

Late Paleocene microfaunas of the Harre borehole (north Jylland, Denmark)

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ABSTRACT

The microfauna of the Late Paleocene Kerteminde Marl, "grey slightly to non-calcareous clay" and Holmehus Formation in the Harre borehole comprises approximately 70 species of benthonic foraminiferids, associated with sponge spicules, radiolaria, diatoms, fish debris and rare mollusc fragments.

The Kerteminde Marl contains a diverse, dominantly calcareous benthonic foraminiferid fauna, indicating deposition in a well-oxygenated outer shelf environment. In the "grey slightly to non-calcareous clay", non-calcareous agglutinants dominate, indicating increase in depth and restriction of circulation. Planktonic foraminiferids are apparently absent. The Kerteminde Marl and "grey slightly to non-calcareous clay" correlate with the upper part of the Maureen Formation (North Sea Marl) of the North Sea (benthonic Subzone NSB1b and planktonic Subzone NSP2 of King, 1989).

The Holmehus Formation contains a moderately diverse assemblage of non-calcareous agglutinating foraminiferids of the *Rhabdammina*-biofacies, indicating deposition in a restricted bathyal environment. It can be correlated with the Lista Formation of the North Sea (agglutinant Subzone NSA1b).

Correlation with other localities in Denmark is briefly discussed, and a correlation of the Late Paleocene of Denmark and the North Sea is presented, incorporating dinoflagellate and nannofossil data.

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INTRODUCTION

The Harre borehole (Fig. 1 in the introductory chapter) was continuously cored from the surface, through the Oligocene, Eocene and Late Paleocene, into the topmost Danian limestones. The interval studied here (between 222.5 meters below surface (m.b.s.) and 254 m.b.s.) comprises the section from the base of the Kerteminde Marl to the base of the Ølst/Fur Formations. This sequence corresponds approximately to the Selandian (Perch-Nielsen & Hansen, 1981); a formal lithostratigraphic name for the interval between the Holmehus Formation and the Kerteminde Marl has not yet been defined.

At Harre the lowest part of the Late Paleocene succession is a light grey marl (calcareous clay"stone) becoming less calcareous upwards (256.9 m.b.s. - 244.5 m.b.s.). This passes up into a dark grey non-calcareous pyritic silty claystone (244.5 m.b.s. - 229.9 m.b.s.). These units are referred to respectively as the Kerteminde Marl and the non-calcareous clay" in the literature (e.g. Perch-Nielsen & Hansen, 1981). They are here referred to the Kerteminde Marl and the informal unit "grey slightly to non-calcareous clay". The highest member of the succession (229.9 m.b.s. - 222 m.b.s.) is a green waxy non-calcareous clay", identified as the Holmehus Formation by Heilmann-Clausen *et al.* (1985).

SAMPLES STUDIED

Thirty samples were studied, collected (where possible) at approximately 1 metre intervals from the cores. The samples weighed between 80 and 300 grams. They were oven-dried at 80^o C, then soaked for one hour in white spirit (petroleum spirit). The white spirit was then poured off, and hot water added. After being left to stand for one hour, with frequent stirring, they were washed through a 120 micron sieve. If the sample was still incompletely disaggregated, the process was repeated, until a residue comprising only microfossils and diagenetic minerals (pyrite and siderite) remained.

GENERAL ASPECTS OF THE MICROFAUNA

The microfauna comprises dominantly agglutinating and calcareous benthonic foraminiferids, with sponge spicules, diatoms and radiolaria common at some levels. Occasional ostracods, mollusc fragments and echinoid skeletal debris are also recorded (Fig. 1).

