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CENOZOIC FORAMINIFERAL BIOSTRATIGRAPHY OF THE CENTRAL NORTH SEA

by

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With 2 figures and 2 tables

ZUSAMMENFASSUNG

An 29 Bohrungen aus dem Bereich der zentralen Nordsee wurde eine stratigraphische Analyse an 147 benthonischen Foraminiferenarten mit über 60 agglutinierten Arten und einigen planktonischen Formen durchgeführt. Dazu wurde das RASC (ranking and scaling) Computerprogramm für Zonierung und Feststellung paläontologischer Ereignisse herangezogen. Die Tiefenwerte der physikalischen Log marker A–G in den Bohrungen wurden ebenso in das Computerprogramm einbezogen. Zehn Zonenabschnitte werden vorgeschlagen: 1) *Subbotina pseudobulloides* Zone – Danien; 2) *Trochammina ruthven murrayi – Reticulophragmium paupera* Zone – Selandien; 3) *Coscinodiscus* spp. Zone – oberes Selandien/unteres Ypresien; 4) *Subbotina patagonica* Zone – Ypresien; 5) *Reticulophragmium amplectens* Zone – Mittel/Obereozän; 6) *Globigerinatheka index* Zone – Obereozän; 7) *Rotaliatina bulimoides* Zone – Rupelien; 8) *Globigerina* ex gr. *officinalis* Zone – Oberoligozän/Untermiozän; 9) *Globorotalia praescitula – G. zealandica* Zone – Unter/Mittelmiozän; 10) *Cassidulina teretis* Zone – Mittelpliozän/Pleistozän.

Der Log marker A tritt am Ende der Kreide auf; Log marker B liegt allgemein im Danien; Log marker C und D begleiten die Tuffe in der Nähe der Paleozän/Eozän-Grenze; Log marker E liegt am Top des Untereozäns; Log marker F liegt nahe der Eozän/Oligozän-Grenze; und der Log marker G tritt am Ende des Bereichs Unter/Mittelmiozän auf. Eine Verbreitungstabelle zeigt die durchschnittliche und gesamte Reichweite von 30 agglutinierten Taxa. Diese Tabelle ist mit geringen Veränderungen auch im offshore-Gebiet Kanadas anzuwenden.

ABSTRACT

A stratigraphic analysis was made of 147 benthic foraminifera, including over 60 agglutinated ones and some planktonic taxa in 29 wells, central North Sea. Use was made of the ranking and scaling (RASC) computer program for zonation and normality testing of paleontological events. The depth picks of physical log markers A-G in the wells were also included in the RASC input file. Ten interval zones are proposed, including: (1) *Subbotina pseudobulloides* Zone - Danian; (2) *Trochammina ruthven murrayi - Reticulophragmium paupera* Zone - Selandian; (3) *Coscinodiscus* spp. Zone - Late Selandian/Early Ypresian; (4) *Subbotina patagonica* Zone - Ypresian; (5) *Reticulophragmium amplectens* Zone - Middle/Late Eocene; (6) *Globigerinatheka index* Zone - Late Eocene; (7) *Rotaliatina bulimoides* Zone - Rupelian; (8) *Globigerina* ex. gr. *officinalis* Zone - Late Oligocene/Early Miocene; (9) *Globorotalia praescitula - G. zealandica* Zone - Early/Middle Miocene; (10) *Cassidulina teretis* Zone - Middle Pliocene/Pleistocene.

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Log marker A occurs at the top Cretaceous; log marker B on average is in the Danian; log markers C and D delineate the tuffs near the Paleocene/Eocene boundary; log marker E is top Early Eocene; log marker F is near the Eocene/Oligocene boundary and log marker G occurs at the top of the Early/Middle Miocene. A range chart depicts the average and total stratigraphic range of 30 agglutinated benthic taxa. This chart, with minor modifications, is also applicable offshore eastern Canada.

INTRODUCTION

The Tertiary Graben of the central North Sea served as a link between the expanding Norwegian-Greenland Sea and the shallow epicontinental seas of Northwest Europe. We are studying the Tertiary shelly microfossil assemblages of the central North Sea as part of a long-term investigation to further our understanding of the taxonomy, geographic distribution and paleoecology of agglutinated foraminifera as well as their utility for stratigraphy.

Following the widespread deposition of Danian chalk, south of about 60° N, the North Sea Basin

