PAPER 1

Foraminiferal Biozonation in the Early Pleistocene in the Central North Sea

BY

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Contents

Abstract

Pliocene and Pleistocene deposits from 66 boreholes from the central and northern North Sea have been examined for their content of benthic foraminifera. In this area the Pliocene/Pleistocene boundary is generally placed at the bottom or middle of the Elphidium oregonense Subzone or at the last local occurrence of Cibicides grossus. A detailed study of the temporal relationship between these two species in the western part of the Danish sector shows, that the last local occurrence of Cibicides grossus in this area is older than the Elphidium oregonense Subzone.

On the basis of the results concerning the Lower Pleistocene an emendation of the foraminiferal biostratigraphy for this sub-series is proposed and related to previous work on the biostratigraphy and palaeogeography of the North Sea area.

The investigation indicates the existence of two distinct new subzones within the Elphidiella hannai/Cassidulina teretis range:

The oldest of the two new subzones is an Acme-zone with Buliminidae as the characteristic taxon, and it is named the Stainforthia/Bulimina Subzone. The depositional environment was a boreal shelf with a water depth presumed to exceed 100 m. Based on its stratigraphic position and enviromental indications the Subzone is referred to the Tiglian stage.

The youngest of the two new subzones is a local Range-zone, defined by the presence of the arctic species Elphidiella gorbunovi, and it is named the Elphidiella gorbunovi Subzone. The depositional environment was an arctic shelf with a water depth of less than 50 m. The occurrence of Elphidiella gorbunovi in the central North Sea thus indicates a cold interval in either the Eburonian or the Menapian stage.

Succeeding the Elphidiella gorbunovi Subzone, the foraminiferal fauna and the sediment indicate increasingly near-coastal environment and a warming of the climate.

Key-words: Biostratigraphy - Foraminifera - Biozonation - North Sea -Lower Pleistocene - The Pliocene/Pleistocene boundary - Cibicides grossus - Elphidium oregonense - Stainforthia/Bulimina Subzone - Elphidiella gorbunovi Subzone.

Introduction

Material from 53 boreholes from the Danish sector and 13 boreholes from the Norwegian sector of the North Sea, have been examined for foraminiferal content. The results are used as basis for a suggested emendation of the foraminiferal biostratigraphy for the Lower Pleistocene of the North Sea. The new zonation is related to the stratigraphies and palaeogeographies presented in previous works.

Most of the boreholes are from around latitude 56° N, i.e. the southern to central North Sea (Fig. 1). For convenience this area (55° - 57° N) is termed the central North Sea in the present paper.

This study further presents a detailed investigation of faunal assemblages, sediments and seismics from the uppermost Pliocene and lowermost Pleistocene in the central North Sea area. The purpose of this part of the investigation is to establish the temporal relationship between Elphidium oregonense and Cibicides grossus in the area (Fig. 2).

All material was examined for its content of the following species: Pararotalia serrata ten Dam & Reinhold, Cibicides grossus ten Dam & Reinhold, Elphidiella rolfi Gudina et al., Elphidium oregonense Cushman & Grant, Cassidulina teretis Tappan, Elphidiella hannai Cushman & Grant, Stainforthia fusiformis (Williamson), Elphidiella gorbunovi Stschedrina, Elphidium ustulatum Todd and Elphidium albiumbilicatum (Weiss). These are considered the most important foraminiferal species used in Lower Pleistocene biostratigraphy in and around the North Sea region.

The base or the middle of the Elphidium oregonense range or the last local occurrence (LLO) of Cibicides grossus are generally used to indicate the Pliocene/Pleistocene boundary in the southeastern, central and northern North Sea (van Voorthuysen et al., 1972; Doppert, 1980; King, 1983;), while the last occurrence (LAD) of Elphidiella rolfi and the LAD of Pararotalia serrata are used to indicate the Pliocene/Pleistocene boundary in the Arctic and in the southern North Sea respectively (Feyling-Hanssen, 1990; Cameron et al., 1983). Elphidiella gorbunovi and Stainforthia fusiformis are used to define the two new Subzones presented in this paper, while the LLO of Cassidulina teretis or the LLO of Elphidiella hannai indicate the top of Lower Pleistocene (e.g. Knudsen & Ásbjörnsdóttir, 1991; Sejrup et al., 1987). The common presence of Elphidium ustulatum usually indicates Pre-Eemian time (Gregory & Bridge, 1979). Elphidium albiumbilicatum is found in Quaternary and Pliocene deposits, and usually indicates a brackish, shallow-water environment (Jensen, in prep.; Feyling-Hanssen, 1983; Lutze, 1965). Pararotalia serrata is commonly found south of the study area (Funnell, 1989; King, 1989), and Elphidiella rolfi has been found only in the arctic (e.g. Feyling-Hanssen, 1990). These two species were not encountered in the examination. Planktonic species of stratigraphic importance are absent in the material as well.

At the end of the paper a palaeontological part is found with species descriptions, original references, taxonomic remarks, etc., with the main focus on the Elphidiidae.

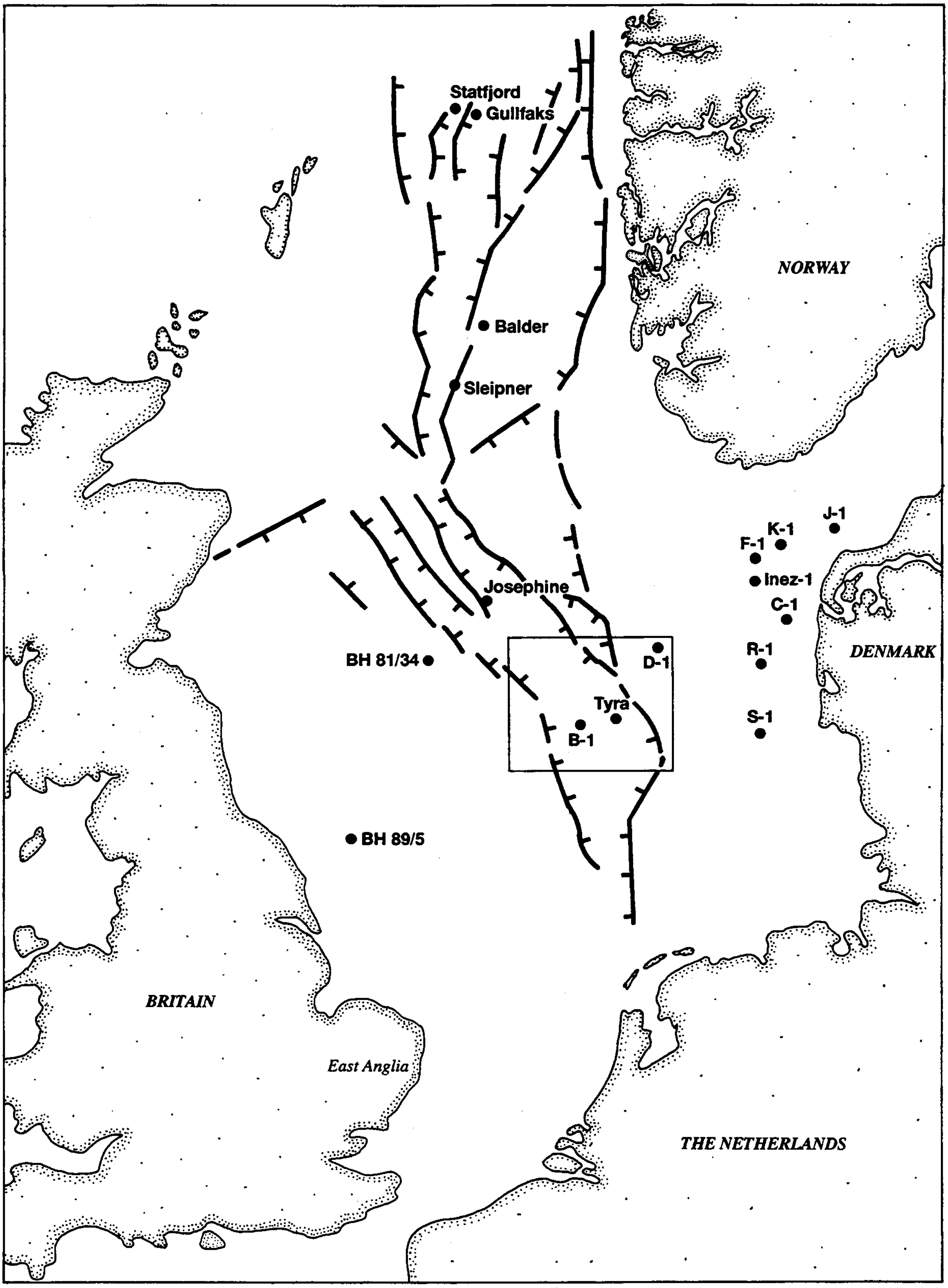

Fig. 1: Map of the North Sea area showing the general outline of the Central Trough structure and some of the localities mentioned in the text. The sites in the Danish part of the Central Trough area are shown on Fig. 6a.

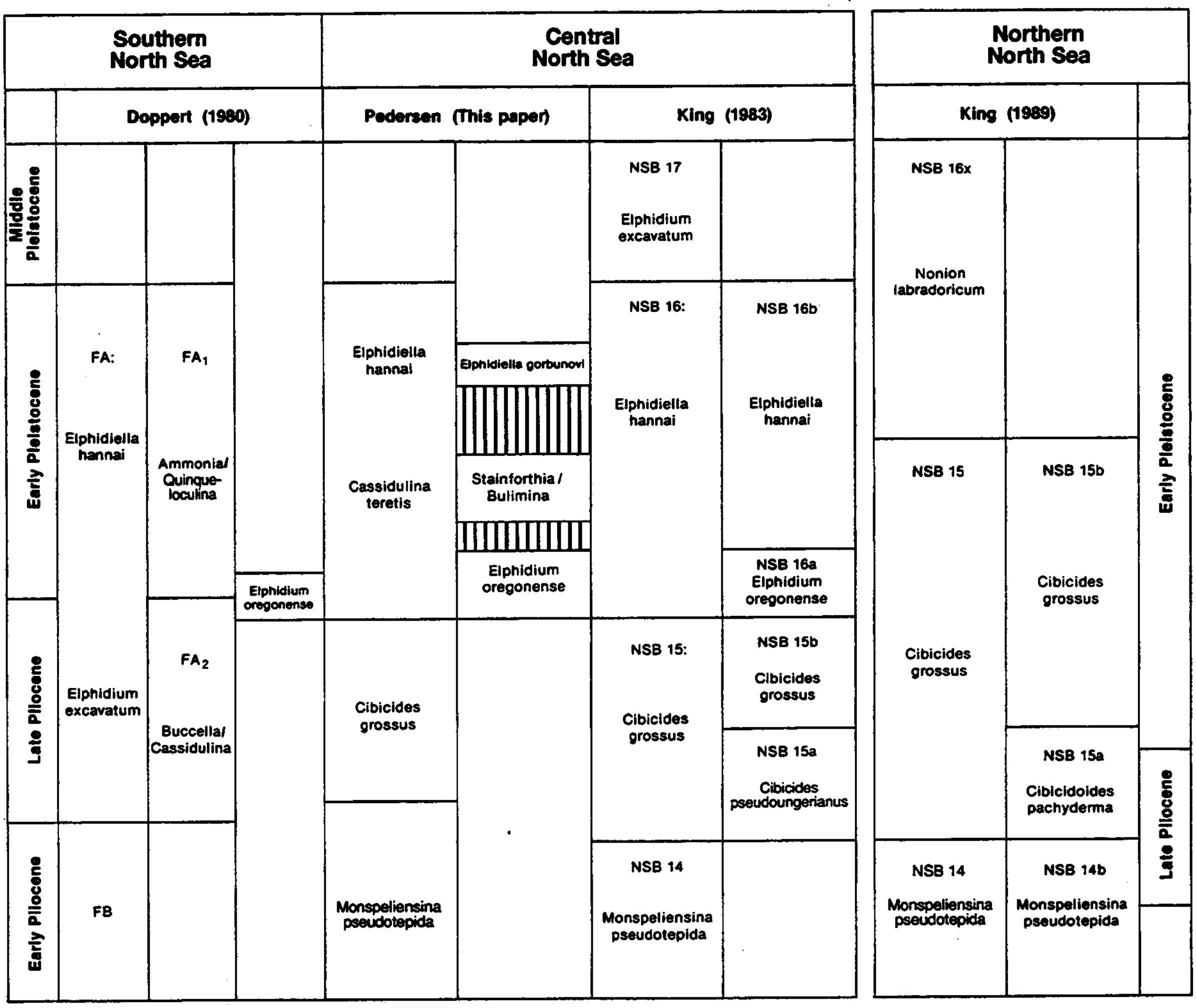

Fig. 2: Correlations between the emended zonation and previously published biozonations.

The Early Pleistocene of the North Sea area

The Pliocene/Pleistocene boundary

The international Pliocene/Pleistocene boundary is defined by the International Commission on Stratigraphy (ICS) in the Vrica stratotype subsection B in Italy (Bassett, 1985; Harland et al., 1989). The boundary is situated below a zone with dominance of sinistral Neogloboquadrina pachyderma (Ehrenberg), but above the LAD of Globigerinoides obliquus extremus Bolli & Bermüdez, and above the first occurrence (FAD) of Globigerinoides tenellus Parker. All three foraminiferal species are planktonic. The boundary in the Vrica subsection is placed 3-6 m (10 - 20.000 years) above the top of the palaeomagnetic Olduvai event (Bassett, 1985).

