

# Biostratigraphic correlation of Late Paleocene to Oligocene sequences in the Harre borehole (north Jylland, Denmark) with those in the North Sea.

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King, C., 1994: 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, Aarhus, 1994.

## ABSTRACT

The Late Paleocene to Late Oligocene microfaunas in the Harre borehole are correlated with the microfossil zones recently proposed for the North Sea by King (1983, 1989). The Vejle Fjord Formation correlates to the upper part of Zone NSB 8, probably entirely within Subzone NSB 8c. Subzone NSB 8b is not identified, probably indicating a discontinuity between the Vejle Fjord Formation and the Branden Formation. The Branden Formation is referred to NSB 8a and NSP 9c, and there is probably a hiatus between this formation and the underlying Viborg Formation. The lower part of the Viborg Formation is referred to Subzone NSB 7a while the upper part tentatively is referred to Subzone NSB 7b. The Lillebælt Clay Formation is referred to Zones NSA 4 and NSP 6. A significant stratigraphic gap is present between the Lillebælt Clay and the Viborg Formations. The Røsnæs Clay Formation is also incomplete, and is referred to Zone NSB 3a and NSP 5a. The Ølst and Fur Formations contained no foraminifers, but are tentatively correlated to the Balder and Sele Formations of the North Sea. The Holmehus Formation is correlated to the Lista Formation and is referred to Zone NSA 1. The grey slightly to non-calcareous clay is referred to Zone NSP 2, to which zone also the Kerteminde Marl is referred. This indicates a hiatus between the Danian limestone and the Kerteminde Marl. The upper part of the grey slightly to non-calcareous clay might correlate to the basal part of the Lista Formation of the North Sea, while the remaining part of the unit and the underlying Kerteminde Marl is correlated to the Maureen Formation/North Sea Marl.

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## INTRODUCTION

As analysis of the vertical ranges of microfossils in the Cenozoic sequences of over two hundred offshore North Sea wells has led to the recent proposal of three parallel zonal schemes for the sequence from Paleocene to Early Pleistocene (King, 1983, 1989). These zones are based on planktonic organisms (including planktonic foraminiferids, diatoms, and radiolaria), calcareous benthonic foraminiferids, and non-calcareous agglutinating foraminiferids. The planktonic zones are prefixed "NSP", the calcareous benthonic zones "NSB", and the agglutinant zones "NSA" (Fig. 1).

The Cenozoic sediments in Denmark form part of the North Sea Basin, and equivalents of many of the North Sea zones have already been recognised in Denmark (King, 1983, 1989). The completely cored sequence in the Harre borehole (Fig. 1 in the introductory chapter) has enabled a detailed study of the Late Paleocene to Late Oligocene interval, and provides data enabling more precise correlations to be made with the North Sea sequence, although the Eocene sequence at Harre is too incomplete to provide additional information.

The results presented here are based on the study by

the author of about sixty samples from the Harre borehole, provided by Ole Bjørnslev Nielsen, and also incorporate data from other papers in this volume (King, 1994a, b, this volume), which deal with the microfauna of the Late Paleocene and Eocene. Details of the lithostratigraphy are given by Friis (1994, this volume) and Nielsen (1994, this volume). The microfaunas are here summarised in 'downhole' order, as most of the zones are defined by 'tops' (highest occurrences of taxa), or downsection assemblage changes.

## THE LITHOSTRATIGRAPHIC UNITS

### Vejle Fjord Formation (9.75 m.b.s. - 67.5 m.b.s.)

Samples examined from the upper part of the Vejle Fjord Formation (between 9.75 meter below surface (m.b.s.) and 23.75 m.b.s.) proved to be unfossiliferous, probably due to superficial leaching (decalcification). The highest fossiliferous sample studied, at 23.75 - 24.0 m.b.s., contains a microfauna including the foraminiferids *Pararotalia canui* and *Valvulineria mexicana gramensis*. *P. canui* ranges through Zones NSB 7 and NSB 8 in the North Sea (Early and Late Oligocene), but is most common in Zone NSB 8 (Late Oligocene); *V. m. gramensis* is longer-ranging, but is particularly common in the upper part of Zone

