PAPER 2

Pliocene - Middle Pleistocene Biostratigraphy in the Central Danish North Sea wells E-1, P-1 and TWB-12

BY

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Contents

Abstract

Six foraminiferal assemblage zones and 6 subzones have been identified in the boreholes TWB-12, P-1 and E-1. The zones cover the interval from the Pliocene to the Middle Pleistocene.

In TWB-12 and E-1 the Pliocene/Pleistocene boundary is placed at the first common occurrence of the species Elphidium oregonense. This species was not found in P-1, and the boundary is here, tentatively, placed above the last local occurrence of Cibicides grossus.

The palaeoecological variations indicated by the Pleistocene assemblages, suggest several oscillations both in water depth and in palaeotemperature. A cold, shallow water interval with Elphidium oregonense at the Pliocene/Pleistocene boundary is followed by a Early Pleistocene warm, deep water interval with a high content of the genera Stainforthia and Bulimina. These deposits are probably from the warm Tiglian stage. The succeeding Early Pleistocene faunal assemblages indicate a cold, upwards shallowing environment, and in this interval the arctic species Elphidiella gorbunovi often has a short ranged occurrence.

The faunal assemblages of the overlying deposits are characterized by the species Elphidium ustulatum and Elphidium albiumbilicatum, and indicates nearshore/ deltaic conditions. This part of the sequence probably includes the Early/Middle Pleistocene boundary.

The uppermost assemblages in the examined sequence indicate arctic, shallow water conditions. They are, probably, of Saalian age, and are referred to Middle Pleistocene.

Key-words: Biostratigraphy - Foraminiferal zonation - North Sea - Lower Pleistocene - Middle Pleistocene - The Pliocene/ Pleistocene boundary

Introduction

An examination of the collection of North Sea Neogene and Pleistocene foraminifera housed at the Danish Geological Survey (DGU) has resulted in the proposal of an emendation of the biozonation for the Lower Pleistocene in the North Sea area (Pedersen, 1995). This emendation included a redescription of the previously established Zones NSB 16/NSB 16x (King, 1983; 1989), and the definition of two new Subzones. Samples from the boreholes TWB-12, P-1 and E-1 (Fig. 1) were used as reference material, and the main purpose of the present paper is to present the foraminiferal assemblages of these strata in the three boreholes.

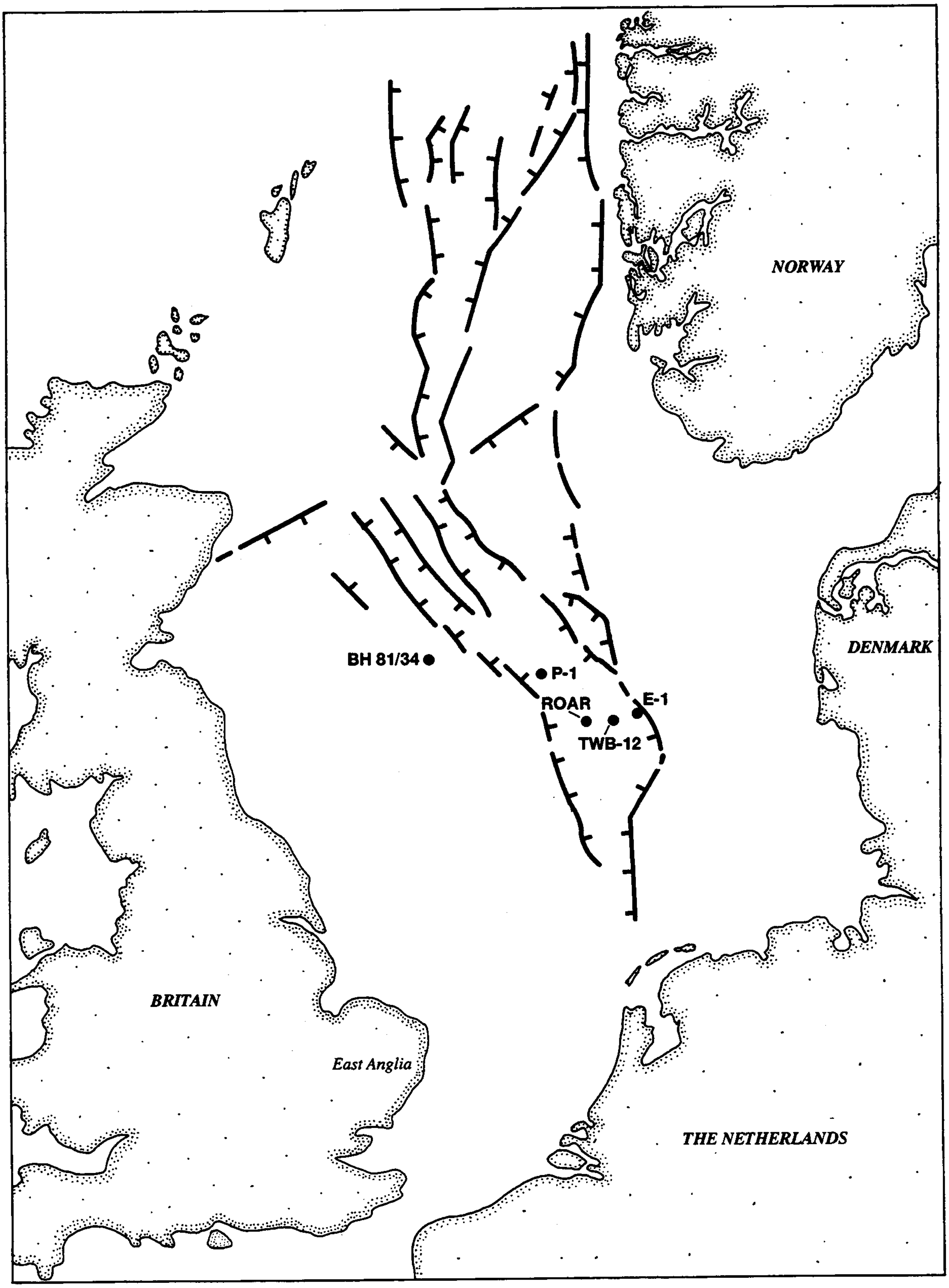


Fig. 1: Map showing the Central North Sea with main structural elements and the localities mentioned in the text.

Material and methods

Borehole TWB-12 (55° 42′ N, 4° 44′ E; Fig. 1) was drilled by the "Mærsk Olie og Gas A/S" in 1983. The present water depth at the site is 41 m. Borehole P-1 (56° 02′ N, 3° 46′ E; Fig. 1) was drilled by Gulf Oil Company of Denmark in 1973. The water depth at the site is 66 m. Borehole E-1 (55° 43′ N, 4° 51′ E; Fig. 1) was drilled by Gulf Oil Company of Denmark in 1968. The present water depth at the site is 37 m.

The material from the boreholes represents ditch cutting samples, collected with a minimum of 10 m (30 feet) intervals.