Aguirre & Pasini (1985) estimated the age of the Pliocene/Pleistocene boundary at 1.64 Ma, using a top Olduvai age of 1.67 Ma. Shackleton et al. (1990) using astronomical calibration (orbital models) and oxygen isotopes in material from deep-sea cores have, however, revised the dating of the top of the Olduvai Event to 1.77 Ma, thus indicating an age of 1.75 - 1.76 Ma for the Pliocene/Pleistocene boundary in the Vrica section.

In deposits from the North Atlantic Ocean the top of the palaeomagnetic Olduvai event approximately coincides with the change from mainly dextral to mainly sinistral specimens of Neogloboquadrina pachyderma. The change is probably caused by a drop in water temperature, and the datum is used to biostratigraphically place the Pliocene/Pleistocene boundary in this area (Weaver & Clement,1986).

Neogloboquadrina pachyderma may appear in deposits in the northern North Sea, but Pleistocene and Upper Pliocene samples collected from the more restricted environment of the central North Sea, rarely contain any planktonic foraminifera.

The scarcity of planktonic foraminifera has made it necessary to base the North Sea biostratigraphy on benthic species. This makes it difficult to correlate the North Sea area with the type profile in Italy, and thus problematic to recognize the Pliocene/Pleistocene boundary in the North Sea region.

Biostratigraphers working in the area have, therefore, been forced to rely on the onset of the Quaternary climatic deterioration in the North Sea region as an indicator of the boundary (e.g. Buch, 1972). This climatic change is characterized by a decrease in the faunal diversity and an increase in the number of arctic species in the faunal assemblages (Buch, 1972). The change is, however, not an abrupt event, but an ongoing process during the entire Upper Pliocene. The faunal assemblages respond to this with a gradual extinction of the Lower Pliocene species Heterolepa dutemplei, Siphotextularia sculpturata, Melonis affine, Monspeliensina pseudotepida a.o., and a gradual increase in the frequency of the Pleistocene species including Cassidulina teretis, Elphidiella hannai, Haynesina orbiculare and Elphidium excavatum (e.g. Knudsen & Ásbjörnsdóttir, 1991; Doppert, 1980).

In the North Sea area the species Elphidium oregonense has a very short range, and in 1972 van Voorthuysen et al. correlated their Elphidium oregonense Zone with the pollen stratigraphy and showed, that in the Dutch deposits Elphidium oregonense appears during a fall in temperature in the Praetiglian stage (Fig. 3). Since then Elphidium oregonense has been used as an indicator of the Pliocene/Pleistocene boundary in those parts of the North Sea region, where it occurs (Doppert, 1980; King, 1983; a.o.) (Fig. 2). Part of the Praetiglian stage was later correlated with the paleomagnetic Reunion-event (2.01-2.04 Ma) (Jenkins et al., 1985) (Fig. 3), while Zagwijn (1992) suggests approximately 2.3 Ma.

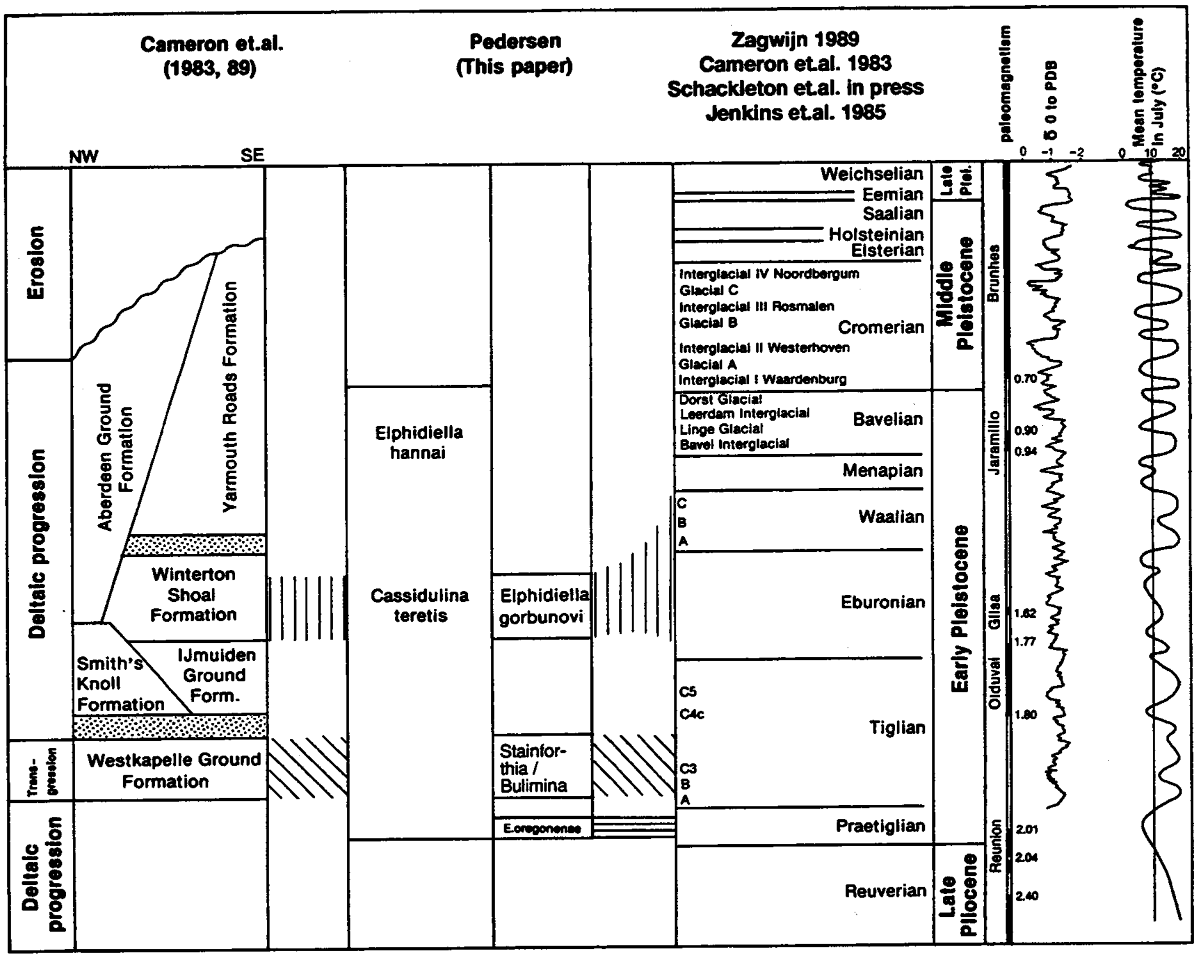

Fig. 3: Correlations between the two new Subzones and previously published stratigraphies.

The short stratigraphical range of Elphidium oregonense makes it very useful as a marker-species in the North Sea deposits. The species is, however, recorded mainly from the Dutch and Danish sectors. Outside these sectors it has been necessary to use other criteria as biostratigraphic indicators of the Pliocene/Pleistocene boundary in the North Sea region.

In the Norwegian and British sectors the species Cibicides grossus is the last typically Lower Pliocene species to disappear, and the Pliocene/Pleistocene boundary is placed at the LLO of this species (Knudsen & Ásbjörnsdóttir, 1991; Seidenkrantz, 1989; Sejrup et al., 1987).

In the southwestern part of the North Sea, next to the British coast, the boundary between the Pliocene Red Crag and the Pleistocene Westkapelle Ground Formation is a hiatus corresponding to the uppermost Pliocene and the Lower Praetiglian, and both Cibicides grossus and Elphidium oregonense are absent (Cameron et al., 1989). The Pliocene/Pleistocene boundary is here biostratigraphically recognized by the last occurrence of the Pliocene foraminiferer Pararotalia serrata. This datum is generally found near the paleomagnetic Gauss-Matuyama boundary (2.4 Ma) (e.g. Cameron et al., 1983) (Fig. 3).

In the arctic area the Pliocene/Pleistocene boundary is placed by Feyling-Hanssen (1985) within his Cassidulina teretis Zone, and by McNeil (1989) within his Cibroelphidium ustulatum Interval Zone (Elphidium ustulatum in this paper). The two Zones are found above the Cibicides grossus Zone/Interval Zone. Feyling-Hanssen (1990) introduced a zone characterized by Elphidiella rolfi between the last occurrence of Cibicides grossus and the Pliocene/Pleistocene boundary in northern Greenland.

It should be noted, that, unless otherwise specified, the base of the Lower Pleistocene in this paper is considered concurrent with the base of the Elphidium oregonense Subzone.

The Early Pleistocene

In the North Sea the upper boundary for Lower Pleistocene is placed biostratigraphically at the LLO of Elphidiella hannai or the LLO of Cassidulina teretis (e.g. Sejrup et al., 1987; Funnell, 1989; Feyling-Hanssen & Knudsen, 1986), but additional biostratigraphic subdivision of the Lower Pleistocene has proved difficult. Subdivisions of the Lower Pleistocene of the North Sea area have, however, been made on the basis of seismics, logs, palaeomagnetics, sediments, pollen ect., and a summary of the chronostratigraphic and palaeoenviromental indications of these investigations is presented below. The estimations of the ages of the stages are based mainly on Shackleton et al., 1990, Jenkins et al., 1985 and Zagwijn, 1992.

During the cold Praetiglian stage the sea-level was relatively low, probably due to the large North American ice-cap of that time (2.3 -2.0 Ma) (King, 1989; Jenkins et al., 1985). The low sea-level together with a deltaic progradation from the Rhine and the North German-Baltic river-systems reduced the marine area of the North Sea, and marine Praetiglian deposits are thin or absent outside the subsiding areas of the Netherlands and the Central Trough (Cameron et al., 1989; Zagwijn, 1989).

At the start of the warm Tiglian stage (2,0 - 1.8 Ma) the temperature increased and the sea-level rose, causing the most extensive transgression in the Early Pleistocene of the North Sea region (Cameron et al., 1987; 1989; Zagwijn, 1989). The marine deposits of the southern North Sea referred to the Westkapelle Ground Formation were deposited during the lower part of the Tiglian stage (Cameron et al., 1989) (Fig. 3).

During the upper part of the Tiglian stage (1.9 - 1.8 Ma) the sea-level fell as the temperature decreased, and a large delta started to prograde from the southeast into the North Sea. This caused a regression, which continued during the rest of the Early Pleistocene. In the southern North Sea the deltaic sediments are named the IJmuiden Ground, Winterton Shoal and Yarmouth Road Formations and are probably contemporary with the Aberdeen Ground Formation found further north in the British sector (Jeffery et al., 1991) (Fig. 3).

The regression continued into the Middle Pleistocene, and from 0.9 to 0.4 Ma (Bavelian to Elsterian) the North Sea was restricted to a small, shallow sea situated in the central and northern part of the present North Sea (Cameron et al., 1987; 1989; Zagwijn, 1989). The area south of 55° N was non-marine, and freshwater ostracodes of presumably "Cromerian Complex" age have been found in BH 81/29 (56° N) (Penney, 1990) (Figs. 1 and 3).

The tops of the Aberdeen Ground Formation and the Yarmouth Road Formation were eroded during the Elsterian glacial stage (0.4 Ma), when the formation of the Scandinavian ice-sheets caused major changes in the river patterns of Northwestern Europe (Cameron et al., 1987, 1989; Harland et al., 1989; Zagwijn, 1989) (Fig. 3).

Material

The samples investigated in this study are mainly ditch cuttings taken with sampling intervals of 10 m (30') or more from hydrocarbon wells. Due to the character of this material downhole contamination is almost certain, and the stratigraphically last occurrence of a species is, therefore, considered a more certain datum, than its first occurrence.

The samples from the borehole A-2 and the material from the Norwegian sector are core samples, which eliminate the possibility of downcore contamination.

The size fraction available was between 0,1 mm and 1,0 mm, most often 0,25 - 0,5 mm. The fossils analysed were hand-picked by several persons, and the selections may have been biased in favour of the larger species.

The data on which this paper is based are shown in tables 1, 2 and 3. In the Danish/German sector depths are measured as feet below KB (bKB). Water depth at sites are generelly 45-80 m (150'-250'), and their locations are shown on Fig. 6a.

In the Norwegian sector the depths are measured as feet below seafloor (bsf), and the water depths at the sites are 100-150 m (300'-450'). Only the locations of those northern North Sea sites mentioned in the text are shown (Fig. 1).

The material used in the present study is kept at the Geological Survey of Denmark (DGU) and at the Department of Earth Sciences at the University of Aarhus. The specimens shown on the plates are kept at DGU (no. 1992-amp-1 - 1992-amp-12).

The faunal succession

Central North Sea

A distribution chart of the species characteristic of the Lower Pleistocene in the central North Sea is shown in Fig. 4.

The stratigraphically oldest fauna examined in this paper is characterized by Heterolepa dutemplei, Melonis affine, Siphotextularia sculpturata, Monspeliensina pseudotepida, Cibicides grossus and Cassidulina pliocarinata. These species gradually becomes extinct in the North Sea region in the Pliocene and Cibicides grossus is usually the last to disappear, while Elphidiella hannai, Elphidium excavatum, Cassidulina aff. subglobosa and Cassidulina teretis becomes more frequent. In association with this faunal change, Elphidium oregonense makes a short appearrences. Following the LLO of Elphidium oregonense Stainforthia fusiformis and other Buliminidae becomes frequent. Stainforthia fusiformis gradually fades out along with the LLO of Cassidulina aff. subglobosa. Stratigraphically higher in the sequence Elphidiella gorbunovi appears and disappears before the end of the Elphidiella hannai/Cassidulina teretis range. Above the LLO of Elphidiella hannai/Cassidulina teretis the faunal assemblages is characterized by Elphidium albiumbilicatum and Elphidium ustulatum.

