sanriku Coast of northern Japan, northwestern Pacific. According to the diatom biostratigraphy, the age of the studied section ranges from the latest early Pliocene down to the earliest middle Miocene. On the basis of the present analysis, 17 biohorizons and possible biohorizons are discriminated as potential biostratigraphic markers. Seven acme events are also listed. The biohorizons show overall consistency with the stratigraphic ranges of species given by earlier studies of onshore sections in northern Japan, which indicates regional implications of those biostratigraphic events. In addition, dominance of protoperidiniacean species in the late late Miocene to early Pliocene assemblages from the present hole compares with a similar dominance of the same age reported previously in the Bering Sea and northern North Pacific. This implies establishment of nutrient-rich surface water in the wide region of the northwestern to north Pacific in the late Miocene.

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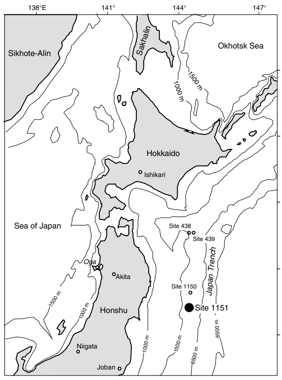
INTRODUCTION

Neogene dinoflagellate cysts have been studied increasingly for the past two decades, particularly in the North Atlantic–western Europe region, using Deep Sea Drilling Project (DSDP)/Ocean Drilling Program (ODP) material in a number of cases (e.g., Edwards, 1986; Powell, 1986a, 1986b; Mudie, 1987, 1989; Wrenn, 1988; Head et al., 1989a, 1989b, 1989c; de Vernal and Mudie, 1989; Head and Wrenn, 1992; de Verteuil and Norris, 1992, 1996; Head, 1993, 1994a, 1994b, 1997; Lentin et al., 1994; Matsuoka et al., 1997). These studies have provided a significant framework for Neogene biostratigraphy and paleoecology. In contrast, very few deep-sea boreholes have been studied from the North Pacific (e.g., Bujak, 1984).

Onshore sections including oil exploration boreholes in and around Japan have been the subject of recent progress in Cenozoic dinoflagellate cyst biostratigraphy, particularly through the correlation and dating of shallow-marine strata from sites where higher latitudes or diagenetic alteration have caused planktonic microfossils to be generally rare (Kurita and Matsuoka, 1994; Kurita and Obuse, 1994, 1997; Kurita and Kusunoki, 1997; Kurita and Yokoi, 2000; Kurita et al., 2000). These studies, however, have been conducted mostly on Paleogene sediments, and there remains little follow-up to the pioneering work on Neogene dinoflagellate cysts in this region by K. Matsuoka (e.g., Matsuoka, 1974, 1983; Matsuoka et al., 1987; Matsuoka and Bujak, 1988). Recently, Obuse and Kurita (1999) reported briefly on dinoflagellate cyst ranges and zonation of the late early Miocene to Pliocene onshore sections in northern Japan, using ages calibrated to detailed diatom biostratigraphy, thereby refining the biostratigraphy presented by Matsuoka et al. (1987). Continued evaluation and age calibration of the Neogene dinoflagellate zone boundaries and biohorizons, however, remains needed because all previous studies are based on composite sections from onshore localities remote from each other and with frequent hiatuses.

The present study aims to outline a biostratigraphy based on organic-walled dinoflagellate cyst assemblages from the lowest middle Miocene through uppermost lower Pliocene section of Hole 1151A, ODP Leg 186, drilled in the forearc area off the Sanriku Coast of northern Japan, northwestern Pacific (Fig. F1) (Sacks, Suyehiro, Acton, et al., 2000). We also discuss biohorizons that are potentially useful for regional correlation and apply a precise age calibration to them. Comparison is made between the present data set and the previous zonation scheme by Matsuoka et al. (1987) and by Obuse and Kurita (1999), both of which are based on onshore sections at various localities in northern Japan. Age calibration for the present study is based on the diatom biostratigraphy by Maruyama and Shiono (this volume).

F1. Index map, p. 14.



MATERIALS, CHRONOSTRATIGRAPHIC BACKGROUND, AND METHODS

For the present study, 34 samples were selected to cover the uppermost lower Pliocene to middle Miocene of Hole 1151A. The shallowest is Sample 186-1151A-16R-1, 45–48 cm (downhole depth = 209.35–209.38 meters below seafloor [mbsf]), whereas the deepest is Sample 186-1151A-109R-3, 41–46 cm (1107.31–1107.36 mbsf). For a detailed description of the studied samples, see **"Appendix A,"** p. 11. Downhole depths of a certain sample, where given, are indicated by the depth of the top of the sampled interval.

According to the diatom biostratigraphy by **Maruyama and Shiono** (this volume), the shallowest sample was located at ~5 m below the lowest occurrence (LO) of *Neodenticula koizumii* (3.53–3.95 Ma), whereas the deepest sample was located between the LO of *Denticulopsis lauta* (15.9 Ma) and the LO of *Denticulopsis praelauta* (16.3 Ma). Thus, our samples range from the uppermost lower Pliocene down to the lowermost middle Miocene. The studied section represents a time interval of between 3.5 and 16 Ma and constitutes a stratigraphic record of about 12.5 m.y. in duration within a mid-latitude forearc setting in the northwestern Pacific. It should be noted, however, that the section includes a significant hiatus between Samples 186-1151A-101R-1, 71–73 cm, and 186-1151A-101R-1, 90–91 cm (1027.31–1027.50 mbsf), in which an interval of upper Miocene (12–14 Ma) sediments is missing. This interval corresponds to the lower *Denticulopsis praedimorpha* Zone (NPD5B) to the upper *Denticulopsis hyalina* Zone (NPD4B) based on the diatom biostratigraphy by Yanagisawa and Akiba (1998). As a result, our material contains eight samples belonging to the lower Pliocene, thirteen to the upper Miocene, two to the upper middle Miocene, and eleven to the lower middle Miocene.