The samples from the borehole TWB-12 were prepared for quantitative analyses of the foraminiferal assemblages according to standard techniques (Meldgaard & Knudsen; 1979), using sieves with mesh diameters of 0.1 and 1.0 mm.

The material from P-1 and E-1 consisted of previously picked faunal assemblages, and no information concerning the preparation methods was obtained. The available size fractions ranged from 0.1 to 1.0 mm, but narrowed to between 0.25 and 0.5 mm in many of the samples. No information was given concerning the relationships between the picked specimens and the total faunal assemblages. The assemblages may have been picked with a bias towards the larger species/specimens.

The boremud obscured the lithology of the samples in TWB-12, and the sediment characters could, therefore, not be described in details. Information about the lithology of the lower parts of the examined sequences of the boreholes P-1 and E-1 was supplied by the Well Data Summary Sheets for the boreholes (Koch et al., 1981).

The analyzed material from TWB-12 is housed at the Department of Earth Sciences, University of Aarhus, and the material from P-1 and E-1 at the Danish Geological Survey, Copenhagen.

Foraminiferal zones and palaeoecology

The analyzed sequence has been divided into 6 foraminiferal assemblage zones (Hedberg, 1972), with one of the zones further subdivided into 6 subzones. Due to caving, the zonal boundaries are placed at the upwards last local occurrence or decline of an index species, and the zones are described from the top of the borehole and downwards. The top samples of all three boreholes were barren or contained only reworked foraminifera. Only a few scattered specimens of planktic foraminifera were observed in the sequence.

The observed ranges and concentrations of selected species are shown on Figs. 2a, 3 and 4, and the environmental parameters for TWB-12 are given on Fig. 2b (see also appendix A).

ZONE 1: The Haynesina orbiculare - Cassidulina reniforme zone.
This zone was found in the boreholes TWB-12 and P-1. The dominant species is Elphidium excavatum, which occurs mainly as the arctic forma clavata (see Feyling-Hanssen, 1972), and the zone is characterized by abundant Cassidulina reniforme and Haynesina orbiculare. Another characteristic species in the zone is Elphidium bartletti.

Faunal assemblages dominated by Elphidium excavatum forma clavata and Cassidulina reniforme are often found in glacio- marine environments (e.g. Nagy, 1965), and abundant Haynesina orbiculare may indicate an area influenced by glacial melt-water (K.L. Knudsen, pers. com.). The faunal composition suggest an arctic to subarctic, shallow water palaeoenvironment (Fig. 2b).

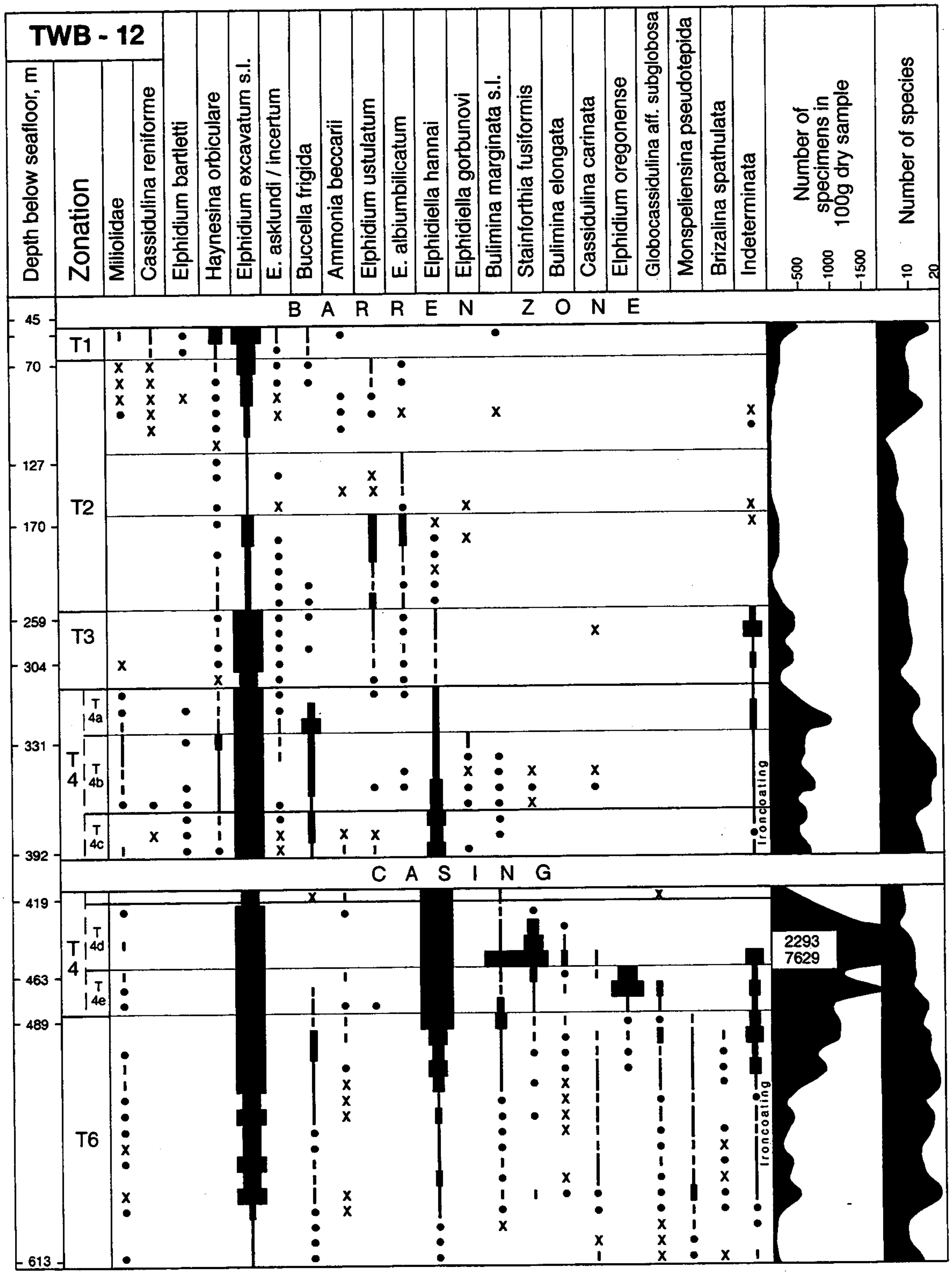
The sediment in Zone 1 (TWB-12) consists mainly of a quartz sand, which supports the interpretation of a shallow water palaeoenvironment.

ZONE 2: The Elphidium ustulatum - Elphidium albiumbilicatum zone.
This zone was found in the boreholes TWB-12 and P-1. The assemblage is dominated by Elphidium excavatum, forma clavata, but characterized by relatively high frequencies of Elphidium ustulatum and, in the lower part of the zone, Elphidium albiumbilicatum. Other characteristic species are Haynesina orbiculare and, in the upper part of the zone, Cassidulina reniforme. A few scattered specimens of Elphidiella hannai occur in the lower part of the zone.

