Eocene microfaunas of the Harre borehole (north Jylland, Denmark)

CHRIS KING

King, C., 1994: Eocene microfaunas of the Harre borehole (north Jylland, Denmark). *Aarhus Geoscience*, Vol. 1, pp. 73-80, Aarhus, 1994.

ABSTRACT

Three successive microfaunal assemblage are recognised in the Røsnæs Clay Formation and Lillebælt Clay Formation of the Harre borehole. The lower part of the Røsnæs Clay Formation contains a microfauna comprising abundant planktonic and benthonic foraminiferids, with rare ostracods, which correlates with microfaunas recorded at outcrop in Bed R3 of the Røsnæs Clay Formation. The upper part of the Røsnæs Clay Formation contains a sparse microfauna of non-calcareous agglutinating foraminiferids similar to those from Bed R4 at outcrop.

The microfaunas indicate the presence of an unconformity between the Røsnæs Clay Formation and the Lillebælt Clay Formation. Beds R5, R6 and L1 - L3 are unrepresented. The Lillebælt Clay Formation contains an assemblage of non-calcareous agglutinating foraminiferids and radiolaria, which probably indicates correlation with Bed L4 of the Lillebælt Clay Formation as seen at outcrop. This unit is overlain unconformably by the (Oligocene) Viborg Formation.

The microfaunas indicate that the lower part of the Røsnæs Clay Formation was deposited in a well-oxygenated bathyal environment open to oceanic circulation with a very reduced clastic sediment supply; the upper part of the Røsnæs Clay Formation and the Lillebælt Clay Formation were deposited in a bathyal environment with restricted circulation at the sea floor.

C. King, Paleoservices Ltd. Unit 15, Paramount Industrial Estate, Sandown Road, Watford, WD2 4XA, England.

INTRODUCTION

Nineteen samples from the Røsnæs Clay Formation and Lillebælt Clay Formation in the Harre borehole (Fig. 1 in the introductory chapter), from depths between 177.65 m.b.s. (meters below surface) and 190.65 m.b.s., were provided by Ole Bjørslev Nielsen (for sample positions see Fig. 1). The lithostratigraphy of these units is described by Nielsen (1994, this volume).

Several samples from the underlying Ølst and Fur Formations were also examined, but these proved to contain no foraminiferids or ostracods, and are not further discussed here.

The samples studied weighed between 30 - 100 grams (dry weight); they were oven-dried at about 80^{0} C and then soaked in hot water for an hour to induce disaggregation. The samples were then washed on a 120 micron sieve, to separate the microfossils from the clay fraction. If a clean residue did not result from this first sieving, the residue was soaked in a 10% solution of "Calgon" (sodium hexametaphosphate) for one hour and sieved again. This technique produced completely clean residues in all cases.

The microfauna recovered from the samples is tabulated on Fig. 1 and Table 1.

MICROFAUNA

1. Røsnæs Clay Formation.

190.65 m.b.s.. This sample contains abundant glauconite, but no microfauna.

190.25 m.b.s. - 189.25 m.b.s.. These samples contain a very abundant microfauna: at least 2×10^{4} foraminiferids per 100 grams of sediment. The microfauna is dominated by planktonic foraminiferids, which comprise c. 95% of the total foraminiferid assemblage.

The planktonic foraminiferids, although abundant, are of low diversity. The only genera identified are *Subbotina* (including *Dentoglobigerina*?) and rare *Acarinina*. *Subbotina* comprises over 99% of the planktonic foraminiferids; the specimens exhibit considerable morphological variation, but can all be assigned to the "*Globigerina linaperta* group" of Stainforth *et al.* (1975). The variation within this species-group in the Røsnæs Clay Formation is extensively illustrated by Berggren (1960), under the name of *G. yeguaensis*. They have been subsequently identified as *G. patagonica* (Berggren, 1969), or alternatively as *G.* ex gr. *triloculinoides* and *G.* ex gr. *bulloides* (Dinesen, 1972). Blow (1979) has re-determined Berggren's figured specimens mainly as *Subbotina hornibrooki*, *S. triangularis*, *Dentoglobigerina?* sp. 1, and transitio-