The samples were treated with HCl and HF at room conditions to eliminate carbonate and siliceous minerals. The organic residues were then concentrated using zinc bromide heavy liquid (specific gravity = 2.0), screened on a 20-µm sieve, and mounted on slide with polyvinyl alcohol and polyester resin. No oxidation was carried out in the sample processing.

A Carl Zeiss Axioplan microscope was used for microscopic analysis. Each microscope slide was scanned at 160× along the shorter side of the coverslip. Cysts were counted until ~200 specimens had been enumerated or, if less, until five traverses had been counted. Identification was conducted at 600× using differential interference contrast light. Each raw count of a given taxon in a sample was converted to a percentage against the total count in the sample as shown in Table **T1.** A "+" in Table **T1** indicates the presence of reworked cysts and other palynomorphs. In Figure **F2,** the percentages are converted as follows:

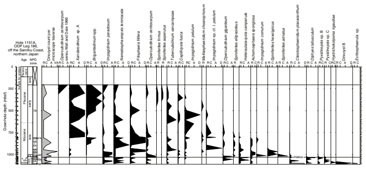
R = rare (<5%).
C = common (5%–10%).
A = abundant (10%–30%).
D = dominant (30% or more).

In addition, the abundance of dinoflagellate cysts relative to the total mounted residue was evaluated by means of the average number of cyst specimens per traverse. This evaluation assumes that the density of residue strewn on the slide is constant for all the samples, which is only approximately true in this case. Thus, the relative abundance indicated here should be regarded as no more than a broad estimate. In Figures **F2** and **F3,** the relative abundance is expressed as follows:

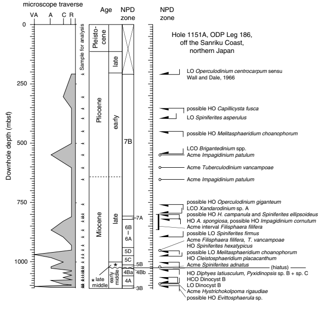
R = rare (less than an average of 8 specimens per microscope traverse).
C = common (8–15 specimens per traverse).
A = abundant (15–45 specimens per traverse).
VA = very abundant (45 or more specimens per traverse).

T1. Neogene dinoflagellate cysts range chart, p. 17.

F2. Neogene dinoflagellate cyst distribution, p. 15.



F3. Dinoflagellate cyst biohorizons and acme events, p. 16.



The cyst nomenclature used in this study generally follows Williams et al. (1998).

Terms are as follows:

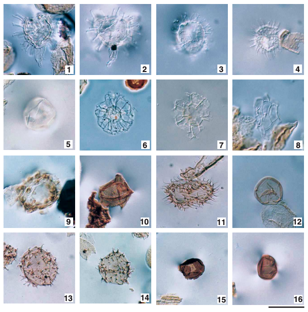
LO = lowest occurrence.
LCO = lowest common occurrence.
HO = highest occurrence.
HCO = highest common occurrence.

All the material discussed in this paper is housed in the palynological collection at the Department of Geology, Faculty of Science, Niigata University.

RESULTS

More than 70 dinoflagellate cyst taxa were encountered from the Pliocene–middle Miocene of Hole 1151A. The analytical results are shown as an occurrence chart in Table **T1.** Stratigraphic occurrences of selected dinoflagellate cyst taxa are compiled in Figure **F2.** Taxonomic listing of the encountered taxa is indicated in **"Appendix B,"** p. 12, and selected cysts are shown in Plate **P1.**

P1. Neogene dinoflagellate cysts, p. 19



The abundance of dinoflagellate cysts relative to the total mounted residues fluctuates through the studied section (Fig. **F2**). The abundance peaks were observed in Sections 186-1151A-109R-3, 109R-1, and 106R-3 (lower middle Miocene), 101R-1, 100R-3, 96R-3, 95R-1, and 84R-3 (upper middle to upper Miocene), and 109R-3 and 51R-3 (lower Pliocene). In general, abundance peaks appear more frequently in the lower upper Miocene and below (i.e., approximately the lower half of the studied section).

Cyst preservation was good enough to allow identification at species level even in the lowest samples. Most specimens show no significant corrosion, although folding or slight deformation of cysts was frequent.

Most recorded species belong to gonyaulacacean genera including *Cleistosphaeridium, Diphyes, Filisphaera, Hystrichokolpoma, Impagidinium, Nematosphaeropsis, Operculodinium, Pyxidinopsis,* and *Spiniferites*. This group dominates the assemblages from the lower upper Miocene and lower section. Other groups recorded in the present study contain protoperidiniacean species including *Brigantedinium, Capillicysta, Lejeunecysta,* and *Xandarodinium*. The assemblages from the uppermost lower Pliocene through upper upper Miocene interval are particularly characterized by the frequent dominance of the protoperidiniacean taxa *Brigantedinium* spp. and *Xandarodinium* sp. A.

DISCUSSION

Biostratigraphic Events

From the present data set, 17 biohorizons that include LOs, HOs, LCOs, and a HCO were discriminated for potential biostratigraphic markers (Table **T2;** Fig. **F3**). They include possible biohorizons based only on relatively sporadic occurrences of the taxa. Seven acmes (abundance peaks) are also listed.

T2. Dinoflagellate cyst biohorizons and acme events,p. 18.