Elphidium albiumbilicatum occurs commonly in significant numbers in very shallow, low salinity waters in boreal to boreo-arctic regions (Lutze, 1965).

The sediment (TWB-12) consists of sandy clay with decayed plant remains, wood fragments and a few small pebbles, and the number of specimens is extremely low (Fig. 2a). The environmental indication of the sediments and of the faunal assemblages in Zone 2 (Fig. 2b), suggest a brackish, mainly boreal, very shallow water palaeoenvironment. The environment was probably nearshore, deltaic or estuarine, and the deposit may partly be of non-marine origin.

The lowermost faunal assemblage in Zone 2 (TWB-12) indicate colder conditions in this part of the zone than above (Fig. 2b).



LEGEND: Total number of specimens in 100g dry sample.

x 1; • 2-5; ı 6-10; | 11-25; ▌ 26-50; ■ 51-100; ■ 101-150; ■ > 150

Fig. 2a: Range and concentration of selected species in TWB-12. Iron coating obscures the identity of the species in the samples from below 259 m, occasionally resulting in many indeterminate specimens.

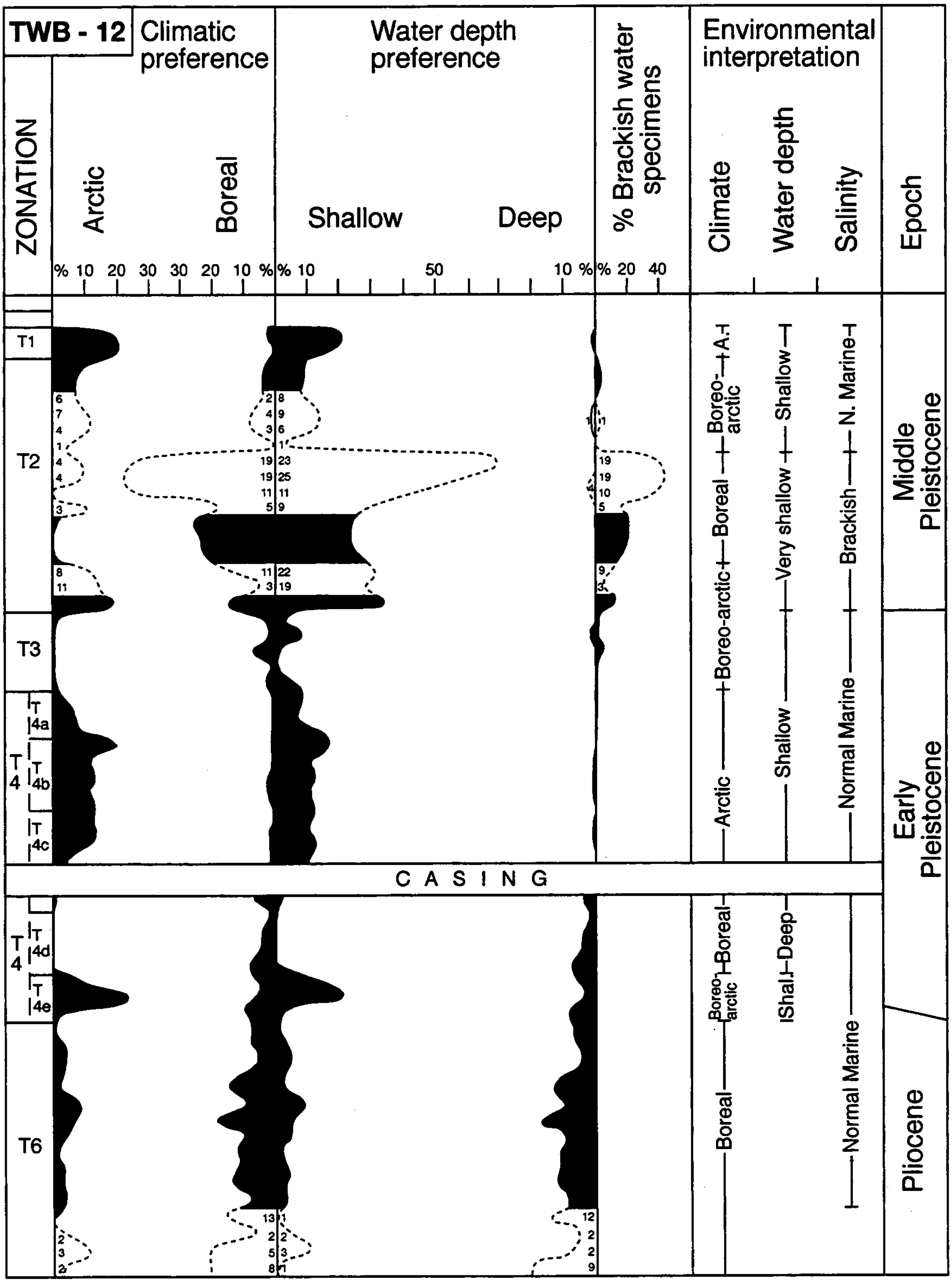
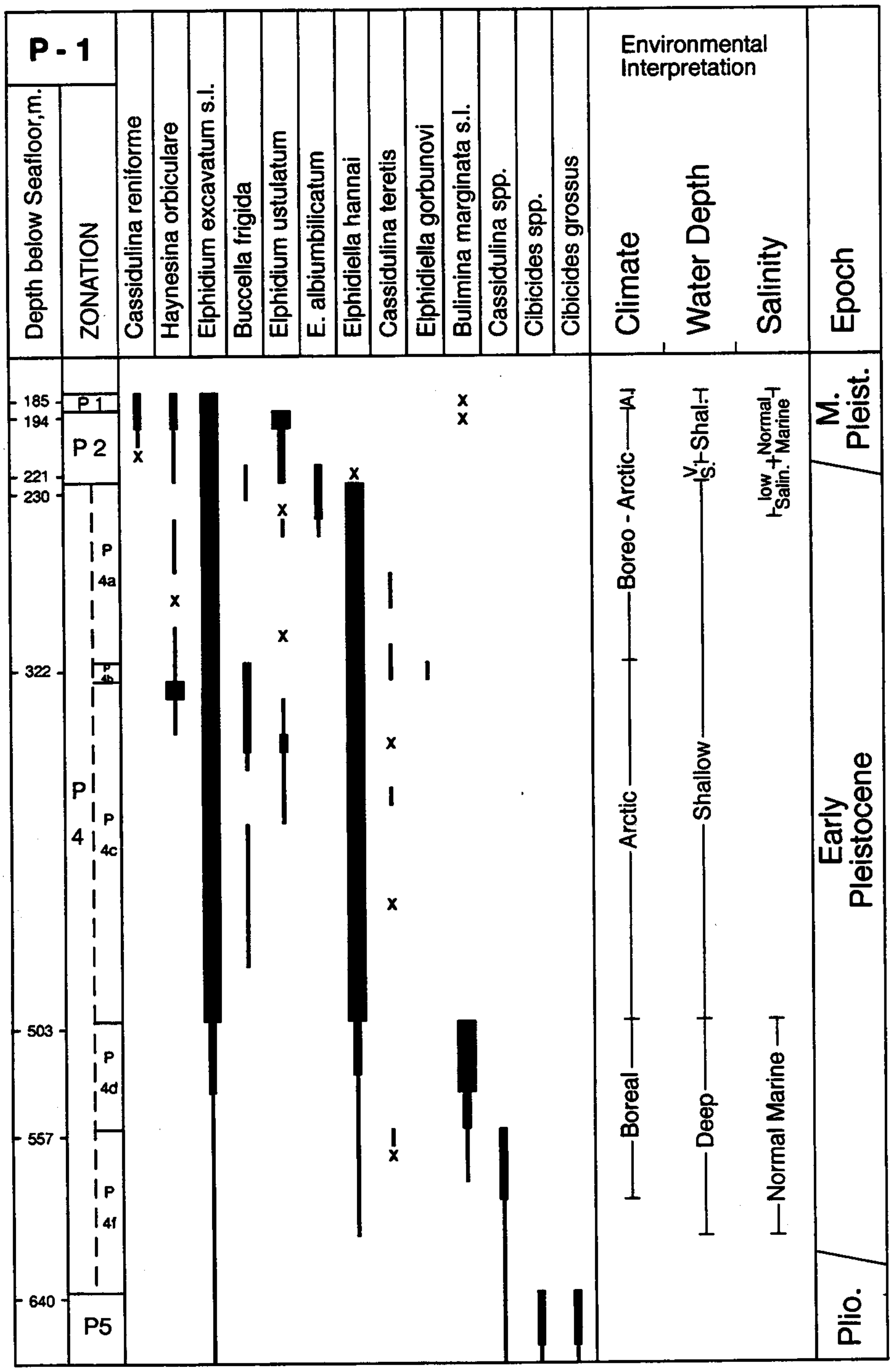
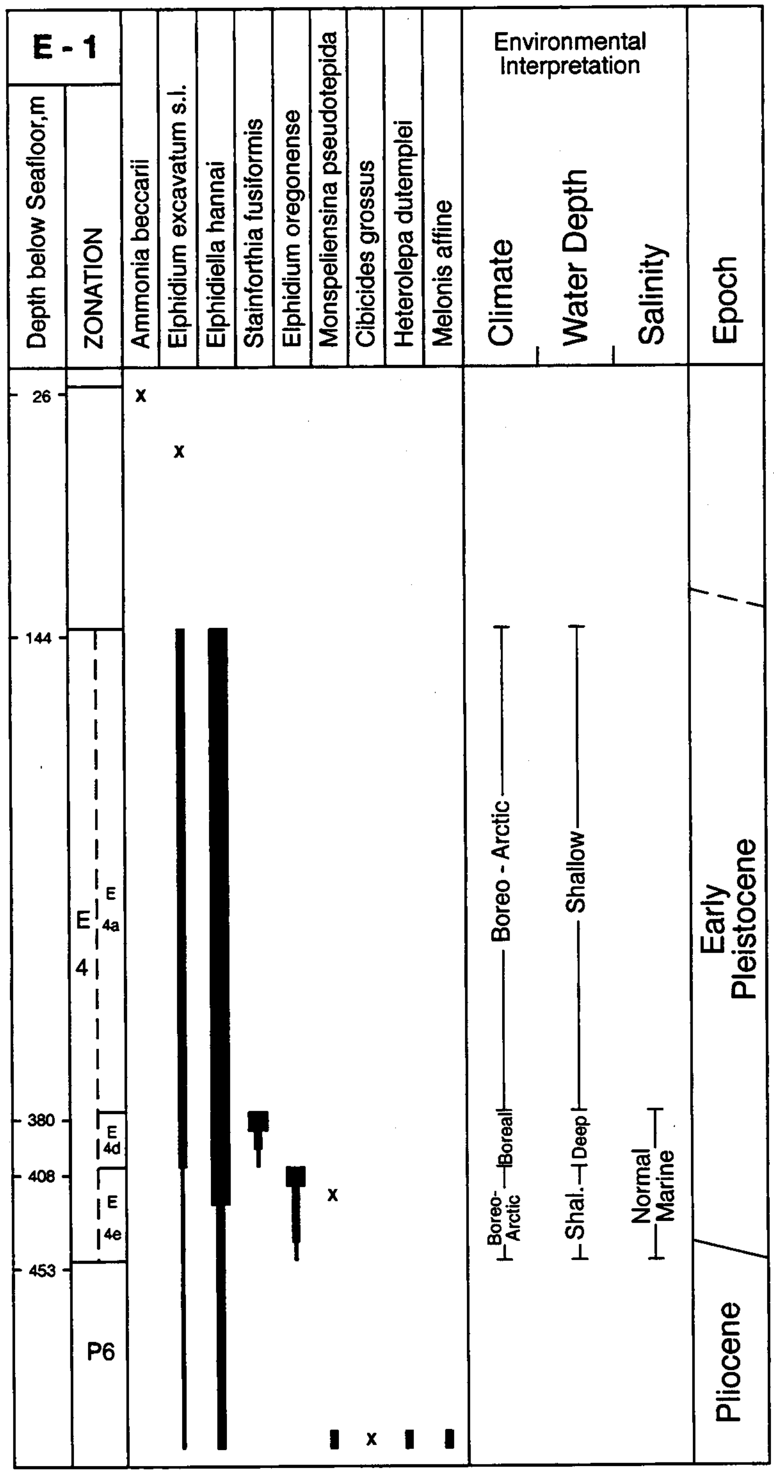