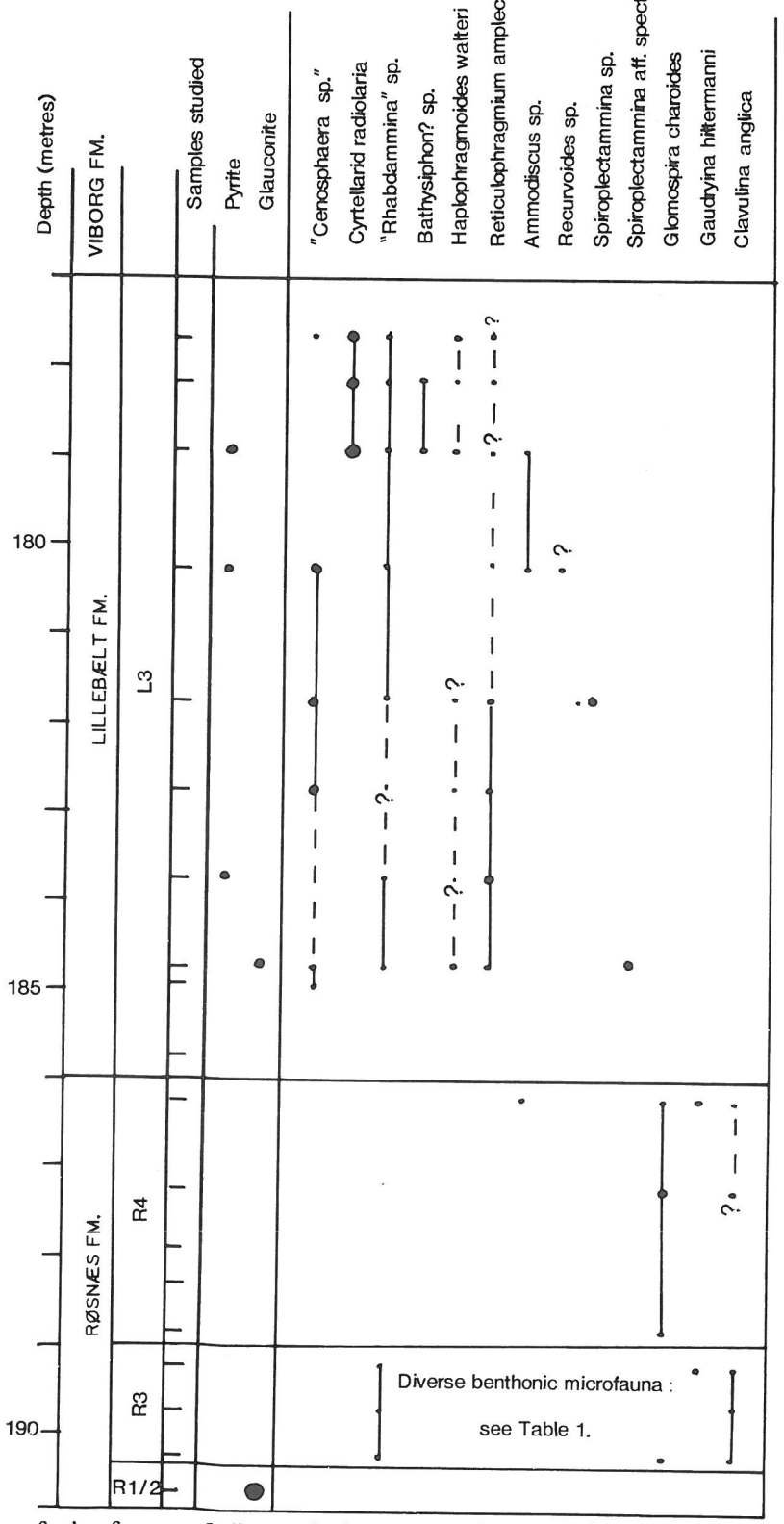

Fig. 1. Distribution of microfauna and diatoms in the Røsnæs Clay Formation and Lillebælt Clay Formation of the Harre borehole (see also Table 1).

nal forms between these 'species'. *Acarinina* is represented by small specimens, difficult to identify specifically, but including *A.* cf. *mckannai*.