In the lower upper Miocene to middle Miocene section of Hole 1151A, a number of dinoflagellate cyst biohorizons were recognized, whereas the assemblages from the uppermost lower Pliocene to upper upper Miocene section, being generally dominated by *Brigantedinium* spp. and *Xandarodinium* sp. A, do not display so many appearances and disappearances of species. This contrast may be, partly at least, affected by the contrast in sedimentation rate.

Correlation with Previous Studies in Northern Japan

When compared to studies by Matsuoka et al. (1987) and Obuse and Kurita (1999), which are based on composite onshore sections in northern Japan (Fig. F1), parallels in the general biostratigraphic trends are clearly seen.

First, comparison is made with the biostratigraphy and biozones proposed by Matsuoka et al. (1987), who studied material from the Oga and Niigata areas in the backarc side of the Honshu Island (Fig. F1). The distinctive contrast between the assemblages from the *Diphyes latiusculum* Zone (late early to early middle Miocene) and those from the higher horizons, as stated by Matsuoka et al. (1987), is easily recognized in the present data set as a series of HOs of species including *Diphyes latiusculum* in the lower middle Miocene. However, it should be noted that in the present section this contrast is accentuated by the hiatus between the lower middle Miocene and the upper Miocene.

The general trend of stratigraphic changes in species composition in the upper Miocene to lower Pliocene interval is expressed by Matsuoka et al. (1987) as the disappearances of *Achomosphaera spongiosa* (as *Achomosphaera* sp. A in Matsuoka et al., 1987), *Spiniferites hexatypicus,* and *Spiniferites ellipsoideus,* which are followed by abundant occurrences of *Brigantedinium simplex*. These stratigraphic changes were used by Matsuoka et al. (1987) to establish the boundary between the *Capillicysta fusca* Zone and the *Achomosphaera callosa* Zone. Similar stratigraphic changes were recognized in the present study as the successive HOs of *Spiniferites hexatypicus, Achomosphaera spongiosa,* and *Spiniferites ellipsoideus* in the upper Miocene, which were followed by the base of abundant occurrences of *Brigantedinium* spp., and then by the LO of *Operculodinium centrocarpum* sensu Wall and Dale, 1966 (as *Operculodinium centrocarpum* in Matsuoka et al., 1987). This major biostratigraphic trend is therefore observed both in the present section and in the backarc location studied by Matsuoka et al. (1987), although there are slight discrepancies in the ages of the biohorizons.

Differences between the results of the present study and those of Matsuoka et al. (1987) include the Miocene biohorizons of *Evittosphaerula* sp., *Pyxidinopsis* spp., and *Operculodinium giganteum,* which were not reported by Matsuoka et al. (1987). In contrast, the Pliocene assemblages of Matsuoka et al. (1987) are apparently more diverse than those of the present study. This may be due to the predominance of protoperidiniacean species in the Pacific assemblages that might have masked out other species. These differences may be attributed to the paleoecological differences between the forearc and the backarc.

Initial work by Matsuoka et al. (1987) was extended by Obuse and Kurita (1999) in their study of onshore sections in northern Japan from more widespread localities including the Joban, Niigata, Akita, Oga, and Ishikari areas (Fig. F1). Obuse and Kurita (1999) also provided more detailed age constraints, based on diatom biostratigraphy, in their range chart of species from the upper lower Miocene to upper Pliocene interval. Their results were generally similar to those of Matsuoka et al.

(1987), although they were able to refine the biostratigraphy and identify several new biostratigraphically useful taxa.

A comparison of the present data set with that of Obuse and Kurita (1999) shows a number of mutually recognized biohorizons. Those include the LO of *Operculodinium centrocarpum* sensu Wall and Dale, 1966, the HO of *Spiniferites hexatypicus,* the HO of *Achomosphaera spongiosa* (including cf. *A. spongiosa*), the HO of *Heteraulacacysta campanula,* the LO of *Spiniferites firmus,* the LO of *Melitasphaeridium choanophorum,* the HO of *Operculodinium giganteum,* the HO of *Cleistosphaeridium placacanthum,* the HO of *Diphyes latiusculum,* the HO of Dinocyst B (as "penitabular dinocyst" in Obuse and Kurita, 1999), the HO of *Pyxidinopsis* spp. (as *Pyxidinopsis* cf. *tuberculata* in Obuse and Kurita, 1999), and the HO of *Evittosphaerula* sp. (as *E. paratabulata* in Obuse and Kurita, 1999). These biohorizons have little differences in the order of stratigraphic appearances, although the ages of the biohorizons may vary slightly in some cases.

In addition to these biohorizons, some of the acme events in the present section are also correlatable to the records from the onshore localities. For example, the acmes of *Tuberculodinium vancampoae* and *Impagidinium patulum* are recorded in the lower Pliocene both in the present study and in Obuse and Kurita (1999). If these acme events are proven to be isochronous, they should be useful for biostratigraphic correlation.

The overall similarity between the present offshore data set from the forearc setting and earlier studies based on onshore material from various localities including the backarc region indicates a clear potential for regional stratigraphic correlation. Further study is needed, however, because there are still discrepancies in the ages of some biohorizons. These may be explained by contrasting paleoenvironments between the forearc side facing the Pacific and the more isolated backarc side facing the Sea of Japan. Or they may be due to effects of sampling interval, inadequate lithology, or other geologic and nongeologic biases.

Paleoclimatologic Implications for the Forearc Basin

The dinoflagellate cyst assemblages from the uppermost lower Pliocene–upper upper Miocene interval of the present section are marked by the predominance of protoperidiniacean species of *Brigantedinium* spp. and *Xandarodinium* sp. A, which contrasts with those from the underlying interval. This may be interpreted in the context of paleoceanographic changes in the forearc basin, such as those in temperature, salinity, and/or nutrient supply.