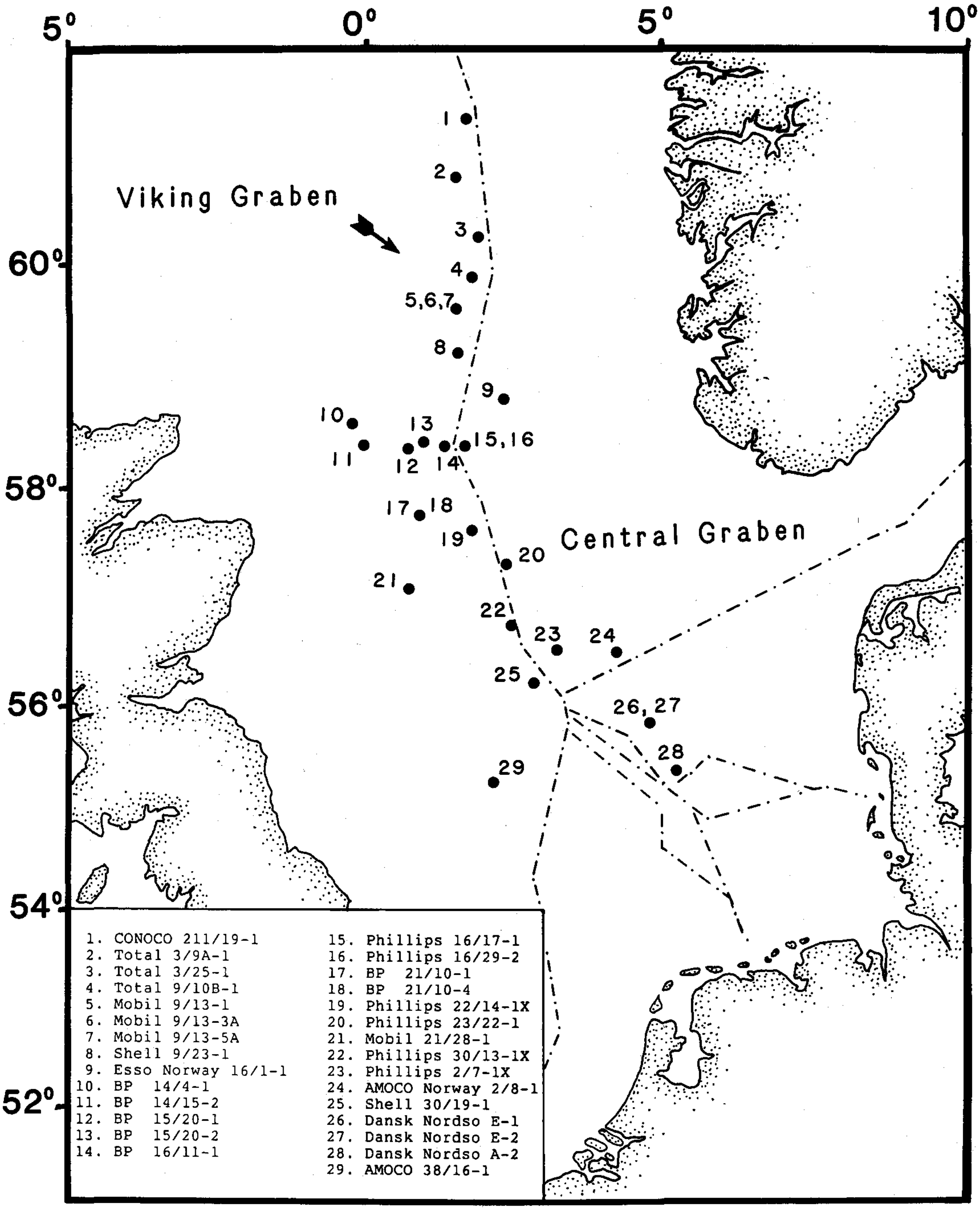


Fig. 1.
Location of 29 exploration wells, Central North Sea..

underwent rapid subsidence (Sclater and Christie 1980; Gradstein and Berggren 1981; Wood 1981). As a result, terrigenous clastic sediments in excess of 3 km thick accumulated in the central portion of the basin. Thickest sediments are found in the Central Graben, whereas the Viking Graben received between 2 and 3 km of sediment. Mudstones predominate, with deep marine clastic fans, like those of the Forties and Frigg oil fields developing during the early stage of Tertiary subsidence. In the Ekofisk area post-Danian olistostromes occur. By Middle Miocene time the North Sea trough had been filled, leaving a neritic environment with a predominantly calcareous benthic microfauna dominated by *Cassidulina*, *Elphidium*, *Fursenkoina*, and *Cibicidoides*.

The post-Danian, Paleocene through Early-Middle Miocene mudstones harbour a rich and diversified flysch-type agglutinated benthic fauna (Gradstein and Berggren 1981). In this study we report on the stratigraphic distribution of the benthic fauna in 29 exploratory wells. Over 2000 cuttings, sidewall cores and some core samples were analyzed (table 1; figure 1). In order to standardize the taxonomic nomenclature, all well samples were investigated by the senior author; assistance was provided by the junior authors on this project. A large collection of North Sea type specimens, housed with the senior author is available for comparative studies. The taxonomy of the benthic foraminifera follows Gradstein and Agterberg (1982), Gradstein and Berggren (1981) and Kaminski *et al.* (this volume). A revision of the taxonomy of the agglutinated morphotypes encountered is in progress and will be reported on elsewhere. The final stratigraphic analysis presented here involves the disappearance levels (tops) of 147 benthics, including over 60 agglutinated ones and some planktonic taxa.

For the purpose of this study the microfossil distribution data were augmented by the relative position in the wells (in feet or meters of depth below the rotary table) of physical log markers A through G as defined by A.C. Morton and R.B. Knox (personal communication, 1984).

Table 1.
Central North Sea wells and thickness of Cenozoic internal studied; wells are listed approximately from north to south as shown in figure 1. Wells marekd with an asterisk (*) employed coring techniques in addition to cuttings sampling.

Conoco	211/19-1	2000 - 5925'
Total	3/9A-1	1355 - 2180 m
Total	3/25-1	554 - 2580 m
Total	9/10B-1	1682 - 2952 m
Shell	9/23-1*	900 - 6700'
Mobil	9/13-1	1800 - 8700'
Mobil	9/13-3A	990 - 8840'
Mobil	9/13-5	1600 - 8900'
Dansk Nordso	A-2*	4650 - 6080'
Dansk Nordso	E-1*	4400 - 6698'
Dansk Nordso	E-2*	4710 - 6470'
BP	14/4-1	280 - 989 m
BP	14/15-2	509 - 1931 m
BP	15/20-1	1240 - 1966 m
BP	15/20-2	870 - 2343 m
BP	21/10-1	4970 - 7980'
BP	21/10-4	1217 - 2808 m
BP	16/11-1	793 - 2200 m
Esso Norway	16/1-1*	1250 - 9025'
Phillips	2/7-1X	2030 - 9700'
Phillips	16/17-1	3579 - 9500'
Phillips	16/29-2	2000 - 8945'
Mobil	21/28-1	2090 - 4600'
Phillips	22/14-1X	3400 - 9875'
Phillips	23/22-1	1525 - 10125'
Amoco Norway	2/8-1	1190 - 8210'
Phillips	30/13-1X	525 - 10102'
Shell	30/19-1*	1410 - 10500'
Amoco	38/16-1	1480 - 3870'