Northern North Sea

Neither Cibicides grossus nor Elphidium oregonense is observed in the material from the Norwegian sector. King (1989) established a Nonion labradoricum Zone (NSB 16x) to succeed his Cibicides grossus Subzone (NSB 15b) in the northern North Sea (Fig. 2). In the material investigated in this study Nonion labradoricum is common in the faunal assemblages containing Cassidulina teretis. At a single site in the Norwegian sector, Statfjord(7721), (material originally examined by Feyling-Hanssen) a sample containing significant numbers of Bulimina marginata occurs. The faunal assemblage of the sample is dominated by Elphidium excavatum, and otherwise characterized by Cassidulina teretis and Elphidium groenlandicum.

In the Balder(DB1) and the Sleipner(3003) boreholes Elphidiella gorbunovi is found in 3 samples (Fig. 1) (previously described by Feyling-Hanssen (1980) as Elphidiella sibirica), in faunal assemblages characterized by Cassidulina teretis, Elphidium bartletti and Elphidium groenlandicum. The range of Cassidulina teretis extents above the LLO of Elphidiella gorbunovi. (See also Feyling-Hanssen, 1990; King,1989; Sejrup et al., 1987 and Feyling-Hanssen & Knudsen, 1986).

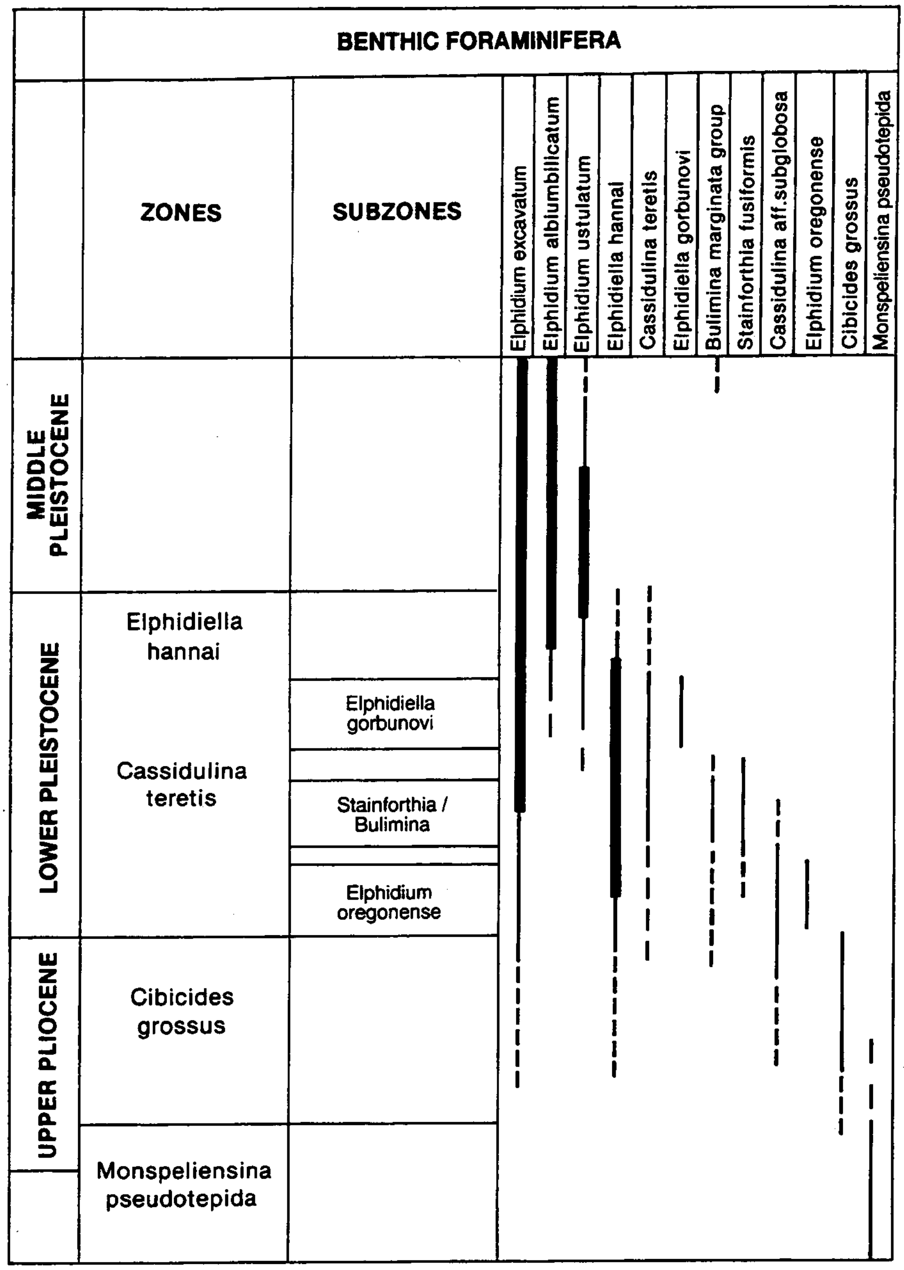

Fig. 4: Distribution chart of the species characteristic of the Lower Pleistocene in the Danish central North Sea. Compiled mainly from the boreholes E-1, P-1 and TWB-12.

The emended zonation

The most detailed of the previously established foraminiferal zonations for the Early Pleistocene of the North Sea Basin were made by Doppert (1980) and King (1983, 1989), while a detailed chronostratigraphy has been compiled by Zagwijn (1989; 1992). The correlation of these zonations and stratigraphies with the emended zonation for Lower Pleistocene proposed in this paper is shown in Figs. 2 and 3. A correlation between some of the examinated sites from the Danish sector is shown on Fig. 5.

The study of the Lower Pleistocene deposits from the North Sea region presented in this paper has revealed two, not previously described, faunal assemblages in the central North Sea. The two new assemblages can be recognized and correlated in most of the examined boreholes in the Central Trough area, and are thus considered valid as Subzones in the region. The two new Subzones are placed within NSB 16b (King, 1983) or FA1 (Doppert, 1980), and are found as well above the Elphidium oregonense Subzone (NSB 16a King, 1983; F_I Doppert, 1980) as above the Cibicides grossus Zone (NSB 15b King, 1983, 1989) (Fig. 2). The two new Subzones are formally presented and defined below, together with comments on the implications for the previously established zonation.

Monspeliensina pseudotepida Zone.
This Zone was defined by King (1983) as Zone NSB 14 and is included in the emended zonation without revision.

Age: The top of the Zone is defined by the last occurrence of Monspeliensina pseudotepida (van Voorthuysen), and King (1983) refers this Zone to the Early Pliocene. In 1989 King, through correlation with the North Atlantic Ocean, revises the age of his Pliocene and Pleistocene Zones, and the range of Monspeliensina pseudotepida now extends into the Late Pliocene. The results found in this study, and discussed later in this paper, may indicate, that the range of Monspeliensina pseudotepida is diachronous.

Areal Distribution: The Monspeliensina pseudotepida Zone is present at almost all those examined sites, where Pliocene deposits occurs. In Diamant-1, Elly-1, Gert-1 and Gert-2 the LLO of Monspeliensina pseudotepida (Figs. 6a and 6b) is concurrent with the LLO of Cibicides grossus ten Dam & Reinhold. The Monspeliensina pseudotepida Zone is thin or absent in the northern North Sea (Seidenkrantz, 1992; King, 1989).

Cibicides grossus Zone.
This Zone was defined by King (1983) as Zone NSB 15 and is included in the emended zonation without revision.

Age: King (1983) referred this Zone to the Late Pliocene. In 1989, however, King placed the Pliocene/Pleistocene boundary at the first appearence (FAD) of the sinistral Neoglobo-quadrina pachyderma (Ehrenberg) (1.77 Ma in the North Atlantic), and stated that in the northern North Sea the LAD of Cibicides grossus ten Dam & Reinhold is found well above this datum (Fig. 2). In the southern and central North Sea the LLO of Cibicides grossus occurs below the FAD of Elphidium oregonense Cushman & Grant (2.00 Ma) (King, 1989), thus implying a strong diachronism of the LLO of Cibicides grossus between the northern and central/southern areas of the North Sea.

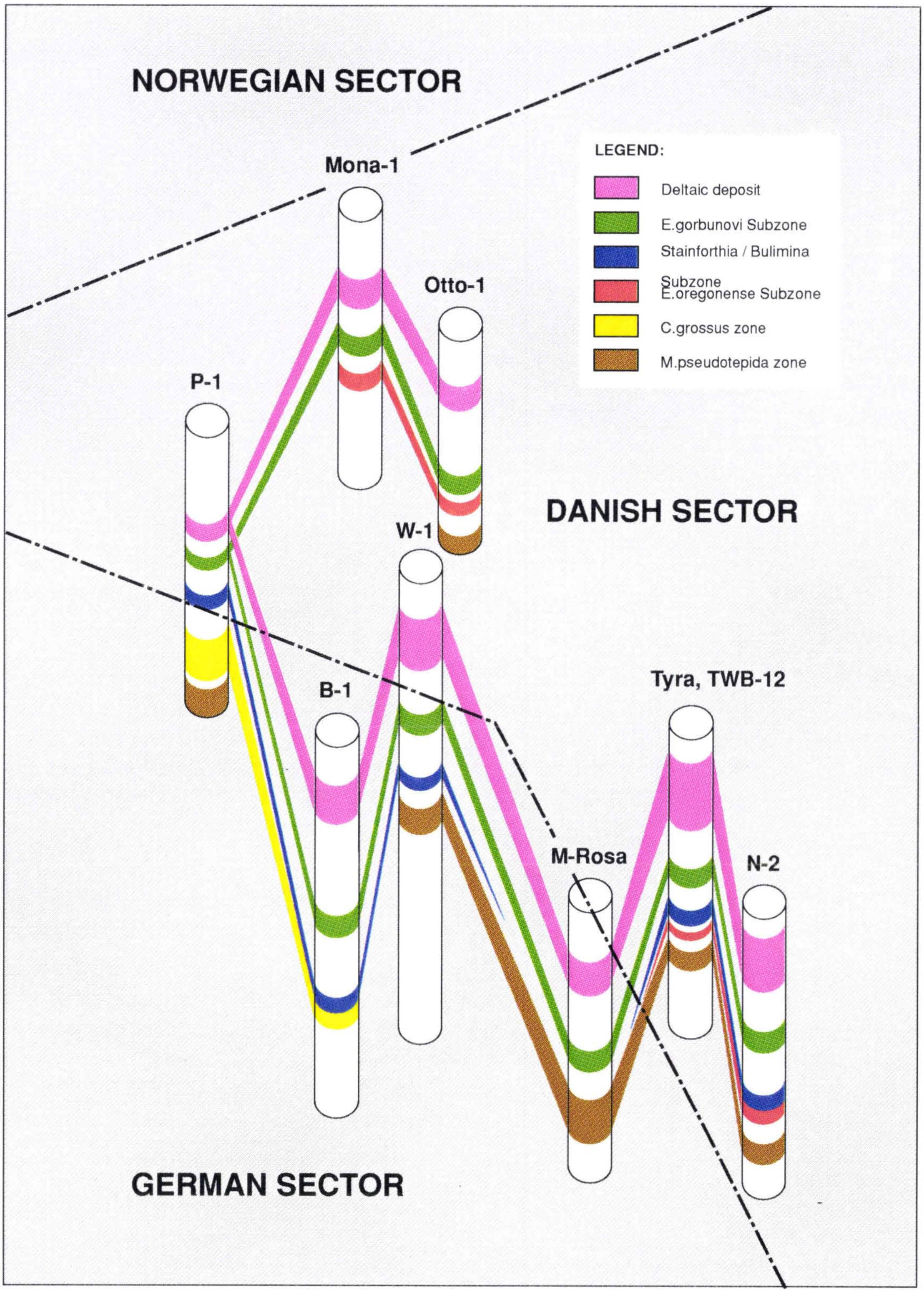

Fig. 5: Correlation between some of the examined sites from the Danish sector.