A similar biostratigraphic contrast was noted by Bujak (1984), who studied Neogene material from DSDP Leg 19 in the Bering Sea and the northern North Pacific. He reported that the late Miocene to Pleistocene assemblages are dominated by protoperidiniacean genera such as *Brigantedinium, Lejeunecysta, Selenopemphix,* and *Xandarodinium,* whereas the older assemblages lack this characteristic. Bujak (1984) concluded that the onset of protoperidiniacean cyst dominance could signal the establishment of nutrient-rich water because almost all protoperidiniacean dinoflagellates, as he stated, are heterotrophic and require organic nutrients.

Recently, Matsuoka (1999) discussed the role of protoperidiniacean dinoflagellates in the marine ecosystem, particularly in shallow depths, and proposed a food web among the algal community that places the heterotrophic dinoflagellates including protoperidiniaceans as the consumer (predator) of smaller algae including diatoms and other photosynthetic microorganisms. Emphasizing the predating nature of protoperidiniacean dinoflagellates, this model indicates that increase of protoperidiniaceans in cyst assemblages can be a record of eutrophication.

It is notable that both the present data and that of Bujak (1984) show the onset of protoperidiniacean cyst dominance occurring in the late Miocene, both in off the Sanriku Coast and in the Bering Sea and the northern North Pacific. Following the suggestion of Bujak (1984) and Matsuoka (1999), the dominance in these regions would be a direct consequence of the establishment of diatom-rich algal community, or nutrient-rich water, in the late Miocene in the northwestern Pacific–Bering Sea region. This possible paleoceanographic change may be a result of global cooling that might have caused enhancement of bottom-water circulation as well as higher concentrations of silica in high latitudes.

Remaining questions about this issue include that the onset of protoperidiniacean cyst dominance in the late Miocene appears not to be very clear in the assemblages from the backarc location of northern Japan according to the studies by Matsuoka (1983), Matsuoka et al. (1987), and Obuse and Kurita (1999). This may be related to the paleoenvironmental differences between the areas, as a backarc location might be more isolated. In addition, it may be important in further study to relate the Miocene diatomaceous successions in the backarc area with dinoflagellate cyst records as well as with other paleoenvironmental indicators.

CONCLUSION

Dinoflagellate cysts from the uppermost lower Pliocene through middle Miocene of Leg 186, constrained by a diatom biostratigraphy, are shown to have excellent potential for biostratigraphy and paleoenvironmental reconstruction. We present 17 biohorizons and possible biohorizons and several acme events based on an abundant and well-preserved record. Because these biostratigraphic events compare favorably with published data from onshore sections in northern Japan, a basically consistent floral development is recognized through the northern Japan area, including both the forearc and backarc sides, leading to potentially useful regional stratigraphic correlation. More detailed study of dinoflagellate cysts from the present section should serve as a standard reference for Pliocene through middle Miocene correlation and dating by dinoflagellate cyst biostratigraphy in northern Japan and its surrounding areas.

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APPENDIX A

List of Studied Samples

Core, section, interval (cm)	Depth (mbsf)
186-1151A-	
16R-1, 45–48	209.35
26R-1, 44–46	305.74
31R-1, 45–48	354.05
35R-3, 45–48	395.55
41R-1, 45–47	449.95
46R-3, 45–48	501.05
51R-3, 45–48	549.15
57R-1, 43–46	603.93
62R-1, 45–48	652.05
73R-1, 45–48	757.75
77R-3, 45–48	799.15
78R-3, 45–48	808.85
79R-1, 45–48	815.45
80R-3, 44–48	829.04
84R-3, 48–52	866.58
87R-3, 45–48	895.35
91R-1, 45–48	930.85
93R-1, 45–48	950.15
95R-1, 45–48	969.35
96R-3, 46–50	982.06
98R-3, 26–27	1001.06
100R-3, 17–18	1020.17
101R-1, 32–33	1026.92
102R-1, 44–47	1036.64
102R-3, 34–37	1039.54
103R-1, 52–54	1046.42
104R-1, 45–48	1056.05
105R-1, 45–48	1065.75
106R-1, 45–48	1075.45
106R-3, 45–48	1078.45
108R-1, 38–39	1094.68
108R-3, 15–16	1097.45
109R-1, 45–47	1104.35
109R-3, 41–46	1107.31

APPENDIX B

List of Recorded Taxa

Dinoflagellate Cysts

[Rw] = occurrence as reworked specimens only.