Benthonic foraminiferids constitute less than 5% of the fauna, but their diversity is high. Over fifty species have been identified (Table 1). Calcareous taxa (rotaliids and nodosariids) are dominant; the most common taxa are *Anomalinoides nobilis, Cibicides* gr. *ungerianus, C. westi, Cibicidoides* gr. *eocaenus, Gavelinella* aff. *danica* ("*Anomalina grosserugosa*"), *Dentalina* spp., *Lenticulina* spp., *Oridorsalis* gr. *umbonatus, Pulsiphonina prima, Vaginulinopsis* gr. *decorata* and *Vulvulina flabelliformis*. Agglutinating foraminiferids include frequent *Clavulina anglica, Dorothia* sp. and (at 189.25 m.b.s.) *Gaudryina hiltermanni*. The 'non-calcareous' agglutinants *Bathysiphon* sp. and *'Rhabdammina'* sp. occur rarely.

There does not appear to be any significant difference between the microfauna of the three samples studied from this interval. Detailed taxonomic analysis is not included here, as this assemblage will be discussed in more detail (together with foraminiferids from the Røsnæs Clay Formation at other localities) in a forthcoming publication.

Ostracods occur in all three samples, but are relatively rare (less than one specimen per 500 foraminiferids). The commonest species is identified as *Oertliella? bowerbankiana. O.? [Trachyleberis] bowerbankiana* is common in the middle London Clay Formation in the eastern London Basin, but has not previously been recorded from Denmark. *Brachycythere triangulare, Cytherella londinensis, Krithe londinensis, Trachyleberidea prestwichiana* and *Cardobairdia* sp. are also recorded.

188.85 m.b.s. - 186.25 m.b.s..

These samples contain common fish debris (teleost scales and bones, and occasional shark teeth), and a sparse and generally poorly preserved microfauna of agglutinating foraminiferids. The foraminiferids include *Ammodiscus* sp., *Bathysiphon* sp., *Clavulina anglica, Gaudryina hiltermanni* (only at 186.25 m.b.s.), and *Glomospira charoides.*

2. Lillebælt Clay Formation.

184.95 m.b.s. - 177.65 m.b.s.

These samples contain relatively rare and poorly preserved agglutinating foraminiferids, associated with poorly preserved ?glauconitised, pyritised and siliceous radiolaria. No calcareous benthonic or planktonic foraminiferids are recorded.

The agglutinating foraminiferids are partly crushed and distorted, generally small, and difficult to identify, but about eight genera can be recognised, including *Ammodiscus, Bathysiphon, Haplophragmoides, Reticulophragmium, 'Rhabdammina'* and *Spiroplectammina. Reticulophragmium [Cyclammina] amplectens* can be definitely identified in samples between 181.75 m.b.s. and 184.75 m.b.s., and possible (but very poorly preserved) examples of this species occur also at higher levels. Specimens tentatively identified as *Haplophragmoides walteri* are also present, and *Spiroplectammina* aff. *spectabilis* (of King, 1983) occurs at 184.75 m.b.s., but other specimens are not readily identifiable at the species level.

Two types of radiolaria occur:

(1) spherical reticulate forms (similar to *Cenosphaera* sp. of King, 1983). These are common (as ?glauconitised specimens) in the lowest part of the Lillebælt Clay Formation (at 184.75 m.b.s. and 184.95 m.b.s.). Pyritised or siliceous specimens occur between 180.25 m.b.s. and 182.25 m.b.s.; and siliceous specimens occur rarely at higher levels.

(2) "bell-shaped" forms; these are probably cyrtellarid radiolarians, similar to the form figured by Hughes (1981, Plate 15.3, figure 13) as a nassellinide radiolarian from the Middle Eocene of the southern North Sea. They occur commonly as glauconitised? specimens, in the upper part of the Lillebælt Clay Formation (177.65 m.b.s. - 178.75 m.b.s.).

CORRELATION

1. General comments

The microfaunal assemblages in the Harre borehole can be correlated with microfaunas recorded in other boreholes and surface sections in northern and central Jylland and northwest Sjælland.