EARLY MIOCENE	10	Diatom sp. 4 (King 1983)	9	Plectofrondicularia seminuda	10	Spirosigmoilinella sp. A (King 1989)
	LATE OLIGOCENE	9c	Diatom sp. 3 (King 1983) #	8c	Bolivina antiqua #	9
8b				Elphidium subnodosum		
8a				Asterigerina g. guerichi #		
EARLY OLIGOCENE	9b	(un-named)	7b	Rotaliatina bulimoides #	8	Karrerella chilostoma
	9a	Globorotalia danvillensis	7a	Cassidulina carapitana #	7	Cribrostomoides scitulus
LATE EO	8c	Globigerinatheka index	6b	Uvigerina germanica	6b	Karrerulina conversa
	8b	(un-named)	6a	Cibicidoides truncanus	6a	Amm. macrospira
MIDDLE EOCENE	8a	Truncorotaloides spp.	5c	Planulina costata	5	Spiroplectammina aff. spectabilis
	7	Pseudohastigerina spp.	5b	Lenticulina gutticostata		
			5a	Neoeponides karsteni		
EARLY EOCENE	6	"Cenosphaera" sp. #	4	(un-named)	4b	# Reticulo. amplexens
	5b	Pseudoh. wilcoxensis	3b	Bulimina sp. A (King 1989)	4a	Textularia plummerae
	5a	Subbotina gr. linaperta #	3a	Gaudryina hiltermanni #	3	(un-named) #
LATE PALEOCENE	4	Coscinodiscus sp. 1 #	2	(un-named)	2	Verneuilinoides subeocaenus
	3	(un-named) #	1c	Bulimina trigonalis	1	Trochammina # ruthvenmurrayi Spiroplectammina # spectabilis
	2	"Cenodiscus" sp.	1b	Stensioeina beccariiiformis #		
EARLY PC.	c	Gt. chapmani	1a	Tappanina selmensis		
	1 b a	Gt. pseudobulloides				

Fig. 1. North Sea Paleocene to Early Miocene microfossil zonation (after King, 1983, 1989). Reticulo. = Reticulophragmium; Amm. = Ammomarginulina. # indicates zones/subzones identified at Harre.

#### NSB 8.

Samples at 28.25 - 28.50 m.b.s. and 32.75 - 33.0 m.b.s. proved to be barren. A sample at 37.05 m.b.s. - 37.25 m.b.s. contains *V. m. gramerzsis*, *Fursenkoina schreibersiana* and *Bulimina elongata*. This associa-

tion is again characteristic of the upper part of Zone NSB 8. Further samples, down to the sample at 50.75 - 51.0 m.b.s., also contain *B. elongata* and *V. m. gramerzsis*, and are all referred to Zone NSB 8. A similar assemblage occurs in samples from the Vejle

Fjord Formation at outcrop in Vejle Fjord area, collected by the author.

A sample at 49.75 m.b.s. contains frequent pyritised specimens of 'Diatom sp. 3' (King, 1983, plate 1, Figure 4); this distinctive species is widespread in the North Sea, where it is the index species of planktic Subzone NSP 9c (mid-Early Oligocene to Late Oligocene). It has not previously been recorded in onshore sections, except possibly by Dilley (in Curry *et al.*, 1978, p. 25).

The lowest fossiliferous sample examined in the Vejle Fjord Formation, at 65.75-66.0 m.b.s., contains a markedly different foraminiferid fauna. Significant species occurring here include *Nonion granosum*, a characteristic species of Zone NSB 8. *Glabratella?* sp. A (of King, 1989) is also present; this taxon occurs in Zones NSB 9 and the upper part of Zone NSB 8 in the North Sea (King, 1983, plate 3, figs. 13-15), but has not previously been recorded onshore, except possibly by Dinesen (1959) in the Vejle Fjord Formation at outcrop (see King, 1983).