At the base of the Kerteminde Marl (between 255 m.b.s. and 256.9 m.b.s.), a well-preserved abundant and diverse microfaunal assemblage is recorded, highly dominated by calcareous foraminiferids. From 255 m.b.s. to 244.5 m.b.s., calcareous foraminiferids are also present, but occur with progressively decrea-

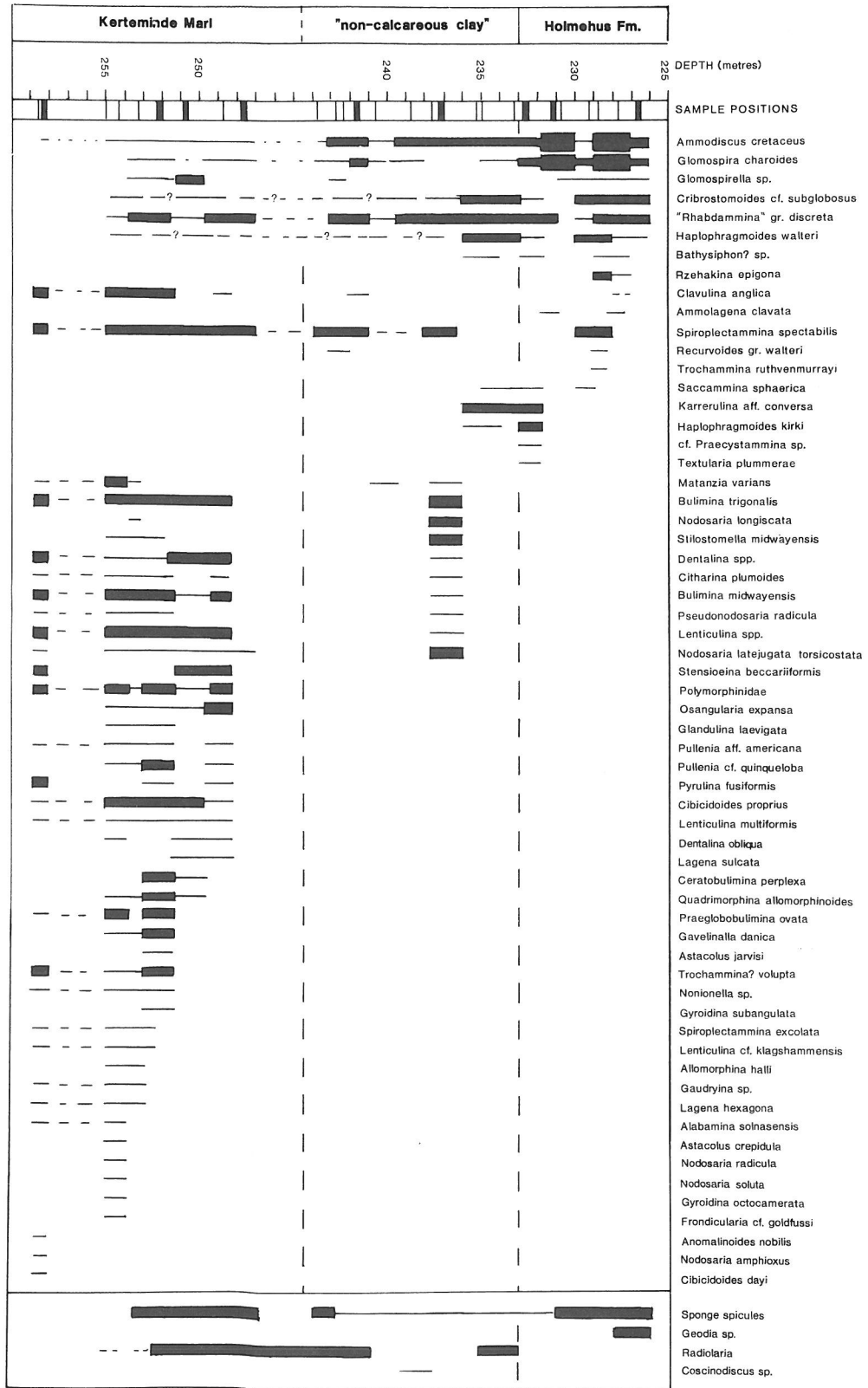


Fig. 1. Distribution of microfauna and diatoms in the Kerteminde Marl, the "grey slightly to non-calcareous clay" and the Holmehus Formation of the Harre borehole.

sing frequency, while agglutinating foraminiferids increase in abundance. In the "grey slightly to non-calcareous clay", non-calcareous agglutinants are common, but calcareous foraminiferids are recorded at only one level, although poorly-preserved calcareous-cemented agglutinants occur locally.