Descriptions of Eocene microfaunas from Denmark are given by Berggren (1960, 1969) and Dinesen (1972), but no comprehensive study has yet been published. The discussion here is based on an extensive series of samples from the Røsnæs Clay Formation and Lillebælt Clay Formation, collected by Claus Heilmann-Clausen, Ole Bjørslev Nielsen and the author. Localities investigated include Fur, Hinge, Ølst, Ørby, Albækhoved (Vejle Fjord) and Ulstrup (Røsnæs).

It is intended to describe the microfaunal assemblages recovered from these samples in the near future. They have demonstrated that the individual Beds of the Røsnæs Clay Formation and the Lillebælt Clay Formation, recently defined by Heilmann-Clausen *et al.* (1985) each have distinctive microfaunas, and that these are persistent laterally throughout the area studied.

2. Røsnæs Clay Formation

190.65 m.b.s.

This can probably be correlated with the basal Røsnæs Clay Formation (Beds R1 or R2 of Heilmann-Clausen *et al.*, 1985). At Ølst and Hinge, these units contain abundant glauconite, and a very sparse microfauna.

190.25 m.b.s. - 189.25 m.b.s.

The microfauna from this interval indicates correlation with Bed R3 of the Røsnæs Clay Formation. Diagnostic features include the dominance of *Subbotina* gr. *linaperta* among the planktonics; the absence of *Globorotalia pseudoscitula* and *Pseudohastigerina wilcoxensis* ; the presence of *Cibicides westi*; and the absence of *Bulimina* sp. A (King, 1989) and *Cancris* sp. A (King, 1989), which are common in Beds R4 to R6.

188.85 m.b.s. -186.25 m.b.s.

The agglutinating foraminiferid association in these samples indicates correlation with the lower part of Bed R4.

The nearest surface exposures of the Røsnæs Clay Formation are at Knuden (Island of Fur). Calcareous microfossils have been obtained here only from the unit described by Friis, Nielsen and Heilmann-Clausen (1981) as "brownish-orange calcareous clay". The microfauna from Knuden includes many of the benthonic foraminiferids occurring at Harre in the interval 190.25 m.b.s. - 189.25 m.b.s., but planktonic foraminiferids are virtually absent. It can be correlated with the upper part of Bed R5, which is absent in the Harre section. Minor internal discontinuities are common in the Røsnæs Clay Formation, and each section examined differs in detail.

3. Lillebælt Clay Formation.

The association of agglutinating foraminiferids and radiolaria in this unit probably indicates correlation with Bed L4 of the Lillebælt Clay Formation. *Spiroplectammina* aff. *spectabilis*, which is recorded only in the lowest part of the Lillebælt Clay Formation at Harre, ranges in other sampled sections from Bed L2 into the basal metre of Bed L4. The radiolaria have been recorded elsewhere only from Bed L4, although their distribution is affected by post-mortem dissolution.

4. Conclusions

The microfaunas indicate that the Røsnæs Clay Formation at Harre is represented only by Bed R1/R2, R3 and the lower part of R4. There is a hiatus between the Røsnæs Clay Formation and the Lillebælt Clay Formation; strata from the middle of Bed R4 to Bed L3 (inclusive) are apparently absent. The Lillebælt Clay Formation is represented only by Bed L4, which is overlain unconformably by the (Oligocene) Viborg Formation.

Correlation between these sequences and the microfaunal succession in the North Sea is discussed in another paper in this volume (King, 1993).

DEPOSITIONAL ENVIRONMENTS

1. Røsnæs Clay Formation

Bed R3

The very high abundance of planktonic foraminiferids indicates a high productivity and/or slow rate of sedimentation. The very high planktonic/benthonic ratio would be normally regarded as suggesting depths of > 200 metres (see Murray, 1979), although direct corre-

lation between depth of deposition and abundance of planktonic foraminifera is hazardous; a very low rate of sedimentation is one factor which can produce high P/B ratios in relatively shallow (but still bathyal) areas.