The benthonic foraminiferid assemblage of the Vejle Fjord Formation thus indicates correlation with the upper part of Zone NSB 8. Although the species recorded at Harre do not permit an unequivocal conclusion, the assemblage probably indicates that this interval falls entirely within Subzone NSB 8c (late Late Oligocene). No representative of Subzone NSB 8b has been identified; it is probable that this indicates a discontinuity between the Vejle Fjord Formation and the Branden Formation, reflected by the sharp contact between the two units and the abundance of glauconite at the base of the Vejle Fjord Formation.

#### **Branden Formation (67.5 m.b.s. - 119.45 m.b.s.)**

The fossiliferous samples studied in the Branden Formation, between 67.75 - 68.0 m.b.s. and 112.25 - 112.50 m.b.s., are all characterised by the presence of *Asterigerina guerichi guerichi*, often in abundance. This enables correlation with the lowest part of Zone NSB 8, the 'abundant *A. guerichi guerichi*' Subzone of the North Sea (Subzone NSB 8a) (basal Late Oligocene). Other species occurring in the Branden Formation, including *Nonion granosum*, *Sigmomorphina regularis* and *Turrilina alsatica*, are longer-ranging Oligocene and early Miocene taxa. *Karrerria* sp.

(King, 1983, plate 5, figure 27) is present at 77.75 - 78.0 m.b.s.; this taxon is common in the North Sea (ranging through Zones NSB 6 to NSB 8), but has not previously been recorded onshore.

A similar microfauna, dominated by *A. guerichi guerichi*, occurs in a sample from the Branden Formation at its type locality (a disused clay pit at Branden), collected for the author by Dr. P. Gaemers.

'Diatom sp. 3' of King, 1983 (recorded above from the Vejle Fjord Formation) occurs in a sample at 112.25 - 112.50 m.b.s., indicating again a position within planktonic Subzone NSP 9c.

The lowest part of the Branden Formation, below 112.50 m.b.s., has not yielded diagnostic fossils. This interval is highly glauconitic, and rest with a sharp contact on the Viborg Formation. It seems probable that there is a hiatus at this contact (see comments below).

#### **Viborg Formation (119.45 m.b.s. - 177.50 m.b.s.)**

The foraminiferid fauna of the Viborg Formation consists to a large extent of relatively long-ranging species. The topmost part of the Formation (samples between 119.45 and 125.75 m.b.s.) has yielded no diagnostic species, but is tentatively referred to Zone NSB 7, as it lies below the 'abundant *A. guerichi*' interval. *Turrilina alsatica* is common to abundant throughout the Formation; in the North Sea this species ranges through Zones NSB 8 and NSB 7. *Frondicularia budensis* occurs in samples between 125.75 - 126.0 m.b.s. and the base of the Formation at 176.75 - 177.50 m.b.s.. This species is characteristic for the lower part of Subzone NSB 7b and Subzone NSB 7a in the North Sea, although ranging down into the upper part of Zone NSB 6.

*Cassidulina carapitana* is present rarely in the basal sample of the Viborg Formation, at 175.25 - 175.50 m.b.s.. This species is the index species of Subzone NSB 7a.

*Rotaliatina bulimoides*, the index species of the Early Oligocene Zone NSB 7, is not recorded from Harre. It has not been recorded elsewhere in Denmark, although it is present in the offshore Danish sector of the North Sea (Rasmussen, 1974 and author's obser-

vation) and is very widely distributed in the Early Oligocene of the North Sea and adjacent onshore areas. It is most common in the upper part of Zone NSB 7. Its absence in Denmark may reflect environmental controls, but more probably indicates the existence of a significant discontinuity between the Branden Formation and the Viborg Formation. As noted above, the upper part of the Viborg Formation here cannot be directly correlated; the interval between 125.75 m.b.s. and 175.25 m.b.s. is tentatively assigned to the lower part of Subzone NSB 7b, while the basal part of the Formation (below 175.25 m.b.s.) is definitely assigned to Subzone NSB 7a.

