Recent and Late Quaternary dinoflagellate cysts from the area of the Greenland –Iceland –Faeroe –Scotland Ridge

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ABSTRACT-Dinoflagellate cyst assemblages are described from Recent and Late Quaternary sediments recovered from Vema cores taken in the area of the Greenland – Iceland – Faeroe – Scotland Ridge. The dinoflagellate assemblage interpreted as indicating the Flandrian, "climatic" amelioration occurred in the sediments on the northern flank of the ridge whereas no evidence was found for this amelioration in the cores to the south. In the southern area, cyst assemblages proved an older climatic amelioration possibly of Eemian age. The potential for using dinoflagellate cysts to correlate oceanic and continental shelf areas is stressed.

INTRODUCTION

In 1966-67 I was introduced to the study of Quaternary dinoflagellates cysts by Professor Charles Downie of the University of Sheffield. I am pleased, therefore, to be adding this contribution on Quaternary dinoflagellate cysts to a volume dedicated to him, in gratitude for his guidance, advice and friendship over the years.

The Greenland - Iceland - Faeroe - Scotland Ridge is a bathymetric feature that separates the Norwegian Sea-Greenland Sea basins from the main North Atlantic basin. It is an aseismic area whose depth has undoubtedly affected shallow and deep water circulation, sedimentation and the distribution of both flora and fauna today and in the recent past. This ridge interrupts the normal North Atlantic bathymetric pattern but its origin and structure are still poorly understood although it is known to be intimately associated with the opening of the North Atlantic. It is thought to have been particularly important during the Quaternary, at a time when the climate was markedly fluctuating, acting as a partial control over the entry of dense, cold bottom water into the North Atlantic. This is of prime importance in terms of total North Atlantic circulation and indeed this dense cold bottom water has been traced as a distinct water mass into many distant ocean basins (Sejrup et al., 1984).

In 1979 I became involved with a group of scientists working in collaboration with Dr. D. Eisma of the Nederlands Instituut voor Onderzoek der Zee (N.I.O.Z.) in studying a group of Vema cores from around the Greenland-Iceland-Faeroe-Scotland Ridge to understand better this feature and its effects during the Quaternary. A series of twelve Vema cores collected by the R.V. Vema during 1966, 1969 and 1970 were selected. These cores sample the uppermost sediment cover on the ridge, on its flanks and in the deeper parts of the adjacent basins, and were chosen for good core length, availability and to give some correlation with the foraminiferal stratigraphy of Kellogg (1976) for the Norwegian Sea. A list of the cores studied with their geographical location, water depth and brief description is given in the appendix; their positions are also shown in Fig. 1.

Studies of Quaternary dinoflagellate cysts over the past few years have underlined the fact that this group is proving to be an important link in the elucidation of the marine Quaternary record on the shelf and in the deep ocean. Work in the North Sea has allowed the recognition of climatic ameliorations from sequences which were favourable or unfavourable for the recovery of dinoflagellate cyst assemblages. The recognition of rich and diverse cyst assemblages characterised by high proportions of such cyst species as Operculodinium centrocarpum (Deflandre & Cookson) Wall and Bitectatodinium tepikiense Wilson in the North Sea allows us to recognise times when the North Atlantic Current was following a northerly course similar to that of today in sequences otherwise interpreted as being deposited in a severe arctic-like climate (Harland et al., 1978; Gregory & Harland, 1978). In many ways, the present study tests the possible correlation of these North Sea sequences with those in the northern North Atlantic Ocean and Norwegian Sea and with other sequences in the eastern Atlantic and in the Bay of Biscay, and with similar work undertaken by Turon (1980, 1981) in the Rockall area. In this way, it becomes possible to use the occurrence of dinoflagellate cysts in the interpretation of the palaeoceanographic changes in the North Atlantic.