Fig. 2b: The environmental indications of the foraminiferal assemblages in TWB-12 base on preferences listed in Appendix A. For samples containing less than 100 specimens/100 g, the actual number of specimens are supplied.



LEGEND: x very rare; ❙ rare, ▮ common; ■ abundant

Fig. 3: Range and estimated concentration of selected species in P-1.



LEGEND: x very rare; ▎ rare, ▌ common; █ abundant

Fig. 4: Range and estimated concentration of selected species in E-1.

ZONE 3: The Elphidium excavatum zone.
This zone was found only in the borehole TWB-12. The faunal assemblages of Zone 3 are strongly dominated by Elphidium excavatum s.l. (> 90%). Most of the specimens are the arctic forma clavata, but the boreal forma selseyensis (see Feyling-Hanssen, 1972) is found as well. The number of Elphidiella hannai increases slightly in this zone.

A strong dominance by only one species may indicate an extreme environment. Elphidium excavatum forma clavata occurs in a wide range of environments (Murray, 1971), but is generally characteristic of arctic to subarctic climates (Feyling-Hanssen, 1972).

The sediments consist almost entirely of mollusc shells and fine grained quartz-sand.

ZONE 4: The Elphidiella hannai - Cassidulina teretis zone.
This zone was found at all three sites. Zone 4 is dominated by Elphidium excavatum s.l. and Elphidiella hannai, often with Buccella frigida as a common associate. Cassidulina teretis was found only in P-1. The lower part of Zone 4 in P-1 has a high content of Cassidulinidae, including Cassidulina carinata and Globocassidulina aff. subglobosa.