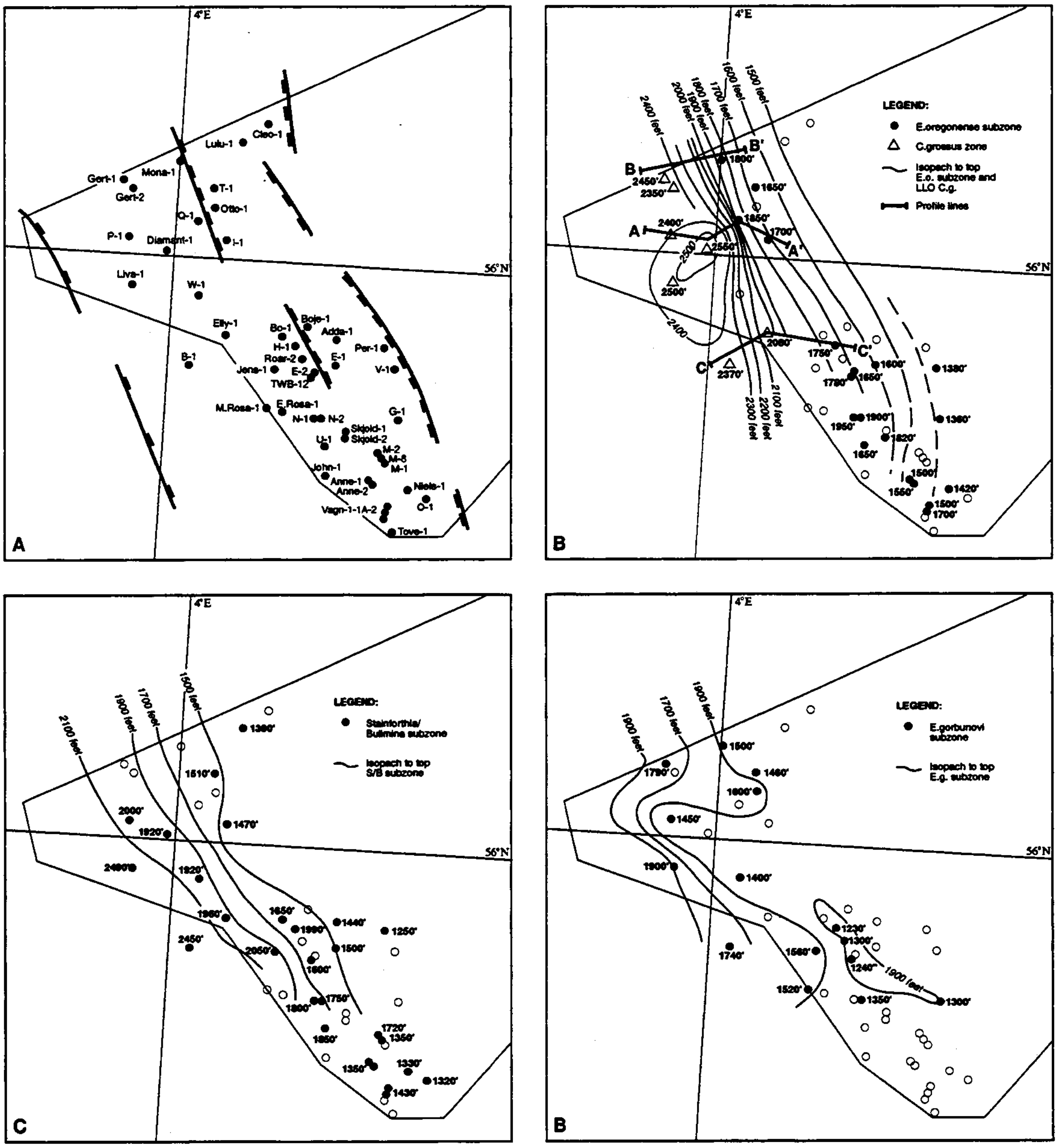

Fig. 6a: Detailed map of the Danish part of the Central Trough area showing examined sites and the general outline of the Central Trough.

Fig. 6b: Detailed map of the Danish and German parts of the Central Trough area with contour lines (depths in feet) to the top of the Elphidium oregonense Subzone and to the last local occurrence (LLO) of Cibicides grossus. The profiles indicated by the lines AA, BB and CC are shown on Fig. 7.

Fig. 6c: Detailed map of the Danish and German parts of the Central Trough area with contour lines (depths in feet) to the top of the Stainforthia/Bulimina Subzone.

Fig. 6d: Detailed map of the Danish and German parts of the Central Trough area with contour lines (depths in feet) to the top of the Elphidiella gorbunovi Subzone.

Areal Distribution: The Cibicides grossus Zone is recognized in Liva-1 and P-1 in the westernmost part of the Danish sector (Figs. 6a and 6b). The Zone is further recorded from the German (B-1), British and Norwegian sectors, the Arctic area and Siberia (McNeill, 1988, 1989; King, 1989; Feyling-Hanssen, 1990; Seidenkrantz, 1992; Jensen, in prep.; Laursen, in prep.).

Environmental indications: In the central North Sea Cibicides grossus normally occurs in a glauconitic clay, with no sand or coarser material. This indicates a low-energy environment for Cibicides grossus, and, presumably, relatively deep water far from the coast.

Elphidiella hannai - Cassidulina teretis Zone.
This Zone is equivalent to the Elphidiella hannai Zone (NSB 16) (King, 1983) and part of the Nonion labradoricum Zone (NSB 16x) (King, 1989). Zone NSB 16x replaces NSB 16 in the northern North Sea, where the scarcity of Elphidiella hannai Cushman & Grant makes the use of Zone NSB 16 difficult. The minimal overlap in the areal distributions of Elphidiella hannai and Nonion labradoricum (Dawson) does, however, make it difficult to establish the relationship between the two Zones. The author of this paper suggests that Cassidulina teretis Tappan is used as index fossil in those areas of the North Sea where Elphidiella hannai does not occur.

Reference section: Boring P-1: 360 - 800 m (1100 - 2520') bKB.

Redefinition: The interval from the last local occurrence of Cibicides grossus to the last local occurrence of Elphidiella hannai/Cassidulina teretis. The top of the Zone is placed, where both Elphidiella hannai and Cassidulina teretis have disappeared.

Redescription: The dominant foraminiferer in this Zone is usually Elphidium excavatum (Terquem). Elphidiella hannai and Cassidulina teretis are common associates, and other frequent foraminifera include Buccella frigida (Cushman) and Haynesina orbiculare (Brady). In the lowermost part of the Zone Cassidulina aff. subglobosa Brady occurs. At the top of their ranges Elphidiella hannai and Cassidulina teretis become rare, and it is difficult to decide whether their presence is due to reworking. In those strata the species Elphidium albiumbilicatum (Weiss) and Elphidium ustulatum Todd become increasingly frequent.

Events: Three events may be recognized in this Zone:

(1): the short range occurrence of Elphidium oregonense,

(2): an interval characterized by a high content of Stainforthia fusiformis (Williamson) and Bulimina spp,

(3): the short range occurrence of the arctic species Elphidiella gorbunovi Stschedrina.

These events are used to define the three Subzones defined below.

Age: Early (- Middle) Pleistocene.

In the central North Sea Elphidiella hannai is used as the biostratigraphic indicator of the Lower Pleistocene (e.g. Buch,1972; van Voorthuysen et al., 1972), and it usually disappears after Cassidulina teretis. In the northern North Sea Cassidulina teretis may range into the Middle Pleistocene (Sejrup et al., 1987), while Elphidiella hannai almost disappears at the top of the Cibicides grossus Zone (Seidenkrantz, 1992; King, 1989).

Areal Distribution: The Elphidiella hannai - Cassidulina teretis Zone is recognized in the entire North Sea area. In the southern and eastern parts of the area Elphidiella hannai is usually common, while Cassidulina teretis only occurs sporatically. At the northern and western sites Cassidulina teretis is common, while Elphidiella hannai almost disappears in the Pleistocene deposits. This areal distribution pattern is probably facies related, with Elphidiella hannai in the shallow water areas and Cassidulina teretis in deeper water (Funnell, 1989; Mackensen & Hald, 1988).

Elphidium oregonense Subzone (Local Range-subzone).
This Subzone was defined by King (1983) as Subzone NSB 16a, and is included in the emended zonation without revision.

Age: Praetiglian (2.3 - 2.0 Ma) (van Voorthuysen et al., 1972; Jenkins et al., 1985; Zagwijn, 1992).

Amino acid measurements on specimens of Elphidium oregonense Cushman & Grant from Tyra TWB-12 (Fig. 6a) were carried out by H. P. Sejrup at Bergen Amino acid Laboratory (BAL) (tabel 4). At present the results can not be converted directly to years, but the aIle/Ile (D-alloisoleusine/L-isoleusine) values of the specimens from the central North Sea does not indicate an age significantly different from that assigned to the Elphidium oregonense Subzone in the southern North Sea, i.e. 2.00 Ma. (pers. comm. H.P. Sejrup).

Areal Distribution: Elphidium oregonense is found in samples from the Danish sector of the North Sea (Figs. 5, 6b and 7) , and it is well known from the southern North Sea (van Voorthuysen et al., 1972; Doppert, 1980). King (1989) mentions it as very rare in the northern North Sea.

Environmental indications: In the central North Sea Elphidium oregonense is found in coarse sediments consisting mainly of quartz-sand and small pebbles, and usually containing mollusc shells. This indicates a high-energy environment, presumebly, near the coast and with relatively shallow water.

Stainforthia/Bulimina Subzone (Acme-subzone).

Reference section : (1) Tyra, TWB-12: 510 - 530 m (1570 - 1660') bKB.
(2) E-1: 300 - 310 m (1500 - 1530') bKB.

Description : This Subzone is characterized by the acme of Stainforthia fusiformis (Williamson) and Bulimina spp. Other common species include Elphidium excavatum (Terquem), Elphidiella hannai Cushman & Grant, Cassidulina teretis Tappan and Haynesina orbiculare (Brady).

Age: Early Pleistocene.

The stratigraphic position and the enviromental indications of the Subzone suggest, that it may be referred to the Tiglian stage.

Events: Cassidulina aff. subglobosa Brady becomes extinct in the area in this Subzone.

Areal Distribution: The Subzone is recorded from the central North Sea area, and it is encountered as well above the Elphidium oregonense Subzone as above the Cibicides grossus Zone (Figs. 5, 6c, 7 and 8).

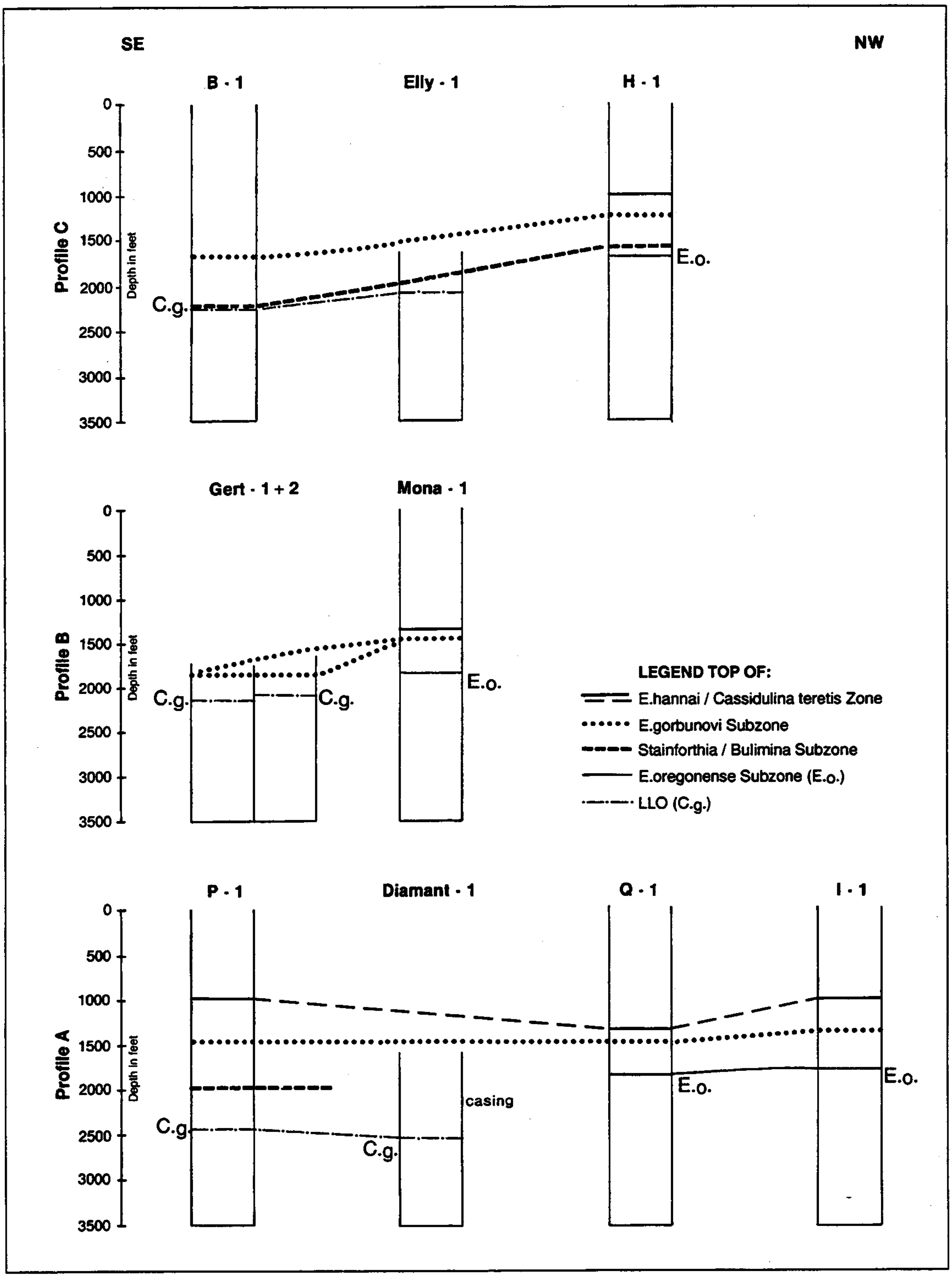

Fig. 7: Profiles across the Danish and German parts of the Central Trough area showing the top of the mentioned zones and subzones in selected boreholes. E.o. indicates the Elphidium oregonense Subzone and C.g. indicates the presence of Cibicides grossus. For the position of the profiles, see Fig. 6b.

Environmental indications: The faunal assemblage in the Subzone indicates full-marine conditions, boreal climate and water depths greater than found in the strata above or below (>100 m; Murray, 1971). In the Reference section Tyra, TWB-12, the number of specimens decline upwards in the Subzone.

Elphidiella gorbunovi Subzone (Local Range-subzone).

Reference section: (1) Tyra, TWB-12: 410 - 460 m (1240 - 1360') bKB.
(2) P-1: 460 - 470 m (1400 - 1430') bKB.

Definition: The Subzone is defined by the range of Elphidiella gorbunovi Stschedrina.

Description: Common species in the Subzone include Elphidium excavatum (Terquem) forma clavata Cushman, Buccella frigida (Cushman), Haynesina orbiculare (Brady) and Elphidium bartletti Cushman. The top of the Elphidiella gorbunovi Subzone is stratigraphically before the first common occurrence of Elphidium albiumbilicatum (Weiss) and Elphidium ustulatum Todd in the investigated area.

Age: Early Pleistocene.

The stratigraphic position and the enviromental indications of the Subzone suggest, that it may be referred to a cold interval in either the Eburonian or the Menapian stage.