The preservation of foraminiferids in the Kerteminde Marl and "grey slightly to non-calcareous clay" is generally poor, except at the base. The agglutinants are often partly crushed, and the calcareous foraminiferids are generally partly crushed and corroded. It seems probable that calcareous foraminiferids were originally present throughout the Kerteminde Marl and "grey slightly to non-calcareous clay", but that they have been preferentially removed by carbonate dissolution in the upper, "grey slightly to non-calcareous part. This suggestion is supported by the vertical transition which can be observed, from samples with well-preserved calcareous foraminiferids, through samples with only corroded specimens, to samples without calcareous foraminiferids; while a similar, non-calcareous, agglutinating foraminiferid assemblage occurs throughout. Measurements of foraminiferid diversity and agglutinant/calcareous benthonic ratios (AG1 ratio of King, 1990) are therefore suspect.

In the Holmehus Formation, only non-calcareous microfossils, i.e. agglutinating foraminiferids and siliceous sponge spicules, are preserved. Sponge spicules are present in the transitional layer to the underlying unit.

THE LITHOSTRATIGRAPHIC UNITS

Kerteminde Marl

Benthonic foraminiferids

Between 255.5 m.b.s. and 244.5 m.b.s., the diverse assemblage of calcareous benthonic foraminiferids is dominated by *Bulimina trigonalis*, *Cibicidoides proprius*, and *Stensioeina* [*Gavelinella*] *beccariiformis*. *Bulimina midwayensis*, *Globulina* spp., *Lenticulina* spp. and *Praeglobobulimina ovata* are also common, together with the AG2 agglutinants (King, 1990) *Clavulina anglica* and *Matanzia varians*. *Stensioeina beccariiformis* is common or abundant between 244.5 m.b.s. - 247.85 m.b.s. and 255.15 - 255.5 m.b.s., but apparently absent at other levels. Other characteristic

Late Paleocene species in this assemblage include *Ceratobulimina tuberculata*, *Citharina plumoides*, *Gavelinella danica*, *Lenticulina multiformis*, *Nodosaria torsicostata*, and *Trochammina* [*Gyroidinoides*] *volupta* (abundant at the base). The most abundant and diverse foraminiferid assemblage occurs between the base of the Kerteminde Marl, at 255.5 m.b.s., and 249 m.b.s..

Non-calcareous agglutinating foraminiferids (AG2 group of King, 1990) also occur throughout this section. At the base of the section (255.15 m.b.s. - 255.5 m.b.s.), the AG1% (percentage of non-calcareous agglutinants, King, 1990) is 5-10%, but it rises to c. 50% at 253 m.b.s. and continues similarly to 244.5 m.b.s., with an increasing diversity upwards. Species recorded, notably including *Spiroplectammina spectabilis*, are the same as recorded in the overlying interval.

Planktonic foraminiferids

Planktonic foraminiferids appear to be entirely absent from the Kerteminde Marl at Harre.

Ostracods

Single specimens of *Cytherella* sp. and *Phacorhabdotus* sp. are recorded at 253 m.b.s..

Sponge spicules

Occasional pyritised sponge spicules are recorded at 251.25 m.b.s. and 250.25 m.b.s.. Almost all samples between 250 m.b.s. and 229.1 m.b.s. contain small siliceous sponge spicules (simple monaxons), occurring commonly at some levels.

Diatoms

Pyritised diatoms (*Coscinodiscus* sp.) occur very commonly at the base of the section.

Radiolaria

Rather poorly preserved spherical and ?lenticular reticulate radiolaria are recorded commonly between 249 m.b.s. and 238.5 m.b.s.. Similar specimens, but too poorly preserved to be positively identified as radiolaria, occur at other levels, especially between 252 m.b.s. and 249.25 m.b.s.. These radiolaria cannot be

positively identified, but are very similar morphologically to the radiolaria usually identified as *Cenodiscus* sp. which occur in the lower part of the Late Paleocene in the North Sea, characterising Zone NSP2 of King (1983).

Fish debris

Teleost fish bone fragments occur consistently, and at some levels commonly, in the upper part of the Kerteminde Marl.