The benthonic foraminiferids can be compared with the Eocene assemblages described from the North Atlantic by Berggren (1975), Berggren and Aubert (1976) and Murray (1979). Characteristic "shelf" species such as *Anomalinoides [Cibicidina]* gr. *gunobelini* and *Cibicidoides proprius* (? = *C. alleni*), which occur abundantly in most Early Eocene sediments in southern England and Belgium, are absent. The species *Gaudryina hiltermanni, Gavelinella* aff. *danica ('Anomalina grosserugosa'),* and *Vaginulinopsis [Marginulina]* gr. *decorata*, which characterise the "outer shelf - upper slope" fauna of Berggren (1975) (c.200m depth) occur commonly in this unit. However, *Stilostomella, Buliminella, Aragonia* and *Pleurostomella*, which also occur at Harre in this unit, are characteristic elements of the deeper-water Eocene microfaunas recorded from Orphan Knoll (Berggren and Aubert, 1976), which are considered to indicate deposition in lower and middle bathyal environments (c. 1000m and deeper). Thus, based on the criteria used by Berggren and Aubert, a depth intermediate between c. 200m and c. 1,000m is probable.

The ostracod fauna is similar in composition to the faunas recorded from the Eocene and Late Paleocene of the Rockall Plateau (Benson, 1971; Ducasse and Peypouquet, 1980). These faunas are regarded by Benson as indicating middle to lower bathyal depths (500 metres).

In conclusion, the evidence from planktonic and benthonic foraminiferids and ostracods all indicates a bathyal environment (> 200 metres). The evidence is predominantly in favour of a middle bathyal environment (c. 500 metres). The diversity of the benthonic microfauna, and the rarity of non-calcareous agglutinating taxa, indicates a well-oxygenated sea floor, while the abundance of planktonics suggests a reduced clastic supply and the influence of open oceanic circulation.

Bed R4

The limited fauna of agglutinating foraminiferids in this unit does not permit any satisfactory estimate of depth, but an upper bathyal environment seems most probable. The absence of calcareous benthonic foraminiferids suggests a restricted (oxygen-poor) environment.

2. Lillebælt Clay Formation

The foraminiferal fauna of the Lillebælt Clay Formation consists exclusively of non-calcareous agglutinating taxa. The assemblage conforms to the "flysch-type" agglutinating fauna of Gradstein and Berggren (1981) in the following respects:

(1) Exclusively agglutinating taxa - no calcareous benthonic or planktonic taxa.

(2) Low numbers of individuals, and moderate taxonomic diversity.

(3) Predominantly single chambered and uniserial genera (*'Rhabdammina', Bathysiphon, Ammodiscus*), with less frequent multi-chambered forms (*Haplophragmoides, Reticulophragmium*).

Gradstein and Berggren conclude that the "flysch-type fauna" is characteristic of bathyal and abyssal environments in which bottom-water circulation is restricted, leading to low oxygen and high CO_2 levels, which inhibit calcification of living foraminiferids and prevent fossilisation of calcareous tests. Accurate estimates of depth are very difficult. Such faunas are present intermittently in the centre of the North Sea Basin from Late Paleocene to Late Miocene (the "*Rhabdammina*-biofacies" of King, 1983), and their presence may reflect the periodic development of stagnant oxygen-poor "pools" in the centre of the Basin. The "*Rhabdammina*-biofacies" is particularly widespread in the North Sea Basin in the late Early Eocene and Middle Eocene, in beds equivalent in age to the Lillebælt Clay Formation.

ACKNOWLEDGEMENTS

The author wishes to thank Ole Bjørslev Nielsen for supplying samples from the Harre borehole, for information on the lithostratigraphy, and for the opportunity to carry out this study. Ole Bjørslev Nielsen and Claus Heilmann-Clausen are thanked for their assistance in sampling Eocene sections, and for their hospitality during the author's visits to Denmark.
Facilities for processing the samples and typing the

manuscript were provided by Paleoservices Ltd.