PREVIOUS BIOSTRATIGRAPHIC STUDIES

The Cenozoic microfossil record of the North Sea region has been the subject of several biostratigraphic studies. In the most comprehensive zonation to date, King (1983) concentrates on the upper part of the stratigraphic ranges or tops of almost 100 benthic and over 25 planktonic foraminifera, including taxa of diatoms and some Miocene *Bolboforma*. Seventeen interval zones using benthics and 16 using planktonic taxa are proposed. The zonation is largely based on species occurring in the "outer sublittoral-epibathyal biofacies", which in our terminology translates into outer neritic to upper bathyal environments. The zonation appears to be particularly useful for the area around the Central Graben. King (1983) provides an excellent summary of the interrelation of his zonation with that developed by Doppert (1980) and Doppert and Neele (1983) for the Netherlands and by a number of different authors for shorter stratigraphic intervals in Denmark, West Germany and England. The eleven-fold assemblage zonation developed by Doppert and co-workers for the Netherlands uses over 90 species (mostly calcareous benthic taxa), typical of shallow to deep neritic environments.

Ioakim (1979) studied the dinoflagellate succession in the cores from the Esso Norway 16/1-1 well, central North Sea. Nine (preliminary) assemblage zones were distinguished from Paleocene through Early Miocene and correlated to Rockal Bank and Labrador Shelf. The most recent organic microfossil zonation for the Cenozoic of the North Sea is that of Costa (in press). Twenty concurrent range zones are proposed using both appearance and disappearance of taxa in Western Europe, North Sea and Norwegian Sea. It is primarily intended for regional correlations of Paleocene through Pliocene strata. Unfortunately, literature on the actual occurrences of the zonal taxa in the North Sea wells studied by us for foraminifera is non-existent. For this reason it is not possible to do a first-order correlation to Costa's zones.