Areal Distribution: The Elphidiella gorbunovi Subzone is identified in the Danish, German and British sectors of the central North Sea (Figs. 5, 6d, 7 and 8). In the borehole TWB-12 (quantitatively analysed) the species forms <5 % of the total fauna. Elphidiella gorbunovi is also known from the Lower Pleistocene of the northern North Sea, and from the Arctic area and Sibiria (Feyling-Hanssen, 1990; McNeil, 1988, 1989; Voloshinova et al., 1970).

Environmental indications: Elphidiella gorbunovi is an arctic species first described from the Recent of the Kara Sea (Stschedrina, 1946) (Fig. 9). The faunal assemblage in the Subzone indicate water depths <50 m and an arctic climate (Stschedrina, 1946; Voloshinova, 1958; Loeblich & Tappan, 1953).

Elphidium albiumbilicatum and Elphidium ustulatum are common in the upper part of the Elphidiella hannai - Cassidulina teretis Zone, and characteristic of the deposits above. These deposits are referred to the Middle Pleistocene, and will not be treated further in this paper.

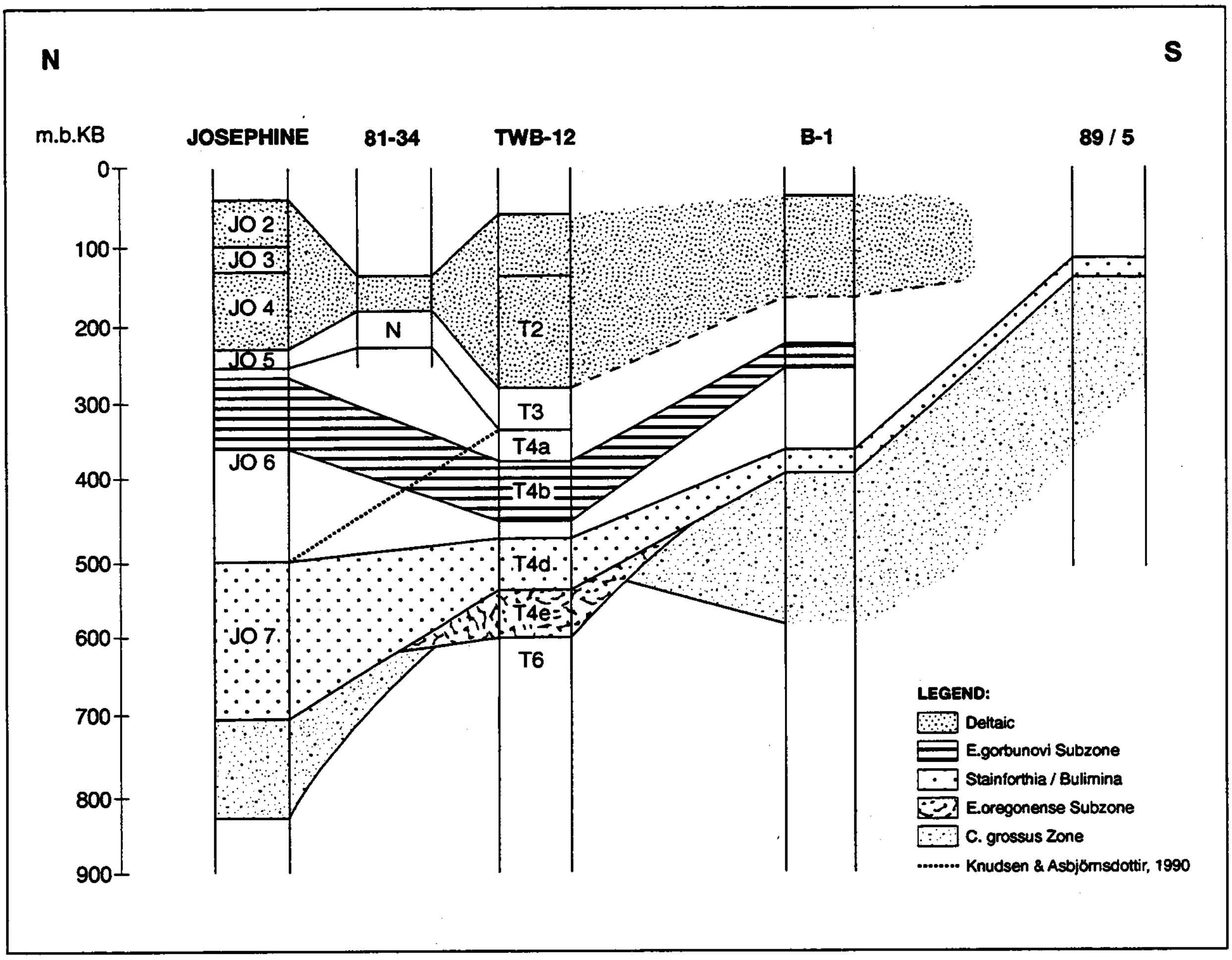

Fig. 8: Stratigraphic correlation of Tyra, TWB-12 form the Danish sector with zonations from boreholes in the British and German sectors.

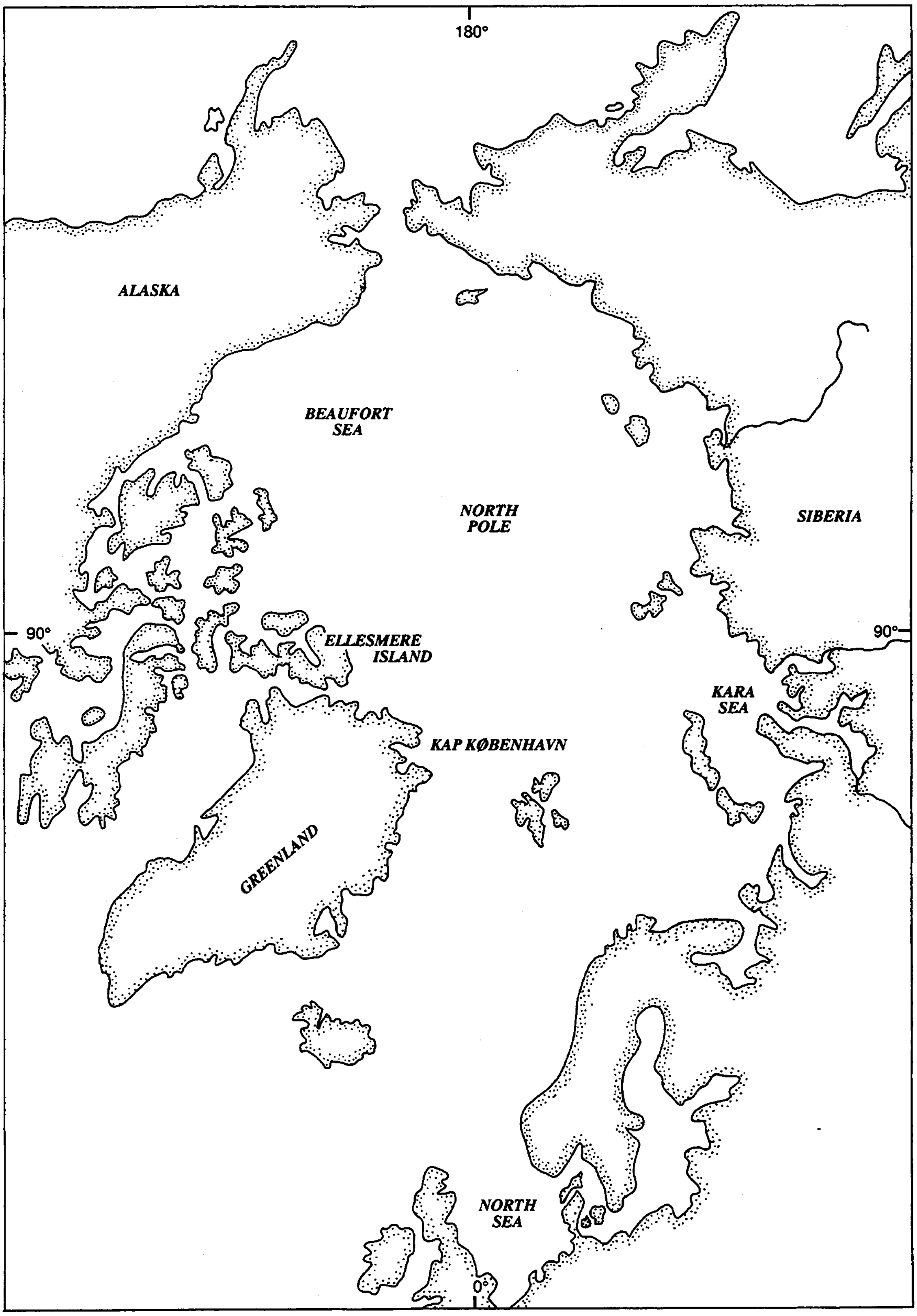

Fig. 9: Map of the Arctic area showing the sites mentioned in the text.

Correlations and discussion

The Cibicides grossus Zone and the Elphidium oregonense Subzone

Central North Sea

In the NSB zonation (King, 1983; 1989) Cibicides grossus and Monspeliensina pseudotepida are index species for the zones NSB 14 and NSB 15, respectively, and their ranges do not overlap. In the central North Sea the faunal analyses reveal, that the Cibicides grossus Zone occurs in Liva-1 and P-1, and also in B-1 in the German sector (Laursen, in prep.) and in BH 89/5 in the British sector (Jensen, in prep.). In the boreholes Gert-1, Gert-2, Diamant-1 and Elly-1, however, the two species are found in the same samples. The LLO of Cibicides grossus is here concurrent with the LLO of Monspeliensina pseudotepida, and, thus, though the index species is present, the Cibicides grossus Zone appears to be missing at the three sites. This may be caused by:

1: diachronism in the occurrence of Monspeliensina pseudotepida, i.e. the species disappearing later than stated by King (1983; 1989).

2: diachronism in the occurrence of Cibicides grossus, i.e. the range of the species starting earlier than stated by King (1983; 1989).

3: specimens of Monspeliensina pseudotepida may have been reworked into the Cibicides grossus Zone.

4: material from a thin (< 10 m) unsampled Cibicides grossus Zone may have caved into the range of Monspeliensina pseudotepida during the drilling, i.e. downhole contamination.

The author of this paper has, therefore, chosen to further consider the LLO of the species Cibicides grossus rather than the top of the Cibicides grossus Zone (Fig. 6b).

In the central North Sea area Elphidium oregonense and Cibicides grossus do not occur in situ at the same site, and the temporal relationship between the two species has long been uncertain. The investigation of faunal assemblages, seismics and sediments from boreholes in the western part of the Danish sector attempts to clarify this relationship (Figs. 5, 6b and 7).

The examination of the sediments reveals a probable explanation for the separated occurrence of the two species: Elphidium oregonense is found in coarse sediments consisting mainly of quartz-sand and small pebbles, and usually containing mollusc shells, while Cibicides grossus normally occurs in a glauconitic clay, with no sand or coarse material. This indicates a low-energy environment for Cibicides grossus, and, presumably, relatively deep water far from the coast, while the indication for Elphidium oregonense is of a high-energy environment, presumably, near the coast and with lower water depth. A facies difference that may be regional and/or time-related.

Correlations between the boreholes containing Elphidium oregonense and those containing Cibicides grossus reveals, that the stratum containing Elphidium oregonense is found 2-300 m (5-600') above the LLO of Cibicides grossus (Fig. 7). This seems to indicate, that Cibicides grossus either becomes extinct in the central North Sea before the appearance of Elphidium oregonense or that erosion later removed the top of the Cibicides grossus range. Examination of the seismics from the central North Sea shows salt-related tectonics disturbing the Quaternary reflectors in the southeastern part of the Central Trough area. In the western area, where Cibicides grossus is found, the reflectors are, however, parallel, dipping only slightly to the west, with no indications of faults, channels, submarine slopes or other unconformities. Local erosion of 2-300 m of sediments is, therefore, considered unlikely, and deposits contemporary with the Elphidium oregonense Subzone should be present above the LLO of Cibicides grossus. In P-1 a subzone with a high content of Cassidulina spp. (subzone P4f) is found above the Cibicides grossus Zone (Pedersen, 1995). This subzone is, tentatively, considered older than the Elphidium oregonense Subzone found east of the site, but the two subzones may also be contemporary.

The author of this paper is in favor of the theory, that Cibicides grossus becomes extinct in the North Sea area, during the Late Pliocene and Early Pleistocene regressions. In the central North Sea Cibicides grossus disappears before the first occurrence of Elphidium oregonense, and the extinction of Cibicides grossus is probably hastened by a deltaic progradation from the southeast (Zagwijn, 1989).

The Elphidium oregonense Subzone is very thin, and the faunal content does not appear to vary within the Subzone. It is, therefore, not possible to determine whether its full range is preserved at all the sites.

Northern North Sea

In the northern North Sea Cibicides grossus ranges above the rare occurrences of Elphidium oregonense, as well as above the FAD of the sinistral Neogloboquadrina pachyderma (1.77 Ma, Shackleton et al., 1990) (King, 1989).

Elphidium oregonense is an inner shelf, coldwater species (Anderson, 1963). It is found only rarely in the northern North Sea, but may have a different range in the this area, than in the southern and central North Sea.

At the Gullfaks site in the northernmost North Sea the LLO of Cibicides grossus is found to be contemporary with the last occurrence of Neogloboquadrina atlantica (2.3 Ma, Weaver & Clement, 1986) (Seidenkrantz, 1992). In the northern North Sea the water depths are generally greater than in the central part, and the environment less sensitive to climatic changes. It is, therefore, possible that Cibicides grossus survived longer in the this part of the North Sea.