The faunal compositions and the relatively high foraminiferal concentration and diversity (Fig. 2a) indicate an environment with normal salinity, relatively shallow water and a mainly arctic to boreo-arctic climate (Fig. 2b).

The sediments are sandy to silty clay with an increase in the clay content downhole in all the three boreholes.

Zone 4 can be subdivided into 6 subzones. Three of these will be described separately because of their regional significance.

SUBZONE 4b: The Elphidiella gorbunovi Subzone.
The Subzone is dominated by Elphidium excavatum, Elphidiella hannai and Buccella frigida, but characterized by the presence (local range) of the arctic species Elphidiella gorbunovi. Haynesina orbiculare and various Miliolidae increase in numbers compared to the overlying assemblages. A few specimens of Elphidium bartletti, Elphidium ustulatum and various Buliminidae are found in this Subzone (TWB-12).

The foraminiferal assemblage of Subzone 4b indicates a normal marine, inner shelf environment in an arctic to boreo-arctic climate (Fig. 2b). Elphidiella gorbunovi is found living in the arctic Kara Sea (Polar Sea) at water depths between 16.5 - 47 m (Stschedrina, 1946), and Voloshinova (1970) considers the species to indicate water depths <70 m.

Shallow water species characterize the faunal assemblages throughout the Subzone (Fig. 2b). Nevertheless a higher faunal diversity and a larger content of Miliolidae and Buliminidae than in the overlying assemblages (Fig. 2a) may indicate slightly deeper water in Subzone 4b.

SUBZONE 4d: The Stainforthia/Bulimina Subzone.
This Subzone was found at all three sites. Subzone 4d is dominated by Elphidium excavatum s.l. and Elphidiella hannai, but is characterized by a high frequency of Stainforthia fusiformis and/or Bulimina marginata s.l. and Bulimina elongata. The number of specimens reaches an absolute maximum in this Subzone (>7000 per 100 g sample in TWB-12).

The faunal composition, the high concentration of specimens and a high diversity (Fig. 2a) indicate, that the Subzone was deposited in a boreal, normal marine, inner shelf environment. The high frequency of Stainforthia fusiformis, Bulimina marginata s.l. and Bulimina elongata in the lower part of the Subzone (TWB-12) suggests that the water was deepest during the deposition of this part of the sequence.

In TWB-12 a casing was set near the bottom of Subzone 4c, and the characteristics of the sediment consequently obscured by casing material.

SUBZONE 4e: The Elphidium oregonense Subzone.
This Subzone was found in the boreholes TWB-12 and E-1. The most abundant species are Elphidium excavatum and Elphidiella hannai, but the Subzone is characterized by the presence (local range) of the species Elphidium oregonense, which is found in high numbers. Globocassidulina aff. subglobosa often has its first downhole occurrence within this Subzone in the North Sea area (Pedersen, 1995).

Elphidium oregonense is found in recent faunal assemblages in the arctic Bering Sea at water depths 25-50 m (Anderson, 1963). The Subzone 4e was presumably deposited in a boreo-arctic, normal marine, inner shelf environment, but the lower numbers of Stainforthia fusiformis and the other Buliminidae indicate somewhat lower water depth than in Subzone 4d.

ZONE 5: The Cibicides grossus Zone.
This zone was found only in the borehole P-1. The top of the zone is placed at the downhole first significant occurrence of Cibicides grossus. Most of the species observed in the faunal assemblage are extinct, but the high content of the genus Cassidulina may indicate a deeper water environment than Subzone 4e (see also Pedersen, 1995).

ZONE 6: The Monspeliensina pseudotepida Zone.
This Zone was found in the boreholes TWB-12 and E-1, but due to the poor fauna found in E-1, the description will be based entirely on TWB-12.

Zone 6 is characterized by the first common downhole occurrences of Monspeliensina pseudotepida and Brizalina spathulata. Elphidium excavatum and Elphidiella hannai are the dominant species, but they decrease in numbers towards the base of the Zone. Other significant species are Bulimina marginata s.l., Globocassidulina aff. subglobosa and Cassidulina carinata and further downhole also Melonis affine, Cassidulina pliocarinata and Heterolepa dutemplei.

The composition of the faunal assemblages and the high faunal diversity (Fig. 2a), combined with a glauconitic clay sediment, indicate a boreal, normal marine, shelf palaeoenvironment in the upper part of the Zone (Fig. 2b).

In the lower part of the Zone the sediment consists of sand (with plant-remains) overlying non-glauconitic clay, and the foraminiferal content is extremely low (Fig. 2a). This part of the Zone, is probably a nearshore/deltaic/non-marine deposit.

Correlation and age

The chronostratigraphic correlations of younger Neogene and Quaternary deposits in the North Atlantic region is usually based on planktic foraminifera (e.g Weaver & Clement, 1986). In the restricted environment of the southern and central North Sea, the planktic foraminifera, however, occur only sporadic, and the foraminiferal stratigraphy has to be based on benthic species with, often, rather un-certain chronostratigraphic allocations.

A correlation of the zones in TWB-12, P-1 and E-1 with previously published zonations for the area will be presented below (see also Fig. 5).