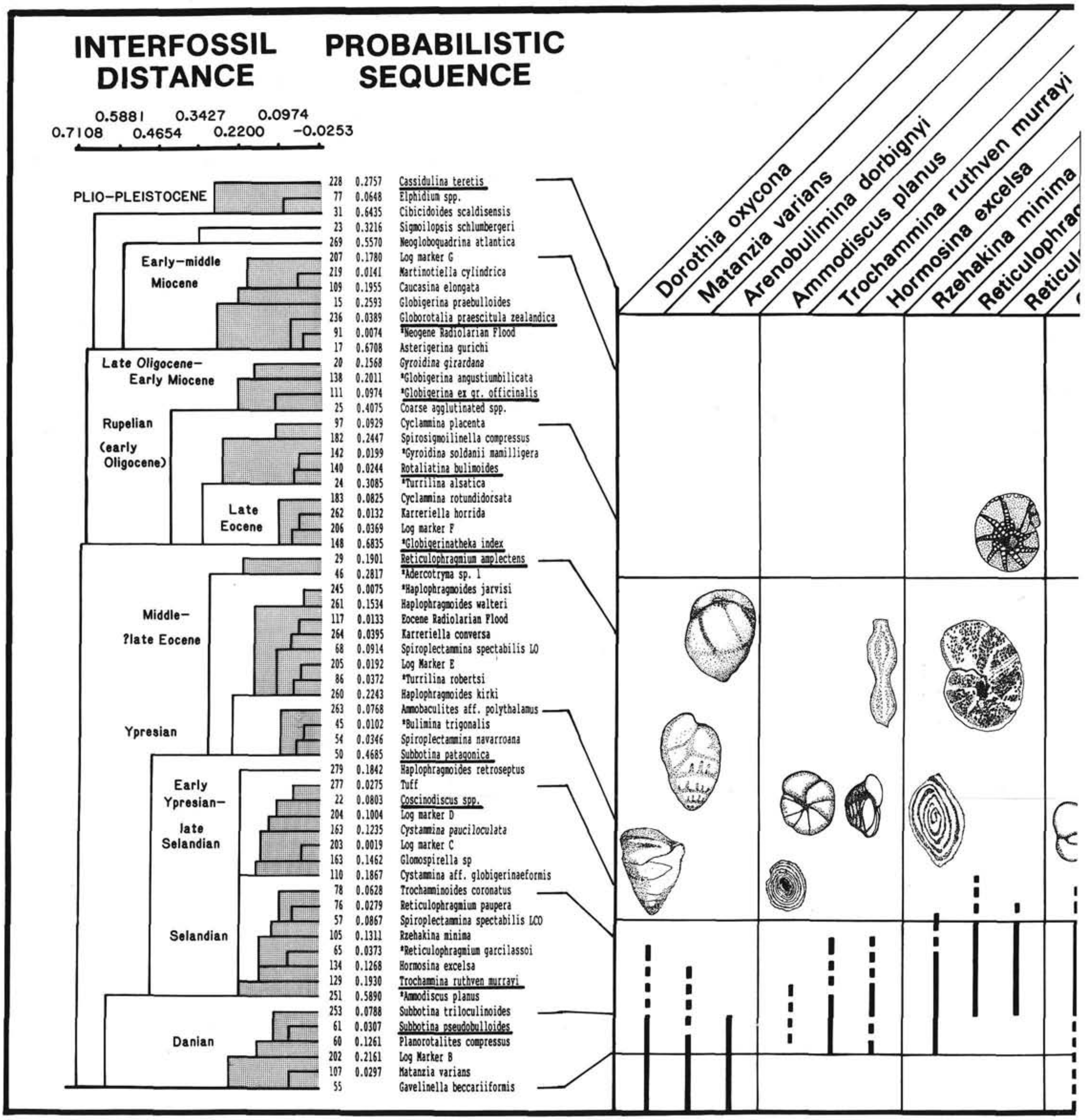
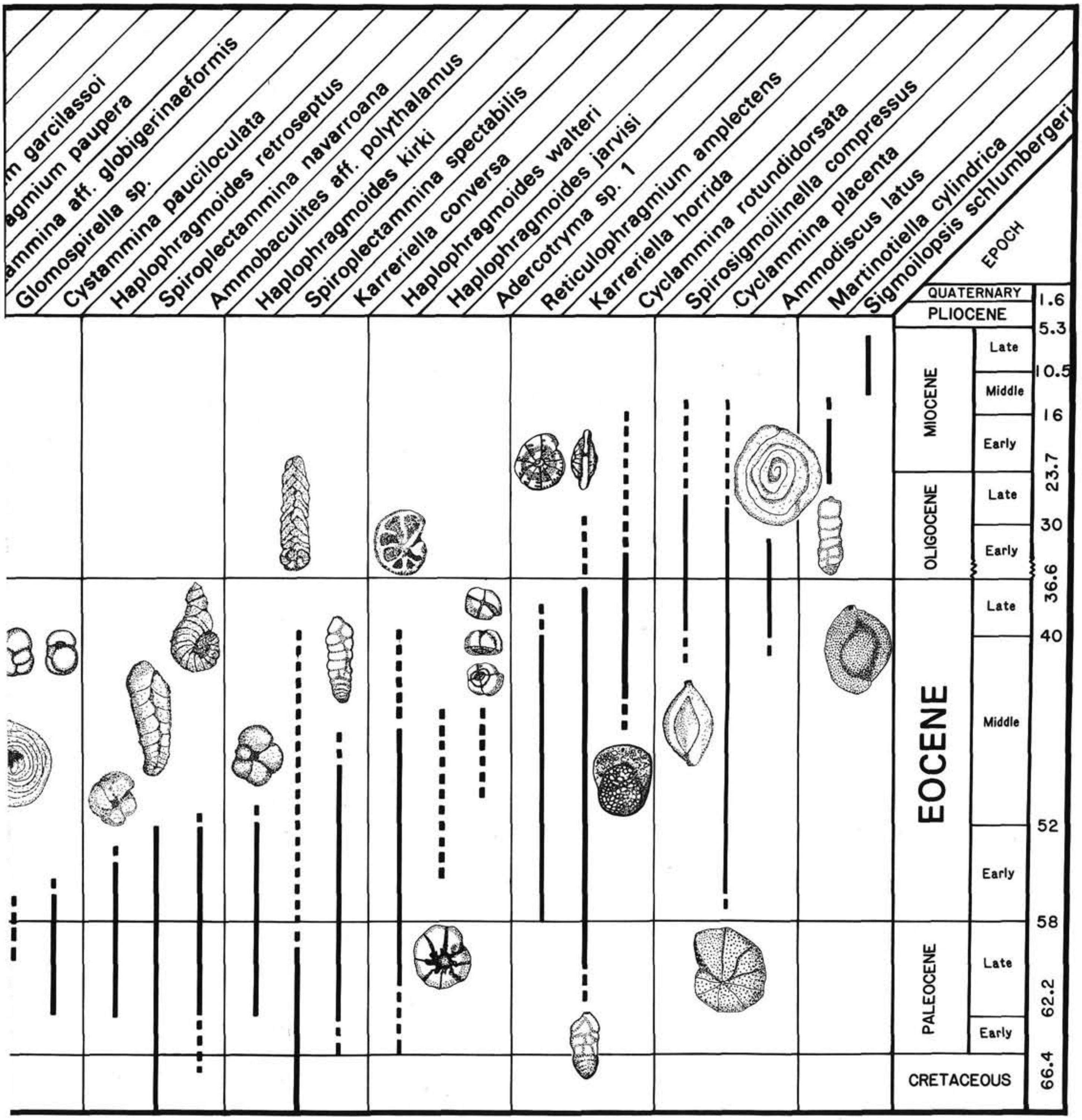


Fig. 2.
Average stratigraphic distribution of twenty-nine agglutinated benthic foraminifera, Cenozoic, central North Sea.
Isolated first or last ocurrences are shown with dashed lines. The zonation to the left is the scaled optimum sequence for the average tops of 54 foraminifera and siliceous microfossils and physical log markers A-G in 29 wells. Dendrogram values along y-axis are distances between events in relative time. Scaling is stratigraphically downward, in line with the study of the wells. The generalized ten-fold zonation is representative for the regional Cenozoic stratigraphy (see text). There are 11 unique events (= rare events) shown with **. A shading pattern has been used to enhance the stratigraphically most useful part of the dendrograms. The large interfossil distances at the top of the Danian, Late Selandian-Early Ypresian, Middle-Late Eocene, Late Eocene-Early Miocene and Middle Miocene are sedimentary cycle boundaries.