Achomosphaera ramulifera (Deflandre, 1937) Evitt, 1963.
Achomosphaera spongiosa Matsuoka and Bujak, 1988.
cf. *Achomosphaera spongiosa* Matsuoka and Bujak, 1988.
Achomosphaera sp. A.
Batiacasphaera minuta (Matsuoka, 1983) Matsuoka and Head, 1992.
Brigantedinium irregulare Matsuoka, 1987.
Brigantedinium simplex (Wall, 1965) ex Lentin and Williams, 1993.
Brigantedinium spp.
Capillicysta fusca Matsuoka and Bujak in Matsuoka et al., 1987.
Cleistosphaeridium placacanthum (Deflandre and Cookson, 1955) Eaton et al., 2001.
Cordosphaeridium minimum (Morgenroth, 1966) Benedek, 1972 sensu Benedek and Sarjeant, 1981.
Cribroperidinium giuseppei (Morgenroth, 1966) Helenes, 1984.
Dapsilidinium pastielsii (Davey and Williams, 1966) Bujak et al., 1980.
Deflandrea sp. [Rw].
Dinocyst A
Dinocyst B
Dinocyst C
Diphyes latiusculum Matsuoka, 1974.
Diphyes sp. cf. *D. latiusculum* Matsuoka, 1974.
Evittosphaerula sp.
Filisphaera filifera Bujak, 1984.
Glaphyrocysta sp. indet. [Rw].
Habibacysta? sp.
Heteraulacacysta campanula Drugg and Loeblich Jr., 1967.
Hystrichokolpoma denticulata Matsuoka, 1974.
Hystrichokolpoma rigaudiae Deflandre and Cookson, 1955.
Hystrichosphaeropsis obscura Habib, 1972.
Impagidinium cornutum Matsuoka and Bujak, 1988.
Impagidinium paradoxum (Wall, 1967) Stover and Evitt, 1978.
Impagidinium patulum (Wall, 1967) Stover and Evitt, 1978.
Impagidinium sp. cf. *I. patulum* (Wall, 1967) Stover and Evitt, 1978.
Impagidinium sp. cf. *I. japonicum* Matsuoka, 1983.
Impagidinium sp. cf. *I. manumii* Matsuoka and Bujak, 1988.
Impagidinium sp. cf. *I. velorum* Bujak, 1984.
Impagidinium sp. A.
Impagidinium sp. B.
Impagidinium sp. D.
Impagidinium sp. E.
Impagidinium spp./sp. indet.
Lejeunecysta hyalina (Gerlach, 1961) Artzner and Dörhöfer, 1978.
Lejeunecysta spp.
Lingulodinium brevispinum Matsuoka and Bujak, 1988.
Lingulodinium machaerophorum (Deflandre and Cookson, 1955) Wall, 1967.
Litosphaeridium? *parvum* Matsuoka and Bujak, 1988.
Melitasphaeridium choanophorum (Deflandre and Cookson, 1955) Harland and Hill, 1979.
Nematosphaeropsis lemniscata Bujak, 1984.
Oligosphaeridium albertense (Pocock, 1962) Davey and Williams, 1969 [Rw].
Operculodinium centrocarpum (Deflandre and Cookson, 1955) Wall, 1967.

Operculodinium centrocarpum (Deflandre and Cookson, 1955) Wall, 1967 sensu Wall and Dale, 1966.
Operculodinium giganteum Wall, 1967.
Operculodinium israelianum (Rossignol, 1962) Wall, 1967.
Operculodinium sp. cf. *O. israelianum* (Rossignol, 1962) Wall, 1967.
Operculodinium longispinigerum Matsuoka, 1983.
Operculodinium sp. A.
Operculodinium? sp. B.
Palaeocystodinium sp. cf. *P. golzowense* Alberti, 1961.
Pyxidinopsis sp. A.
Pyxidinopsis sp. B.
Pyxidinopsis sp. C.
Quadrina condita de Verteuil and Norris, 1992.
Reticulatosphaera actinocoronata (Benedek, 1972) Bujak and Matsuoka, 1986.
Selenopemphix nephroides Benedek, 1972.
Selenopemphix quanta (Bradford, 1975) Matsuoka, 1985.
Selenopemphix selenoides Benedek, 1972.
Selenopemphix spp.
Spinidinium spp. [Rw].
Spiniferites adnatus Matsuoka and Bujak, 1988.
Spiniferites asperulus Matsuoka, 1983.
Spiniferites ellipsoideus Matsuoka, 1983.
Spiniferites sp. cf. *S. ellipsoideus* Matsuoka, 1983.
Spiniferites firmus Matsuoka, 1983.
Spiniferites hexatypicus Matsuoka, 1983.
Spiniferites lenzii Below, 1982.
Spiniferites membranaceus (Rossignol, 1964) Sarjeant, 1970.
Spiniferites pseudofurcatus (Klumpp, 1953) Sarjeant, 1970.
Spiniferites ramosus (Ehrenberg, 1838) Mantell, 1854.
Spiniferites sp. cf. *S. serratus* Matsuoka, 1983.
Spiniferites strictus Matsuoka, 1983.
Spiniferites/Achomosphaera spp.
Trinovantedinium boreale Bujak, 1984 [Rw].
Tuberculodinium vancampoae (Rossignol, 1962) Wall, 1967.
Xandarodinium sp. A.

Acritarchs

Cyclopsiella granosa (Matsuoka, 1983) Head et al., 1992.

Figure F1. Index map. Previous DSDP sites in the same area, Sites 438 and 439, Leg 57, as well as onshore localities of Neogene dinoflagellate cysts studied by Matsuoka (1983), Matsuoka et al. (1987), and Obuse and Kurita (1999) are indicated by small open circles.