MATERIALS AND METHODS

A suite of two hundred and fifty-four samples from twelve Vema cores were processed for their dinoflagellate cyst content. The samples had been taken at 25 cm intervals for the most part, and the sample positions are shown in the figures that follow. The full data



Fig. 1. Sketch map of the Norwegian Sea showing the location of the Vema cores studied.

set is held in the collections of the Palaeontology Research Group at the British Geological Survey in Keyworth, Nottingham.

All the samples had initially been sent to the Nederlands Instituut voor Ondersoek der Zee where they were disaggregated with weak ultrasonic treatment, peptised with sodium chloride, separated at the $2 \mu m$ size fraction and stored wet. A sub-sample of the $> 2 \mu m$ fraction was then forwarded to me for palynological preparation. The preparation technique is standard and employs the sintered glass funnel method of Neves & Dale (1963), but avoids the use of any oxidising processes so as not to lose any of the more fragile peridiniacean cysts (Dale, 1976). A single slide was counted to give an idea of the richness of the samples and to give the proportions of the cysts present. The technique was standardised so as to give reasonably consistent results, but these can only be semi-quantitative. Rich samples were counted so as to give a minimum of 125 specimens. With such a count and with no more than about a dozen species present the real proportion will occur between 3% and 9% at either side of the estimated percentage at two standard deviations (2σ), depending upon the actual number of specimens counted (Van der Plas & Tobi, 1965). This study, which includes many samples that are barren or virtually barren of cysts, does not require a more precise method. A better indication of the true productivity would result if such data as the number of specimens/gm, sedimentation rates and amount of bioturbation was available. The proportions of the cysts present in relation to the numbers of cysts counted gives a good indication of the reliability of the data. The number of specimens per slide is a useful, if limited, indicator of the richness of the samples.

RESULTS

The cores are discussed individually before any synthesis or correlation is attempted but first the present day dinoflagellate cyst flora for the area (Harland, 1983) is given below based on thanatocoenoses in bottom sediments. The species are listed in order of numerical importance:-

Bitectatodinium tepikiense Wilson = Gonyaulax spinifera (Claparède & Lachmann) Diesing 10% - 50%

- Operculodinium centrocarpum (Deflandre & Cookson) Wall = Gonyaulax grindleyi (Reinecke) Von Stosch present - 50%
- Nematosphaeropsis labyrinthea (Ostenfeld) Reid = Gonyaulax spinifera (Claparède & Lachmann) Diesing present - 10%

Impagidinium sphaericum (Wall) Harland = Gonyaulax spinifera (Claparède & Lachmann) Diesing

			prese	ent - 10%
Protoperidinium cysts		present – 10%		
Spiniferites elongatus	Reid	Ξ	Gonyaulax	spinifera
(Claparède & Lachmann) Diesing				0 - 10%
S. lazus Reid = $Gonyaulax sp.$ indet.				0 - 10%

S. ramosus (Ehrenberg) Mantell = Gonyaulax spinifera (Claparède & Lachmann) Diesing 0 - 10%

The assemblages are dominated by either *Bitectatodinium tepikiense* or *Operculodinium centrocarpum* (Deflandre & Cookson) with the former being slightly more important in assemblages south of the Greenland – Iceland – Faeroe – Scotland Ridge (Harland, 1983).

The results obtained from this study are depicted in Figs. 2 to 11 and show the proportions of the various cyst species plotted against sediment depth for the main Vema cores studied, together with the number of cysts recovered on each individual slide.

Vema 23 -58, 23 -70 and 23 -75

These cores proved to be almost entirely barren of dinoflagellate cysts and, therefore, have not been plotted diagrammatically. They probably reflect unfavourable, arctic climatic conditions throughout their entire length.

Vema 23 -76 (Fig. 2)

This core yielded reasonable dinoflagellate cyst floras that showed a marked increase in productivity/richness at the top of the core where the assemblages are dominated by O. centrocarpum. Nematosphaeropsis labyrinthea (Ostenfeld), Impagidinium spp. and Spiniferites lazus also occured. This sequence is somewhat difficult to interpret, but may show the incoming of conditions compatible with the Flandrian or present 'interglacial' between 35 cm and 60 cm below the core top. This cyst flora may be interpreted as indicating good open water conditions and is similar to the modern assemblage.