CENTRAL NORTH SEA ZONATION

The stratigraphic distribution of the local disappearance levels of 147 benthic foraminifera, including over 60 agglutinated and some planktonic taxa in 29 exploratory wells, was investigated using the ranking and scaling (RASC) method. This method can process a complex and noisy stratigraphic record for stratigraphic zonations, and deal with the record in an objective manner (Agterberg and Nel 1982a,b; Gradstein and Agterberg 1982; Gradstein *et al.* 1985). Ranking is a pairwise comparison technique that tries to determine the most likely sequence of biostratigraphic events as recorded in different stratigraphic sections. Scaling determines the spacing of these events in relative time, using the frequency of cross-over in relative position of the events in the wells. The relative position of the events in the final ranked and scaled optimum



sequences is essentially an average of all the relative positions encountered. In this sense the RASC zonation is not vulnerable to outliers in the original data. Tests on stratigraphic normality of the individual (well) record relative to the calculated standard reveal where the outliers are. Details on data preparation, the method, data processing and interpretation of results are in Gradstein *et al.* (1985). The results presented in this study were acquired with a personal computer version of the RASC program, using an IBM-XT with mathematical co-processor, 512 k RAM and EPSON MX dot matrix printer.

A close look at the North Sea analytical data shows that the southern wells (blocks 21-38) contain more Oligocene-Miocene calcareous taxa, including several species of planktonics, than the northern wells which contain a more diversified Paleocene agglutinated record. This pattern of geographic differentiation was further confirmed using correspondence analysis (G. Bonham Carter, personal communication, 1985). This method clarifies the spatial distribution of co-occurring taxa. There may be several reasons for this biogeographic trend, one of them being the fact that the principal deep-water connection was to the north in the Norwegian Sea. The latter region does not have much of an indigenous planktonic record. Another reason is that the post-Danian, Late Paleocene-Eocene bathyal mudstone facies did not preserve much of a carbonate record, owing to diagenetic effects (Gradstein and Berggren 1981). A third reason is climatic; apparently the transition from carbonate-rich to carbonate-poor rocks in Cenozoic time can be traced from south to north over the central North Sea (Ziegler 1981). The biogeographic analysis indicates that for detailed regional studies two zonations are required, one emphasizing the northern Paleogene record and the other the southern Oligocene-Miocene record. In this study we stress the generalized zonation which combines features from both the Central Graben and Viking Graben deep-water troughs.

The generalized Cenozoic North Sea zonation uses the RASC thresholds $k_c = 8$ and $m_c = 5$, which means that zonal taxa must occur in 8 or more out of 29 wells and each pair of taxa in the scaled optimum sequence in 5 or more wells. This threshold reduces the original data set of 147 events to 49, including 8 planktonic and 25 agglutinated taxa and the log markers A-G of Knox and Morton (personal communication, 1984), as found in the majority of wells studied. The histograms that display the interfossil distances between the ranked taxa (figure 2) are quite stable when RASC runs with other k_c and m_c threshold parameters are used. For example, we tried $k_c = 9$ and 10 and $m_c = 6$ and 7, which incorporate 45 and 41 taxa respectively. In all cases the same zones are recognized.

In order to enhance the zonation with index taxa that are rare or other taxa that are thought to be potentially of such use, the RASC method allows introduction of so-called special or unique events (UE). Twelve events were selected that occur in less than $k_c = 8$ wells, but are worth noting. These events are the highest occurrence of (from old to young) *Ammodiscus planus*, *Reticulophragmium garcilassoi*, *Bulimina trigonalis*, *Turrilina robertsi*, *Haplophragmoides* (?) *jarvisi*, *Adercotryma* sp. 1, *Globigerinatheka index*, *Turrilina alsatica*, *Globigerina* ex gr. *officinalis*, *G. angustiumbilicata* and Neogene radiolarian flood. In the final RASC calculations, stratigraphic neighbors of these events are identified. A neighbor is a species that occurs in the scaled optimum sequence and also in the well(s) with the UE, and stratigraphically as close as possible to it. Each UE is positioned halfway between these neighboring events in the scaled optimum sequence.

Ten interval zones are recognized (figure 2; table 2), with the characteristic taxa listed stratigraphically in order of average disappearance. A more detailed zonation (which uses lower k_c and m_c values) is possible for local correlation. The regional (deep-water) zones are from older to younger:

Zone *Subbotina pseudobulloides*
Age Danian (Zones P1 - P2)
Taxa *Gavelinella beccariiformis*, *Matanzia varians*, *Planorotalites compressus*, *Subbotina pseudobulloides* and *S. triloculinoides*.
This zone corresponds to King's (1983) Zone of the same name and age. *Gavelinella beccariiformis* has been reported from sediments as young as Zone P5 (Tjalsma and Lohmann 1983). This fits with its disappearance along the Canadian Atlantic margin together with *Aragonia velascoensis* and just below the appearance of *Pseudohastigerina* (post P5), (Gradstein *et al.* 1985, p. 346). In the central North Sea the disappearance of *G. beccariiformis* is approximately 5 m.y. earlier, and may be related to the change near the end of the Danian from predominantly carbonate to clastic sediments.

Zone *Trochammina ruthven murrayi* - *Reticulophragmium paupera*
Age Selandian, Late Paleocene (Zones P3 - P4).
Taxa *Ammodiscus planus* (UE), *Trochammina ruthven murrayi*, *Hormosina excelsa*,

Table 2.
Correlation of the foraminiferal zonation for the Central and Viking Graben, North Sea, with the standard calcareous planktonic biostratigraphy and the neritic North Sea zonation of KING (1983).