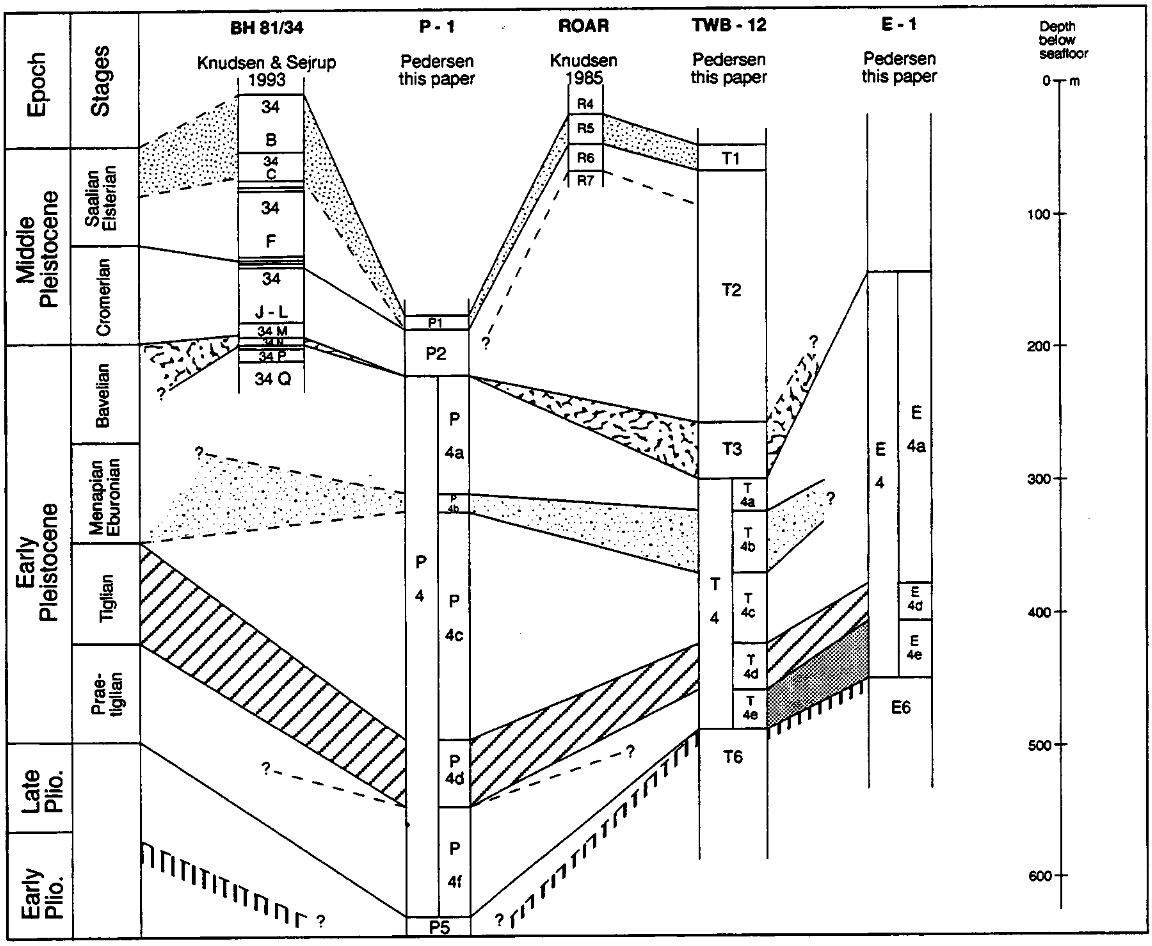


Fig. 5: Correlation and chronostratigraphical allocation of the zones in the three boreholes.
The correspondance of zonation for TWB-12 in Knudsen & Ásbjörnsdóttir (1991) compared to this paper: Zone B = T1, Zones C,D and E = T2, Zone F = T3, Zone G = T4a, Zone H = T4b and T4c, Zone I = T4d, Zone J = T4e, and Zone K = 6.

The Pliocene.

King (1983; revised and extended 1989) established a biozonation for the North Sea area. In the present paper the Monspeliensina pseudotepida Zone (Zone 6) may be correlated with NSB 14 (King, 1983), while the Cibicides grossus Zone (Zone 5) is correlated with the younger NSB 15 (King, 1983) (Fig. 6). Caving and the possibility of reworking makes it difficult to determine whether the two index species are, in some areas, concurrent (see also Pedersen, 1995).

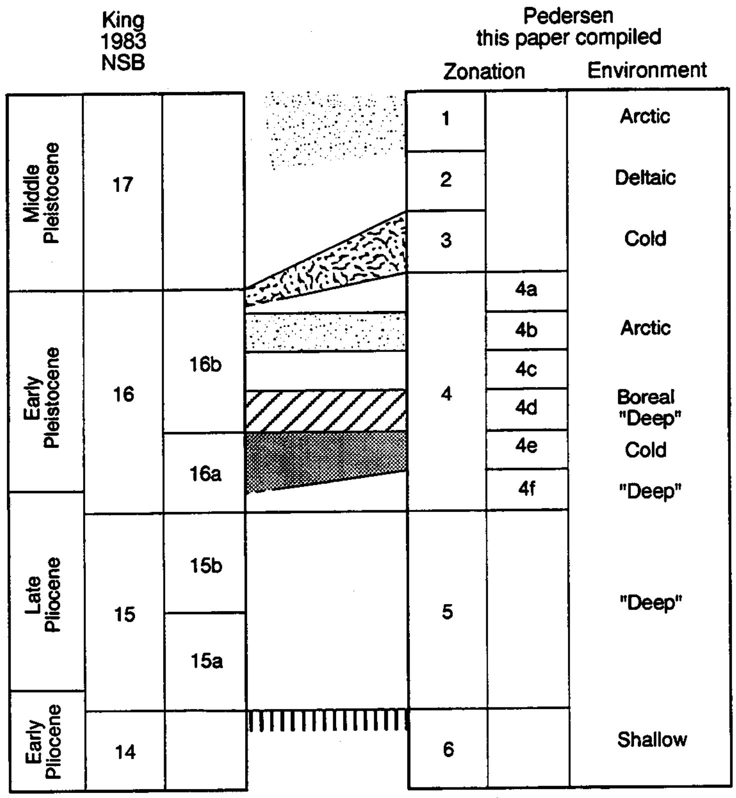


Fig. 6: Comparison between biozonation established by King (1983, 1989) and compilation in this paper.

The Pliocene/Pleistocene boundary.

The internationally accepted Pliocene/Pleistocene boundary is defined in Italy, just above the top of the palaeomagnetic Olduvai event, and thus dated to 1.75-1.76 Ma (Bassett, 1985; Aguirre & Pasini, 1985; Harland et al., 1989; Shackleton et al., 1990). In the North Atlantic Ocean this approximately coincide with a biostratigraphic event, i.e. the change from mainly dextral to mainly sinistral specimens in the planktic species Neogloboquadrina pachyderma (Weaver & Clement, 1986). Since planktic species rarely occurs in deposits from the southern and central North Sea, biostratigraphers working in these areas have often used the presence of Elphidium oregonense (2.3 Ma) (van Voorthuysen et al., 1972; Doppert, 1980; King, 1983; Zagwijn, 1992), the last occurrence of Pararotalia serrata (2.47 Ma) (Cameron et al., 1984) or changes in the palaeoenvironmental signal indicating transition to a colder climate (Knudsen & Ásbjörnsdóttir, 1991). The Pliocene/Pleistocene boundary used locally in the North Sea area are, thus, about 0.5 - 1.0 Ma older than the international boundary. For further discussion of the Pliocene/Pleistocene boundary in the North Sea area, see Pedersen (1995).

The Subzone 4e contains Elphidium oregonense, and in TWB-12 and E-1 the Pliocene/Pleistocene boundary is placed at the estimated first common occurrence of this species. This placement is chosen partly for convenience, but also because the Subzone appears to contain the oldest arctic/boreo-arctic species found in situ in the sequence, and thus gives the earliest evidence of the climatic deterioration of the climate toward the Pleistocene glacial stages.

At the P-1 site the Pliocene/Pleistocene boundary is placed at the top of the Cibicides grossus Zone (Zone 5), a datum which is probably older than the Elphidium oregonense Subzone found at the two other sites (Pedersen, 1995).

The Early Pleistocene.

In the present paper Zone 3 and Zone 4 are referred to the Lower Pleistocene, and the Early Pleistocene thus covers the time interval between approximately 2.3 and 0.8 Ma (Zagwijn, 1992).

The lowermost part of Zone 4 (P-1), Subzone 4f, could represent a deeper water facies, contemporaneous with Subzone 4e, but is, tentatively, considered to be older.