The Stainforthia/Bulimina and Elphidiella gorbunovi Subzones

Central North Sea

Borehole TWB-12 in the Tyra West field (Fig. 1) is chosen as representive for the sites investigated in the Danish sector, and correlations between this borehole and investigations from the British and German sectors are shown in Fig. 8. The zonation in TWB-12 is based on quantitative foraminiferal analysis on material from cutting samples (Pedersen, 1987; 1995).

BH 89/5: In borehole BH 89/5 (Fig. 1) Jensen (in prep.) is making quantitative foraminiferal analysis on core samples, and the Stainforthia/Bulimina Subzone is recognized within the Elphidiella hannai/Cassidulina teretis range (Fig. 8).

Josephine and BH 81/34: Quantitative foraminiferal analysis have been made on cuttings from the Josephine borehole (Fig. 1) by Knudsen & Ásbjörnsdóttir (1991). The Stainforthia-/Bulimina Subzone is well defined at the Tyra site (Subzone T4d) (Pedersen, 1995), but it is not found in the Josephine borehole (Knudsen & Ásbjörnsdóttir, 1991). The depositional environment is, however, the same in the zone Jo7 at Josephine as in Subzone T4d at Tyra, and the zone Jo7 is considered correlatable with Subzone T4d (Fig. 8). Knudsen & Ásbjörnsdóttir (1991) correlates the decline in the number of Cassidulina teretis at the top of zone Jo7, with the decline in the number of Elphidiella hannai at the top of Zone T4 at Tyra (Knudsen, pers. comm. 1991), thus suggesting, that the samples containing Elphidiella gorbunovi in Josephine (upper part of zone Jo6) are younger than the Elphidiella gorbunovi zone in TWB-12 (Subzone T4b). Since Cassidulina teretis and Elphidiella hannai have separate enviromental preferences, and, therefore, may react differently to environmental changes, the author of this paper has chosen to disagree with the correlation above, and to correlate the samples containing Elphidiella gorbunovi in zone Jo6, with the Elphidiella gorbunovi Subzone defined in TWB-12 and P-1.

In TWB-12, above the Elphidiella gorbunovi Subzone, faunal assemblages with a strong dominans (> 90 %) of Elphidium excavatum, occurs (Zone T3) (Pedersen, 1995). Similiar Zones are found in 81/34 (Zone 34 N) (Knudsen & Sejrup, 1993) and Josephine (Zone Jo5) (Knudsen & Ásbjörnsdóttir, 1991). Zone 34 N is considered older than the palaeomagnetic Brunhes/Matuyama boundary (0.7 Ma), but younger than the normal-magnetic Olduvai event (ca. 1.8 Ma) (Knudsen & Sejrup, 1993). These correlations, thus, dates the Elphidiella gorbunovi Subzone to between 1.8 and 0.7 Ma.

B-1: In cutting samples from borehole B-1 (Fig. 1) Laursen (in prep.) finds faunal assemblages quite similar to those in TWB-12 incl. the Stainforthia/Bulimina Subzone and the Elphidiella gorbunovi Subzone (Tabel 1, Figs. 5, 6b, 7 and 8).

The site of the B-1 borehole in the German sector was a coastal area during the upper Early Pleistocene (Bavelian, 1.00 - 0.75 Ma) (Zagwijn, 1989), but neither the faunal assemblages nor the sediments found in the Elphidiella gorbunovi Subzone indicates a near-coastal environment, either at B-1 or at any of the other sites. The Subzone is, therefore, considered older than the Bavelian Complex stage.

It is not possible to refer the Elphidiella gorbunovi Subzone to a specific stratigraphic stage within the interval (1.8 - 1.00 Ma), but considering the arctic indication of the faunal assemblage, it must belong in a quite cold interval, and the Subzone is, therefore, tentatively referred to either the Eburonian or the Menapian stage (Fig. 3).

Northern North Sea

Elphidiella gorbunovi is found in arctic faunas of Early or Middle Pleistocene age at two of the investigated sites in the Norwegian sector. It is not possible to determine whether these faunal assemblages are contemporary with the Elphidiella gorbunovi Subzone found in the central North Sea.

Regions outside the North Sea area

Elphidiella gorbunovi is found by McNeil (1988) in Pliocene deposits on Ellesmere Island and in the Beaufort-Mackenzie Basin (Fig. 9), and by Voloshinova et al. (1970) in unspecified Quaternary deposits in Western Sibiria.

McNeil (1989) defines a Pleistocene Cibroelphidium ustulatum Interval Zone (Elphidium ustulatum in this paper) above a Cibicides grossus Interval Zone in the Beaufort-MacKenzie Basin, and mentions Elphidiella gorbunovi as one of the species typical of this Zone (Fig. 9).

Within the ranges of Elphidium ustulatum and Elphidiella hannai Feyling-Hanssen (1990) defines an Elphidiella gorbunovi Zone in northern Greenland as the youngest part of the Kap København Formation (Fig. 9), somewhere above the Pliocene/Pleistocene boundary.

Both Elphidiella hannai and Elphidiella gorbunovi are, however, found Recent in areas connected with the Arctic ocean (Stschedrina, 1946; Cushman & Grant, 1927), and their presence in the Arctic deposits can, therefore, not be used in correlating with the North Sea.

Conclusion

In the central and southern North Sea it has so far been possible to recognize the international Pliocene/Pleistocene boundary only, where palaeomagnetic analyses identified the top of the Olduvai Event (1.77 Ma). It is likely that this Event is situated within the upper part of the Stainforthia/Bulimina Subzone, and/or that the Elphidiella gorbunovi Subzone is found just above the Event. More investigations may, therefore, make it possible for one or both of these datums to serve as biostratigraphic markers for the boundary.
Within the central North Sea, the last local occurrence of Cibicides grossus appears to be older than the Elphidium oregonense Subzone (approximately 2.00 Ma). In the northern North Sea Cibicides grossus ranges above the change from mainly dextral to mainly sinestral Neogloboquadrina pachyderma (1.77 Ma), and the datum here appears to be younger than the very rare findings of Elphidium oregonense. This may imply a diachronism in the LLO of Cibicides grossus between the northern and the central North Sea, and make the use of the datum uncertain.

No data has yet been presented indicating a diachronism in the occurrence of Elphidium oregonense, and, where present, this datum appears to be the most reliable of the biostratigraphic markers in that time and area. In this paper the base of the Lower Pleistocene has, therefore, for practical purpose, been considered concurrent with the base of the Elphidium oregonense Subzone.

Immediately above the Elphidium oregonense Subzone and above the top of the Cibicides grossus Zone occurs an interval with faunal assemblages indicating deep water and an ameliorated climate. In the central North Sea this interval is characterized by a large number of Stainforthia fusiformis and other Buliminidae, and is identified as the Stainforthia/Bulimina Subzone. The environmental indications of the faunal assemblage makes a Tiglian age likely.

It is not possible to refer the Elphidiella gorbunovi Subzone to a specific stratigraphic stage, but the stratigraphic and environmental implication of the faunal assemblage indicates one of the cold stages in the Early Pleistocene, and biostratigraphic correlations to sites in the British and German sectors narrows the range to either the Eburonian or the Menapian stage.

Palaeontological notes

In the following notes, concerning range and ecology of diagnostic species used in the present investigation, the suprageneric classification is arranged according to Loeblich & Tappan (1988).

Order: FORAMINIFERIDA Eichwald.
Suborder: ROTALIINA Delage.
Superfamily: CASSIDULINACEA d'Orbigny.
Family: CASSIDULINIDAE d'Orbigny.
Subfamily: CASSIDULININAE d'Orbigny.
Genus: Cassidulina d'Orbigny.
Type species: Cassidulina laevigata d'Orbigny 1826.

Cassidulina aff. subglobosa Brady
1884 Cassidulina subglobosa Brady, p. 430, pl. 54, Fig. 17.

Remarks: Cassidulina aff. subglobosa's apperture is rather variable, but sometimes resembles the apperture of the typical Cassidulina subglobosa Brady. In shape, however, the test shows a greater affinity to Cassidulina brocha Poag or the Cassidulina reniforme Nørvang type, which has non-inflated chambers (Knudsen, 1977; Pedersen, 1987; 1995).

Stratigraphic range in the North Sea: This small Cassidulina occurs in and below the Stainforthia/Bulimina Subzone and may be an indicator of lowermost Early Pleistocene and uppermost Late Pliocene.

Cassidulina teretis Tappan
Plate I, Fig. 5.
1951 Cassidulina teretis Tappan, p. 7; pl. 1, Fig.30

Environmental preference: Arctic/Boreo-arctic (Mackensen & Hald, 1988).

Stratigraphic range in the North Sea: Early Pliocene-Lower (Middle) Pleistocene (King,1983). Cassidulina teretis appears to range into the Middle Pleistocene in some parts of the North Sea (Sejrup et al., 1987).

Superfamily: TURRILINACEA Cushman.
Family: STAINFORTHIIDAE Reiss.
Genus: Stainforthia Hofker.
Type species: Virgulina concava Höglund, 1947.

Stainforthia fusiformis (Williamson)
Plate II, Fig. 1.
1858 Bulimina pupoides var. fusiformis Williamson, p. 63; pl. 5, Figs. 129-130.

1973 Stainforthia fusiformis (Williamson) - Haynes, pp.124; pl.5, Figs. 7-8.

Remarks: In the central North Sea an interval containing large numbers of Stainforthia fusiformis and other Buliminidae occurs both above the Elphidium oregonense range and above the LLO of Cibicides grossus.

Environmental preference: Boreal, mainly 50-100 m (Murray, 1971).

Stratigraphic range in the North Sea: Miocene-Recent (Kihle & Løfaldli, 1974).

Superfamily: PLANORBULINACEA Schwager.
Family: CIBICIDIDAE Cushman.
Subfamily: CIBICIDINAE Cushman.
Genus: Cibicides de Montfort.
Typespecies: Cibicides refulgens, de Montfort, 1808.

Cibicides grossus ten Dam & Reinhold
Plate I, Fig. 1-2.

1941 Cibicides lobatulus (Walker & Jacob) var. grossus ten Dam & Reinhold, p. 62;pl. 5, Fig. 5; pl.6, Fig. 1.

1980 Cibicides grossus (ten Dam & Reinhold) - Doppert; pl.5, Figs. 3a-c. Stratigraphic range in the North Sea: Pliocene (King, 1983). In the northern North Sea also into Early Pleistocene (King, 1989).

Superfamily: ASTERIGERINACEA d,Orbigny.
Family: EPISTOMARIIDAE Hofker.
Subfamily: EPISTOMARIINAE Hofker.
Genus: Monspeliensina Glacon & Lys.
Typespecies: Monspeliensina vulpesi, Glacon & Lys, 1968.

Monspeliensina pseudotepida (van Voorthuysen)

1950 Streblus beccari (Linneaeus) var. pseudotepidus van Voorthuysen, p.45, pl.4, Fig. 8a-c.

1976 Monspeliensina pseudotepida (van Voorthuysen) - Meuter & Laga; pl. 1, Fig. 5.

Stratigraphic range in the North Sea: Late Miocene-Early Pliocene (Doppert, 1980). King (1989) also into Late Pliocene.

Family: ELPHIDIIDAE Galloway.
Subfamily: ELPHIDIINAE Galloway.
Genus: Elphidiella Cushman.
Type species: Polystomella arctica Parker & Jones, 1864.
Remarks:

Stschedrina (1946) claimed to find intermediate forms between Elphidiella and Elphidium and, consequently, does not accept the genus Elphidiella as a valid taxon. Hansen & Lykke-Andersen (1976) did, however, study the test structures of several Elphidiidae in detail and found definite differences between the two genera. They demonstrated that the "double" row sometimes occuring in Elphidium groenlandicum Cushman merely is a single irregular row, while Elphidiella hannai Cushman & Grant is a true Elphidiella.

Elphidiella gorbunovi (Stschedrina), 1946.
Plate II, Fig. 2-3 + 6.

Synonymy:
1946 Elphidium gorbunovi n.sp. Stschedrina, p. 144; pl. 4, Figs. 21a-b.

1958 Elphidiella gorbunovi (Stschedrina) - Voloshinova, p. 184; pl. 10, Fig. 8a, b.

1970 Pseudoelphidiella gorbunovi (Stschedrina) - Voloshinova et al., p. 179; pl. 49, Fig. 3.

1980 Elphidiella sibirica (Goes) - Feyling-Hanssen, p. 10.

1990 Elphidiella gorbunovi (Stschedrina) - Feyling-Hanssen, p. 29; pl. 6, Figs. 15, 16.

Original description. Translated from Russian.

Test large, almost round, convex on both sides with an even or slightly lobulate peripheral margin. Umbilical region protruding on both sides. The initial part of the last whorl is provided with a broad, thin, laminar keel along the periphery. Chambers in the last whorl in the adult forms number from 15 to 20. Chambers narrow, long and slightly curved. Sutures broad, slightly depressed with a double row of numerous pores. Wall of the test very thick, of a greenish or yellowish colour, pierced by large, oblique canals extending out from the openings between the bridges and forming a herringbone pattern on the wall of the test, which is very characteristic for this form. This pattern is especially visible on the initial part of the test. Umbilical region covered with sculpture composed of transparent shell material. Aperture consists of a row of elongated openings at the base of the low apertural face. Diameter of the test up to 1 mm.

Remarks: Voloshinova et al. (1970) suggest that Elphidiella gorbunovi and Elphidium groenlandicum may be identical. Hansen & Lykke-Andersen (1976), however, demonstrated that the "double" row sometimes occuring in Elphidium groenlandicum is merely a single irregular row. The material from the Norwegian sector examined in this paper, further, contained typical specimens from both species, and the author found several definite differences between the two species. First of all the double row of sutural pores in Elphidiella gorbunovi is well defined and clearly separated, while the sutural pores of Elphidium groenlandicum usually forms a single, slightly uneven line. Elphidium groenlandicum also does not posses a keel, and the wall of Elphidium groenlandicum is more coarsely pored than Elphidiella gorbunovi (Plate II).