DANSK SAMMENDRAG

Den Eocæne lagserie i Harreboringen er ikke komplet. I Ølst/Fur Formationerne findes ingen kalkholdige mikrofossiler, men, baseret på askestratigrafien, ser der ud til at mangle de øverste dele af disse formationer. Kun enkelte enheder fra Røsnæs- og Lillebælt Ler Formationerne er tilstede. Der er konstateret tre forskellige mikrofauna selskaber i disse to formationer. Det nederste faunaselskab er karakteriseret af både planktoniske og benthoniske foraminiferer samt ostracoder, og det ligner meget et selskab, der fundet i enheden R3. Herover findes et selskab bestående af ikke-kalkskallede agglutinerende foraminiferer, der ligner det selskab, der er tilstede i enheden R4. Øverst findes endeligt et selskab bestående af ikke-kalkskallede agglutinerende foraminiferer og radiolarer, der korrelerer med det der findes i enheden L4. Der findes stratigrafiske gab mellem Ølst og Røsnæs Ler Formationerne, mellem Røsnæs og Lillebælt Ler Formationerne samt mellem sidstnævnte og den Oligocæne Viborg Formation. Søvind Mergel er helt fraværende i boringen.

Aflejringsmiljøet under aflejring af den enhed, der repræsenterer det ældste faunaselskab (R3), har formentlig været bathyalt. Det høje forhold mellem planktoniske og benthoniske foraminiferer (P/B) tyder på en vanddybde på over 200 m, men en meget lav aflejringsrate, som formentlig har været der i den pågældende periode, vil også kunne resultere i et højt P/B forhold under lave bathyale forhold. Den benthoniske artssammensætning er karakteristisk for vanddybder mellem 200 og 1000 m, medens ostracoderne tyder på en vanddybde på ca. 500 m. Miljøet under aflejringen af enheden R4 er sværere at vurdere, men det har formentlig været lidt mindre dybt (øvre bathyalt) og med begrænset iltforsyning til bundvandmasserne. Foraminiferselskabet i Lillebæltleret, L4, er af såkaldt "flysch-type", og findes på bathyale og abyssale dybder, hvor der er et lavt iltindhold, men til gengæld et højt CO_2-indhold. Disse forhold er formentlig opstået som følge af en begrænset vandcirkulation, og bevirker, at kalkskallede planktoniske organismer ikke bevares i sedimenterne. Forhold som disse er tidligere beskrevet i blandt andet den centrale del af det tidlig til mellemste Eocæne Nordsøbassin.

REFERENCES

Benson, R.H., 1971: Preliminary Report on the Ostracods of Holes 117 and 117A. *In*: Laugthon, A.S., Berggren, W.A. *et al. (eds.)* Initial Rep. Deep Sea drill. Proj., 12, pp. 427-432.

Berggren, W.A., 1960: Some planktonic Foraminifera from the Lower Eocene (Ypresian) of Denmark and Northwestern Germany. *Stockholm Contr. Geol.*, 5 (3). pp. 41-108, 13 pl.

Berggren, W.A., 1969: Paleogene biostratigraphy and planktonic foraminifera of North Europe. *Proceedings First International Conference on Planktonic Microfossils*, Geneva 1967. 1, pp. 121-160.

Berggren, W.A., 1975: Late Paleocene - Early Eocene benthonic foraminiferal biostratigraphy and paleoecology of Rockall Bank. *Micropaleontology*, 20, pp. 426-448, 6 pl.

Berggren, W.A. and Aubert, J., 1976: Eocene benthonic foraminiferal biostratigraphy and paleobathymetry of Orphan Knoll (Labrador Sea). *Micropaleontology*, 22, pp. 327-346, 4 pl.

Blow, W.H., 1979: The Cainozoic Globigerinida, 3 vols. 1413 pp. E.J. Brill. Leiden.

Dinesen, A., 1972: Foraminiferselskaber fra de jyske eocæne formationer. *Dansk geol. Foren.* Årsskrift 1971, pp. 70-78.

Ducasse, O. and Peypouquet, J.P., 1979: Cenozoic ostracods: their importance for bathymetry, hydrology and biogeography. *In:* Montadert, L. & Roberts, D.G. *(eds.)* Initial Rep. Deep Sea drill. Proj., 48. pp. 343-363.

Friis, H. and Nielsen, O.B., 1979: Guide to Excursions. 7th and 8th of October 1979. *International* Geological Correlation Programme Project 124. *53 pp., Aarhus University (unpublished report).*

Friis, H., Nielsen, O.B. and Heilmann-Clausen, C., 1981: Guide to Excursion 14th May 1981. *International Geological Correlation Project 124* 71 pp. Aarhus University (unpublished report).