"Grey slightly to non-calcareous clay"

Benthonic foraminiferids

In the "grey slightly to non-calcareous clay" (244.5 m.b.s. - 229.9 m.b.s.), the foraminiferid assemblage consists exclusively of agglutinating foraminiferids, except in one sample. The agglutinants are almost entirely non-calcareous or slightly calcareous (AG1) taxa, dominantly *Ammodiscus cretaceus*, *Glomospira charoides*, *Haplophragmoides walteri*, *Rhabdammina* gr. *discreta*, *Spiroplectammina spectabilis* and crushed *Haplophragmoides*?/*Trochammina*? spp; the latter probably include *Cribrostomoides* sp. *Karrerulina* [*Plectina*] *conversa* is common at the top of this interval (between 234.2 m.b.s. - 229.9 m.b.s.) but is not recorded at other levels. The vertical distribution of *Spiroplectammina spectabilis* is notably irregular; it is very abundant - indeed the dominant agglutinant - in most samples, but in others it is entirely absent. Rare specimens of AG2, calcareous-cemented, agglutinants (*Clavulina anglica*, *Matarzia varians*), also occur, but are usually poorly preserved.

In the sample at 234 m.b.s. - 234.25 m.b.s., this agglutinating assemblage is accompanied by about ten species of calcareous foraminiferids, rather corroded but identifiable, including common *Bulimina trigonalis*. This isolated assemblage does not differ in any significant respect from the calcareous benthonic assemblage occurring below 244.5 m.b.s..

Planktonic foraminiferids

Planktonic foraminiferids appear to be entirely absent from the "grey slightly to non-calcareous clay" at Harre.

Sponge spicules

Almost all samples between 250 m.b.s. and 229.1 m.b.s. contain small siliceous sponge spicules (simple monaxons), occurring commonly at some levels.

Diatoms

Pyritised diatoms (*Coscinodiscus* sp.) occur very commonly in the sample at 234.60 - 234.75 m.b.s..

Radiolaria

Rather poorly preserved spherical and ?lenticular reticulate radiolaria are recorded commonly between 249 m.b.s. and 238.5 m.b.s..

Fish debris

Teleost fish bone fragments occur consistently, and at some levels commonly, in the grey slightly to non-calcareous clay.

Holmehus Formation

Benthonic foraminiferids

A generally well-preserved and abundant assemblage of non-calcareous agglutinating foraminiferids is present throughout the Holmehus Formation, dominated by *Ammodiscus cretaceus* and *Glomospira charoides*. *Cribrostomoides scitulus*, *Haplophragmoides walteri*, *Rhabdammina* gr. *discreta* and *Spiroplectammina spectabilis* are common at some levels. *Rzehakina epigona* is recorded commonly in one sample; one specimen of *Trochammina ruthvenmurrayi* is recorded at 225.25 m.b.s.; and *Ammolagena clavata* is also present. These latter three species are characteristic components of the foraminiferid assemblage in the late Thanetian Lista Formation in the North Sea, but have not previously been recorded onshore in the North Sea Basin.

No calcareous foraminiferids have been observed in the Holmehus Formation.

Sponge spicules

Siliceous sponge spicules are common to abundant, including many specimens of desmas (lumpy and curved spicules derived from lithistid sponges) and ster-

rasters (ovoid spicules of the genus *Geodia*). They occur both as dissociated spicules and as associated masses of spicules which can be seen to represent partially fragmented sponge skeletons.

Radiolaria

Rather poorly preserved spherical and ?lenticular reticulate radiolaria are recorded commonly between 228.75 m.b.s. - 229 m.b.s..

Fish debris

Teleost bone fragments occur sparsely.

COMPARISON WITH OTHER SECTIONS IN DENMARK

The Harre borehole is the only Late Paleocene section in Denmark with a microfaunal record through the entire Kerteminde Marl, "grey slightly to non-calcareous clay" and Holmehus Formation, and therefore comparisons are limited. The distribution of foraminiferids in the Viborg 1 borehole is plotted by Flagler (1940), but the species are identified only by numbers, and no specific names are given. Nevertheless, and in spite of a significant gap in the Viborg cores, the vertical distribution pattern of foraminiferids in the Kerteminde Marl and grey slightly to non-calcareous clay can be seen to be very similar to that in the Harre borehole, with a diverse calcareous microfauna at the base, but becoming increasingly dominated by agglutinants at higher levels. The Holmehus Formation in the Viborg 1 borehole contains an assemblage of sponge spicules and non-calcareous agglutinants, as at Harre.