Vema 27 -42 (Fig. 3)

This core yielded an interesting dinoflagellate cyst record that consists of two parts. The upper part was virtually devoid of cysts but was dominated by B. tepikiense, i.e. from the top of the core to about 3.35 m, and may be interpreted as representing poor and unfavourable environmental conditions. Below this upper part is a lower section, i.e. from 3.35 m to the base of the core at 6.70m, which contained rich cyst floras dominated by *B*. tepikiense with minor proportions of O. centrocarpum with Spiniferites and Protoperidinium cysts. This lower part of the sequence is thought to represent an ameliorative episode possibly of sufficient magnitude to be thought of as an interglacial. No Flandrian sediments were recognised in this core which was taken from the ridge as no assemblages comparable with the modern assemblage were found.

Vema 27 -60 (Figs. 4 and 5)

This core provided a poor record except in the upper part i.e. top to 6.4 cm depth where a modern (Flandrian) assemblage may be demonstrated but without the cyst species *B. tepikiense*. The assemblage, overwhelmingly dominated by *O. centrocarpum* and with good proportions of *N. labyrinthea*, is of Flandrian aspect. Kellogg (1976) also examined this core in his study of the foraminifera of the Norwegian Sea, and the two sets of results are compared in Fig. 5. The samples of modern aspect compare closely at the top of the core but the ameliorative episode recorded by Kellogg (1976) between 4.0 m and 5.5 m cannot be recognised from the dinoflagellate cyst evidence.

Vema 27 -85 (Fig. 6)

A poor cyst flora occurred here except for the uppermost 25 cm which yielded reasonable assemblages. This same pattern of cyst distribution was seen in cores 23-76and 27-80 but here a marked change in dominance between *B. tepikiense* and *O. centrocarpum* occurred between 25 and 50 cm depth, at about the same horizon as cyst abundance begins to rise. The event seen here in core 27-85 has already been recognised in work carried out on Quaternary sediments for Legs 80 and 81 of the Deep Sea Drilling Project (Harland, in press a, b).

V23-76



Fig. 2. Dinoflagellate cyst biostratigraphy of Vema core 23-76. Sample positions are shown by ticks. Proportions are calculated from the number of cysts/slide as shown.

Vema 27 -86 (Figs. 7 and 8)

There was variable recovery of dinoflagellate cysts from this core but again the results showed an inverse relationship in the proportions of *B. tepikiense* and *O. centrocarpum* at about 1.0 m depth. No clear rise in cyst abundance occurred at the top of this core. Vema 27–86 was also one of Kellogg's (1976) cores which he dated as Flandrian, corroborating my results on dinoflagellates at the top of the core but the marked amelioration he recorded between 2.5 m and 3.5 m, has not been found in the present study (Fig. 8). The pattern is similar to that seen in Vema 27–60 but the "climatic" amelioration, as evidenced by the foraminiferal data, was not found in the cyst record (fig. 7). Sampling intervals in this core (Vema 27-86) are large and consequently sediments containing these assemblages may have been missed. Core 27-60 has a similar pattern of cyst distribution to core 27-86 and the samples are more closely spaced.

Vema 27 - 98

Few dinoflagellate cysts were found in this core. The sediments were sandy in character and the lack of cysts may be a sorting phenomenon as cysts act like sedimentary particles of silt size (Dale, 1976).

Vema 27 -102 (Fig. 9)

The cyst abundances between core levels 2.0m and 5.5m indicated a "climatic" amelioration. In this interval

V27-42



Fig. 3. Dinoflagellate cyst biostratigraphy of Vema core 27-42.

the cyst species *B. tepikiense* is dominant with minor amounts of *O. centrocarpum* and *Spiniferites* spp. A similar assemblage is seen in core 27-42 and the two cores can be correlated. Core 27-102 does not appear to have any Flandrian record with high proportions of *O. centrocarpum* similar to the modern thanatocoenosis (Harland, 1983). Neither this core, nor core 27-42, were analysed by Kellogg (1976) for foraminifera.