Environmental preference: Elphidiella gorbunovi was found living in the arctic Kara Sea at depths from 16,5 to 47 m (Stschedrina, 1946).

Stratigraphic range in the North Sea: Early Pleistocene (Elphidiella gorbunovi Subzone)-(Pedersen, this paper).

Elphidiella hannai Cushman & Grant
Plate I, Fig. 6-7.

1927 Elphidiella hannai Cushman & Grant, p. 77; pl. 8, Fig. 1.

Remarks: Elphidiella hannais aperture consists of a row of pores, but the apertural face and the initial part of the last coil is often obscured by a covering of papillae. Elphidiella hannai's periphery is often subacute in small specimens, while in large specimens usually becomes broadly rounded.

Elphidiella hannai is found Recent in the northern Pacific (Cushman & Grant, 1927; Funnell, 1989).

Environmental preference: Arctic/Boreo-arctic, Littoral - Inner shelf (Cushman & Grant, 1927; Funnell, 1989).

Stratigraphic range in the North Sea: Pliocene-Early Pleistocene (King, 1989).

Genus: Elphidium de Montfort.
Typespecies: Nautilus macellus var. B Fichtel & Moll, 1798.

Elphidium albiumbilicatum (Weiss)

1954 Nonion pauciloculum Cushman subsp. albiumbilicatum Weiss, p. 157; pl.32, Figs. 1-2.

1971 Elphidium albiumbilicatum (Weiss) - Knudsen (ed.); In: Feyling-Hanssen et al., pp. 265; pl. 10, Figs. 15-19, pl.19, Figs. 4-8.

Remarks: The high content of Elphidium albiumbilicatum in the Middle Pleistocene deposits found in the central North Sea, is thought to indicate lowered salinties as found in deltaic or near-shore conditions.

Environmental preference: Boreal/Boreo-arctic, tidal to inner shelf, tolerates brackish water (Lutze, 1965, Feyling-Hanssen, 1983).

Stratigraphic range in the North Sea: Late Pliocene-Recent (Jensen, in prep.; Kihle & Løfaldli, 1974).

Elphidium oregonense Cushman & Grant
Plate I, Fig. 2-3.

1927 Elphidium oregonense Cushman & Grant, p. 79; pl. 8, Fig. 3.

Remarks: Elphidium oregonense is strongly compressed with nearly parallel sides and a broadly rounded periphery. It is strongly umbonate with a very distinct boss at the umbilicus. Elphidium oregonense further has an aperture consisting of a low broad opening at the base of the apertural face, and usually distinct supplemental pores set in the apertural face.

Environmental preference: Arctic, Inner shelf. Recent enviroment: inner shelf, <50 m, 2-9°C (Anderson, 1963). Elphidium oregonense was found living in the arctic Bering Sea (Anderson, 1963).

Stratigraphic range in the North Sea: (Late Pliocene-) Earliest Pleistocene (Doppert, 1980).

Elphidium ustulatum Todd

1957 ?Elphidium ustulatum Todd, p. 230; pl. 28, Fig. 16.
Stratigraphic range in the North Sea: Pleistocene. The species is usually limited to Pre-Eemian, but may range into the Weichselian (Lykke-Andersen, 1987, King, 1989).

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Danish summary/dansk sammendrag

På basis af en undersøgelse af bentiske foraminiferer fra 66 boringer fra den centrale og nordlige Nordsø foreslås en udvidet zonation for Nedre Pleistocæn i Nordsøen.

En undersøgelse af den tidsmæssige sammenhæng mellem den sidste regionale optræden af Cibicides grossus i den centrale Nordsø, og Elphidium oregonense Subzonen i samme område viste, at den sidste regionale optræden af Cibicides grossus er ældre end Elphidium oregonense Subzonen. Undersøgelsen viste også at de to arter tilhører hver sin facies, idet Cibicides grossus optræder i finkornede, glauconit-holdige sedimenter, mens Elphidium oregonense findes i grovkornede sedimenter, hovedsageligt bestående af kvartssand og skalgrus.

Såvel over den sidste regionale optræden af Cibicides grossus som over Elphidium oregonense Subzonen er der i den centrale Nordsø fundet to nye Subzoner, der defineres i denne artikel. Den nedre af disse Subzoner (Stainforthia/Bulimina Subzone) karakteriseres af et højt indhold af Stainforthia fusiformis og andre Buliminidae, og indikerer et miljø med forholdsvist varmt klima og dybt vand. Det foreslåes at denne Subzone henføres til det varme Tegel interval.

Et stykke over Stainforthia/Bulimina Subzonen optræder den arktiske foraminifer Elphidiella gorbunovi i et ganske kort interval, og tilstedeværelsen af denne art i den centrale Nordsø anvendes som definition af Elphidiella gorbunovi Subzonen. Korrelationer til den Britiske del af Nordsøen giver en alder på denne Subzone på 1.8 -1.00 Ma, og da Subzonens faunaer mest består af arktiske/subarktisk arter henføres den til en af de kolde episoder i enten Eburon eller Menap intervallet.

Over Elphidiella gorbunovi Subzonen bliver Elphidium albiumbilicatum og Elphidium ustulatum de karakteristiske arter og både faunaer og sediment tyder på stadigt mere kystnære forhold. Disse aflejringer kan formodentligt helt eller delvist henføres til Mellem Pleistocæn.

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Plates I+II

Plates

Plate I

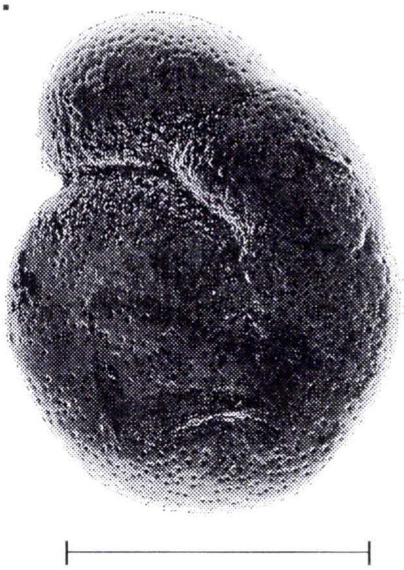
Scale 0,1 mm.
Fig. 1. Cibicides grossus ten Dam & Reinhold, 1941. Spiral view. Borehole P-1. Sample no. 2630. DGU no. 1992-amp-10.
Fig. 2. Cibicides grossus ten Dam & Reinhold, 1941. Edge view. Borehole P-1. Sample no. 2630. DGU no. 1992-amp-10.

Scale 1,0 mm.
Fig. 3. Elphidium oregonense Cushman & Grant, 1927. Side view. Borehole H-1. Sample no. 1740. DGU no. 1992-amp-9.
Fig. 4. Elphidium oregonense Cushman & Grant, 1927. Edge view. Borehole H-1. Sample no. 1740. DGU no. 1992-amp-9.

Scale 0,1 mm.
Fig. 5. Cassidulina teretis Tappan, 1951. Side view. Borehole Lulu-1. Sample no. 1210. DGU no. 1992-amp-2.
Fig. 6. Elphidiella hannai Cushman & Grant, 1927. Edge view. Borehole H-1. Sample no. 1440. DGU no. 1992-amp-5.
Fig. 7. Elphidiella hannai Cushman & Grant, 1927. Detail showing papillae on apertural face. Borehole H-1. Sample no. 1440. DGU no. 1992-amp-5.

Plate I

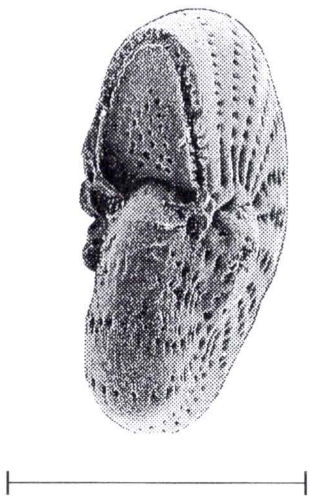
1.



2.

3.

4.



5.

6.

7.

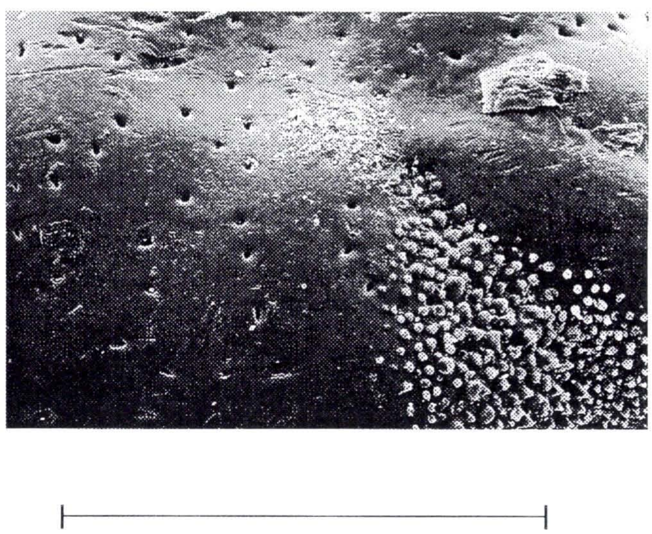


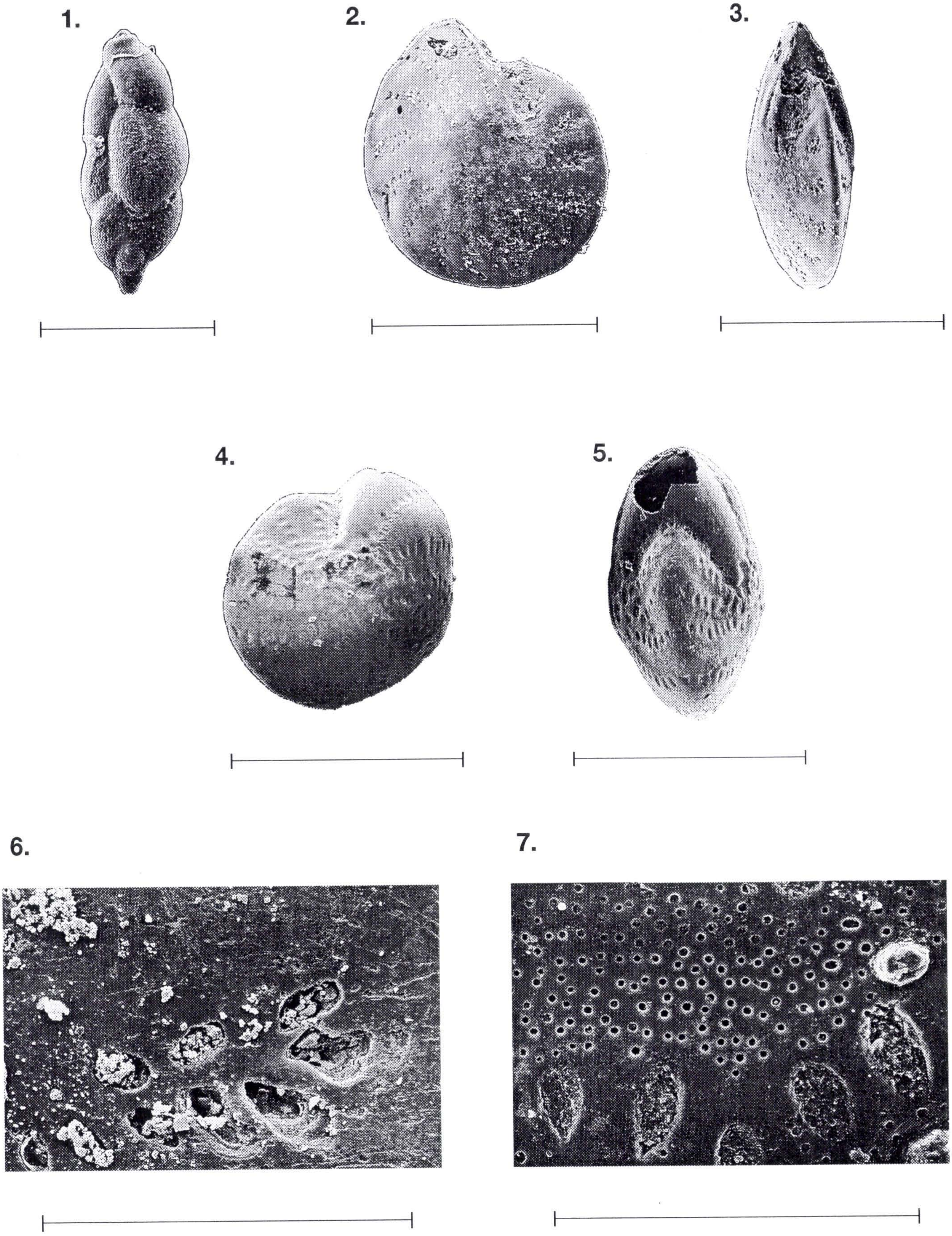
Plate II

Scale 0,1 mm.
Fig. 1. Stainforthia fusiformis (Williamson), 1858. Borehole H-1. Sample no. 1590. DGU no. 1992-amp-11.

Scale 1,0 mm.
Fig. 2. Elphidiella gorbunovi (Stschedrina), 1946. Side view. Borehole H-1. Sample no. 1320. DGU no. 1992-amp-1.
Fig. 3. Elphidiella gorbunovi (Stschedrina), 1946. Edge view. Borehole H-1. Sample no. 1320. DGU no. 1992-amp-1.
Fig. 4. Elphidium groenlandicum Cushman, 1933. Side view.
Kap København, Lok. 50. DGU no. 1992-amp-4.
Fig. 5. Elphidium groenlandicum Cushman, 1933. Edge view.
Kap København, Lok. 50. DGU no. 1992-amp-4.