The diverse calcareous microfauna recorded from the Kerteminde Marl at Harre can be closely matched with the microfaunas recorded from equivalent levels at Egsmark, Svejstrup (Fig. 1 in the introductory chapter) and other localities in north and central Jylland (Hofker, 1966). A very similar assemblage is also recorded from the Kerteminde cliff section, Funen (Hofker, 1966).

Samples from the Holmehus Formation at Albæk-hoved (Fig. 1 in the introductory chapter), collected by the author under the guidance of Claus Heilmann-Clausen, contain a foraminiferid assemblage consisting entirely of non-calcareous agglutinants, domi-

nated by *Ammodiscus cretaceus* and *Glomospira charoides*, very similar to the assemblage from Harre, but rather less diverse.

DEPOSITIONAL ENVIRONMENTS

Kerteminde Marl and "grey slightly to non-calcareous clay"

The calcareous benthonic foraminiferid assemblage occurring in the Kerteminde Marl is quoted by Berggren & Aubert (1975) as a typical Midway-type fauna, characterising well-oxygenated outer shelf environments, with depths of deposition between 50m-200m. The absence of planktonic foraminiferids in this interval is a feature seen throughout the North Sea Basin at this time, suggesting that they were totally excluded from the Basin. This may be due to a combination of relatively low sea levels and unfavourable circulation patterns in the North Atlantic.

The occurrence of non-calcareous agglutinants at higher levels, and their increase in proportion to the calcareous taxa, coupled with an apparent decline in the diversity of the calcareous benthonics, suggests increasing depths and more restricted circulation, although the pattern of vertical microfaunal change is probably affected by post-mortem dissolution, as discussed above. These agglutinants include species typical of the flysch-type assemblage of Gradstein & Berggren (1981) (*Rhabdammina*-biofacies of King, 1983). They characterise bathyal environments with restricted circulation, and hence low oxygen levels.

Holmehus Formation

At all localities studied, the Holmehus Formation contains a totally non-calcareous agglutinating foraminiferid microfauna. There is no positive evidence for post-mortem decalcification, and it is considered probable that the preserved microfauna reflects accurately the original foraminiferid assemblage. The assemblage is a typical flysch-type/*Rhabdammina*-biofacies association, which, as discussed above, is believed to represent deposition in a restricted bathyal environment i.e. depth of deposition greater than 200 metres.

CORRELATION WITH THE LATE PALEOCENE OF THE NORTH SEA

The Cenozoic sequence in the North Sea has been assigned by King (1983) to parallel series of planktonic and benthonic microfossil zones (respectively NSP and NSB zones), defined mainly by the highest (last) occurrences of individual taxa or assemblages (Fig. 2). Subsequently (King, 1989), a further series of zones based on non-calcareous agglutinating foraminiferids has been defined.

Planktonic Zone NSP4 (basal Eocene and late Thanetian), defined by the occurrence of common diatoms (including *Coscinodiscus* sp. 1 and *C. spe. 2*) corresponds in the North Sea and Denmark to the ash series (Ølst Formation/Fur Formation). Agglutinant Zone NSA2 is coeval with planktonic zone NSP4. It is characterised by a very restricted benthic microfauna, comprising a low-diversity assemblage of poorly preserved non-calcareous agglutinating foraminiferids (chiefly *Haplophragmoides* spp.). This microfauna has not yet been identified in Denmark.

The top of planktonic Zone NSP3 (middle Thanetian), defined by the lowest occurrence of a *Coscinodiscus*-dominated assemblage, corresponds to the Ølst Formation/Holmehus Formation junction. The top of agglutinant Zone NSA1 (coeval with Zones NSP3 and NSP2) is defined by the incoming downsection of a diverse assemblage of non-calcareous agglutinating foraminiferids of the *Rhabdammina*-biofacies, including *Spiroplectammina spectabilis*, which is defined as the index-species. The microfauna in the Holmehus Formation is very similar to the microfauna occurring in the upper part of this Zone in the North Sea, in the Lista Formation.