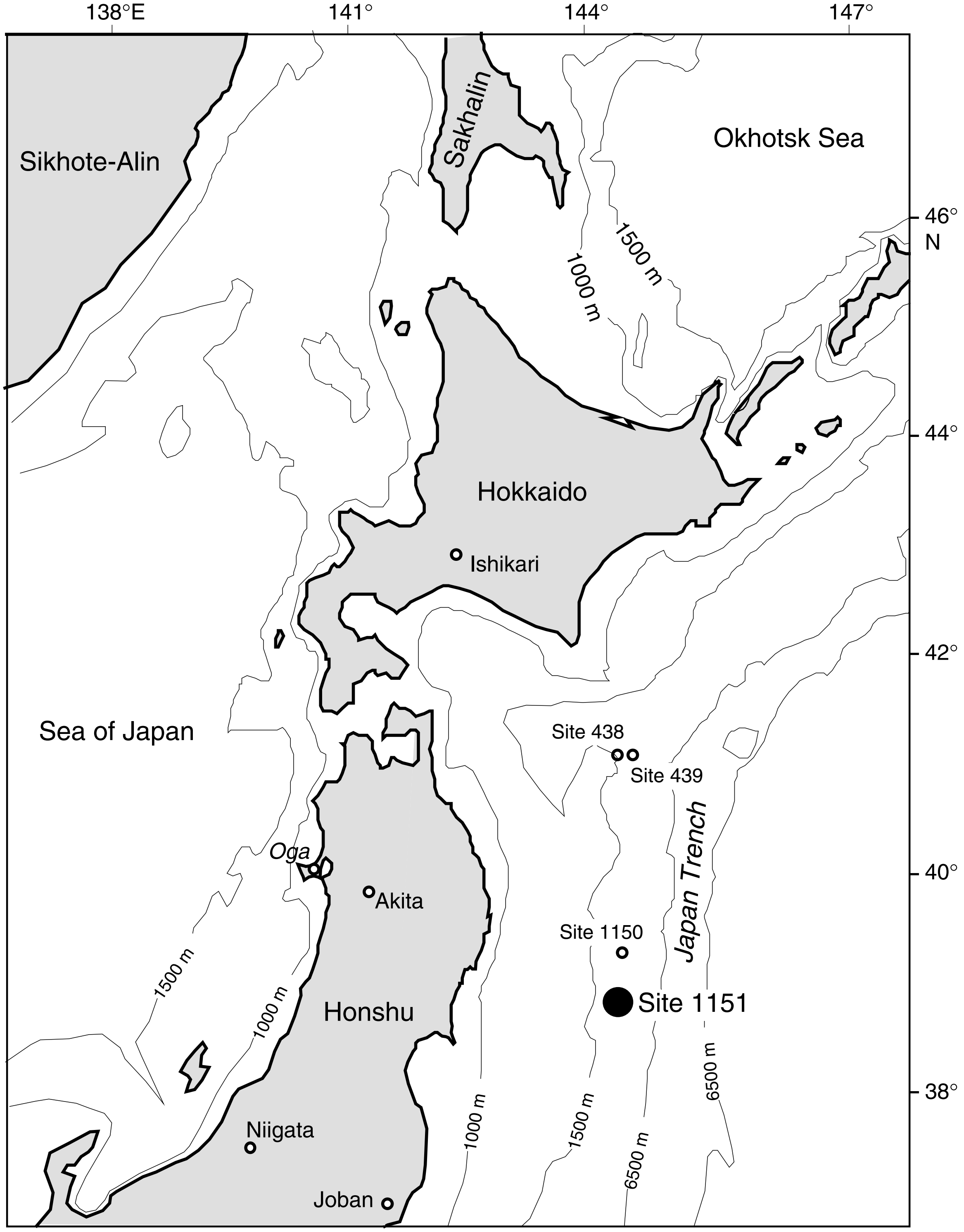

Figure F2. Occurrences of selected Neogene dinoflagellate cyst species from Hole 1151A, Leg 186. Relative frequency of each species is expressed as follows: R = rare (<5%), C = common (5%–10%), A = abundant (10%–30%), D = dominant (30% or more). The relative abundance of dinocysts is expressed as R = rare (less than an average of 8 specimens per microscope traverse), C = common (8–15 specimens per microscope traverse), A = abundant (15–45 specimens per microscope traverse), and VA = very abundant (45 or more specimens per microscope traverse). NPD = code names for diatom biozone by Yanagisawa and Akiba (1998).