	EPOCH		Blow '79	THIS STUDY	King 1983	
	Quaternary Pliocene		N19–N21	Cassidulina teretis		
5.3	MIOCENE	L		▨	NSP11	
10.5		M	?N6–N11	Globorotalia praescitula – – G. zealandica		
16		E				
23.7	Oligocene	L	?P21–N5	Globigerina ex gr. officinalis		
30		E		Rotaliatina bulimoides		NSB7
36.6	EOCENE	L	P15–P17	Globigerinatheka index	NSP8	
40		M		Reticulophragmium amplectens		NSB5 – – NSB4
52		E	P6b–P8	Subbotina patagonica	NSP5–NSB3	
58	Paleo–cene	L	P5–P6b	Coscinodiscus spp.	NSP4	
			P3–P4	☆	NSP2–NSB1	
62.2		E	P1–P2	Subbotina pseudobulloides	NSP1	
66.4						

☆ Trochammina ruthven murrayi
Reticulophragmium paupera

Reticulophragmium garcilassoi (UE), *Rzehakina minima*, *Spiroplectammina spectabilis* LCO (last common or consistent occurrence), *Reticulophragmium paupera*, *Trochamminoides coronatus*.

The overlap in occurrence of *Trochammina ruthven murrayi*, *Rzehakina minima* and the primitive cyclamminids *R. garcilassoi* and *R. paupera* is typical of the lower Lizards Spring Formation in Trinidad of P1 to P4 age (Kaminski *et al.*, this volume). Primitive cyclamminids are also known from the Late Paleocene-Early Eocene of Australia (Ludbrook 1972) and Tunisia (F.M.Gradstein, unpublished). In the North Sea wells studied, the zone occurs above carbonate-rich sediments of Danian age. In some wells the positions of the events in this zone and in the overlying *Coscinodiscus* Zone are overlapping, which is the reason why the two zones are not clearly separated in the histograms of figure 2. Based on the estimate for the age of the *Coscinodiscus* Zone of Late Selandian (Sparnacian)-Early Ypresian (see below), the *Trochammina ruthven murrayi-Reticulophragmium paupera* Zone is of Selandian age. It probably equates with part or all of King's Zone NSP2 (large radiolaria).

Zone *Coscinodiscus* spp.
Age Late Selandian-Early Ypresian, Late Paleocene-Early Eocene. (Zones P5-P6b).
Taxa *Cystammina* aff. *globigerinaeformis*, *Glomospirella* sp., *Cystammina pauciloculata*, *Coscinodiscus* spp., (large, pillbox-shaped pyritized diatoms), volcanic ash in sediment (tuff) and log markers C and D (ash beds of low sonic velocity).

The ash-series interval (the Sele and the lower part of the Balder Formations) has been assigned to the *Apectodinium hyperacanthum* Zone (Sparnacian), extending upwards into the *Wetzeliella astra-W. meckelfeldensis* Zones (Early Ypresian), (Ioakim 1979; Knox and Morton 1983; Malm *et al.* 1984). The *A. hyperacanthum* Zone straddles the Paleocene/Eocene boundary. At DSDP Sites 401 and 550 on the Rockal Margin, the distal equivalents of the North Sea tuffs have been shown to lie wholly in nannofossil Zone NP10, (Roberts *et al.* 1985), which corresponds to the Early Ypresian.

Zone *Subbotina patagonica*
Age Ypresian, Early Eocene (Zones P6b-P8).
Taxa *Subbotina patagonica*, *Spiroplectammina navarroana*, *Bulimina trigonalis* (UE), *Ammobaculites* aff. *polythalamus*.

This zone is easily identified because of the often reddish-coloured, 3-1/2 chambered globigerinids, referred to by King (1983) as *G.* ex gr. *linaperta* (Zone NSP5), but belonging in *Subbotina patagonica*. Other planktonics (all rare and in one or two wells only) include *Acarinina densa* (well 15/20-2), *A. soldadoensis*, *A. pentacamerata* and *Pseudohastigerina wilcoxensis* (Esso Norway 16/1-1). The zone can also be recognized in the Rosnaes Clay (Ypresian) of Denmark, in the Labrador Sea and in the Ypresian of Belgium (see Gradstein and Agterberg 1982 for review). The end of the *S. patagonica* peak occurs at the boundary of Zones NP11/NP12, which coincides with the upper boundary of the *Morozovella formosa formosa* Zone, at the time of Anomaly 24, slightly older than 55 m.y. (Berggren *et al.* 1985). *Ammobaculites* aff. *polythalamus* in Labrador wells on average disappears in the overlying zone of *Reticulophragmium amplectens* (Gradstein *et al.* 1985). *Textularia plummerae* in King's (1983) Zone NSB3 is our *Spiroplectammina navarroana.*

Zone *Reticulophragmium amplectens*
Age Middle (- Late) Eocene
Taxa *Haplophragmoides kirki*, *Turrilina robertsi* (UE), *Spiroplectammina spectabilis* LO (last occurrence with few specimens in isolated samples), *Karreriella conversa*, Eocene radiolarian flood, *Haplophragmoides walteri*, *H. jarvisi* (UE), *Adercotryma* sp. (UE), *Reticulophragmium amplectens.*

This large assemblage of mainly agglutinated taxa is typical for the massive mudstone sequence below levels with *Globigerinatheka index* and *Rotaliatina bulimoides* (see below), in which agglutinated taxa are less prevalent. *Haplophragmoides* (aff.) *walteri* in some wells disappears in the Oligocene *Rotaliatina bulimoides* Zone.

The immediately overlying zone with *Globigerinatheka index* is probably Late Eocene in age. In Poland the peak occurrence of *R. amplectens* is in (so-called) Middle Eocene strata. In Labrador-Grand Banks wells the average disappearance of *R. amplectens* and the other agglutinated taxa in this zone is well below the tops of *Turborotalia pomeroli* and *Globorotalia cerroazulensis*, Priabonian, (Late Eocene). In the Labrador Sea (ODP Site 647), the acme of *R. amplectens* is in the Middle Eocene. For this reason the *R. amplectens* Zone may be largely Middle Eocene in age, possibly extending into the Late Eocene. The zone is probably correlative to the Zones NSB4 (*Cylammina amplectens*) and NSB5 (*Planulina palmerae*) of King (1983), although NSB4 is referred by King as Early Eocene in age.