Vema 28 -33 (Fig. 10)

In this core, there was an increase in cyst abundance at the top and a changeover in dominance between *B*. *tepikiense* and *O*. *centrocarpum* at the same level, i.e. at about 50 cm. The remainder of the core yields reasonable assemblages of cysts with fairly balanced proportions of *B*. *tepikiense*, *O*. *centrocarpum* and *Spiniferites* spp.

Vema 28 – 56 (Fig. 11)

The final core was virtually barren of dinoflagellate cysts apart from the uppermost sample at 9 cm. This sample contained an assemblage very similar to that of the modern day, with a high proportion of O. centro-carpum (94.5%) together with subordinate proportions of N. labyrinthea and Impagidinium spp. This is interpreted as a Flandrian assemblage along with samples from cores 27-85, 27-86 and 28-33. Core 28-56 can be compared directly with Kellogg's (1976) work and is substantiated as Flandrian at the top but the work on dinoflagellates does not indicate an older climatic amelioration.

SYNTHESIS

This study has illuminated a number of interesting facts both for the study of dinoflagellate cysts and for the

wider aspects of Quaternary stratigraphy. It has shown that the sequences of marine Quaternary sediments from the deep ocean do yield assemblages of dinoflagellate cysts, and that these may be used in interpreting the climatic history. Since it has already been established that dinoflagellate cysts may be extracted from shelf sediments (Harland, 1977), they provide an enormous potential for correlating the deep ocean with the continental shelf, an attribute that cannot be said of either planktonic foraminifera or coccolithophores. Comparisons with shelf areas will be presented later.

The assemblages recovered from these Vema cores demonstrate sufficient change, even under less than stringent semi-quantitative techniques, to assist in interpreting the palaeoenvironment and hence climate. Results have allowed the studied cores to be grouped into three. The first group contained poor floras and indicate unfavourable, possibly arctic conditions throughout or at least to the limits of the sampling intervals. The second group revealed a poor and unfavourable environment of deposition except for those from the uppermost 0.5 to 1.0 m depth where the assemblages are comparable with those found in the area at the present time. It is of particular interest to record the fact that several of the cores (i.e. 27-85, 27-86 and 28-33) record a changeover in dominance from the cyst species Bitectatodinium tepikiense (one of the many cyst types attributable to Gonyaulax spinifera (Claparède & Lachmann) Diesing) to the cyst species Operculodinium centrocarpum (Deflandre & Cookson) Wall (the cyst of Gonyaulax grindleyi (Reinecke) Von Stosch). This changeover occurs at around the late Devensian/Flandrian boundary (see below) as cyst productivity rises and has been seen elsewhere in the



Fig. 4. Dinoflagellate cyst biostratigraphy of Vema core 27-60.



Fig. 5. Dinoflagellate cyst biostratigraphy of Vema core 27–60 in comparison to Kellogg's (1976) data of total percentage of CaCo₃% warm fauna, and numbers of planktonic foraminifera/gm.

North Atlantic area. These cores all appear to occur to the northern side of the Greenland – Scotland Ridge. The final group of cores, consisting of 27-42 and 27-102, appear to show no Flandrian assemblages but do show a record of a "climatic" amelioration (?interglacial) spanning about 3.0 to 3.5m thickness of sediment dominated by the cyst species *B. tepikiense*. This amelioration cannot be dated at the present time but may correlate with a similar occurrence in the North Sea (Borehole 78/9, unpublished data). The assemblage is different from the Flandrian assemblage discussed earlier and does enable cores 27-42 and 27-102 to be correlated. These cores occur, in contrast to those discussed earlier, on the southern flank of the Greenland – Scotland Ridge.