Gradstein, F.M. and Berggren, W.A., 1981: "Flysch-Type" agglutinated foraminifera and the Maastrichtian to Paleogene history of the Labrador and North Seas. *Mar. Micropaleontol.*, 6, pp. 211-268.

Heilmann-Clausen, C., Nielsen, O.B. and Gersner, F., 1985: Lithostratigraphy and depositional environments in the Upper Paleocene and Eocene of Denmark. *Bull. geol. Soc. Denmark*, 33, pp. 287-323.

Hughes, M.J., 1981: Contribution on the Oligocene and Eocene microfaunas of the southern North Sea.

In: J.W. Neale and M.D. Brasier, *(eds.)* Microfossils from Recent and Fossil Shelf Seas, pp. 186-204, 4 pl.

King, C., 1983: Cainozoic micropalaeontological biostratigraphy of the North Sea. *Rep. Inst. Geol. Sci.* No. 82/7, 40 pp., 6 pl.

King, C., 1989: Cenozoic of the North Sea. *In*: Jenkins, D.G. and Murray, J.W., *(eds.) Stratigraphical Atlas of Fossil Foraminifera*, pp. 418-489. (Second edition). Ellis Horwood, Chichester.

King, C., 1994, this volume: Biostratigraphic correlation of Late Paleocene to Oligocene sequences in the Harre borehole (north Jylland, Denmark) with those in the North Sea. *Aarhus Geoscience*, Vol. 1, pp. 85-92.

Murray, J., 1979: Cenozoic biostratigraphy and paleoecology of sites 403 to 406 based on the foraminifera. *In*: Montadert, L. & Roberts, D.G. *(eds.) Initial Rep. Deep Sea Drill. Proj*., 48, pp. 415-430.

Nielsen, O.B., 1994, this volume: Lithostratigraphy and sedimentary petrography of the Paleocene and Eocene sediments from the Harre borehole, Denmark. *Aarhus Geoscience*, Vol. 1, pp. 15-34.

Stainforth, R.M., Lamb, J.L, Luterbacher, H., Beard, J.H. and Jeffords, R.M., 1975: Cenozoic planktonic foraminiferal zonation and characteristics of index forms. *Univ. Kansas Paleontol. Contrib.* Article 62. 425 pp.

Table 1: Distribution of foraminiferids from samples between 189.25 m.b.s. and 190.25 m.b.s. in the Røsnæs Clay Formation of the Harre borehole. X: present XX: common. About 15 additional unidentified species have been recorded.

	189.25	189.75	190.25
PLANKTONIC TAXA			
Acarinina spp.	x	x	x
Subbotina gr. linaperta	xx	xx	xx
BENTHONIC TAXA			
Ammodiscus cretaceus			x
Angulogerina abbreviata	x	x	x
Angulogerina wilcoxensis	x		
Anomalinoides nobilis	x	x	x
Aragonia aragonensis		x	x
Bathysiphon sp.			x
Bulimina cf. callahani	x		
Buliminella sp.	x		
Cibicides westi	x	x	x
Cibicides gr. ungerianus	xx	xx	xx
Cibicidoides eocaenus	xx	xx	xx
Clavulina anglica	x	x	x
Dentalina spp.	x	x	x
Dorothia sp.	x	x	
Gaudryina hiltermanni	x		
Gavelinella aff. danica	x	x	xx
Globocassidulina cf. globosa	x	x	
Glomospira charoides			x
Gyroidinoides danvillensis	x	x	
Lagena laevis			x
Lenticulina spp.	x	x	x
Nodosaria spp.	x	x	x
Oridorsalis gr. umbonatus	x	x	x
Osangularia expansa		x	
Pleurostomella sp.		x	
Pullenia quinqueloba	x	x	x
Pulsiphonina prima	xx	xx	x
Reussella limbata	x		
'Rhabdammina' sp.			x
Siphonina sp.		x	
Stilostomella sp.	x	x	x
Turrilina brevispira	x	x	x
Vaginulinopsis gr. decorata	x	x	x
Vulvulina flabelliformis	x	x	x