The Viborg Formation (Early Oligocene) rests unconformably on the middle Lillebælt Clay Formation (early Middle Eocene); the Søvind Marl Formation is absent at Harre.

**Lillebælt Clay Formation** (177.50 m.b.s. - 186.0 m.b.s.)

All samples studied from the Lillebælt Clay Formation contain an exclusively agglutinating foraminiferid fauna (King, 1994b, this volume). The samples between 177.65 m.b.s. and 180.25 m.b.s. contain poorly preserved specimens of cf. *Reticulophragmium amplectens*; this taxon is the index species of the late Early Eocene to early Middle Eocene agglutinant Zone NSA 4. From 181.75 m.b.s. to 184.95 m.b.s., *R. amplectens* is definitely present, and this interval is assigned with confidence to Zone NSA 4.

Most samples from the interval between 180.25 m.b.s. and 184.95 m.b.s. contain frequent large spherical radiolaria, of the type referred to as '*Cenosphaera* sp.' in the North Sea. This abundance of '*Cenosphaera*' is diagnostic for planktonic Zone NSP 6, which is approximately coeval with agglutinant Zone NSA 4. In overlying samples within the Lillebælt Clay Formation, rare and fragmentary radiolarians are present which may represent the same taxon.

**Røsnæs Clay Formation** (186.0 m.b.s. - 190.88 m.b.s.)

The Røsnæs Clay Formation in the Harre borehole is incomplete; only Beds R1 and R4 are present (Heilmann-Clausen *et al.*, 1985, King, 1994b, this

volume).

The abundant benthonic foraminifera include *Gaudryiana hiltermanni*, the index-species of benthonic Zone NSB 3, and other characteristic species of the zone, including *Turrilina brevispira*, *Clavulina anglica* and *Cibicides westi*, as at other localities in Denmark (King, 1983). The benthonic foraminiferid assemblage indicates correlation with Subzone NSB 3a.

The planktonic foraminifera of bed R3 in the Røsnæs Clay Formation are dominated by *Subbotina* gr. *linaperta*. This indicates correlation with planktonic Subzone NSP 5a.

**Ølst/Fur Formation** (190.88 m.b.s. - 222.0 m.b.s.)

The Ølst/Fur Formation has not been studied in detail. The few samples examined contained abundant pyritised or siliceous diatoms, but no foraminifers or other benthonic microfossils. The corresponding interval in the North Sea sequence, with similar palaeontological characteristics (the Balder and Sele Formations), is referred to benthonic Zone NSB 2 and planktonic Zone NSP 4. *Coscinodiscus* sp. 1, the index-species of Zone NSP 4, was not seen in the few samples examined, but occurs abundantly at some levels in the Fur Formation on the island of Fur.

**Holmehus Formation** (222.0 m.b.s. - 229.9 m.b.s.)

The Holmehus Formation contains a microfauna consisting exclusively of non-calcareous agglutinating foraminiferids. The downsection appearance of this assemblage, beneath the diatom-dominated assemblage of the Balder and Sele Formations, can be identified throughout the North Sea within the Late Paleocene, and is used to define the top of agglutinant Zone NSA 1. This event coincides with the base of the diatom-rich interval designated as Zone NSP 4.

The microfauna in the Holmehus Formation is closely similar to the microfauna of the 'middle' Thanetian Lista Formation in the North Sea, and includes the key species of Zone NSA 1, *Trochammina ruthvenmurrayi* and *Spiroplectammia spectabilis*. The former species has not previously been recorded from onshore sections, although widely distributed in the North Sea. A very similar microfaunal assemblage

has been obtained from samples from the Holmehus Formation collected by Claus Heilmann-Clausen at Albækshoved.

The Holmehus Formation can thus be regarded as the onshore representative of the Lista Formation.