The top of planktonic zone NSP2 (early Thanetian) is defined by the highest occurrence in the Paleocene of large spherical/lenticular reticulate radiolaria (the apparently lenticular profile may be due to crushing, but these are often identified as *Cenodiscus* sp). As noted above, these are probably represented by poorly preserved specimens occurring sporadically throughout the Kerteminde Marl and "grey slightly to non-calcareous clay". This suggests that the top of Zone NSP2 corresponds to the top of the "grey slightly to non-calcareous clay". The agglutinating microfauna in the Kerteminde Marl and "grey slightly to non-calcareous clay" corresponds to the assemblage in the lower part

of Zone NSA1. The calcareous benthonic foraminiferid assemblage in the Kerteminde Marl and "grey slightly to non-calcareous clay" can be assigned to the early Thanetian Subzone NSB1b.

The top of planktonic Subzone NSP1c (early Thanetian) is defined by the highest occurrence of planktonic foraminiferids in the Paleocene. The assemblage in this Subzone includes *Globorotalia compressa*, *Subbotina triloculinoides*, and rare *Globorotalia chapmani*. The absence of planktonic foraminiferids in the Kerteminde Marl and grey slightly to non-calcareous clay at Harre indicates that it lies entirely within Zone NSP2. Planktonic foraminiferids, including *G. chapmani*, are recorded in the basal part of the Late Paleocene (Lellinge Greensand) of Sjælland (Hansen, 1968). The Lellinge Greensand is believed to be older than the Kerteminde Marl (Perch-Nielsen & Hansen, 1981, and can be correlated with Subzone NSP1.

These comparisons indicate that the Kerteminde Marl and grey slightly to non-calcareous clay can be correlated lithologically and faunally with the upper part of the North Sea Marl of Michelsen (1982) (Maureen Formation equivalent of Deegan & Scull, 1976). The Holmehus Formation can be correlated with the Lista Formation (Deegan & Scull, 1977), which it closely resembles lithologically. The sharply defined lithological boundaries and microfaunal contrasts between the Ølst Formation and the Holmehus Formation, and between the Holmehus Formation and the "grey slightly to non-calcareous clay", imply that there may be significant stratigraphic breaks at these levels.

Comparison of the available palynological data for the Late Paleocene of the North Sea (largely unpublished) and Denmark (derived mainly from the study of the Viborg 1 borehole by Heilmann-Clausen, 1985) also reinforces this correlation, and if available nannoplankton data is added (for Denmark from Thomsen & Heilmann-Clausen, 1983), an integrated correlation can be compiled (Fig. 2), although many details remain to be resolved.