Zone *Globigerinatheka index*
Age Late Eocene
Taxa *Globigerinatheka index* (UE), *Karreriella horrida* (includes *K. apicularis*), *Cyclammina rotundidorsata.*

The interval zone is essentially defined by the highest occurrence in some wells of *Globigerinatheka index*. The average disappearance of the associated taxa has an "errorbar" of at least one zone up and one zone down. The *G. index* event falls within Zone NSP8 of King (1983), equated with NP16 and P13 ($\sim P_{12}$ - P_{14}), Middle Eocene. Such interpretation relies heavily on an age of the event in the Danish Søvind Formation of NP16-17, although in the North Atlantic Ocean the taxon extends from P15-P17, Late Eocene. In the southern well 38/16-1 *G. index* occurs with *Cibicidoides truncanus* (King's Zone NSB6a), known from Zone P13 (Middle Eocene) to top Eocene (Van Morkhoven *et al.* 1986).

Zone *Rotaliatina bulimoides*
Age Rupelian, Early Oligocene (Zones P18-P19).
Taxa *Turrilina alsatica* (UE), *Rotaliatina bulimoides*, *Gyroidina soldanii mammilligera*, *Spirosigmoilinella compressus* and *Cyclammina placenta*. In several wells *Heterolepa mexicana* was also found. Coarse agglutinated benthics on average disappear in this zone, except in the southern wells (blocks 21-30), where the disappearance is one or two zones higher, reflecting younger shallowing upwards. *Spirosigmoilinella compressus* was recorded by Gradstein and Berggren (1981) as "*Rzehakina*" sp. 1. In Labrador-Grand Banks wells *Turrilina alsatica* is more common than *Rotaliatina bulimoides* in beds of the same age. The *R. bulimoides* Zone corresponds to NSB7 (King 1983) of the same name and age.

Zone *Globigerina* ex gr. *officinalis*
Age Late Oligocene-Early Miocene (Zones ? P21-N5)

In several (particularly southern) North Sea wells this interval contains common to abundant small, nondescript globigerinids. This includes the nominate species, *G. angustiumbilicata*, *G. opima nana* and rarely *G. ciperoensis*. Sampling resolution is low in this interval, and Miocene cavings and (?) reworked Eocene-Oligocene taxa hamper recognition of this interval zone, which needs further study.

Zone *Globorotalia praescitula-G. zealandica*
Age Early-Middle Miocene (Zones ?N6-N11)
Taxa *Asterigerina gurichi*, Neogene radiolarian flood (UE), *Globorotalia praescitula* and *G. zealandica*, *Globigerina praebulloides*, *Caucasina elongata and Martinotiella cylindrica*.

In some wells, particularly around the Ekofisk area, (blocks 22-30), agglutinated foraminifera like *Cribrostomoides*, *Glomospira*, *Bathysiphon*, *Hyperammina*, *Trochammina*, *Reophax* and *Cyclammina* extend into this zone, associated with common planktonics. The latter also include *Globigerinoides* spp., *G. trilobus*, *Globoquadrina dehiscens* and *G.* aff. *baroemoensis*, *Globorotalia praemenardii*, *Sphaeroidinella seminulina* and the *Neogloboquadrina continuosa-pachyderma-acostaensis* group. Among the benthics rare *Uvigerina* ex gr. *basicordata* and *U. semiornata kusteri* occur.

Zone *Cassidulina teretis*
Age Middle Pliocene-Pleistocene (Zones N19-N21)
Taxa *Cibicidoides scaldisensis*, *Elphidium* spp. and *Cassidulina teretis*.

In the 16/1-1 well by Esso Norway these benthics co-occur between 1285 and 2300' with the planktonics *Globorotalia crassaformis*, *G. puncticulata*, *G. inflata*, *Orbulina universa* and *Neogloboquadrina atlantica-pachyderma* of Middle Pliocene (late N19-early N21) age. The same zone with similar (rare) planktonics occurs along the Labrador and Grand Banks (Gradstein and Agterberg 1982).

RANGE CHART OF AGGLUTINATED BENTHIC FORAMINIFERA

Approximately 30 taxa of agglutinated benthic foraminifera have distinct stratigraphic ranges in the central North Sea wells studied. The majority of taxa has been referred to in the text discussing the ten-fold zonation. Remarks were added on stratigraphic occurrences in other geological basins. A comprehensive summary for the stratigraphic ranges of the agglutinated benthic taxa is in the range chart of figure 2. The ten-fold interval zonation, which is directly based on the scaled optimum sequence shown to the left of the chart, has been tied to the geochronologic scale on the right using ages of selected events. These ages are estimates using the correlative evidence presented in the text and are based on last occurrence datums:

Cibicidoides scaldisensis	2 Ma
Globigerina praebulloides	15
Globorotalia praescitula	17
Rotaliatina bulimoides	31

Globigerinatheka index	38
Reticulophragmium amplectens	40
Turrilina robertsi	49
Subbotina patagonica	55
Log marker D	58
Log marker C	59
Subbotina pseudobulloides	63

The stratigraphic range of most agglutinated taxa in figure 2 is divided in two or three parts. A solid line shows the average range based on the ranking and scaling results. The dashed line indicates the maximum or total range based on observations in individual wells. Due to the nature of the majority of samples (cuttings) the lower half of ranges is less reliable. The total range of *Haplophragmoides walteri* probably extends beyond Paleocene-Eocene, but this awaits further taxonomic study. With minor modifications this range chart may also be utilized for regional correlations in Labrador and Newfoundland offshore basins. The most important differences are that in the western Atlantic continental margin basins *Arenobulimina* does not extend in the Tertiary, *Rzehakina epigona* replaces *R. minima*, *Trochammina ruthven murrayi* is absent and *Cystammina pauciloculata*, *Ammobaculites* aff. *polythalamus* and *Haplophragmoides kirki* range up in the *Reticulophragmium amplectens* Zone, Middle-?Late Eocene.