**"Grey slightly to non-calcareous clay"** (229.9 m.b.s. - 244.5 m.b.s.)

The benthonic foraminiferid microfauna in this interval is dominated by non-calcareous agglutinants, but in the lower more calcareous Kerteminde Marl it changes progressively downwards to a dominantly calcareous benthonic foraminiferid assemblage. A similar vertical microfaunal assemblage change is observed in the North Sea from the lowest part of the Lista Formation into the upper part of the calcareous claystones of the Maureen Formation (equivalent to the North Sea Marl of the Danish offshore sector), accompanied by a similar downward increase in the calcium carbonate content of the sediments.

Through the interval between the top of the "grey slightly to non-calcareous clay" and 249.25 m.b.s., large spherical/lenticular radiolaria are common. These are rather poorly preserved, but can probably be identified with the '*Cenodiscus* sp.' occurring in the North Sea, which is the index of planktonic Zone NSP 2. This Zone is developed within the basal Lista Formation and the topmost North Sea Marl.

**Kerteminde Marl** (244.5 m.b.s. - 256.9 m.b.s.)

The top of planktonic Zone NSP 1 is defined in the North Sea by the highest occurrence of planktonic foraminiferids within the Paleocene, and occurs within the upper part of the North Sea Marl. In the Harre section, no planktonic foraminiferids were observed in the Kerteminde Marl; an absence of planktonics is observed also in the Kerteminde Marl at other localities in Jylland (see Hofker, 1966, Table 69), except for rare (?reworked) specimens at the base of the Formation. This probably indicates that the Kerteminde Marl falls entirely within planktonic Zone NSP 2 (characterised by the absence of planktonic foraminiferids), and that there is a significant hiatus between the Kerteminde Marl and the Danian limestones. The occurrence of *Stensioeina beccariformis* and other

characteristic species in the Kerteminde Marl indicates correlation with benthonic Subzone NSB 1b ('early' Thanetian). Indigenous planktonic foraminiferids, including *Globorotalia pseudobulloides* and *G. chapmani*, are recorded in the Lellinge Greensand (Hofker, 1966, Hansen, 1968), which underlies the Kerteminde Marl in Sjælland, and this unit can be correlated with planktonic Subzone NSP 1c ('earliest' Thanetian).

## CONCLUSIONS

The Harre borehole provides evidence, supplementing the data from other boreholes and surface outcrops previously summarised (King, 1983, 1989), that the zonal schemes proposed for the Oligocene, Eocene and Paleocene of the North Sea can be utilised in Denmark. The correlations proposed are summarised in Fig. 2. The Vejle Fjord Formation correlates to the upper part of Zone NSB 8, probably entirely within the Subzone NSB 8c. Subzone NSB 8b is not identified, probably indicating a discontinuity between the Vejle Fjord Formation and the Branden Formation. The Branden Formation is referred to NSB 8a and NSP 9c, and there is probably a hiatus between this formation and the underlying Viborg Formation. The lower part of the Viborg Formation is referred to the Subzone NSB 7a while the upper part tentatively is referred to the Subzone NSB 7b, but index species for the upper part of Zone NSB 7 are absent in the Harre cores. The Lillebælt Clay Formation is referred to Zones NSA 4 and NSP 6. A significant stratigraphic gap is present between the Lillebælt Clay and the Viborg Formations, comprising the upper part of the Lillebælt Clay Formation and the Søvind Marl. The Røsnæs Clay Formation is also incomplete, and is referred to Zone NSB 3a and NSP 5a. The Ølst and Fur Formations contained no foraminifers, but are tentatively correlated to the Balder and Sele Formations of the North Sea. The Holmehus Formation is correlated to the Lista Formation and is referred to Zone NSA 1. The grey slightly to non-calcareous clay is referred to Zone NSP 2, to which zone also the Kerteminde Marl is referred. This indicates a hiatus between the Danian limestone and the Kerteminde Marl. The upper part of the grey slightly to non-calcareous clay might correlate to the basal part of the Lista Formation of the North Sea, while the remaining part of the unit and the underlying Kerteminde Marl is correlated to the Maureen Formation and its equivalent in the