Subzone 4e, the Elphidium oregonense Subzone, may be correlated with NSB 16a (King, 1983) (Fig.6). In the southern North Sea area deposits containing this species are referred to Praetiglian (2.3 - 2.0 Ma) (van Voorthuysen et al., 1972; Jenkins et al., 1985; Zagwijn, 1992).

An interval containing large numbers of Buliminidae, Subzone 4d, can be identified in most boreholes in the central North Sea area, and Pedersen (1995) defined a Stainforthia/ Bulimina Subzone on the basis of the TWB-12 and E-1 boreholes. The large content of Elphidiella hannai indicate an Early Pleistocene age (Funnell, 1989) for the Subzone, and the relatively deep water indicated by the foraminiferal assemblage suggests, that the deposition took place before the middle Eburonian sea-level drop (1.5 Ma) (Zagwijn, 1979).

The temperature indicated by the assemblages are higher than encountered anywhere else in the boreholes above the Pliocene/Pleistocene boundary, and the warm Tiglian stage, therefore, seems a likely stratigraphical allocation.

The Subzone 4b is characterized by the presence of the arctic species Elphidiella gorbunovi. An interval containing this species can be identified in Lower Pleistocene deposits in many of the boreholes in the Central North Sea, and an Elphidiella gorbunovi Subzone was defined by Pedersen (1995) on the basis of the TWB-12 and P-1 boreholes.

The presence of the species Elphidiella hannai in North Sea sediments is generally believed to indicate Pliocene or Lower Pleistocene deposits (e.g. Funnell, 1989). The uppermost zone containing high amounts of Elphidiella hannai at the three sites is the Elphidiella hannai - Cassidulina teretis zone (Zone 4) and the upper boundary of the Lower Pleistocene should, therefore, be placed above the top of this zone.

In the TYRA (TWB-12) zonation presented in Knudsen & Asbjörnsdottir (1991), this boundary were placed in the lower part of, what is now called T2. The content of Elphidiella hannai in Zone 3 and lowermost Zone 2 are, however, relatively small, and may be caused by reworking.

Knudsen & Sejrup (1993) reports an almost monospecific assemblage of Elphidium excavatum in the borehole BH 81/34 (Zone 34 N). BH 81/34 does not contain Elphidiella hannai, but, except from this, the assemblages in the Zones 3 (TWB-12) and 34 N (BH 81/34) are very nearly identical. Zone 34 N is found above the last common occurrence of Cassidulina teretis, but stratigraphically below the palaeomagnetic Brunhes-Matuyama boundary, and a correlation of Zone 3 with Zone 34 N, thus, lead to a Early Pleistocene age for Zone 3.

In BH 81/34 the B-M boundary is placed within the, possibly, non-marine Zone 34 M, and several similar intervals are found in Zone T2. The lowermost of these, possibly, non-marine T2 intervals may be contemporaneous with Zone 34 M, but the 10 m sampling interval in the TWB-12 material makes this correlation too uncertain, and the Early/Middle Pleistocene boundary is placed at the top of Zone 3.

The Middle Pleistocene.

The occurrence of specimens of the Lower Pleistocene - or older - species Elphidiella hannai in Zone 3 and the lower part of Zone 2, makes a chronostratigraphical allocation of these zones problematic. Correlations with BH 81/34 (Knudsen & Sejrup, 1993) did, however, indicate an Early Pleistocene for Zone 3, while Zone 2, mainly or totally, may be of Middle Pleistocene age.

Zone 2 (TWB-12) may be correlated with the Zones 34 M, 34 L, 34 K and 34 J (BH 81/34) on the basis of the general faunal content, but a more detailed correlation is not possible. The Zones 34 M - 34 J are considered to be of Cromerian age (Knudsen & Sejrup, 1993).

The upper part of Zone 2 is characterized by the species Elphidium ustulatum, and the uppermost part of the zone (TWB-12) is, tentatively, correlated to the Elphidium ustulatum rich faunal assemblages, Zone R6, found in the two boreholes Roar 41 and Roar 43, 9 km west of the Tyra Field (Knudsen, 1985). The specimen-poor samples found below in Zone

2 may accordingly correspond to the non-marine Zone R7 at Roar (see also Knudsen & Asbjörnsdottir, 1991).

The mainly arctic Zone 1 may be correlated with Zone R5 at Roar, which Knudsen (1985) ascribes to a glacial period older than Eemian, but younger than Early Pleistocene. Amino acid (aIle/Ile) data from the Roar material, showed high Eemian/low Holsteinian values in Zone R6, thus, dating Zone R5 to the Saalian (Sejrup & Knudsen, 1993). In BH 81/34 the Haynesina orbiculare containing faunal assemblages of the Saalian Zones 34 B and 34 C (Knudsen & Sejrup, 1993) shows the greatest similarity with Zone 1 (TWB-12), thus, supporting a Saalian age for this Zone.

Summary and conclusion

The foraminiferal contents of three boreholes from the Central North Sea have been analyzed and the examined sequence is divided into 6 zones. A palaeoecological interpretation is proposed for each zone, and a correlation to previous studies in the North Sea area is attempted.

The lowermost zones (Zones 6 and 5) are stratigraphically allocated to the Pliocene. The faunal assemblages in **the Cibicides grossus Zone** (Zone 5) suggest a relatively deep water palaeoenvironment, while those in **the Monspeliensina pseudotepida Zone** (Zone 6) point to much shallower water, perhaps even non-marine at the base of the Zone.

The first significant occurrence of the species Elphidium oregonense is used as an indication of the Pliocene/Pleistocene boundary.

The Lower Pleistocene **Elphidiella hannai - Cassidulina teretis zone** (Zone 4) is subdivided into 6 subzones, three of which appear to have regional significance.

The palaeotemperature appears to be lower in **the Elphidium oregonense Subzone** (Subzone 4e) than in the Zones 5 and 6, and the water depth more shallow than in Zone 5. This subzone is referred to the Praetiglian stage.

In **the Stainforthia/Bulimina Subzone** (Subzone 4d) the faunal assemblages indicate warm and relatively deep water with normal marine conditions. This subzone may be referred to the warm Tiglian stage.

The faunal assemblages in **the Elphidiella gorbunovi Subzone** (Subzone 4b) and in subzone 4a, indicate gradually colder, more shallow, and more restricted palaeoenvironments.

The trend toward shallower water depths appears to continue in the succeeding Zone 3 and in the Middle Pleistocene Zone 2, but the faunal assemblages indicate upwards gradually warmer water in this part of the sequence.

The faunal assemblages in **the Elphidium excavatum zone** (Zone 3) and in **the Elphidium ustulatum - Elphidium albiumbilicatum zone** (Zone 2) indicate a boreo-arctic to boreal climate, shallow to very shallow water and, in Zone 2, reduced salinity. A characteristic feature of Zone 2 (TWB-12) is the presence of deposits, which may be of non-marine origin. The deposits in Zone 2 are probably of Cromerian age and may represent a fluctuating delta front.