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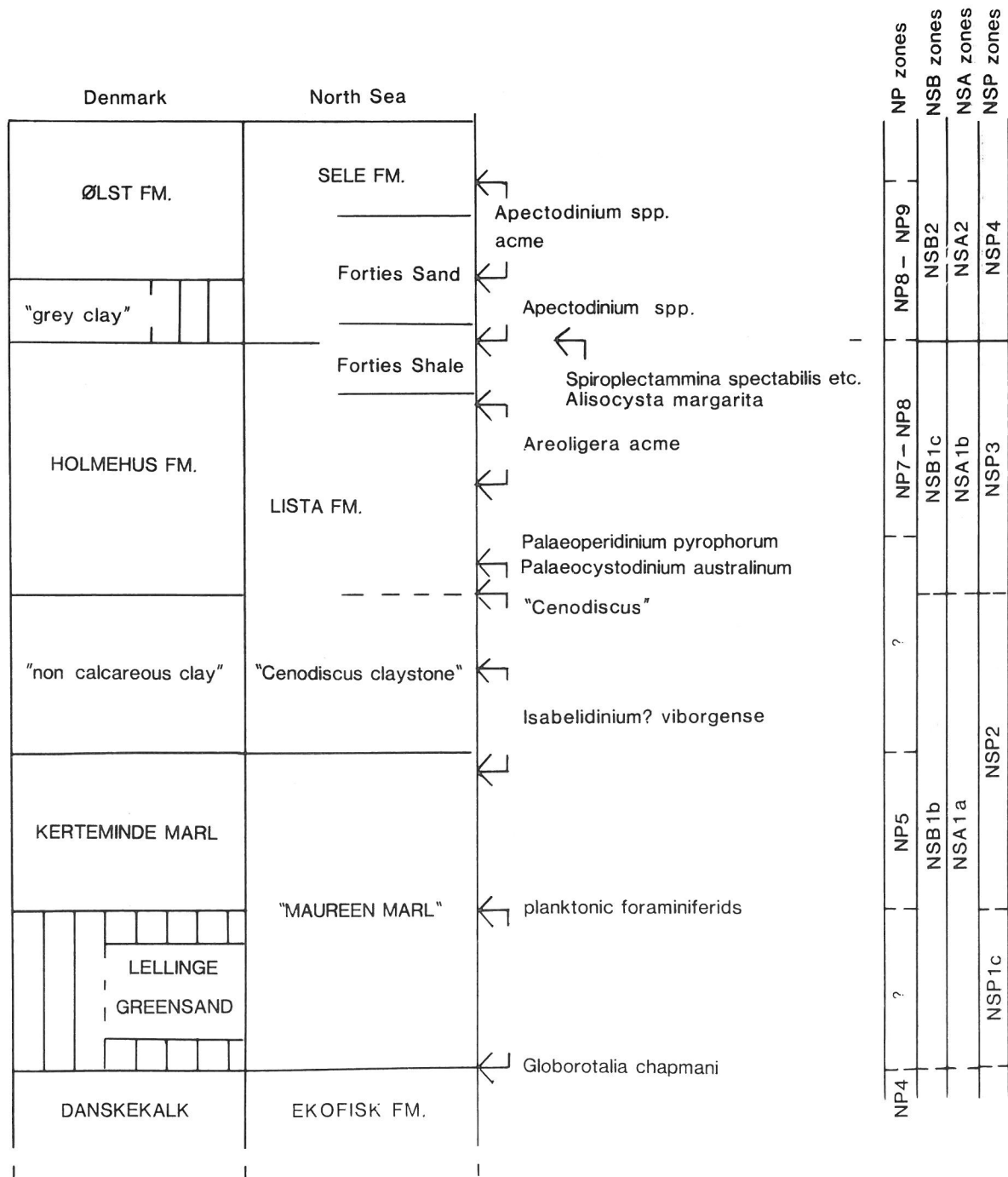


Fig. 2. Correlation of the Late Paleocene succession in Denmark and the North Sea.

Clausen for their hospitality and their guidance in the field in Jylland. David and Alison Ward are also thanked for assistance in various ways on several field trips to Denmark.

DANSK SAMMENDRAG

På baggrund af en mikropalæontologisk undersøgelse af de Paleocæne aflejringer i Harre boringen, omfattende foraminiferer, spongiespikler, radiolarer, diato-

meer mv., er der foretaget en biostratigrafisk opdeling, en vurdering af aflejningsforholdene og en sammenligning med stratigrafien i Nordsøregionen. Kertemindemergelen indeholder overvejende kalkskallede benthoniske former, der tyder på at aflejringen foregik i et velventileret ydre shelf miljø. Det grå kalkfattige ler indeholder kun ikke-kalkskallede agglutinerende benthiske foraminiferer, der tyder på, at aflejringen foregik på større dybde end Kertemindemergelen, og at vandcirkulationen var mindre veludviklet. Planktoniske former er ikke tilstede. Kertemindemergelen og det grå kalkfattige ler korreleres med den øvre del af Maureen Formationen fra Nordsøen, der igen anses for identisk med Nordsøemergelen fra den danske del af Central Graben. Holmehus Formationen indeholder et selskab med moderat diversitet af ikke-kalkskallede agglutinerende foraminiferer tilhørende *Rhabdammina*-biofacies. Dette tyder på, at Holmehus Formationen er aflejret under bathyale forhold med begrænset cirkulation. Formationen korreleres med Lista Formationen fra Nordsøen.

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