STRATIGRAPHIC POSITION OF LOG MARKERS A-G

Through the courtesy of Drs. A.C. Morton and R. Knox (B.G.S., Keyworth, U.K.) we received depth picks for their log markers A-G in the wells studied. These log markers are thought to be chronostratigraphic in nature and according to Morton and Knox (personal communication, 1984) correspond to the following approximate levels:

Marker G - top Middle Miocene
Marker F - top Upper Eocene
Marker E - top Early Eocene
Marker D - top Sele Formation (or equivalent)
Marker C - base Sele Formation (top Paleocene)
Marker B - top Ekofisk Formation (top Early Paleocene)
Marker A - top Cretaceous

We expected the log picks to vary slightly in stratigraphic position relative to the foraminiferal events in the wells and treated the log picks as "fossil events" in the RASC calculations. Figure 2 shows the average stratigraphic position of all events. There is good agreement between the ages assigned by Knox and Morton to the log picks and the ages assigned by us to the accompanying zones.

Log marker A is always found at the level with *Globotruncana* below the Danian zone (not shown in figure 2). Log marker B on average is in the Danian, rather than at the top as suggested. Log markers C and D are in the *Coscinodiscus* Zone that delineates the ash-series,that straddles the Paleocene-Eocene boundary.

The top of log marker E is given as top of Early Eocene in agreement with its average occurrence slightly above the *Subbotina patagonica* Zone, Ypresian. The only serious exception to this average position was found to be in well 23/22-1 where E occurs with Danian planktonics. The latter may be reworked.

Log marker F occurs in the *Globigerinatheka index* interval, Late Eocene. Log marker G fits well at the top of the *Globorotalia praescitula-G.zealandica* Zone,Early-Middle Miocene. An interesting observation is that the markers F and G are associated in figure 2 with breaks in the scaled optimum sequence. These breaks are recognized by large interfossil distances between two events in adjacent zones. The large distance means that there is little or no cross-over in position between the events in the two zones. Such a situation is expected where there is stratigraphic section missing between the zones or a sudden change in facies (may also be due to a hiatus). The latter is the case between the Danian and Selandian zones, where carbonates are replaced by mudstones and sands.

As mentioned earlier, in computer runs without unique events such as *Globigerinatheka index*, log marker F falls exactly at the large interfossil distance between the *Rotaliatina bulimoides* Zone and the underlying *Reticulophragmium amplectens* Zone. Log marker F marks the Eocene-Oligocene boundary in the zonation and the large interfossil distance associated with it suggests a hiatus involving the uppermost Eocene to Early Oligocene. In runs including unique events, the *Globigerinatheka index*-log marker F events are sandwiched between the *R. bulimoides* and *R. amplectens* Zones, indicating that these events are closely tied to the position of a hiatus in many (?) of the wells. These observations require more detailed study.

Log marker G reflects a Late Miocene hiatus in the wells in the central North Sea grabens. Few of the wells studied show unequivocal fossil evidence for a Late Miocene interval (based on rare planktonic foraminifera including *Neogloboquadrina atlantica*,left coiling + *N. acostaensis*).

Another break in the record is suggested at the base of the *Globorotalia praescitula-G. zealandica* Zone, Oligocene-Miocene boundary. A more detailed analysis of the nature of the breaks and the reasons for it is beyond the scope of this communication.

DIACHRONOUS EVENTS, SPIROPLECTAMMINA SPECTABILIS LO AND LCO

One of the features of the RASC method is the ability to test each individual well sequence for stratigraphic normality (Gradstein *et al.* 1985). The test detects which taxa in the individual wells are outliers, relative to the scaled optimum sequence. For example, the last occurrence of *S. spectabilis* (LO) and its last common or consistent occurrence (LCO), which were treated as separate taxa in the calculations, were found to be out of stratigraphic position 5 and 7 times respectively, with a probability exceeding 95%. Further analysis showed that in the southern wells (blocks 23-30), *S. spectabilis* LO is restricted to the Paleocene (below the ash-series); in the block 16 wells it is found one or two stages younger at the top of the *Subbotina patagonica* Zone and the base of the *Reticulophragmium amplectens* Zone. In the blocks 9 and 3 wells it is at the top of the *R. amplectens* Zone. This means that the last occurrence of *Spiroplectammina spectabilis* migrates upwards in time from Late Paleocene in the southern wells to Late Eocene in the northern North Sea wells.

The (average) last common occurrence (LCO) of this form is always below the ash-series in the *Reticulophragmium paupera-Trochammina ruthven murrayi* Zone. This acme apparently extended onto the shelf facies of Western Europe. It is shown by Doppert (1980) in the Paleocene of the Netherlands, extending slightly into the Early Eocene.

Along the Canadian Atlantic margin *Spiroplectammina spectabilis* in general does not occur above the *Acarinina densa* Zone, Early Middle Eocene, although in ODP Site 647, central Labrador Sea it is found as high as NP21. In this oceanic site, it is found as high as core 29, 20 m above the assigned Eocene-Oligocene boundary.

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