Direct comparisons can be made with the work of Kellogg (1976) on Vema cores 27-60, 27-86 and 28-56. His evidence of the incidence of southern planktonic species and the occurrence of biogenic calcareous tests demonstrate both the present day amelioration and a second amelioration interpreted as occurring between 127,000 to 110,000 years B.P. and possibly Eemian in age. Although the Flandrian could be recognised from the evidence presented here, there was no clear evidence

of the earlier "climatic" amelioration. Thus the dinoflagellate cysts in Vema cores on the northern flank and to the north of the Greenland – Scotland Ridge do not record an interglacial event prior to the present day, unlike the record of the planktonic foraminifera. They do, however, seem to record such an event to the south of the Greenland – Scotland Ridge.

It is open to speculation whether this bathymetric feature has had a major affect on the present day dinoflagellate cyst distributions, possibly controlling the nutrient supply from depth in the area by forcing nutrient-rich water to the surface when the North Atlantic Deep Water Current was in operation. It is also possible that during the time of the older "climatic" amelioration, as seen on the southern flank of the ridge, the effect and extent of the warm Norwegian Current were not as great as today, and the North Atlantic Deep Current was not operating fully. Other evidence from both foraminifera and coccoliths (Belanger, 1982) point to both an Eemian event in the Norwegian Sea and the operation of the North Atlantic Deep Water Current. The separate study of the dinoflagellate cyst content has added to our awareness of the complexity of the problem and the importance of the Greenland – Scotland Ridge.





Fig. 6. Dinoflagellate cyst biostratigraphy of Vema core 27-85.

COMPARISONS

Dinoflagellate cyst analysis of Quaternary sequences in the marine realm is still very limited. Comparisons can, however, be made between the present findings and those from two kinds of depositional environment. The first, the deep ocean, is exemplified by the work of Turon (1980, 1981) who has recently completed a study in the Rockall area, and has detailed the dinoflagellate cyst biostratigraphy of the Flandrian. In each of his cores, it is noticeable that there is a change in dominance between B. tepikiense below and O. centrocarpum above, occurring at about the horizon of an ash-level that has been estimated at 9300 B.P. (Ruddiman & McIntyre, 1973). This appears to be a significant event in terms of the dinoflagellate cyst biostratigraphy. Unfortunately, none of Turon's cores revealed any interglacial deposits. Harland (in press a), in work on the Quaternary biostratigraphy of Hole 552A in the Rockall area, also confirms this same 'event' in the Flandrian, but also records what appears to be an interglacial in an

labyrinthea very much like the present day assemblage, but not like that seen and reported upon herein in Vema cores 27-42 and 27-102. In contrast, a rather more complex record from the Goban Spur (Harland, in press b) appears to evidence the presence of a complicated interglacial sequence characterised by *Bitectato-dinium tepikiense*, overlying sediments with poor dinoflagellate floras, in turn overlying a further complex interglacial characterised by the cyst species O. centrocarpum.
The second depositional environment, the continental shelf, is characterised in the North Sea (unpublished data) by such recently studied sediments as those recovered in the B.G.S. Boreholes 75/33 and 81/34.

shelf, is characterised in the North Sea (unpublished data) by such recently studied sediments as those recovered in the B.G.S. Boreholes 75/33 and 81/34. These have yielded sequences of late Devensian to Flandrian age also showing this latest Flandrian 'event' together with other interpreted interglacials. These

older part of the sequence. This older interglacial is

characterised by high proportions of Operculodinium

centrocarpum, Spiniferites spp. and Nematosphaeropsis



Fig. 7. Dinoflagellate cyst biostratigraphy of Vema core 27-86.