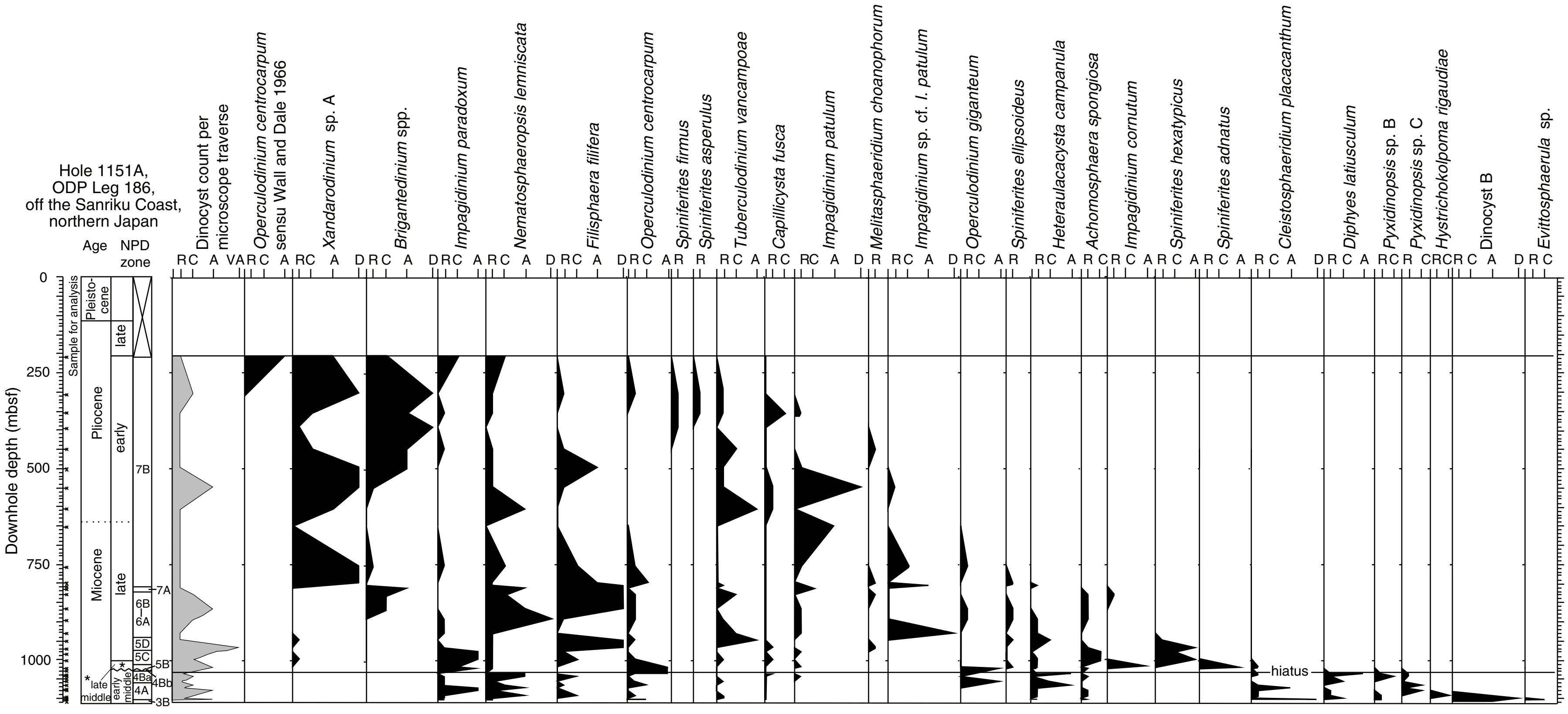

Figure F3. Summary of the middle Miocene–uppermost lower Pliocene dinoflagellate cyst biohorizons and acme events from Hole 1151A, Leg 186, plotted against the downhole depth. Arrows = datum planes, open circles = acme events. R = rare (less than an average of 8 specimens per microscope traverse), C = common (8–15 specimens per microscope traverse), A = abundant (15–45 specimens per microscope traverse), and VA = very abundant (45 or more specimens per microscope traverse). NPD = code names for diatom biozone by Yanagisawa and Akiba (1998).

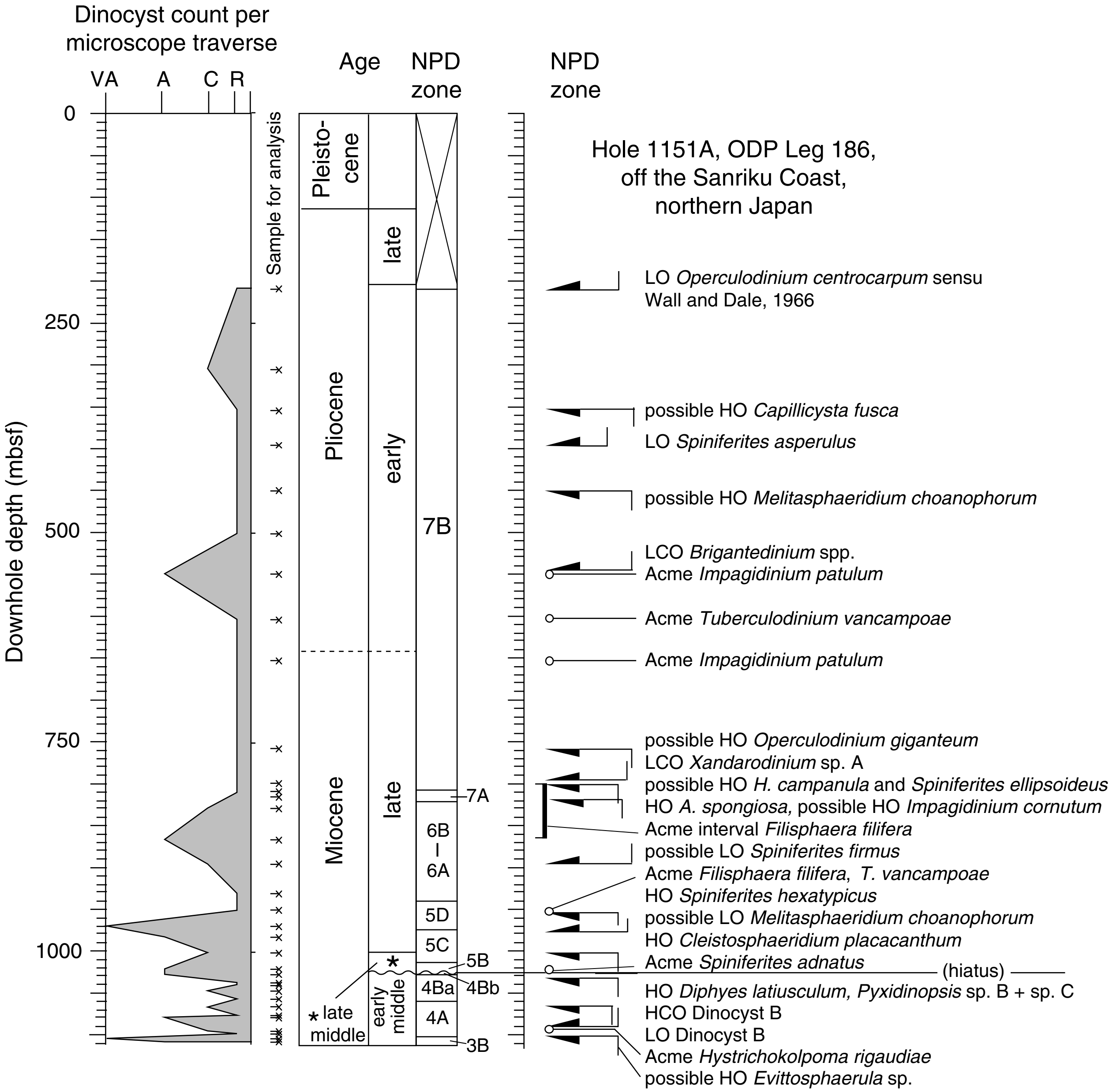

Table T1. Occurrence chart of Neogene dinoflagellate cysts, Hole 1151A. (This table is available in an **oversized format.**)

Table T2. List of middle Miocene–uppermost lower Pliocene dinoflagellate cyst biohorizons and acme events, Hole 1151A.