Scale 0,1 mm.
Fig. 6. Elphidiella gorbunovi (Stschedrina), 1946. Detail showing the double row of sutural pores. Borehole H-1. Sample no. 1320. DGU no. 1992-amp-1.
Fig. 7. Elphidium groenlandicum Cushman, 1933. Detail showing the single uneven row of sutural pores and the coarse pores of the test.
Kap København, Lok. 50. DGU no. 1992-amp-4.

Plate II



Tables 1-4

Table 1: Depth to top of zones/subzones in feet below Kelly Bushing (bKB) in boreholes from the central North Sea (B-1: Laursen, in prep.; other sites: Pedersen, 1987 and this paper). Since most of the material were cutting samples, only the depth to the top of the zones/serie/sub-serie are usually given. The factors for transforming the depths from bKB to feet below seafloor (bsf) are listed as well.

Danish and German sectors							
KB to seafloor	Name	* E. oregon. / △ C. grossus	Stainforthia/ Bulimina	E. gorbunovi	E. hannai/ C. teretis	E. albiumbi./ E. ustulatum	Pre-Pleistocene
177	A-1	* 1500-1590	1350	–	1080	–	–
263	A-2	* 1500-1680	–	–	–	–	–
237	Adda-1	–	1440	–	–	–	1890 L. Pliocene
252	B-1	△ 2370	2370-2550	1740	–	660	–
236	Bo-1	–	1610-1700	–	1520	350-440	2330 Plio. - 2420 Mio.
249	Boje-1	–	–	–	1800	–	2250 Miocene
212	C-1	–	–	–	550	400	900 Miocene
340	Cleo-1	–	–	–	1200	–	1740 Pliocene
282	D-1	–	–	–	1020	360	1140 L. Pliocene
	Diamant-1	△2580	1920	–	<1590	–	2580 L. Pliocene
245	E-1	* 1590-1710	1500	–	710	–	2010 L. Pliocene
257	E-2	* 1650-1680	–	–	1150	–	2800 Pliocene
	Elly-1	△ 2080	1930-1990	–	<1810	–	2080 Pliocene
256	F-1	–	–	–	–	300	360 Oligocene
	Falk-1	–	–	–	360	–	660 Pliocene
282	G-1	* 1360	–	1300	670	–	1380 Pliocene
	Gert-1	△ 2450	–	1790	–	–	2480 Pliocene
	Gert-2	△ 2340	–	–	–	–	2370 Pliocene
274	H-1	* 1710-1770	1590	1230	1110	900	2220 L. Pliocene
310	I-1	* 1710	1350-1470	–	930	–	2600 Miocene
231	Inez-1	–	–	–	–	–	360 Middle Miocene
267	J-1	–	–	–	–	–	350 Cretaceous
244	Jens-1	–	1860-2130	1560	1410	1110	2160 Pliocene
264	John-1	–	–	–	840	–	1380 Pliocene
307	K-1	–	–	–	–	–	570 Oligocene
	Liva-1	△ 2580	2490	1890-1920	–	–	–
214	Lulu-1	–	1390	–	1120	940-1030	1840 Pliocene
250	M-1	–	–	–	960	–	1800 L. Pliocene
245	M-2	–	1720	–	1060	280-1000	1840 Pliocene
237	M-8	–	1350	–	1080	–	1990 Pliocene
336	Mona-1	* 1800	–	1500	1350	400-1820	2850 Miocene
234	N-1	* 1980	1800	–	900	420	–
223	N-2	* 1890	1740-1770	1260-1440	1170	480	1950 Pliocene
259	Niels-1	* 1420	1330	–	1060	–	1600 Pliocene
233	O-1	–	1310-1340	–	1040	–	1460 Pliocene
317	Otto-1	–	–	1530-1680	1380	750	2130 Pliocene
339	P-1	△ 2450	2000	1400	1100	980-1070	2810 L. Pliocene
233	Per-1	–	1170-1350	–	900	–	1560 Pliocene
321	Q-1	* 1850	–	–	1280	–	2600 L. Pliocene
206	R-1	–	–	–	680	–	830 L. Pliocene
264	Roar-2	–	–	1300	1150	1150	1900 Pliocene
231	M. Rosa-1	–	–	1520	1340	710	2210 Pliocene
228	E. Rosa-2	–	–	–	1830	–	2010 Pliocene
195	S-1	–	–	–	–	–	1110 L. Pliocene
243	Skjold-1	–	–	–	1190	–	1730 Pliocene
	Skjold-2	* 1820	–	–	1220	–	2120 L. Pliocene
298	T-1	* 1650	1500-1530	1410	1260	–	2010 Pliocene
246	Tove-1	–	–	–	1340	–	1610 Pliocene
	TWB-12	* 1720	1570-1660	1240	1000	520-1120	–
235	U-1	* 1740-2040	1740-1920	–	1170	–	–
271	V-1	* 1380	–	–	630	–	–
	Vagn-1	* 1500	1380-1470	–	1020	–	1890 Pliocene
	Vagn-1a	* 1680-1750	–	–	1180	–	–
248	Vagn-2	–	–	–	810	–	1920 L. Pliocene
285	W-1	–	1890-1950	1410-1530	1410	630-990	2310 Pliocene

Table 2: Depths to top of zones/subzones in feet bsf in selected boreholes mainly from the Statfjord/Gullfaks area in the Norwegian sector (Pedersen, this paper).

Norwegian sector					
Name	Nonion labradoricum	Stainforthia/ Bulimina	E. gorbunovi	C. teretis	E. groenlandicum
Balder DB1	<90	–	330	90	90
Sleipner–3003	–	–	50	50	4-56
Sleipner–4004	–	–	–	–	73
Sleipner–4003	–	–	–	–	210
Sleipner–4008A	–	–	–	–	260-420
34/10–1019	–	–	–	–	200-230
Statfjord 7721	–	300	–	<270	270–320
3506A	–	–	–	–	–
Statfjord C 79205	80	–	–	<80	80-340
2501 D	–	–	–	–	–
34/10–2020	160-200	–	–	<430	160-430
34/10–1005A	4-380?	–	–	<280	4-380
34/7–2001A	–	–	–	–	190-270
34/10–3008	–	–	–	–	430-460
Sleipner–5001A	–	–	–	–	–

Table 3: List of important species found in selected samples at some of the sites in the western part of the Danish sector. Sample No. indicates sample depth in feet bKB.

Diamant–1	
Sample No.	Species
1590	Elphidiella hannai
1620	Cassidulina teretis Haynesina orbiculare Buccella frigida Quinqueloculina seminulum group
1650	Elphidium excavatum Elphidiella hannai Cassidulina teretis Haynesina orbiculare Buccella frigida Quinqueloculina seminulum group
1680	Elphidium excavatum Cassidulina teretis Haynesina orbiculare
1710	Elphidium excavatum Haynesina orbiculare Cassidulina teretis Elphidiella hannai Buccella frigida Pyrgo sp.
1830	Elphidiella hannai Elphidium excavatum Cassidulina teretis
1920	Elphidiella hannai Cassidulina teretis Bulimina marginata group Casing
2040	Elphidiella hannai Elphidium excavatum Cassidulina teretis Haynesina orbiculare Cassidulina spp. Cibicides sp.

Diamant–1	
Sample No.	Species
2100	Elphidium excavatum Elphidiella hannai Cassidulina teretis
2160	Casing
2190	Casing
2250	Casing
2310	Elphidiella hannai Elphidium excavatum
2400	Elphidium aff. excavatum
2460	no foraminifera
2490	no foraminifera
2520	Elphidiella hannai Elphidium excavatum
2550	Elphidiella hannai Cassidulina teretis/carinata Elphidium excavatum
2580	Cibicides grossus Bulimina marginata group Monspeliensina pseudotepida Sigmoilopsis schlumbergeri Cassidulina pliocarinata Cassidulina teretis/carinata Elphidiella hannai Melonis affine Bolivina spathulata Cassidulina aff. subglobosa

Continued..

Elly-1	
Sample No.	**Species**
1810	Elphidiella hannai Haynesina orbiculare Elphidium excavatum
1900	Elphidiella hannai Elphidium excavatum Haynesina orbiculare miliolid
1930	Elphidiella hannai Cassidulina teretis Elphidium excavatum Cassidulina aff. subglobosa Lenticulina spp. miliolid Bulimina marginata group Stainforthia fusiformis
1960	Elphidium excavatum Elphidiella hannai Cassidulina teretis Ammonia batavus Bulimina marginata group (abundant)
1990	Elphidiella hannai Bulimina marginata group Cassidulina aff. subglobosa Cassidulina teretis Cibicides grossus (one specimen)
2020	Elphidiella hannai Cassidulina teretis Elphidium excavatum Cassidulina aff. subglobosa miliolid
2050	Elphidiella hannai Cassidulina teretis Cassidulina aff. subglobosa Elphidium excavatum Cibicides grossus (one specimen)
2080	Cibicides grossus (abundant) Lenticulina spp. Elphidiella hannai Nodosaria sp. Elphidium oregonense Monspeliensina pseudotepida Sigmoilopsis schlumbergeri

Elly-1	
Sample No.	**Species**
2110	Elphidiella hannai Sigmoilopsis schlumbergeri Cibicides grossus Lenticulina spp. Elphidium excavatum Elphidium bartletti Monspeliensina pseudotepida polymorphinid
2200	Cibicides grossus Elphidiella hannai miliolid Lenticulina spp. Cassidulina teretis Elphidium excavatum Monspeliensina pseudotepida
2320	Siphotextularia sculpturata (abundant) Monspeliensina pseudotepida Elphidium excavatum Cibicides grossus (abundant) miliolid
2410	Pullenia bulloides Siphotextularia sculpturata Pullenia bulloides Cassidulina pliocarinata Sigmoilopsis schlumbergeri Melonis affine Globigerina sp. Elphidiella hannai Loxostomum lammersi Cibicides grossus Haplophragmoides sp. miliolid
2500	Elphidium excavatum Florilus boueanun miliolid Melonis affine Sigmoilopsis schlumbergeri Cassidulina pliocarinata Siphotextularia sculpturata

Continued..

Gert–1	
Sample No.	Species
1790	Elphidium excavatum Cassidulina teretis Elphidiella gorbunovi
1880	Elphidium excavatum Cassidulina teretis Lenticulina spp.
1970	Elphidium excavatum Elphidiella hannai Haynesina orbiculare Cibicides grossus (one specimen)
2060	Elphidium excavatum Haynesina orbiculare Elphidiella hannai Cassidulina teretis
2120	Elphidiella hannai Elphidium excavatum Haynesina orbiculare
2210	Elphidium excavatum Elphidiella hannai Cassidulina aff. subglobosa
2300	Haynesina orbiculare
2420	Cassidulina teretis Bulimina marginata group Sigmoilopsis schlumbergeri (one specimen)
2450	Cassidulina teretis/carinata Monspeliensina pseudotepida Elphidiella hannai Bulimina marginata group Cibicides grossus Elphidium excavatum
2480	Cassidulina aff. subglobosa Bolivina spathulata Cassidulina pliocarinata Elphidiella hannai Bulimina marginata group Monspeliensina pseudotepida Buccella frigida Elphidium excavatum

Gert–2	
Sample No.	Species
2310	Elphidiella hannai Bulimina marginata group Elphidium excavatum
2340	Elphidiella hannai Monspeliensina pseudotepida Bulimina marginata group Cibicides grossus
2370	Monspeliensina pseudotepida Sigmoilopsis schlumbergeri Bolivina spathulata Elphidium excavatum

Continued..

Liva–1	
Sample No.	Species
1860	Cassidulina teretis Elphidium excavatum Elphidiella hannai Lagena sp. Cibicides grossus (one specimen)
1890	Elphidiella hannai Elphidiella gorbunovi miliolid Cassidiulina cf. teretis Haynesina orbiculare Elphidium excavatum
1920	Elphidiella gorbunovi Elphidiella hannai miliolid Cassidiulina cf. teretis Elphidium excavatum Haynesina orbiculare
2490	Elphidium excavatum Bulimina marginata group Elphidiella hannai Cassidulina aff. subglobosa Cassidulina teretis Stainforthia fusiformis Haynesina orbiculare
2520	Elphidiella hannai Cibicides grossus (one specimen) Elphidium excavatum Bulimina marginata group Haynesina orbiculare Cassiduline carinata Cassidulina teretis Lagena sp. Lenticulina spp.

Liva–1	
Sample No.	Species
2550	Elphidiella hannai Elphidium excavatum Bulimina marginata group Elphidiella gorbunovi (one specimen)
2580	Elphidiella hannai Cibicides grossus Elphidium excavatum Bulimina marginata group Haynesina orbiculare Cassidulina aff. subglobosa Cassidulina teretis
2610	Elphidium excavatum Stainforthia fusiformis Cassidulina teretis Cassidulina aff. subglobosa Cibicides grossus Elphidum aff. bartletti Bulimina marginata group Elphidiella hannai Lenticulina spp.

Table 4: Amino acid measurements made on specimens of Elphidium oregonense from Tyra, TWB-12 carried out by H. P. Sejrup at Bergen Amino acid Laboratory (BAL).

Lab.id	Location	Field nr.	Depth (m)	Species	HYD
BAL 2371	Tyra west	TWB-12 / 1690	460.0	Elph. oreg.	0.535
					0.546
BAL 2372	Tyra west	TWB-12 / 1720	460.0	Elph. oreg.	0.799
					0.629