Fig. 8. Dinoflagellate cyst biostratigraphy of Vema core 27-86 in comparison to Kellogg's (1976) data.

interglacials are dominated both by the cyst species O. centrocarpum and B. tepikiense. Records from other boreholes such as Borehole 78/9 (see Skinner & Gregory, 1983) showed a strong amelioration (at about 18.0-19.0 m drilled depth) based on benthic foraminiferal evidence. This amelioration can be correlated with the Blake Palaeomagnetic Event at 0.075-0.125million years B.P., and is associated with a dinoflagellate cyst assemblage dominated by *B. tepikiense* and high proportions of *Spiniferites* spp. at some levels. This



V27-102

Fig. 9. Dinoflagellate cyst biostratigraphy of Vema core 27-102.



Fig. 10. Dinoflagellate cyst biostratigraphy of Vema core 28-33.

assemblage is very similar to those indicating an amelioration seen in Vema cores 27–42 and 27–102 and possibly they all represent the same "climatic" amelioration. But this is uncertain because of a lack of good dating control of many of the North Sea boreholes and the two Vema cores under discussion.

In summary, it appears that the youngest dinoflagellate cyst event, occurring sometime in the Flandrian at c.9300 B.P., is seen from the Bay of Biscay to Rockall into the Norwegian Sea and the North Sea. The older ameliorative (interglacial) episode, recognised in cores 27-42 and 27-102, is generally not seen further north than about 63° N in the North Atlantic but may have been recognised in North Sca sequences particularly those from Borehole 78/9 (Skinner and Gregory, 1983).

DISCUSSION

Possible correlations and uses of the study of dinoflagellate cysts in the open marine environment may be alluded to only. A major restraint is our lack of knowledge of the detailed autecology and synecology of dinoflagellate cysts (Dale, 1983). Although some work has been published on various cyst thanatocoenoses, not enough information is available on the distribution of living dinoflagellate cysts and their introduction into bottom sediments. Noteable exceptions include Dale (1976) and Balch et al. (1983). An illustration of this particular problem is the turnover from samples dominated by B. tepikiense to O. centrocarpum during the Flandrian. O. centrocarpum is known as a cosmopolitan cyst species with a centre of concentration mainly in north-temperate and arctic waters (Harland, 1983). B. tepikiense has a somewhat similar distribution and a centre of concentration to the south and southeast of Iceland, i.e. to the south of the Greenland - Iceland -Faeroe - Scotland Ridge. If the thanatocoenoses of these species from present day bottom sediments reflects the distribution of the living cysts and their parent thecae, then we have a method for recognising an event in the surface waters of the North Atlantic during the Flandrian. A detailed knowledge of the autecology of these species is needed and would allow more to be learned of the surface water conditions. If this thanato-

V28-56



Fig. 11. Dinoflagellate cyst biostratigraphy of Vema core 28-56 in comparison to Kellogg's (1976) data.

coenesis does not accurately reflect the distribution of living cysts, then it may, in this instance, be necessary to look at their *post-mortem* transporation along the ocean floor by currents such as the North Atlantic Deep Water Current. This current is certainly operating today and may be responsible partly for the lack of the Flandrian succession in the more southerly Vema cores. The Flandrian succession appears to be well represented in the Rockall area (Turon, 1980, 1981), such that the thanatocoenosis recorded by Harland (1983) may be enriched in specimens of *B. tepikiense* either because of reworking from older sediments or because of scour and transportation by the North Atlantic Deep Water Current.

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The Norwegian Sea is thought to have had permanent ice cover during most of the past 150,000 years with only that period from 121,000 to 119,000 years B.P. being comparable or warmer than today, and the present period from 13,000 years B.P. to the present time (Kellogg, 1976, Kellogg *et al.* 1978) being relatively ice free. Only during these two incursions of warm water into the Norwegian Sea is the North Atlantic Deep Water Current thought to have come into operation (Streeter *et al.*, 1982). The dinoflagellate cyst evidence may be interpreted to support the present day situation with the warm water incursion, North Atlantic Deep Water Current and scour on the southern slope of the