Datum	Core, section, interval (cm)	Depth (mbsf)
	186-1151A-	
LO *Operculodinium centrocarpum* sensu Wall and Dale, 1966	16R-1, 45–48/26R-1, 44–46	209.35/305.74
HO (possible) *Capillicysta fusca*	26R-1, 44–46/31R-1, 45–48	305.74/354.05
LO *Spiniferites asperulus*	35R-3, 45–48/ 41R-1, 45–47	395.55/449.95
HO (possible) *Melitasphaeridium choanophorum*	35R-3, 45–48/ 41R-1, 45–47	395.55/449.95
Acme *Impagidinium patulum*	51R-3, 45–48	549.15
LCO *Brigantedinium* spp.	51R-3, 45–48/57R-1, 43–46	549.15/603.93
Acme *Tuberculodinium vancampoae*	57R-1, 43–46	603.93
Acme *Impagidinium patulum*	62R-1, 45–48	652.05
HO (possible) *Operculodinium giganteum*	62R-1, 45–48/ 73R-1, 45–48	652.05/757.75
HO (possible) *Heteraulacacysta campanula*	73R-1, 45–48/ 77R-3, 45–48	757.75/799.15
HO (possible) *Spiniferites ellipsoideus*	73R-1, 45–48/ 77R-3, 45–48	757.75/799.15
LCO *Xandarodinium* sp. A	78R-3, 45–48/ 79R-1, 45–48	808.85/815.45
HO *Achomosphaera spongiosa* and *Impagidinium cornutum*	79R-1, 45–48/ 80R-3, 44–48	815.45/829.04
Acme interval *Filisphaera filifera*	77R-3, 45–48 through 84R-3, 48–52	799.15–866.58
LO (possible) *Spiniferites firmus*	87R-3, 45–48/ 91R-1, 45–48	895.35/930.85
HO *Spiniferites hexatypicus*	91R-1, 45–48/ 93R-1, 45–48	930.85/950.15
Acme *Filisphaera filifera* and *Tuberculodinium vancampoae*	93R-1, 45–48	950.15
LO (possible) *Melitasphaeridium choanophorum*	95R-1, 45–48/ 96R-3, 46–50	969.35/982.06
HO *Cleistosphaeridium placacanthum*	98R-3, 26–27/100R-3, 17–18	1001.06/1020.17
Acme *Spiniferites adnatus*	100R-3, 17–18	1020.17
— (hiatus)—	—	—
HO *Diphyes latiusculum*, *Pyxidinopsis* sp. B, and *Pyxidinopsis* sp. C	101R-1, 32–33/102R-1, 44–47	1026.92/1036.64
HCO Dinocyst B	105R-1, 45–48/106R-1, 45–48	1065.75/1075.45
LO Dinocyst B	108R-1, 38–39/108R-3, 15–16	1094.68/1097.45
Acme *Hystrichokolpoma rigaudiae*	108R-1, 38–39	1094.68
HO (possible) *Evittosphaerula* sp.	108R-3, 15–16/109R-1, 45–47	1097.45/1101.35

Note: LO = lowest occurrence, HO = highest occurrence, LCO = lowest common occurrence, HCO = highest common occurrence.

Plate P1. Selected Neogene dinoflagellate cysts from Hole 1151A, Leg 186. All photographs are at the same magnification. Scale bar = 50 µm. Each figure contains a slide number and X–Y stage coordinates of a Carl Zeiss 45–35–02 stage for an Axioplan microscope. **1–4, 8.** Sample 186-1151A-109R-3, 41–46 cm; (1) *Diphyes latiusculum* (B-1/83.0×20.8), (2) *Diphyes latiusculum* (B-1/86.0×7.8). (3) *Cleistosphaeridium placacanthum* (B-1/84.5×14.3), (4) *Lingulodinium machaerophorum* (B-1/83.1×25.0), (8) *Evittosphaerula* sp. (B-1/83.0×17.1). **5, 9.** Sample 186-1151A-46R-3, 45–48 cm; (5) *Filisphaera filifera* (B-1/80.2×6.7), (9) *Tuberculodinium vancampoae* (B-1/93.4×16.7). **6, 13–15.** Sample 186-1151A-73R-1, 45–48 cm; (6) *Nematosphaeropsis lemniscata* (B-1/81.9×4.9), (13) *Xandarodinium* sp. A (B-1/79.4×12.2), (14) *Xandarodinium* sp. A (B-1/84.2×7.2), (15) *Brigantedinium simplex* (B-1/86.2×5.1) **7.** *Reticulatosphaera actinocoronata* (Sample 186-1151A-105R-1, 45–48 cm) (B-1/84.5×5.7). **10–12, 16.** Sample 186-1151A-26R-1, 44–46 cm; (10) *Lejeunecysta* sp. (B-1/79.7×11.7), (11) *Selenopemphix quanta* (B-1/84.7×21.7), (12) *Selenopemphix nephroides* (B-1/82.0×12.5), (16) *Brigantedinium irregulare* (B-1/78.5×13.5).