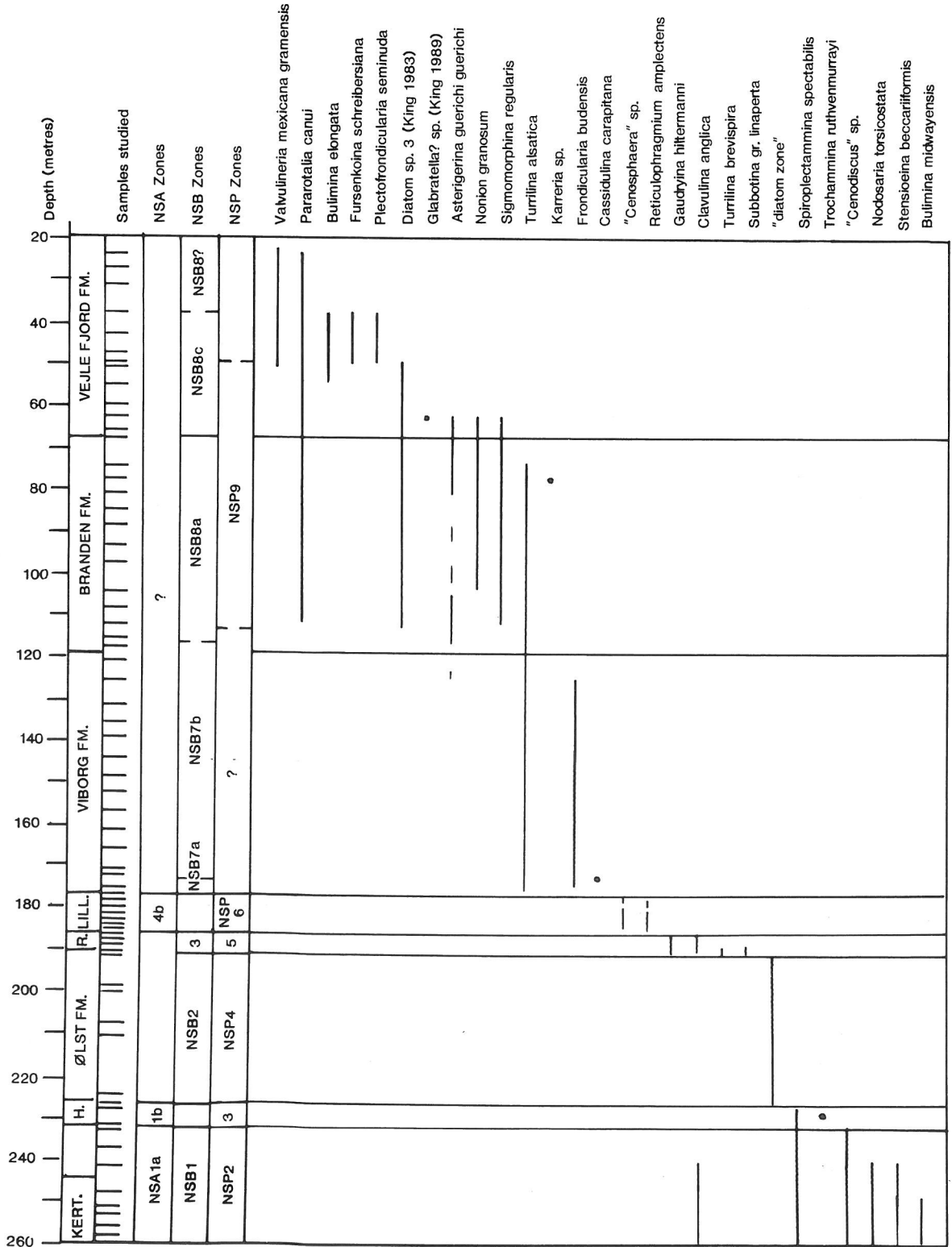


Fig. 2. Ranges of some stratigraphically significant microfossils in the Harre borehole, and correlation of the Harre section with the North Sea microfossil zones. H. = Holmehus Formation; R. = Røsnæs Clay Formation; LILL. = Lillebælt Clay Formation.