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Greenland - Iceland - Faeroe - Scotland Ridge. There is, however, no clear evidence for warm water extending into the Norwegian Sea between 124,000 and 115,00 years B.P. but warm water was probably present south of the ridge possibly without the action of the North Atlantic Deep Water Current. The change in dominance between B. tepikiense and O. centrocarpum within the younger warm water pulse at c.9300 B.P. may correlate with the onset of Termination I.B. (Duplessy et al., 1981) which marks a period when the polar front was close to the Greenland - Iceland - Faeroe - Scotland Ridge (Sejrup et al., 1984), and may be substantially different from both the fully glacial and fully interglacial situation. Whatever the final outcome of this kind of discussion, there is considerable potential in using dinoflagellate cysts as additional indicators of changing oceanographic conditions and particularly for linking the oceanic record with sequences on the continental shelf.

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APPENDIX

Location and Description of Cores

VEMA 23-58

Lat: 65° 46'N, Long: 07° 07'W Corrected Depth: 1796 m Core Length: 784 cm Foraminiferal marls, sandy marls and oozes interbedded with layers of sandy clay. Laminated and slightly burrowed. Almost entirely barren of dinoflagellate cysts.

VEMA 23-70

Lat: 70° 59.1'N, Long: 06° 41.4'E Corrected Depth: 3047 m Core Length: 716 cm Interbedded marl and sandy marl with sandy clay and clay. Irregularly interbedded. Dinoflagellate cyst floras extremely poor.

VEMA 23-75

Lat: 64° 48'N, Long: 01° 19'W Corrected Depth: 2930 m Core Length: 644 cm Gray mud with uppermost part brown in colour. Poor dinoflagellate cyst floras throughout.

VEMA 23-76

Lat: 63° 39'N, Long: 01° 22'E Corrected Depth: 1734 m Core Length: 1014 cm Foraminiferal – volcanic glass underlain by layers of foraminiferal sandy marls. Excellent dinoflagellate cyst recovery.

VEMA 27-42

Lat: 61° 50.5'N, Long: 01° 27.8'W Corrected Depth: 954 m Core Length: 675 cm Foraminiferal sandy clay with a single layer of volcanic sand. Good dinoflagellate cyst recovery.

VEMA 27-60

Lat: 72° 11'N, Long: 08° 34.8'E Corrected Depth: 2525 m Core Length: 741 cm Alternating zones of foraminiferal sandy clay, sandy clay and clay with foraminiferal clay at the top. Good dinoflagellate cyst recovery. **VEMA 27-85** Lat: 67° 21.7', Long: 04° 01.6'E Corrected Depth: 1227 m Core Length: 798 cm Alternating zones of foraminiferal sandy clay, and sandy clay. Dinoflagellate cyst recovery reasonable. **VEMA 27-86** Lat: 66° 36.4'N, Long: 01° 07.1'E Corrected Depth: 2900m Core Length: 608 cm An upper part of alternating zones of foraminiferal sandy clay, foraminiferal sandy marl and chalk and sandy clay, and a lower part of a large zone of sandy clay interrupted by a horizon rich in manganese nodules. Good dinoflagellate cyst recovery. **VEMA 27-98** Lat: 60° 39.2'N, Long: 07° 25.5'W Corrected Depth: 980m Core Length: 453 cm Alternating sand and clayey sand with clay at base. Dinoflagellate cyst recovery extremely poor. **VEMA 27-102** Lat: 62° 07.7'N, Long: 14° 12.3'W Corrected Depth: 1641 m Core Length: 1014 cm Marl interbedded with zones of black ash, sand and foraminiferal ooze. Good dinoflagellate cyst recovery. **VEMA 28-33**

Lat: 62° 54'N, Long: 00° 35'E Corrected Depth: 1170 m Core Length: 513 cm Sandy marl with some volcanic ash and sandy clay. Good dinoflagellate cyst recovery.

VEMA 28-56

Lat: 68° 02'N, Long: 00° 07'W Corrected Depth: 2941 m Core Length: 837 cm Interbedded zones of foraminiferal marl, ooze, sandy clay and volcanic ash. Poor dinoflagellate cyst recovery.