The Zone 3 - Zone 2 sequence is interpreted to range across the Lower/Middle Pleistocene boundary. Delta-related conditions have previously been reported in the North Sea area during the time period from the end of the Tiglian stage to the later stages of the Cromerian Complex (Cameron et al., 1989). According to Cameron et al. (1989) the delta front reached the Central North Sea in the uppermost Lower Pleistocene (Bavelian) and the lowermost Middle Pleistocene (Cromerian). Zone 2 probably belongs in this time-interval.

The Haynesina orbiculare - Cassidulina reniforme zone (Zone 1) apparently represents a shallow water marine deposit from a Middle Pleistocene glaciation, most likely the Saalian.

Barren samples occur in all three boreholes above the foraminiferal zones.

It should be recalled, that the examined material represents cutting samples, and that the sampling intervals in the three boreholes are quite large. Many details may, therefore, either have been obscured by the sampling method or have escaped sampling. Further investigations are needed to provide more detailed information about the stratigraphy of the area.

Acknowledgement

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Danish summary/dansk sammendrag

Tre boringer fra den centrale Nordsø er anvendt som referencemateriale til en udvidet zonation for Nedre Pleistocæn i Nordsøen. I denne artikel præsenteres faunaerne fra det anvendte materiale og der korreleres, dels mellem de tre boringer, dels til andre zoneringer fra området.

De to nederste zoner (Zone 6 og 5) er henført til Pliocæn. Faunaselskabet i Cibicides grossus Zonen (Zone 5) tyder på relativt dybt vand, mens faunaerne i Monspeliensina pseudotepida Zonen (Zone 6) indicerer lavere vanddybder. Dette kan skyldes en faciesforskel mellem P-1 boringen og de mere sydlige boringer, E-1 og TWB-12.

Pliocæn/Pleistocæn grænsen er sat ved bunden af Elphidium oregonense Subzonen eller toppen af Cibicides grossus Zonen. Nedre Pleistocæn inddeles i 6 Subzoner, hvoraf 3 har regional stratigrafiske betydning, og derfor beskrives nærmere.

Elphidium oregonense Subzonen indeholder de ældste faunaer fra den centrale Nordsø, der viser tegn på arktiske til boreo-arktiske forhold. Elphidium oregonense findes i faunaer/sedimenter, der indicerer lavt vand.

Højere oppe i lagserien findes Stainforthia/Bulimina Subzonen karakteriseret af et højt indhold af Stainforthia fusiformis og/eller andre buliminider. Disse faunaer indicerer et miljø med varmt klima og forholdsvist dybt vand. Denne Subzone bliver henført til det varme Tegel interval.

Et stykke over Stainforthia/Bulimina Subzonen kan tilstedeværelsen af den arktiske art Elphidiella gorbunovi indicere at Elphidiella gorbunovi Subzonen kan henføres til en af de kolde episoder i Eburon eller Menap.

Over Elphidiella gorbunovi Subzonen præges faunaerne af Elphidium albiumbilicatum og Elphidium ustulatum, og både faunaer og sediment tyder på meget kystnære forhold. Disse aflejringer kan formodentlig helt eller delvist henføres til Mellem Pleistocæn.

Det øverste faunaer i TWB-12 og P-1 tyder på lavt vand og arktiske forhold. Korrelationer med nærliggende boringer henfører denne del af de undersøgte sekvenser til Mellem Pleistocæn, sandsynligvis Saale.

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Appendix A.

The environmental indications shown on Fig. 2b are based on the environmental preferences of the following species:

Arctic: Buccella frigida, Cassidulina reniforme, Elphidiella gorbunovi, Elphidium bartletti, Elphidium oregonense, Haynesina orbiculare, Islandiella norcrossi.

Boreal: Ammonia beccarii, Brizalina spathulata, Bulimina marginata s.l., Cassidulina carinata, Elphidium albiumbilicatum, Elphidium magellanicum, Globocassidulina aff. subglobosa, Haynesina depressula, Stainforthia fusiformis, Textularia sagittula.

Shallow water: Ammonia beccarii, Buccella frigida, Elphidium albiumbilicatum, Elphidium asklundi/incertum, Elphidium bartletti, Elphidium magellanicum, Elphidium oregonense, Haynesina orbiculare, Haynesina depressula.

Relatively deep water: Brizalina spathulata, Bulimina marginata s.l., Cassidulina carinata, Globocassidulina aff. subglobosa, Pullenia bulloides, Stainforthia fusiformis.

Low salinity: Elphidium albiumbilicatum, Elphidium magellanicum. Elphidium excavatum s.l. tolerates low salinity, but occurs under normal marine conditions as well. This species is, therefore, not included in the calculation of the index.

The information concerning the environmental preferences of the species is compiled from the following papers: Cushman & Grant, 1927; Stschedrina, 1946; Loeblich & Tappan, 1953; Anderson, 1963; Murray, 1971; 1991; Feyling-Hanssen, 1972; Culver & Buzas, 1985.

Appendix B.

The benthic foraminiferal species mentioned in the text are arranged alphabetically in the following list. Bulimina marginata s.l. includes Bulimina marginata d'Orbigny 1826, B. gibba Fornasini 1901 and B. aculeata d'Orbigny 1826.

Ammonia beccarii (Hofker 1951)
Brizalina spathulata (Williamson 1858)
Buccella frigida (Cushman 1922)
Bulimina marginata s.l.
Bulimina elongata d'Orbigny 1846
Cassidulina carinata Silvestri 1896
Cassidulina pliocarinata van Voorthuysen 1950
Cassidulina reniforme Nørvang 1945
Cassidulina teretis Tappan 1951
Cibicides grossus ten Dam & Reinhold 1941
Elphidiella gorbunovi (Stschedrina 1946)
Elphidiella hannai (Cushman & Grant 1927)
Elphidium albiumbilicatum (Weiss 1954)
Elphidium asklundi Brotzen 1943 / incertum (Williamson 1858)
Elphidium bartletti Cushman 1933
Elphidium excavatum (Terquem 1875) forma clavata Cushman 1930
Elphidium excavatum (Terquem 1875) forma selseyensis (Heron-Allen & Earland 1911)
Elphidium magellanicum Heron-Allen & Earland 1932
Elphidium oregonense Cushman & Grant 1927
Elphidium ustulatum Todd 1957
Globocassidulina aff. subglobosa (Brady 1881)
Haynesina depressula (Walker & Jacob 1798)
Haynesina orbiculare (Brady 1881)
Heterolepa dutemplei (d'Orbigny 1846)
Islandiella norcrossi (Cushman 1933)
Melonis affine (Reuss 1851)
Monspeliensina pseudotepida (van Voorthuysen 1950)
Pararotalia serrata (ten Dam & Reinhold 1941)
Pullenia bulloides (d'Orbigny 1846)
Quinqueloculina stalkeri Loeblich & Tappan 1953
Stainforthia fusiformis (Williamson 1858)
Textularia sagittula De France 1824