Danish offshore area, the North Sea Marl.

## ACKNOWLEDGEMENTS

The author wishes to express his thanks to Ole Bjørlev Nielsen for kindly supplying samples from the Harre borehole, to Claus Heilmann-Clausen for much help in Denmark, and to Paleoservices Ltd. for providing facilities for processing the samples and typing the manuscript.

## DANSK SAMMENDRAG

Den øvre Paleocæne til øvre Oligocæne fauna fra Harreboringen er korreleret med de etablerede benthoniske og planktoniske foraminiferzoner fra Nordsøen. På baggrund heraf korreleres også de lithostratigrafiske enheder, og vigtige stratigrafiske gab er blevet lokaliseret. Nogle mikrofossilarter er blevet registreret i landbeliggende lokaliteter for første gang.

Vejle Fjord Formationens øverste del er fossilfri, men fra 23.75 til 51 m u.t. (meter under terræn) findes typiske arter for Zone NSB 8. I nederste del af dette interval findes diatomeer karakteristiske for Zone NSP 9c, "Diatom sp. 3". Nederste del af formationen indeholder foraminiferer kendt fra zonerne NSB 9 og NSB 8. Der er ikke fundet arter i hele formationen, der ikke kan indplaceres i Subzone NSB 8c fra det øverste Øvre Oligocæn, medens ingen karakteristiske arter for Subzone NSB 8b er fundet. Der er således formentlig en hiatus mellem Vejle Fjord Formationen og den underliggende Branden Formation.

Branden Formationen tilhører i sin fulde udstrækning "*Asterigerina gürichi gürichi*" Subzonen i.e. NSB 8a, som henføres til den nederste del af Øvre Oligocæn. I den nederste del af formationen findes også "Diatom sp. 3", indikerende Subzone NSP 9c.

Viborgformationens øverste del indeholder ukarakteristiske former, som dog alle kan findes i Subzone NSB 7b. De nederste ca. 2 m af formationen kan med sikkerhed henføres til Subzone NSB 7a. Begge Subzoner er fra Tidlig Oligocæn.

Lillebæltsleret henføres til Zone NSA 4 og NSP 6, som er omtrentlig samtidige i perioden fra den yngste del af Tidlig Eocæn til den ældste del af Mellem Eocæn, medens Rønæslerets planktoniske foraminiferer henføres til Subzone NSP 5a, og de benthoniske til Subzone NSB 3a.

Ølst og Fur Formationerne er ikke studeret i detaille,

da de ikke indeholder kalkskallede mikrofossiler. Der er ikke, i de få prøver, der er analyseret her, fundet den karakteristiske diatomee *Coscinodiscus* sp. 1 fra Zone NSP 4, men da disse er fundet i andre lokaliteter med samme lithologi som her, dvs. askelag med moler imellem, henføres de to formationer hertil og korreleres til Balder- og Sele Formationerne fra Nordsøen.

Holmehus Formationen indeholder agglutinerende foraminiferer karakteristiske for Zone NSA 1, i lighed med Lista Formationen i Nordsøen, hvormed den derfor korreleres.

Det grå kalkfattige ler indeholder radiolarer af arten "Cenodiscus sp.", karakteristisk for Zone NSP 2. Denne Zone findes i Nordsøen i den øverste del af Maureen Formationen og den nederste del af Lista Formationen.

Kertemindemergelen indeholder ingen planktoniske foraminiferer, hvilket er karakteristisk for Zone NSP 3. Mergelen korreleres med Maureen Formationen og dens Nordsøekvivalenter herunder blandt andet Nordsøemergelen (North Sea Marl).

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